PROCEEDINGS

of the

ENGINEERING INSTITUTION OF ZAMBIA
2017 SYMPOSIUM

Hosted by
The Engineering Institution of Zambia

Theme:
“Industrialisation: Sustainability and Efficiency”

ISBN 978-9982-41-013-7

7th & 8th April, 2017
Avani Victoria Falls Resort, Livingstone, Zambia

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Typeset by: Grain M. Munakaampe

Published by the Engineering Institution of Zambia
Lusaka, Zambia

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Foreword

This book of proceedings collects the papers presented during the Engineering Institution of Zambia (EIZ) 2017 Symposium held in Livingstone, Zambia, 7th April, 2017. The theme of the Symposium "**Industrialisation: Sustainability and Efficiency**" was about new and current scientific and engineering knowledge and practices to efficiently manage the inputs to and the process of industrialisation. Consequently, the papers presented reflect this point; they vary from those reporting mining and agriculture as the main sources of inputs, energy and infrastructure development, and small and medium enterprises (SMEs) as key players in the industrialisation process.

The EIZ Symposium continues the tradition of bringing together researchers, academics and industry professionals from all over the world, a combination which made the symposium as outstanding as it has always been. The symposium particularly encourages interaction among participants in an informal setting to network and share knowledge on current best practices in engineering.

These proceedings will furnish the engineering professionals and other stakeholders with a useful reference book. All of the papers presented here were refereed; we thank all authors and referees for their cooperation in ensuring that the various deadlines were met. We wish to express our appreciation to the members of the EIZ Publications Committee for their efficiency and dedication in ensuring that all the papers were ready for the symposium.

Finally, we acknowledge the support from the EIZ Secretariat in ensuring that all the requirements were put in place for the success of the symposium.

Eng Levy Siaminwe, PhD
Chairman, EIZ Publications Committee

April 2017

A methodical review of condition monitoring of equipment as tool for improving productivity of mines.

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Abstract

The purpose of this paper is to look at the value mine operators would acquire if they applied condition monitoring of mine equipment as a tool for improving equipment effectiveness and productivity of mines. Currently, many mine operators during period of low profits focus on labour reduction as opposed to optimisation of mine equipment through reduction of down time. A critical look at most mining operations shows that a large number of companies still rely on break down maintenance as a major approach to maintaining their equipment.

This paper reviews aspects of condition monitoring and how it can be used to reduce equipment down time and increase machine working life. The overall objective of the application of such methods being to reduce mine or plant operating costs while maintaining safety and long term sustainability. Condition monitoring allows mining companies to schedule the maintenance programme or other actions to be taken before the failure occurs to avoid the consequences of failure. It is typically much more cost effective than allowing the machinery to fail.

This paper is intended as an overview, there are main separate aspects mentioned here that could provide subject for further research and more in depth treatment.

Key words: *condition monitoring, mine equipment, down time, productivity*

Introduction

The mining sector has in the recent past witnessed reduced production due to weak demand from end users of minerals such as China and the European Union (World Bank, 2016). The fall in production has led to a reduction in industry profit and Government revenue. As a result of this scenario, mining companies are looking to do more with less by optimising their productivity mostly by applying the traditional approach of laying off workers. However, what most companies do not realise is the fact that they can still survive period of low profits and capital by optimising equipment performance and enhancing productivity through curtailing downtime without necessarily cutting down on the labour force. Reducing downtime helps to diminish operational costs by ensuring that

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frequent and expensive machine malfunctions and repairs are circumvented by employing predictive maintenance using various forms of condition monitoring.

Condition monitoring is a process of continuously monitoring operational characteristics of a machine to predict the need for maintenance before a deterioration or breakdown occurs (Williams, *et al*., 1994). Condition monitoring aims to prevent unplanned breakdowns, maximise equipment availability and reduce associated hazards. Condition Based Maintenance (CBM) differs from earlier used methods of preventive maintenance by focusing maintenance on actual condition of the machine rather than on planned schedule. Condition monitoring of mining equipment results in increased utilisation, fewer unexpected breakdowns, advance knowledge about required spares and equipment, increased and predictable equipment output and effective utilisation of labour. Condition monitoring also helps to avoid catastrophic failure of mine equipment and plant hence preventing accidents. The principal objective of an efficient condition monitoring system is to detect the process, component and machine faults, thereby, enhancing the quality of manufactured products and reducing the down time and maintenance cost (Acharya, *et al*., 2009). However, predictive maintenance does not mean that routine servicing and adjustment of equipment is done away with. It increases the likelihood that it will not be overlooked or omitted. Well-planned maintenance incorporating predictive techniques increases the confidence and morale of the workforce operating the equipment which in turn results in improved productivity.

To decide if condition monitoring is appropriate or worthwhile in any particular set of circumstances, it is necessary to: a) asses the cost, and b) assess the viability from a technical stand point e.g**.,** is there a suitable quantity or quantities that can be monitored to correctly indicate deterioration in condition and the need for maintenance?

The following parameters are commonly assessed in condition monitoring of equipment: temperature; pressure and flow, infrared, oil analysis and vibration.

Monitoring of temperature, pressure and flow

These are well established techniques and since in condition monitoring a very accurate measurement is not required, but rather a sensing of change of parameter from a given "baseline", relatively simple and inexpensive systems can often be used. Such systems normally employ sensors or transducers and incorporate signal conditioning where required. During operation of mine equipment a multitude of various signals are emitted from the machine tool and the process. In order to extract useful information from machine condition monitoring data, several stages of signal processing and data analysis are normally needed. Therefore, signal conditioning is essential for abnormal patterns, i.e., Sensory Characteristic Features (SCFs), which can be related to physical phenomena or fault conditions. These can be linked to "alarm" systems to notify of excessive change in the measured parameter and indicate automatic shutdown where risk of serious damage or danger is involved. This type of monitoring can be applied to most types of equipment, e.g., conveyor belts, engines, bearings, switch gears, transformers, motors, filters, pumps, hydraulic systems, air conditioning and refrigeration (Williams, *et al*., 1994)

Infrared thermography

Heat is often an early symptom of equipment damage or malfunction, making it a key performance parameter monitored in predictive maintenance (PdM) programmes.

Infrared Thermography (IRT) is the technique for producing an image of invisible infrared light emitted by objects due to their thermal condition. An image produced by an infrared camera is called a thermogram or sometimes a thermograph. Therefore, Thermography allows one to make non-contact measurements of an object's temperature (Hurley, L. (1994),

Infrared thermography detects infrared energy emitted from an object, converts it to a temperature reading, and displays the image of temperature distribution. Temperature is one of the most common indicators of the structural and functional health of equipment and components. Faulty machinery, corroded electrical connections and damaged material components, can cause abnormal temperature distribution (Hurley, 1994). IRT is the process of using thermal imagers to capture infrared radiations emitted by an object to locate any abnormal heat pattern or thermal anomaly which would indicate a possible fault, defect or inefficiencies within a system or machine asset [Newport, www.electricity-today.com]. The basic principle underlying this technique is based upon Planck's law and Stefan-Boltzmann's law which states that all objects with temperature above 0 K (i.e. -273˚C) emits electromagnetic radiation in the infrared region of electromagnetic spectrum i.e. wavelength in the range of 0.75–1000 µm and the intensity of this **IR** (infrared) radiation is a function of the temperature of the body .

Infrared thermography is generally classified in two categories, passive and active thermography (Hurley, 1994). In passive thermography, the temperature gradients are naturally present in the materials and structures under test. However in some cases the thermal gradient is not so prominent as in cases of deeper and smaller defects and is not visible on the surface using passive thermography**.** On the other hand, Active Thermography (figure 1) is an imaging procedure for non-destructive material testing. A heat flow is induced by an energetic excitation of the test object, which can be done in a transmissive or a reflective setup. The resulting heat flow is influenced by interior material layers and defects. These inhomogeneities can be captured on the object surface by high-precision thermographic cameras. The additional application of different evaluation algorithms improves the signal-to-noise-ratio, which allows for detection of smallest defects.

Oil Analysis

Oil is an important source of information for early machine failure detection. Oil in machines is usually used for lubrication to reduce friction between moving surfaces. Comparison with vibration based monitoring, lubrication oil condition monitoring can provide approximately 10 times earlier warnings for machine malfunction and failure (Poley, 2012). Lubrication oil analysis (LOA) includes fluid property analysis (fluid viscosity, additive level, oxidation properties and specific gravity), fluid contamination analysis (moisture, metallic particles, coolant and air) and wear debris analysis (Kumar, *et al.*, 2005). Fluid property and contamination analysis is used to analyse the condition of oil to determine whether the oil itself has deteriorated to such a degree that it is no longer suitable to fulfill its objective. Wear debris analysis is a technique which is used to monitor equipment's operating condition by analysing the content of debris in the lubrication and hydraulic oil samples.

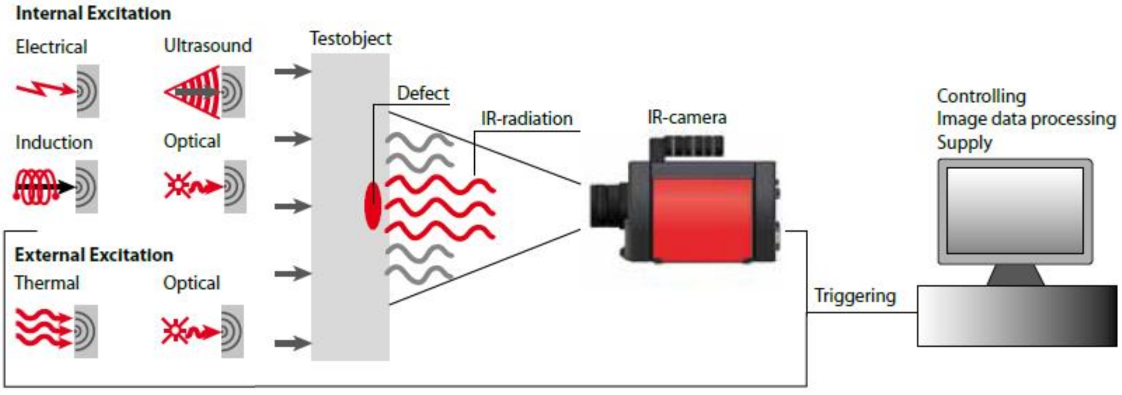

Figure 1. Setup of Active Thermography (InfraTec 2012)

Vibration monitoring

Vibration signature analysis (VSA) is a widely used condition monitoring technique to determine the overall condition of a machine, (Shrivastava, *et al*., 2012) which is based on measurement of vibration severity of the machine under test. Every machine in its working condition produces a vibration and this vibration is a characteristic signature of the machine which does not change over time. However, in cases of structural or functional anomaly or failure, the dynamic characteristics of the machine change which are reflected in its vibration signals. Once an acute vibration signature has been recorded for a machine in good condition it may be used as a baseline to compare with subsequent vibration records taken at prescribed intervals (Acharya, *et al*., 2009). By using various signal analysis techniques one can determine the exact category/type of fault.

Condition motoring of conveyor belts in mines.

Conveyor systems are widely used in both surface and underground mines for the transportation of broken mineral ores. Despite having various configurations, they share certain characteristics that make them suitable for condition monitoring.

Belt conveyor systems generate certain and predictable vibration signatures when operating correctly at various speeds and loading. These vibrations are primarily produced by motors, gearboxes, idlers, pulleys and other mechanical devices used to translate the constant rotational energy of the motors to the varying linear energy required for conveyor operation.

Traditional means of collecting vibration data from conveyors involves using vibration analysers. While this method is accurate, it has drawbacks in a mining environment in that it involves sending personnel to physically collect data at a working conveyor belt.

This scenario exposes the personnel to a lot of risks such as unexpected entanglements in moving parts of the conveyor. Additionally, the traditional method's lack of real-time, constant monitoring makes prediction of equipment failure difficult.

In order to address these challenges, a condition monitoring system, connected to vibration sensors located at various points along the belt conveyor system, delivers continuous data on the conveyer operation and provides constant understanding of the asset's health. Only the most critical components, such as large motors, gearboxes, important roller bearings, and main idlers and pulleys are monitored.

The condition monitoring system's PC-based monitor presents detailed information of the conveyor system status to mining operations personnel, thereby allowing predictions to be made concerning operation of the conveyor belt. Application of condition monitoring to the conveyor belt enables mine operators to address timely predicative failures thereby improving overall mine productivity.

Overall Equipment Effectiveness (OEE)

The strategic outcome of condition monitoring of equipment is the reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually (Gosavi, 2006). Overall equipment effectiveness (OEE) methodology incorporates metrics from all equipment manufacturing states guidelines into a measurement system that helps manufacturing and operations teams improve equipment performance and, therefore, reduce equipment cost of ownership (COO). Condition monitoring of equipment can also employ OEE as a quantitative metric for measuring the performance of a production system. OEE is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality products (Dal, *et al*., 2000; Ljungberg, 1998):

OEE = Availability (A) * Performance efficiency (P) * Rate of quality (Q) (1)

where:

Availability (A) = $\frac{Loading\ time - Downtime}{Loading\ time} * 100$ (2)

Performance efficiency (P) = $\frac{Processed\ amount}{Operating\ time\ /theoretical\ cycle\ time} * 100$ (3)

Rate of quality (R) = $\frac{Processed\ amount - Defect\ amount}{Processed\ amount} * 100$ (4)

This metric has become widely accepted as a quantitative tool essential for the measurement of productivity in manufacturing operations (Samuel, *et al*., 2002).

Conclusion

A critical look at most mining operations shows that a large number of companies still rely on break down maintenance as a major approach to maintaining their equipment.

Condition monitoring of mining equipment and plant can result in increased equipment availability due to predictive maintenance that allows mine operators to have knowledge about pending break downs or machine failure. Furthermore, condition monitoring leads to increased and predictable machine output, quality performance, efficiency and effective utilisation of labour. Condition monitoring also helps to avoid catastrophic failure of mine equipment and plant hence preventing accidents.

Therefore, application of condition monitoring can substantially enable mining firms to raise their productivity and remain viable even during times of depressed commodity prices by eliminating unwarranted costs associated with unplanned break down of equipment.

References

1. A. Shrivastava and S. Wadhwani, (2012) "Vibration signature analysis for Ball Bearing of Three Phase Induction Motor," IOSR Journal of Electrical and Electronics Engineering, vol. 1, no. 3, pp. 46 –50

2. A. Al-Habaibeh, F. Zorriassatine, N. Gindy (2002), Comprehensive experimental evaluation of a systematic approach for cost effective and rapid design of condition monitoring system using Taguchi's method. Journal of Material Processing Technology, 124 pp. 372–383.

3. Dal, B., Tugwell, P. and Greatbanks, R. (2000), "Overall equipment effectiveness as a measure for operational improvement: a practical analysis", International Journal of Operations & Production Management, Vol. 20 No. 12, pp. 1488-502.

4. Gosavi, A. (2006), "A risk-sensitive approach to total productive maintenance", Automatica, Vol. 42 No. 8, pp. 1321-30.

5. Kumar, S., Mukherjee P.S., Mishra N.M., (2005) "Online condition monitoring of engine oil", industrial Lubrication and Tribology, Vol. 57, No. 6, pp. 260.

6. Hurley, L. (1994), Infrared techniques for electric utilities. X.P.V. Maldague (Ed.), Infrared Methodology and Technology, Gordon and Breach Science Publishers, Great Britain pp. 265–317

7. Ljungberg, O. (1998), "Measurement of overall equipment effectiveness as a basis for TPM activities", International Journal of Operations & Production Management, Vol. 18 No. 5, pp. 495-507.

8. Poley, J., 2012, "The metamorphosis of oil analysis", Machinery Failure Prevention Technology (MFPT)

9. Newport, R.: Improving Electrical System Reliability with Infrared Thermography: Part 2. <http://www.electricity-today.com/et/june99/infrar.html>. 20th July, 2016

10. Samuel, H.H., John, P.D., Shi, J. and Qi, S. (2002), “Manufacturing system modelling for productivity improvement”, Journal of Manufacturing Systems, Vol. 21 No. 4, pp. 249-60.

11. Bagavathiappan, S., Lahiri, B.B., Saravanan, T., Philip J., Jayakumar T., (2013 “Infrared thermography for condition monitoring,” Infrared Physics and Technology, vol. 60, pp. 35 –55.

12. Acharya, S. K., Amalendu D., Gupta V.K., Anilkumar K.R., Bhattacharjee S., (2009) “Vibration signature analysis as a diagnostic tool for Condition Assessment of rotating equipment. Experience at TAPS,” Proceedings of the National Seminar & Exhibition on Non-Destructive Evaluation, pp. 56–63.

13. Turner, J.D. and Austin, L., 2003, "Electrical techniques for monitoring the condition of lubrication oil", Measurement Science and Technology, Vol. 14, pp. 794

14. Williams, J.H, Davies, A and Drake, P, R (1994) Condition monitoring, *Chapman Hall*, London

15. (World Bank, 2016) World Bank East Asia and Pacific Economic Update: Growing Challenges, Pp 49- 52

A Mine Design for Baluba Centre Limb East Fringe Area Between 495mL and 510mL Mining Levels From Structural Sections SS28E to SS30E Using Sublevel Caving

Olivia Malambo[1] and Bunda Besa[1]

Abstract

Although several mining softwares exist concerning underground mine design, they fall far short of what is truly required for a particular and specific underground mine being the ground characteristics and properties. Such properties are the geological, geotechnical, rock mechanics and geometrical characteristics of the ground which then determine the design parameters of that area.

This paper shows in detail the information on the ground characteristics and properties of Baluba mine's Centre Limb East Fringe area hence giving the detailed design standards and dimensions to be used with respect to Sublevel Caving mining method in the generation of a mine design. This design is to give an engineering procedure of mining the ore block in between 495mL and 510mL mined out levels of Baluba Centre Limb East (CLE) Fringe area. Also, this paper examines the economic viability of the design generated by determining the direct mining costs and profit to be realized.

This project was proven viable with the use of AutoCAD software to design a new mining level called 500m level in terms of development drives and stopes for exploitation with a capital investment of US$500 000 and total calculated costs US$456 987.63, hence generating US$6.4 million mining profit (surplus).

Keywords: *Underground, Sublevel Caving, Design standards, Mine design, Economic viability.*

1.0 Introduction

Underground mine designing is a process of planning and coming up with the best optimum engineering layout for underground workings and activities to be carried out so as to optimise production which will increase the profits but minimise the costs while maintaining safety standards as per jurisdiction. It involves artistic and scientific knowledge methods to carry out the different complex activities and processes to reach, extract and transport the ore (Mario, 2001). A mine design is defined as an engineering design layout of the entire mine subsystems and operations defining a complete mine structure and sequence of mining activities.

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In order to design a mine, the following must be taken into consideration; the geotechnical, geological and rock mechanics properties of the area which will help determine the design standards required for rock support, ventilation, transport, mine services and also the general safety and precautions (ZCCM, 1990). This project's purpose is to come up with a mine design using Sublevel Caving (SLC) mining method for Baluba Centre Limb East Fringe (CLE) area between the levels 495mL and 510mL from Structural Sections SS28E to SS30E which is going to provide all the necessary technical information on how to proceed with the exploitation of the ore reserves on the above mentioned section of the mine.

2.0 Problem Statement

Following the previous mining activities that took place at Baluba mine, it is evident that mining was not technically or safely done in some areas because the mine echelon was followed. This is shown by the existence of the large blocks of ore that remained in between voids created by the old mined out mining levels. These blocks of ore were not mined because of insufficient geological and geotechnical information that was given which could not be used in designing new mining levels in those areas at that time. This was as a result of few boreholes made in the area such that there was little information available to allow mining. Therefore, as exploration works continued, mining also continued on the levels below without following the standard mining echelon leaving unmined ore blocks above.

Due to the depletion of reserves at Baluba, there is need to find and mine the remaining ore reserves as well as those left out in between mined out areas, while finding safe and economic ways of mining them. It is for this reason that this research project was proposed.

3.0 Objectives

The **main objective** was;

- To generate a mine design for Baluba Centre Limb East Fringe area between 495mL and 545mL mining levels from Structural Sections SS28E to SS30E using Sublevel Caving mining method.

The main objective was achieved through the following **sub-objectives** and these were;

1. To create and design a new mining level called 500mL.
2. To evaluate and determine whether the design was economically viable.

4.0 Methodology

In order to achieve the objectives stated earlier, various methodologies were applied. The methodologies used for each of the objectives are outlined below.

To design a new mining level called 500mL, a mine design had to be made using the Baluba mine design standards to develop mining drives and stopes. This was dependent on the mining method to be used being the SLC mining method. The AutoCAD software was used to make the engineering design of 500mL which included the developments and stopes to be made. The old plans and sections were of input to the design.

Finally, to determine the economic viability of this project, cost analysis of the direct costs to be incurred for 500mL were carried out. Such costs include; labour costs, support costs, mucking and production costs, drilling costs and blasting/explosive costs. The expected Revenue was calculated as a product of; recovery, grade, ore tonnage and the metal price per tonne. Then the profit was calculated subtracting total costs from the revenue. The project profitability indicators were also used to determine the projects economic viability through the discounted cash flow criteria and non-discounted cash flow criteria.

5.0 The 500mL Centre Limb East Fringe (CLE) Design

To design 500mL (CLE), the Baluba ground characteristics were collected. These are shown in Table 1. Figure 1 shows the Baluba ore body model to be extracted. Using mine design softwares Gemcom and AutoCAD, paper level plans and section drawings, the design for 500ml CLE was made. This was done by the addition of the developments and stope outlines placed over the ore inventory, previously defined by the mine geologist using the Gemcom software hence making a complete mine design layout using AutoCAD. For this 500ml CLE to be designed, the drilling and blasting layouts were made using structural sections, the grade and tonnage were then calculated, including an estimate for ore recovery and ore dilution.

5.1 Standard Dimensioning and Design

The dimensions and layout of the developments and excavations made for 500mL CLE were with respect to Sublevel Caving mining method and are exclusive to Baluba mine only hence are as follows;

All the drives, being haulages, footwalls, crosscuts and cone drives, have the dimensions of 3.4m height x 3.2m floor width giving an end size of 10.88m^2 face area as shown in Figure 2. The standard distance between crosscuts is a range between 15 – 20m apart. The shorter distance being 15m is preferred in areas of stronger ground with less or no previous old developments nearby.

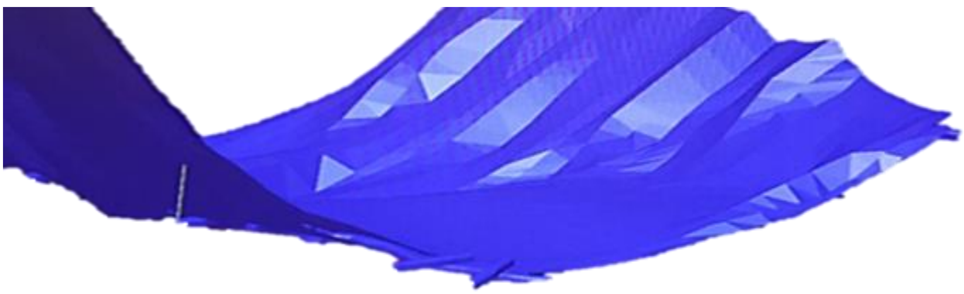

Figure 1. Baluba ore body.

Table 1. Baluba ground and ore body characteristics.

PARAMETER	FOOTWALL		ORE BODY		HANGINGWALL	
	VALUE	COMMENT	VALUE	COMMENT	VALUE	COMMENT
ROCK TYPE		Conglomerate schist		Argillites		Dolomitic schist
RQD VALUE	87%	Good	93%	Very good	89%	Good
RQD RATING	14	Good	14	Good	14	Good
U.C.S	74	Weak	101	Moderately strong	70	Weak
MRMR	67	Fair – good	70	Moderately strong	68	Fair – good
RMS	44	Weak	60	Good	44	Weak
Deposit shape	Irregular but trough form					
Deposit thickness	7.5 to 20m					
Deposit dip/ Dip Direction	55^0 - 0^0 / SE					
Depth	602m					
Grade	2.05 %					

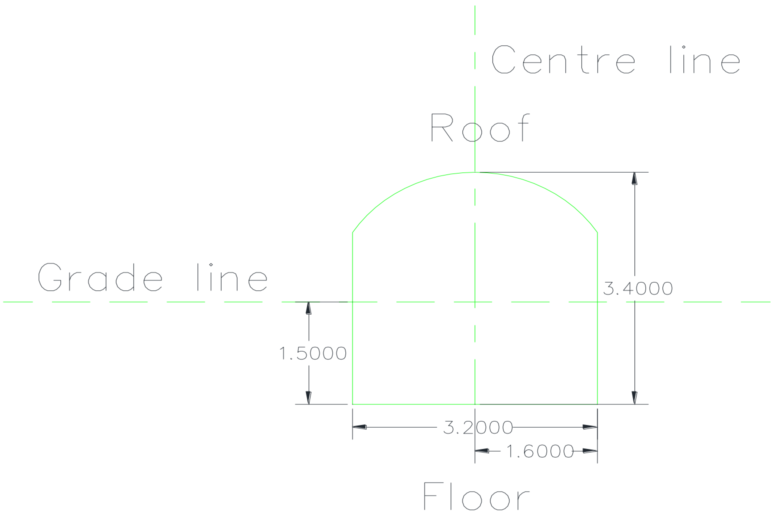

Figure 2. Front elevation of a 3.2 × 3.4m development end.

In areas of weak ground, the distance between the crosscuts is increased to either 18m or 20m. The standard distance between the footwall and the cone drive is 18m – 20m. 18m is used in competent ground areas and this shortens the lengths of the crosscuts in between hence cost reduction is experienced. In the case of weak ground, 20m is chosen and the converse is also true. Figure 3 shows a plan view of the standard dimensions of the footwall, crosscut and cone drive. The clearance from a new development should not be less than 6m radius to another development whether new or an old existing one. For the ease and effective manuverability of trackless heavy equipment such as LHDs, the gradient of any development should not be more than $8^0$0’0’’ up-ramp and not less than -$8^0$0’0’’ down-ramp and the turning radius should not be less than 90^0 internal angle either clockwise or anticlockwise.

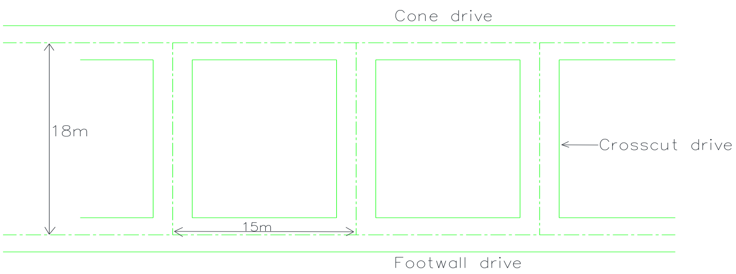

Figure 3. Plan view of the standard dimensions of the drives.

For all types of raises such as slot or ventilation raises, the standard diameter is 1.8m but varies for ventilation raises depending on the amount of ventilation required in an area. In stoping and production, the size of the stope is not standard but depends on the ore body thickness, boundary, dip and the grade of the ore present. The perimeter of the stope follows the outer stoping long holes that are drilled at a dip angle more than the angle of repose of the material in order to allow the flow of blasted material by gravity. All the stope holes are drilled dipping at $45^0 – 60^0$. The outer holes give the stope profile and form a cone shape as the draw point. In steeply dipping ore body, the crown pillar of 3m width is left in between stopes. For the same purpose, in flat ore bodies, rib pillars of 3m width are left. The cone drive is marked with stope rings for production. The ring burden is 2m with the drill hole spacing (toe burden) of 2.4m with the lower and upper limits being 1.9m and 2.9m respectively if using a 76mm drill bit. If an 89mm drill bit is used, the toe burden is 3m with 2.5m and 3.5m as the lower and upper limits. The bulk density of the Baluba ground material is 2.67 t/m^3. With the mentioned dimensions and standards required for sublevel caving mining method, the 500mL CLE design was made using structural sections as shown in Figure 4 depicting drive 3 of SS28E as an example. Furthermore, the detailed plan view of the whole 500mL CLE is shown in figure 5. The green outlines indicate the 500mL CLE developments while the purple outlines indicate the 500mL stopes. Also, the 3D model of the 500mL CLE developments is shown in 3 planes in green colour in Figure 6.

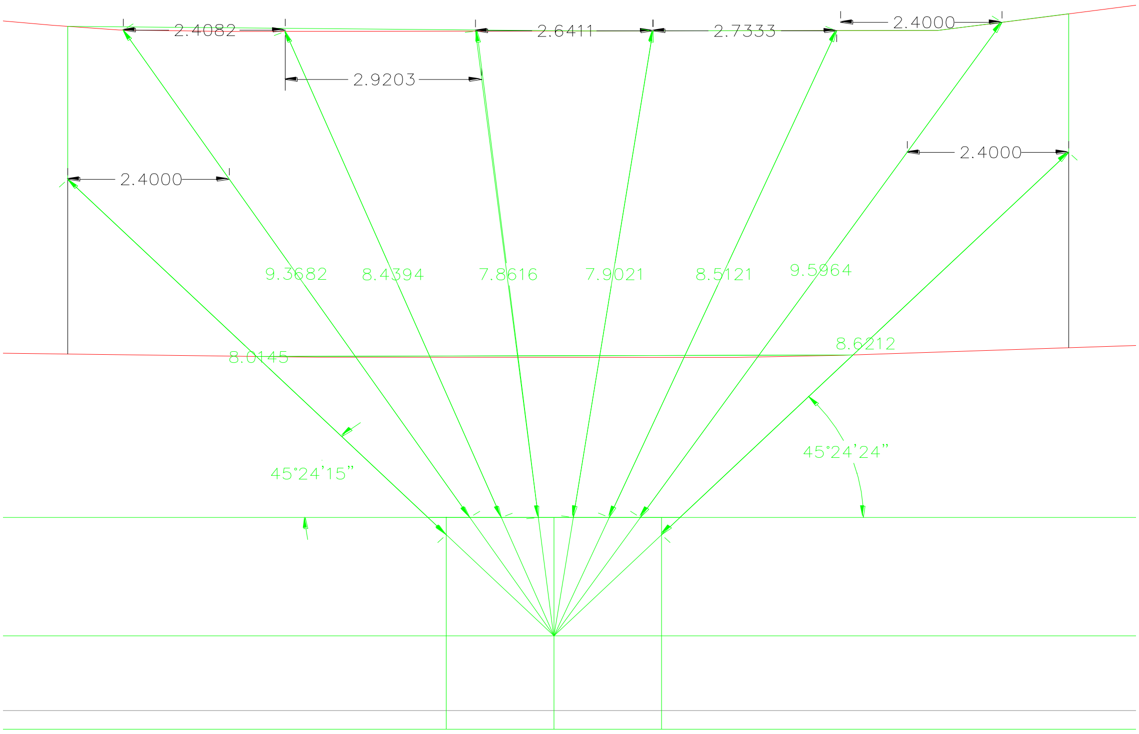

Figure 4. Example of a structural section used to design.

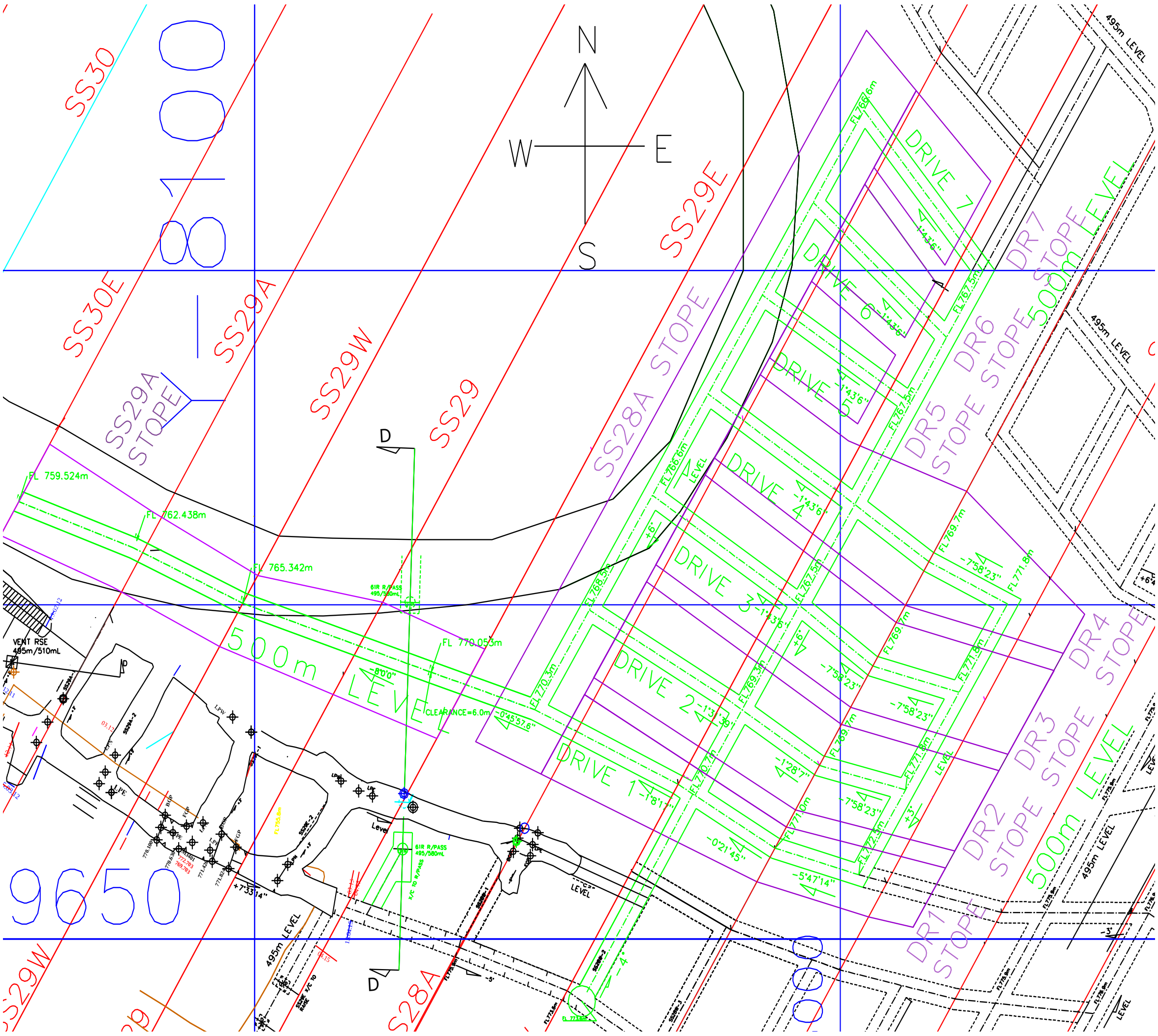

Figure 5. The 500mL (CLE) developments and stopes plan design.

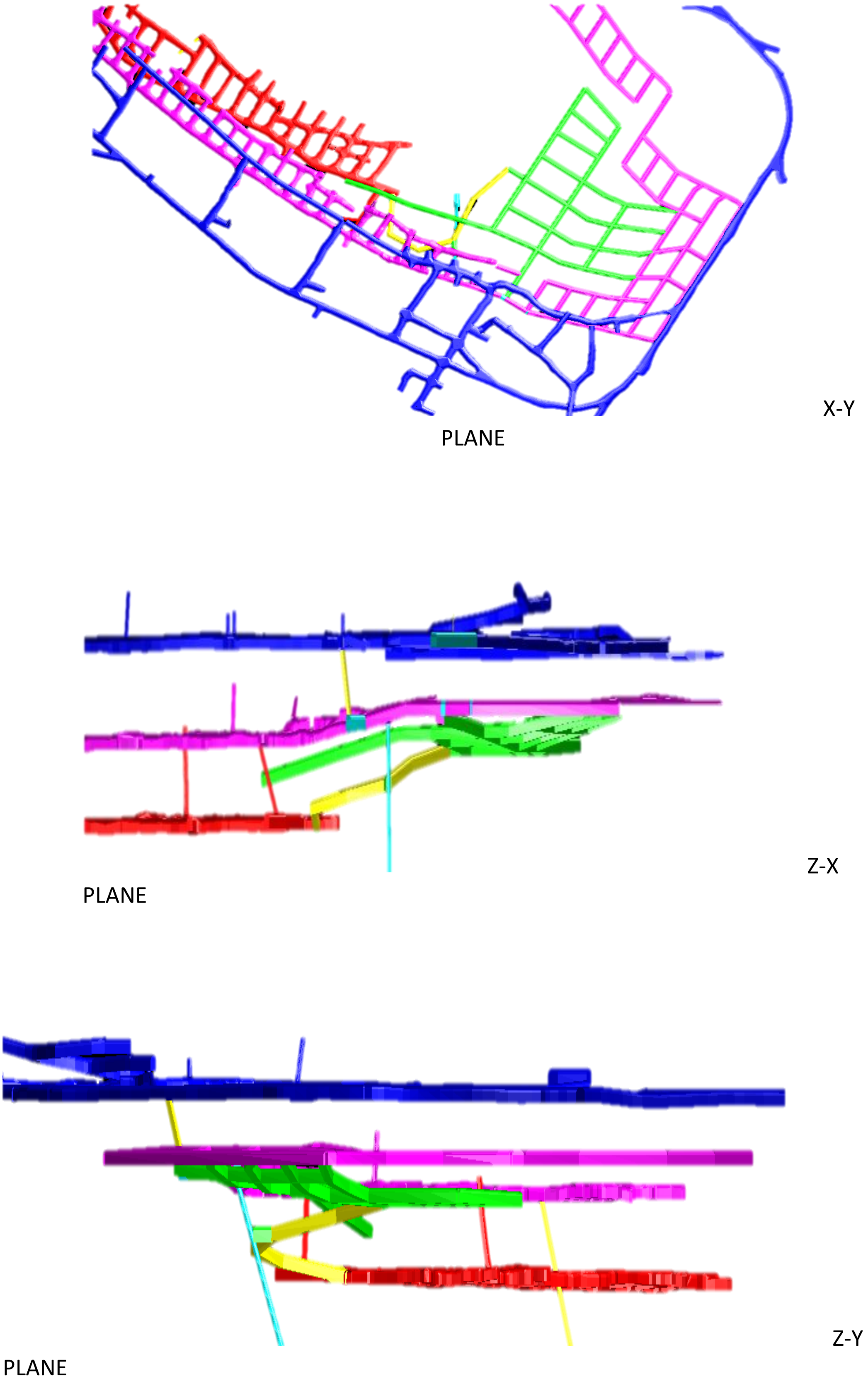

Figure 6. The 500mL CLE developments in 3D model in three planes.

Figure 7 shows the complete 500mL CLE 3D model with the developments in maroon colour below the blue ore body as depicted.

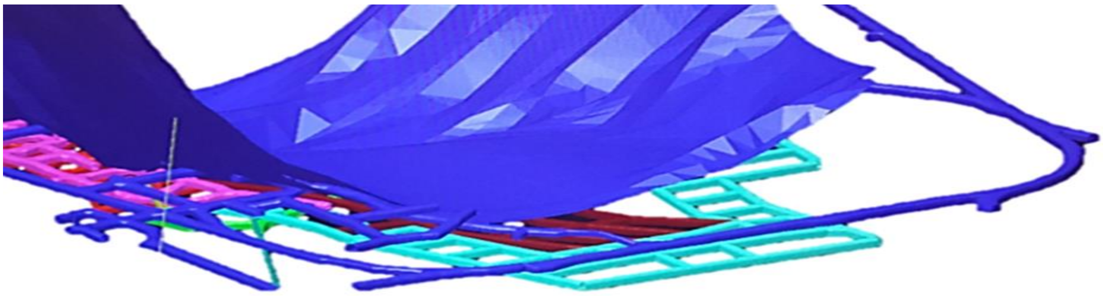

Figure 7. The 500mL CLE 3D model.

Using the relationships expressed below, the stope tonnage details as well as dilution were calculated and the results are shown in Table 2. The design has 9 stopes and has a total length of the development drives of 683m with a total block tonnage of 130107.69t.

Table 2. Stope and tonnage details for 500mL.

STOPE	SECTIONS	AREA		STRIKE LENGTH	TONNAGE		TOTAL TONNAGE	GRADE (%)	DILUTION
		WASTE	ORE		WASTE	ORE			
	SS 28E	25.2039	58.6084						
DRIVE 1	SS 28	20.5086	55.323						
	SS 28W	31.0482	47.9336						
		25.5869	**53.955**	**67.4941**	**4 610.99**	**9 723.19**	**14 334.18**	**2.25**	**32%**
	SS 28E	26.7323	63.7166						
DRIVE 2	SS 28	22.0208	80.9131						
	SS 28W	27.1261	74.3561						
		25.29	**72.99**	**67.8885**	**4 584.68**	**13 231.29**	**17 815.97**	**1.91**	**26%**
	SS 28E	27.086	68.5916						
DRIVE 3	SS 28	16.3718	68.9574						
	SS 28W	24.1506	69.8261						
		22.54	**69.125**	**67.8634**	**4 084.14**	**12 525.13**	**16 609.27**	**1.98**	**25%**
	SS 28E	28.2549	55.0515						
DRIVE 4	SS 28	36.67	93.7993						
	SS 28W	26.8137	71.6989						
		30.58	**73.52**	**66.21**	**5 406.36**	**13 000**	**18 406.36**	**2.1**	**29%**
DRIVE 5	SS 28W	**33.7885**	**68.0339**	**18.0009**	**1 623.96**	**3 269.87**	**4 893.83**	**2.02**	**33%**
DRIVE 6	SS 28W	**36.3628**	**50.7132**	**18.2515**	**1 772.01**	**2 471.33**	**4 243.34**	**2.21**	**42%**
DRIVE 7	SS 28W	**62.2857**	**60.3312**	**18.8966**	**3 142.56**	**3 043.95**	**6 186.51**	**1.84**	**51%**
	DR 1	47.8574	58.7589						
	DR 2	43.3007	70.5569						
	DR 3	30.5756	69.6535						
SS 28A	DR 4	22.4306	64.283						
	DR 5	22.7103	66.7316						
	DR 6	26.1936	62.9255						
	DR 7	38.109	59.048						
		33.0253	**64.5653**	**107.5312**	**9 481.84**	**18 537.25**	**28 019.09**	**2.1**	**34%**
	SS 30E	30.8984	100.5634						
	SS 29A	15.6669	63.3403						
SS 29A	SS29WX/C	15.208	38.6322						
	SS 29	35.9489	83.0487						
	SS 29E	17.3064	51.7371						
		23.0057	**67.4643**	**81.1374**	**4 983.89**	**14 615.25**	**19 599.14**	**2.07**	**25%**
GRAND TOTAL					**39 690.26**	**90 417.26**	**130 107.69**	**2.05**	**31%**

Tonnage calculations

Tonnage = Average area × strike length × bulk density

= block volume $(\mathbf{v})$ × 2.67t/m^3

= 2.67$\mathbf{v}$

Dilution calculation

$$dilution\ (\%) = \frac{total\ waste\ tonnage}{total\ ore + waste\ tonnage}$$

Recoverable ore tonnage

Recovery estimated as 80% of the ore tonnage being the lowest recovery acceptable.

= 80% × 90417.26 tonnes

= **72 334 tonnes**

Total amount of explosives required = 94 723 kg

6.0 Economic Analysis

A mining company's first concern is keeping its costs below the prevailing price of that metal being mined and in this case being the copper metal. The copper industry uses several cost measures; the most common are operating costs. According to the International Financial Reporting Standards (2007), Operating costs are "the physical costs of producing copper which are the direct and indirect costs incurred in mining, concentrating, smelting, and refining copper. They include transportation to the mill, smelter, and refinery, and metallurgical processing of the byproducts."

According to ZCCM Volume E (1990), operating costs for the purposes of this report for Baluba are defined as "the direct mining costs incurred in the mechanical process of extracting the ore from a particular block of ground. The processes include all development entailed in gaining access to that block of ground from the main ramp"

Note that: This economic analysis only includes mining costs and is highly exclusive of the milling, processing and other further metallurgical processes costs. This implies that the calculated profit is just a surplus to be realised without subtracting mineral processing costs, mineral royalty and mining tax. The parameters and costs discussed in this chapter were taken and considered for the economic environment and material prices as at 31st August, 2015 with the exchange rate of the Zambian Kwacha to the US Dollar being at K8.6474 = US$1.00 obtained from the Bank of Zambia and the copper price being US$5127.30/tonne at the London Metal

Exchange market. The production project duration is 7 months hence **n** = 7/12 = 0.583years with the interest rate being ***i*** = 15%. The mining recovery taken as an assumption to be 80% while the milling recovery taken as 90% and the copper grade is 2.05% Cu. Indirect costs are 25% of the direct costs. The results are given in tables 3 and 4.

Table 3. Total direct mining costs for 500m level.

TYPE OF COST	**COST (US$)**
Labour	78 011.92
Drilling	10 422.00
Charging and blasting	183 275.10
Mucking	34 536.97
Support	58 566.00
Secondary blasting	778.10
TOTAL DIRECT COSTS	**365 590.10**

INDIRECT COST = 25% direct costs

= US$91 397.53

TOTAL COST = direct cost + indirect cost

= 365 590.10 + 91 397.53

= US$456 987.63

REVENUE = (mining recovery × mill recovery × grade × ore tonnage × Cu price)

= US$6 842 683.12

SURPLUS = Revenue - Total cost

= US$6842683.12 - US$456 987.63

= US$6 385 695.50

PRESENT VALUE = $PV = \frac{F}{(1+i)^n}$

= US$5 886 015

Table 4. Profitability indicators for 500m level.

PROFITABILITY INDICATOR	RULE	RESULT	COMMENT
NPV (Net Present Value) NPV = PV $[\frac{1-(1+i)^{-n}}{i}]$ – CP	NPV > 0 accept NPV < 0 reject	US$4 925 434.487	**Accept**
IRR (Internal Rate of Return) IRR = $\boldsymbol{i}$ for NPV = 0	IRR > $\boldsymbol{i}$ accept IRR < $\boldsymbol{i}$ reject	67.67%	**Accept**
PI (BC) Profitability index (benefit cost ratio) PI (BC RATIO) = $\frac{PV}{CP}$	PI > 1 accept PI < 1 reject	12	**Accept**
PB (Payback Period) PB = $\frac{CP}{PV}$	Short PB = accept Long PB = reject	1 month	**Accept**
OVERALL COMMENT		**ECONOMICALLY VIABLE**	

7.0 Conclusion

The main objective of this study was to generate a mine design for Baluba Centre Limb East fringe area between 495mL and 510mL mining levels from structural sections SS28E to SS30E, which was successfully met with the help of the two sub-objectives stated at the beginning leading to the design and creation of a new mining level called 500mL CLE.

The 500mL CLE design has a total length of development drives 683m and is divided into 9 stopes with a total tonnage of 130 107.69 tonnes of which 90 417.26 tonnes is ore and 39 690.43 tonnes being waste rock. With an estimation of 80% recovery, the expected recoverable ore is 72 334 tonnes with 31% as the planned and expected dilution.

With the economic analysis carried out being exclusive to mining only, 500mL CLE design was proven economically viable with a mining investment of US$500 000, total mining costs US$456 987.63 and revenue US$6 842 683.12, hence generating US$6 385 695.50 mining surplus. The total duration for the project is 10 months for 3 months is preparatory and development works and 7 months is for stoping and production.

Therefore, this project has given the engineering layout and procedure of mining the left behind ore body block between 495mL and 510mL through the creation of a new optimum engineering mine design called 500mL CLE as a new mining level to exploit the mineral block technically and economically sound with maximum safety.

8.0 Recommendations

1. The necessary geological, rock mechanics and geotechnical information for Baluba Centre Limb East fringe area should be obtained and well defined far before mining operations are to begin so as define the ore body and ground properties correctly and hence generate a proper mine designs that follow the mining echelon sequence hence leaving no unmined blocks of ore between mined levels.

2. To improve and increase the mining recovery as well as reduce dilution, collar blasting should be practiced. Collar blasting is the technique of separate blasting of ore and waste of the Sublevel Caving mining method. This is done by first charging the stope holes from the back of the stope at the hanging wall contact to the ore and waste contact and then stem and blast the holes. This will only blast the ore leaving the waste intact and hanging. The ore is then mucked and hence using the same stope holes, charge and blast the remaining waste block and hence muck it separately. This is an improvement in the ore sorting parameter in sublevel caving.

References

1. Financial reporting in the mining industry. (2007). **International Financial Reporting Standards.** https://www.pwc.com>pdf>ifrs-mining.

2. Mario, A. M. (2001). **Underground Hardrick Mine Design and Planning – A System's Perspective**. Queens University Kingston: Ontario. pp 9 – 10.

3. ZCCM limited technical services (1990). **Baluba Centre and South Limb Study Volume C, Geology Mining and Rock Mechanics**. Technical and procurement services limited (techpro): Baluba, Luanshya. pp C100 – C120.

4. ZCCM limited technical services (1990). **Baluba Centre and South Limb Study Volume E, Economic Analysis**. Technical and procurement services limited (techpro): Baluba, Luanshya.

A Tool for Designing Small-Scale Stand-Alone Photovoltaic Plants

Dingiswayo Chilumbu[1] and Ackim Zulu[2]

Abstract

Solar photovoltaic (PV) systems are becoming acceptable full or partial options for providing energy to areas which are remote from the grid. A readily available process for designing small-scale stand-alone PV systems based on user requirements helps users to take command of the system they may need accounting for factors such as availability and cost. This paper presents a computer-based tool developed in the visual-basic environment that can be used to design a stand-alone PV system. The tool has been developed from design equations for sizing of load, system battery and PV array and estimation of cost. The developed tool has features of a friendly graphical user interface and can be articulated by a user with little or no knowledge of engineering. In this version, flexibility has been built in for interaction with the user for adjustment of the types of PV modules, batteries, and system availability. The results for the test case are in agreement with the step-by-step manual design applied by a design engineer.

Keywords: Computer tools, cost estimation, off-grid systems, photovoltaic, programming, renewable energy.

1. Introduction

There are calls from many sectors of communities, government inclusive, to take development to all parts of the country. One of the modern indicators of development is the availability of affordable and clean energy (World Bank, 2016). The government of Zambia, through the Rural Electrification Authority (REA), has planned to electrify rural areas so that citizens of rural areas are carried along with the development agenda (MEWD, 2009). REA explores various avenues and systems to determine appropriate power solutions for a particular area. Among the feasible energy solutions are solar PV stand-alone systems and grid extension. Taking into account economic considerations, Solar PV stand-alone system is one of the most viable solution as a large proportion of people in rural areas cannot afford electricity bills that may come with grid power. In considering solar power as an option, there is also the attendant relief that may be provided on the usage of grid power in the wake of the current reduction of hydropower generation from sources such as Kariba North Bank power plant which is fed from Lake Kariba (EIZ, 2015).

Zambia is one of the regions in the world with one of the highest availability of the solar resource (IRENA, 2013). The average insolation over the surface of Zambia is 5.5 kWh/m^2/day, with about

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3000 sunshine hours annually. This situation provides high possibilities for PV power plants. Implementation and uptake of PV technology for provision of energy throughout Zambia is reportedly low (Mwansa *et al*, 2015). One reason for this situation is the apparent complex issues encountered by prospective clients to relate their energy requirements to the correct size of the system. Presently, this decision is the preserve of skilled engineers and technicians. As solar PV stand-alone systems become acceptable as full options for providing energy in areas remote from the grid, there is need to have a ready-process for designing a solar PV stand-alone system starting from a user's requirements. There have been previous similar efforts to produce such a computer tool with area-specific application (Ali and Salih, 2013), but the product of the work presented in this paper can be applied almost world-wide.

This paper presents the development of a process for designing a PV standalone system. A computer program is developed using Microsoft Visual Basic. The computer program has interface features which can be articulated by one with little or no knowledge of the underlying engineering principles for PV design but in the end produces a credible PV design output. The paper firstly describes the main components of a conventional PV stand-alone system, and then introduces the principal mathematical relationships for sizing or selecting the components. Following this, the visual basic (VB) computer environment is introduced before describing the algorithm as employed in the VB programme to implement the design of stand-alone PV system. Before the conclusion and recommendations are presented, test results of the use of the program are provided, with an indication of the comparison of the results from a manual process that may be followed by a skilled practitioner.

2. PV Stand-alone Systems

PV systems are generally employed as on-grid or off-grid system. The off-grid form normally subsists as a stand-alone PV system. A solar PV stand-alone power system has the most benefits in remote or rural areas where it exerts its advantages in economy, space utilisation and environmental considerations.

Solar PV stand-alone system mainly consists of the three components: the PV array, the battery bank, and the inverter-charger, as depicted in Figure 1. When there is sunlight, the PV array converts light energy into electrical energy in the DC form. The DC power is used to charge the batteries and an inverter is used to convert the DC voltage of the battery to conventional household AC form which can be fed to AC loads. Stand-alone renewable energy systems based on the PV technology with battery storage system are beginning to play an important role in supplying power to remote areas or grid-isolated areas.

2.1 PV Cell

The PV module consists of individual PV cells that generate DC electrical voltage from the action of sunlight. When the surface of the thin wafer of the cell is struck by photons, the electrons are knocked loose from the atoms in the semiconductor material creating, electron-hole pairs. If conductors are connected to the positive and negative sides, an electrical circuit will form, and electric current (photocurrent) will flow. There are three basic types of common commercial solar cells, named on the basis of the technology employed: monocrystalline silicon, polycrystalline silicon and amorphous silicon (Ali and Salih, 2013).

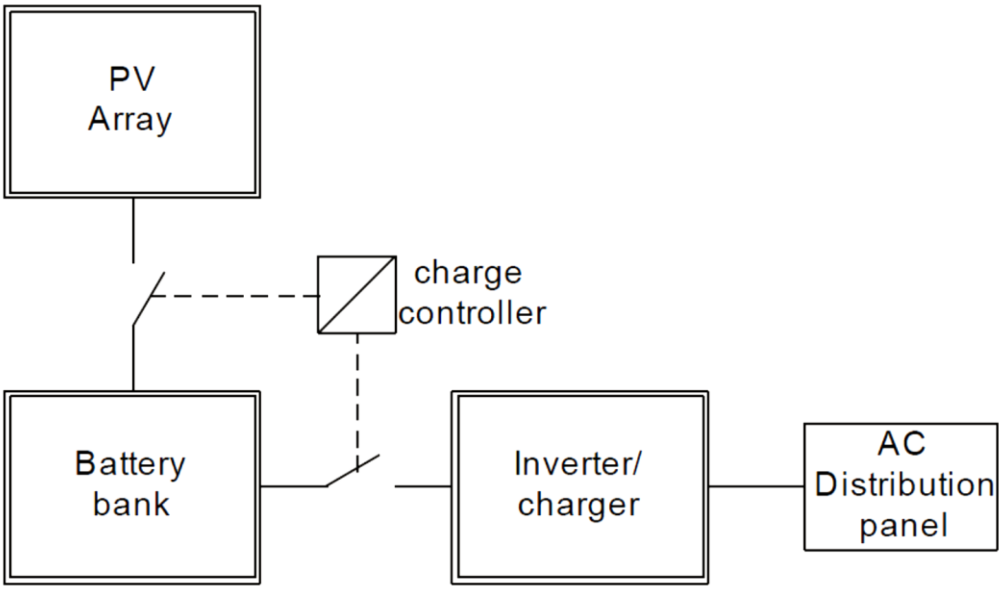

Fig. 1: Stand-alone PV architecture

2.2 Battery Storage

Stand-alone systems require some method to store energy collected during times of sunshine. Any of the current storage technologies of flywheel, compressed air and hydrogen can be employed for energy storage but the most widely-used and most economical technology for PV application is that which uses batteries.

The battery stores electrical energy for use during times when sunlight is not available or for meeting loads during the day when the modules are not generating sufficient power to meet load requirements. To provide electricity over long periods, PV systems require the so-called deep-cycle batteries, which are different from the common shallow-cycle batteries used in automobiles. Deep-cycle batteries, usually of lead-acid type, are designed to discharge and re-charge up to 80% of their capacity several hundreds of times (Masters, 2004).

2.3 Inverter-charger Component

While batteries store electrical energy in form of DC and have a low voltage output, not exceeding 4 V per cell in the current technology, nearly all appliances in Zambia operate on AC at 240 V, 50 Hz. A device, in the form of an inverters that changes DC to AC is therefore needed. Inverters are often categorized according to the type of waveform constructed by the switching devices (thyristors or transistors), and present three main categories, namely (Mohan *et al*, 2003):

- square wave
- modified sine wave
- sine wave

Of the three types, the sine wave category is capable of producing a high quality sine wave comparable to the waveform of utility power. For the two other categories, some form of filtering may be need to remove certain unwanted frequencies and spikes, if the load so demands.

2.4 Auxiliaries

For smooth operation of the PV system other auxiliary components may be added to the system. A charge controller may be employed in the stand-alone PV system to control the state of charge of the batteries, prevent over charging or under charging and over discharging of the batteries.

The Solar PV stand-alone system may also include the following parts: grounding system, fuses, safety disconnectors, metal structures for supporting the modules, power factor correction system, blocking-diodes which prevent back flow of current, bypass diodes which are connected across several cells to limit the power dissipated in shaded cells, and additional devices that are used to ensure optimal or proper operation, such as for monitoring and metering (Masters, 2004).

3. The Design Process

The design process for a stand-alone PV system involves the application of thoughtfully-derived mathematical expressions which relate various parameters of the system. The process also involves invocation of good engineering judgment as used in best practices and application of well-defined assumptions. The presentation in the following sections describes treatment of each stage of the design and also shows the basis for sizing each part of the system.

3.1 Load Analysis

Estimating the size of the load to be served is the first step in the design process. Choosing on whether to go with the all-DC load or all-AC loads or a combination of both DC and AC loads, has an impact on the efficiency and cost of the system. While the all-DC system incorporating loads which operate directly on DC presents the simplest system, the all-AC system gives the closest imitation of the conventional system where ordinary appliances may be obtained from existing channels. In this work, it is taken that the loads would use conventional AC power.

In sizing the amount energy for the load that will run from the AC power source, the energy (watt-hours or kilowatt-hours) consumed by a device is calculated as the product of the nominal power rating of the device and the hours that it is in use.

The following formulae, indicated in (1)-(4), are used for load estimation:

$$\text{AC load} = \sum \left(\text{power of each AC appliance} \times \text{no. of units} \times \text{daily run time}\right) \tag{1}$$

$$\text{DC load} = \sum \left(\text{power of each DC appliance} \times \text{no. of units} \times \text{daily run time}\right) \tag{2}$$

$$\text{Total DC load [Wh per day]} = \text{DC load [Wh per day]} + \frac{\text{AC load [Wh per day]}}{\text{Inverter efficiency}} \tag{3}$$

$$\text{Total load [Ah per day at system volatge]} = \frac{\text{Total DC load [Wh per day]}}{\text{System voltage [V]}} \tag{4}$$

3.2 Battery System Sizing

The process of battery sizing requires providing enough energy storage to carry the load through the periods of absence of sunlight. Sizing a storage system to meet the demand 99% of the time can cost up to triple that of one that meets demand only 95% of the time (Masters, 2004). In this sense, the choice of the value of availability to be used in the design equations is critical.

3.2.1 Battery storage capacity

Energy storage in a battery is given in units of ampere-hours (Ah) at nominal voltage and at a given discharge rate. The ampere-hour capacity depends on the rate at which the current is drawn and the prevailing temperature. Fast discharge of a battery can result in lower Ah capacity, while long discharge times can result in higher Ah capacity. Deep-cycle batteries intended for photovoltaic systems are often specified in terms of their 20-hr discharge rate (C/20), which is more or less a standard, as well as in terms of a much longer C/100 rate that is more representative of how they are actually used (Masters, 2004). The equations in (5)-(13) are used to determine battery capacity.

As a starting point, curves are given for estimating the number of days to be provided for which can be approximated by

$$\text{Storage days (99\%)} \approx 24.0 - 4.73 \times (\text{peak sun hours}) + 0.3 \times (\text{peak sun hours})^2 \quad (5)$$

$$\text{Storage days (95\%)} \approx 9.43 - 1.9 \times (\text{peak sun hours}) + 0.11 \times (\text{peak sun hours})^2 \quad (6)$$

Then,

$$\text{Total storage capacity}\left(\frac{C}{20}, 25^\circ\text{C}\right) = \frac{\text{Usable battery capacity}}{\text{MDOD} \times (\text{T, DR})} \quad (7)$$

where MDOD and T,DR are the maximum depth of discharge (0.8 for lead-acid battery) and discharge rate factor, respectively.

$$\text{Usable storage capacity[Ah]} = \text{Storage days} \times \text{Ah rating per day} \quad (8)$$

$$\text{Minimum storage capacity[Ah]} = \frac{\text{Maximum load power [W]} \times 5\text{hr}}{\text{System voltage [V]} \times \text{maximum depth of discharge}} \quad (9)$$

The total number of batteries in series, N_{bs} is determined from

$$N_{bs} = \frac{\text{System voltage, } V_{dc}}{\text{Nominal battery voltage, } V_b} \quad (10)$$

from which the number strings of batteries in parallel, N_{bp} is determined as

$$N_{bp} = \frac{\text{Total storage capacity [Ah]}}{\text{Capacity of single battery [Ah]}} \quad (11)$$

Therefore, the total number of batteries, N_{bt} can be computed as

$$N_{bt} = N_{bs} \times N_{bp} \quad (12)$$

The actual battery capacity is then

$$\text{Actual battery capacity [Ah]} = \text{Ah per battery} \times N_{bt} \quad (13)$$

3.2.2 Battery efficiency

Three efficiency terms are applied to describe battery performance: coulomb efficiency, η_c, voltage efficiency and energy efficiency. The three efficiencies are defined by (5)-(7) below:

$$\eta_c = \frac{\text{Charge out of battery [C]}}{\text{Charge into battery[C]}} \quad (14)$$

$$\text{Voltage efficiency} = \frac{\text{Discharge voltage}}{\text{Charging voltage}} \quad (15)$$

$$\text{Energy efficiency} = \text{Voltage efficiency} \times \eta_c \quad (16)$$

3.2.3 Inverter

Sizing the inverter involves determining three parameters: the DC voltage rating at the input, the AC voltage rating at the output and the power capacity of the inverter. As a matter of guidance, the power rating of the inverter must exceed the maximum power for the total load, while the DC input voltage and AC output voltage are inferred from the nominal DC system voltage and the voltage rating of the AC load apparatus, respectively.

3.2.4 System voltage

In defining the system voltage, use is made of the inverter's dc input voltage, ac output voltage, continuous power handling capability, and the amount of surge power that can be supplied for brief periods of time. The inverter’s dc input voltage, which is the same as the voltage of the battery bank and the PV array, is then called the system voltage. The system voltage comes in standards of 12 V, 24 V, or 48 V. A widely applied guide, which takes into account the change of output current with a chosen system voltage, is the one shown in Table 1. In all cases the limiting current in the system is 100 A.

Table 1: System voltages

Maximum ac power (W)	**System dc voltage (V)**
<1200	12
1200-2400	24
2400-4800	48

3.3 PV Array Sizing

The product of rated current, I_R and peak hours of insolation provides a good starting point to estimate the Ah delivered to the batteries. A de-rating factor of 10% is applied to account for dirt and gradual aging of the modules. The month with worst insolation data is taken as a design month (Masters, 2004).

The following formulae in (17)-(20) are used for PV array sizing.

Design month’s Ah/day delivered per string is given by

$$\left[\frac{\text{Ah}}{\text{day - string}}\right] = \text{Insolation}\left[\frac{\text{hr}}{\text{day}}\right] \times I_R[\text{A}] \times \eta_c \times \text{derating factor} \quad (17)$$

The number of strings in parallel, N_{pvp} is

$$N_{pvp} = \frac{\text{Total load}\left[\frac{\text{Ah}}{\text{day}}\right]}{\left[\frac{\text{Ah}}{\text{day per module}}\right]} \quad (18)$$

and the number of PV modules in series, N_{pvs} is

$$N_{pvs} = \frac{\text{System DC voltage [V]}}{\text{Nominal module voltage [V]}} \tag{19}$$

from which the total number of module, N_{pvt} is found as

$$N_{pvt} = N_{pvp} \times N_{pvs} \tag{20}$$

3.4 Cost Estimation

The actual cost of the component should be used in the calculation of the total cost of a PV system. In the absence of actual data on component costs, the information in Table 2 can be used for preliminary estimates of total system costs, as of the current time.

Table 2: Cost estimation

Item	**Cost estimation**
Photovoltaics	\$0.55/W
Batteries: true deep-cycle-rolls surrette, 12PC-11PS, 357 Ah, 12 V	\$ 1,055/ battery
Batteries: true deep-cycle-Concorde PVX 1080, 105 Ah, 12 V	\$300/battery

PV module prices range from \$0.4/W -\$0.65/W. Thus an average value of \$0.55/W was used. Battery cost varies with model of the battery and its capacity as shown in Table 2. The values used in Table 2 are indeed just estimates.

4. Microsoft Visual Basic

4.1 Development of Graphical User Interface (GUI)

The GUI provides the user with special graphic or visual indicator, graphic icon, label or text to present to the user the information and actions that are available. In this work, Microsoft Visual Basic was used due to its wide availability and ease of use.

4.2 Visual Basic (VB)

Microsoft Visual Basic is a window programming language application based on the old Basic language. VB can be used to develop system in one package from simple to complicated ones. In VB will one can edit, write and test window applications. Besides these capabilities, VB also includes tools that can be used to write and compile help file, invoke active X control and even other internet applications. VB is an attractive software because it is a combination of graphic and code programming.

5. Design Approach

The initial approach to developing a tool for designing stand-alone PV systems requires determining the applicable mathematical relationships that link the inputs to the outputs. These relationships are shown in the discussion in Section 3.

Part of the information required to design a stand-alone PV system includes the following: electrical load requirements, autonomy days, peak sun hours and temperature effect. It was assumed that the user would use a fixed orientation of PV panels but the use of maximum power point tracking (MPPT) would increase the yield of the power generated from the system, and may not be ruled out. Using a fixed orientation, the solar panels must face North at an inclination of from 0-60° if the location is in the Southern hemisphere. For the regions in Zambia, peak sun hours would be taken as 5.19 hours/day.

6. The Computer Program

6.1 Program Plan

The purpose of the computer program is to design a solar PV stand-alone system from user requirements. The interface has to have functionalities where the user would enter different loads to be powered (load sizing worksheet), an interface for battery sizing and an interface for PV sizing. Others are: code to calculate the total daily load to be powered (load analysis), code to do PV array sizing (determine number of modules required in both series and parallel, hence total number of modules), code to do battery sizing (determining the number of batteries required in both series and parallel, hence total number of batteries) and the code to do cost estimation.

6.2 Components of the Program

Four forms were used in the program for load sizing, battery sizing, PV array sizing and cost estimation.

For navigating through the program, that includes "next" buttons for sequencing calculations and moving to next form; previous buttons to enable user to move to the preceding form in case the user wants to make changes to the entered data.

"Labels" contain information that advise the user. The input area is articulated in "text boxes" while "Picture boxes" also provide an input area and also enhance the appearance of the interface.

6.3 Program Logic

The design process is iterative. A number of iterations for a design are carried out until satisfactory results are obtained. A number of parameters can be adjusted while searching for a satisfactory design.

Using this approach and applying the formulae given in the previous sections, a computer program was developed, based on the logic flow of Figure 2.

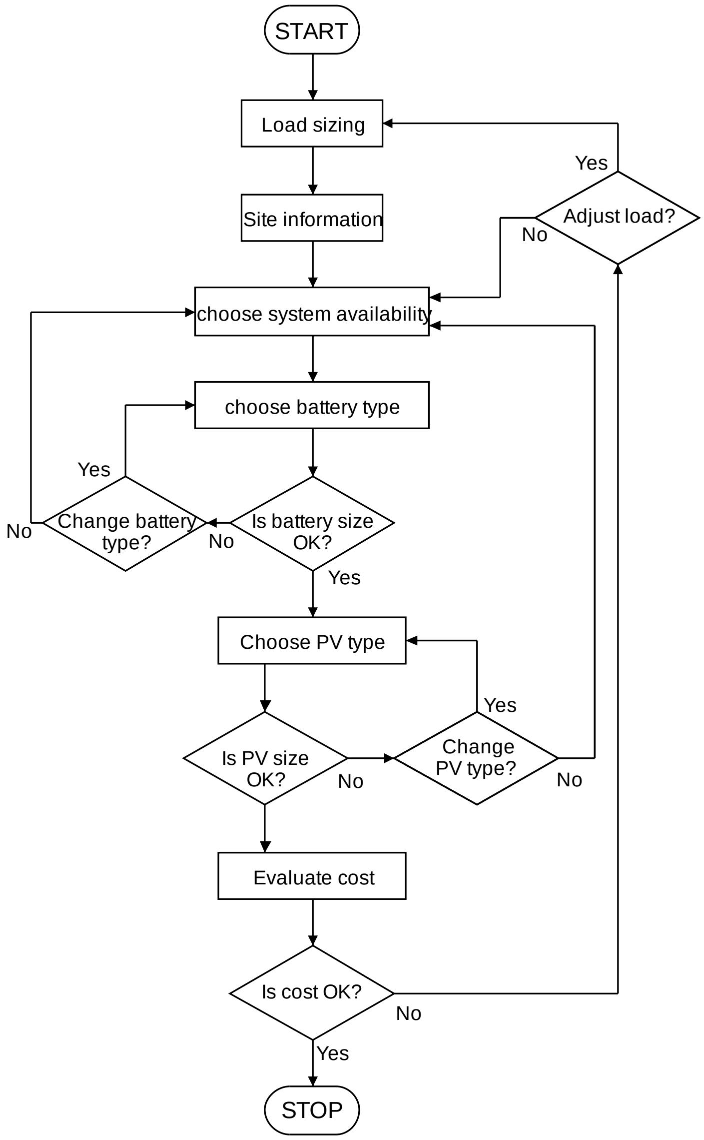

Fig. 2: Flow chart for design of stand-alone PV system

7. Testing the Program

The loads in Table 3 were used to test the developed computer program.

Table 3: Load for testing computer program

Appliance	**Quantity**	**Power Rating (W)**	**Run time (hours)**
Lights-Indoor	8	11	5
Lights-Security	4	11	12
TV Set	1	85	4
Decoder	1	30	4
Laptop	1	40	2
Fridge	1	120	12

7.1 Test Results

Figures 3 and 5 show the screenshots for the inputs and outputs as presented in the testing of the operation of the developed computer program for the load described in Table 3.

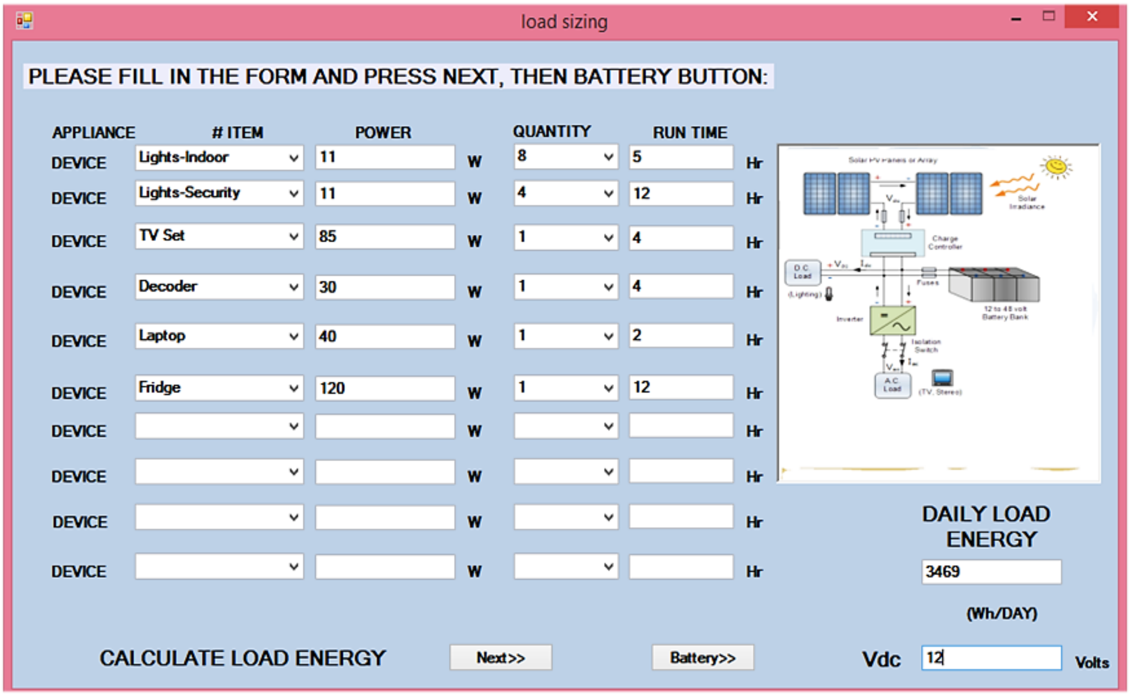

Fig. 3: Load sizing worksheet

Given the loads above, daily load energy demand is 3469 Wh/day. The system voltage is 12 V. A total number of 3 batteries are required with 1 battery in series and 3 batteries in parallel each with a capacity of 357 Ah. A total number of 18 PV modules are required with 1 panel in series and 18 panels in parallel each rated at 256 W. The system seems to have a larger number of batteries and PV modules than one would expect but this is due to the high value of system availability used.

As can be seen a total of $ 5699.4 would be required to power this particular load. Of course the cost can rise above this value if the system is to be implemented to account for other components which have not been included such as inverter, MPPT and conductors.

Using the same choice of components, a step by step manual design was carried out and similar results were obtained.

As explained above the design process is iterative in nature; a number of iterations of designs are carried out until satisfactory results are obtained. Some parameters can be adjusted in the quest for a satisfactory design as indicated in the logic diagram. Load, system availability, battery model and PV model are the parameters which can be adjusted.

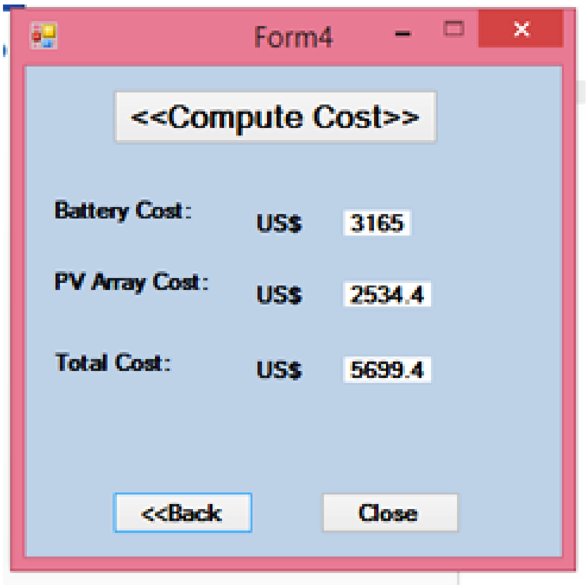

Fig. 5: Cost estimation worksheet

8. Conclusion and Recommendations

A tool has been developed from design equations for sizing of load, system battery, PV array and cost estimation. The developed tool has features of a friendly graphical user interface and can be articulated by a user with little or no knowledge of engineering. In this version, flexibility has been built in for interaction with the user for adjustment of the types of PV modules, batteries, system availability or even the load. The results for the test case are in agreement with the step-by-step manual design applied by an engineer.

Zambia enjoys substantial amount of hours of sunshine. This natural source of energy needs to be harnessed for the benefits of humans. People in remote areas far from the grid who accept solar energy as full option for the provision of energy need to be supported with a ready process for designing a solar PV stand-alone system from their requirements. Making such processes readily available is a step forward in increasing the acceptance rate of solar PV systems.

One foreseeable improvement to the current design process is to adopt one of the more modern load-estimating methods. The current method of estimating load is highly cautious and conservative although it requires little resources, while the modern methods are computationally intensive but give more realistic estimates.

References

Ali, M.M.E and Salih, S.K. (2013), "A Visual Basic-Based Tool for Design of Stand-alone Solar Power Systems" Energy Procedia, Vol. 36, pp 1255-1264.

EIZ (2015), Report on Zesco Load shedding. Available online: http://www.eiz.org.zm/wp-content/uploads/2015/10/151008_Report_On_ZESCO_Load_Shedding.pdf

IRENA (2013), The International Renewable Energy Agency: Renewables Readiness Assessment: Zambia. Available online: http://www.irena.org/documentdownloads/publications/rra_zambia.pdf;

Masters, G.M. (2004) *Renewable and Efficient Electric Power Systems*, John Wiley & Sons, Inc., Hoboken, New Jersey, USA.

MEWD (2009), Ministry of Energy and Water Development: Rural Electrification Master Plan for Zambia 2008-2030: A Blue Print to Providing Electricity to All Rural Areas.

Mohan, N., Undeland, T.M., and Robbins, W.P. (2003), *Power electronics: converters, applications and design*, 3rd ed., John Wiley and sons, Hoboken, New Jersey, USA.

Mwansa, K., Mwanza, M., Zulu, A., Muya, M., Ngendo, D.M., Mpanga, S., Katende, J., Kelebopile, L., Oladiran, T., Onyango, T., Chisale, P., John, S., Zulu, A.M., Hüneke, M., Kapfhamer, S., Zörner, W., Kgathi, D., Mbaiwa, J.E. and Motsholapheko, M.R. (2015), 'State of renewable energy technologies in Southern Africa ', Proceedings of the International Conference on Clean Energy for Sustainable Growth in Developing Countries (CESGDC15), Palapye, Botswana, 16-18 September 2015.

World Bank (2016), World Development Indicators: Highlights: Featuring the Sustainable Development Goals. Available online: http://databank.worldbank.org/data/download/site-content/wdi-2016-highlights-featuring-sdgs-booklet.pdf;

Adding Nuclear Power to Zambia's Energy Mix

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ABSTRACT

The El Nino weather phenomenon that hit Southern Africa in the 2013-15 rainy seasons has adversely affected hydroelectricity generation in Zambia. Business entities have lost millions of dollars through power outages that have negatively affected economic growth. Due to unpredictable weather patterns, Zambia needs to diversify its energy sources. The National Energy Policy (NEP) of 2008 did not provide a legal instrument to govern the nuclear energy sub-sector. Nuclear power is a reliable source of clean energy that can cushion Zambia's power woes. The aim of this paper is to examine if Zambia has enough uranium resources to add nuclear power to its energy mix. Nuclear power plants produce electricity by fission. Uranium-235 isotope from yellowcake is enriched from 0.7% in nature to between 3% and 5% and is used as fuel in the reactor to drive the turbines to produce electricity.

However, the general concern with nuclear power plants has always been regarding safety especially in the disposal of nuclear waste. However, technology has evolved so much that this is not a challenge anymore. Temporal on-site waste management includes vitrification, or ion exchange, or synroc. Long term nuclear waste management being pursued are geological disposal, transmutation, waste re-use and space disposal.

Based on the reported measured and indicated uranium resources in the country, a significant amount of nuclear power can be generated that can help to lessen the energy deficit the country is facing. The signing of a US$ 10 billion over 15 years period Memorandum of Understanding by Zambia and Russian governments to make Zambia a nuclear science centre in Southern Africa for peaceful uses may help to formulate a nuclear energy sub-sector policy

Keywords: Fission, Nuclear Energy, Nuclear Power, Uranium, Yellowcake

1. Introduction

Zambia like many other countries that rely on hydro-electricity, is grappling with energy shortages as a result of climate change. The drought which hit Southern Africa in the 2013-15 rainy seasons has enormously affected Hydro power generation negatively. Hydroelectricity is the second largest source of energy after wood fuel in Zambia. Approximately 68% of the

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electricity generated is consumed by the mining industry followed by households at 19 %, manufacturing 4%, agriculture at 2% and government services at 7% (GRZ, 2008).

Due to strong gross domestic product (GDP) growth of about 5% per annum on average in the last ten years, electricity demand has been growing at an average rate of 3 %, that is, between 150 MW and 200MW each year largely due to increase in economic activity in the agriculture, manufacturing and mining sectors (Zambia Invest, 2016). According to the Zambia Development Agency (2014), Zambia has installed generation capacity of 2,617MW (Table 1) although there is approximately 6,000MW untapped hydroelectricity potential. Approximately 120MW and 150 MW were connected to the national grid from Itezhi Tezhi and Maamba coal power plant in March 2016 and August 2016, respectively (ERB, 2015).

Table 1 : Zambia's installed Electricity Generation Capacity

Power Station	**Installed Capacity(MW)**	**Type of Generation**	**Operator**	**Comment**
Kafue Gorge	990	Hydro	ZESCO	
Kariba North Bank	1080	Hydro	ZESCO	
Victoria Falls	108	Hydro	ZESCO	
Itezhi -Tezhi	120	Hydro	Tata &ZESCO	Connected to the grid in March 2016
Combined Min-Hydro Stations	25	Hydro	ZESCO	
Lusemfwa &Mulungushi	56	Hydro	Lusemfwa Hydro	
Isolated Generation	8	Diesel	ZESCO	
Gas Turbine(Standby	80	Diesel		
Maamba Coal Power Plant	150	Thermal	Maamba Collieries Ltd	Connected to the grid in August 2016
Total Installed Capacity	**2617**			

Modified from: Zambia Development Agency (2014)

In the past rainy seasons, Zambia like most Southern African countries was hit by severe drought caused by the El Nino weather phenomenon (Phys Org, 2016). The drought led to substantial water level drop in the dams where Zambia Electricity Supply Corporation (ZESCO) generates electricity from. Currently, ZESCO is generating approximately 1156MW (Table 2) out of the 2337MW capacity owing to low water levels in the dams (ZESCO, 2015). Kariba North Bank and Kafue Gorge are the most affected Power stations.

Table 2: ZESCO Operating Power Stations

Power Station	**Operating Capacity(MW)**	**Available Capacity(MW)**
Kafue Gorge	990	630
Kariba North Bank	1080	275
Victoria Falls	108	108
Itezhi Tezhi	120	120
Lunzua	14.8	5.9
Lusiwasi	12	8.6
Chishimaba	6.2	3.5
6Musonda	5	4
Shiwang'andu	1	1
Total	**2337**	**1156**

Source: ZESCO (2015)

From 2015 to 2019 (Table 3), Zambia intends to generate 1,624MW (Southern Africa Power Pool, 2015)

Table 3: Planned committed Power Generation Projects 2015 to 2019

No	**Country**	**Committed Generation Capacity, MW**					
		2015	**2016**	**2017**	**2018**	**2019**	**Total**
1	Angola	0	1,280	2,271	0	0	**3,551**
2	Botswana	-	-	-	300	-	**300**
3	DRC	430		150			**580**
4	Lesotho	-	-	-	-	-	-
5	Malawi	-	-	-	74	300	**374**
6	Mozambique	205	40	-	600	-	**845**
7	Namibia	-	15	-	-	800	**815**
8	South Africa	1,828	3,462	3,032	1,476	1,476	**11,274**
9	Swaziland	-	-	-	-	12	**12**
10	Tanzania	150	-	500	1,140	300	**2,090**
11	Zambia	150	-	300	101	1,090	**1,626**
12	Zimbabwe	15	-	120	1,200	1,260	**2,595**
Total		**2,763**	**4,797**	**6,373**	**4,891**	**5,238**	**24,062**

Source: Southern Africa Power Pool (2015)

The drought is having serious effects on Hydroelectricity generation on which the country depends. On account of unpredictable weather patterns resulting from climate change, nuclear power can be Zambia's solution for its energy woes. In the pages that follow, the paper explores the potential of adding nuclear power to Zambia's energy mix. Zambia is endowed with uranium mineral resources that can be used to generate nuclear power to help meet the ever-growing energy demand.

2. History of Uranium Mining and Processing in Zambia

Zambia attained its International Atomic Energy Agency (IAEA) membership in 1969 and is also a signatory to the Non-Proliferation of Nuclear Weapons or the Non-Proliferation Treaty (UNODA, 1995, World Nuclear Association, 2016). Among other things, the treaty is aimed at promoting peaceful uses of nuclear energy and thwarting the spread of nuclear weapons. The first uranium conference in Zambia was organized by IAEA in 1977 and was opened by the then Republic President Kenneth Kaunda (International Atomic Energy Agency, 1979).

Works before independence by Revee (1963) revealed that seventeen different uranium minerals are present in diverse environments in Zambia mainly associated with the Zambian copper mines. However, uranium was only produced at Nkana mine where a pilot plant was completed and commissioned in 1957. In the same year, 52,457 pounds (23, 605kg) of uranium oxide was produced. A production of 101, 080 pounds (45,486 kg) and 76,567 pounds (34,455 kg) was recorded in 1958 and 1959 respectively. Mining and milling operations ceased in July 1959 after the mineralization got exhausted (Revee, 1963).

Despite indications of abundant uranium mineral resources in Zambia as revealed by exploration work in the last decade, the 2008 National Energy Policy (GRZ, 2008) has no legal instruments governing the nuclear energy sub-sector (Table 4). The lack of a National Policy Framework coupled with, at times, public opposition has stagnated the mining and treatment of uranium in the country. A fall in the price of uranium on the international market has further hindered the development of uranium mining and processing projects.

A Bankable Feasibility Study (BFS) was completed on the recovery of the uranium ore at the Lumwana Mining Company (LMC) and 3800 tonnes indicated resources at 0.079%, and 2570 tonnes of uranium inferred resource was declared. Uranium mineralization is in distinctly enriched areas and is mined independently from the copper ore and stored. In December 2008, the Zambia Environmental Management Agency (ZEMA) approved Environmental Impact Assessment (EIA) to process and produce 700 tonnes of uranium per annum commencing in 2010. However, investment in the $230 million Uranium Mill was delayed due to low uranium prices, and hence financing for the project became challenging. Uranium mineralization at Lumwana Mine, occurs within Malundwe open pit together with copper mineralization. By January 2011, LMC had a 4.6 million tonnes stockpile having 0.09 % uranium and 0.8% copper. The stockpile is currently considered as waste to copper mining. The stockpile will continue to be regarded as waste until such a time when project economics will allow to build a uranium processing plant (World Nuclear Association, 2016).

There are several advanced uranium projects in Zambia (Table 5). The notable ones are the Mutanga and Chirundu projects in southern Zambia and the Lumwana project in North Western Zambia. Mutanga owned by GoviEx Uranium Inc of Canada has a NI43-101 compliant measured resource of 500 tonnes at a grade of 0.04% uranium, indicated resource of 2,235 tonnes and an inferred resource of 16,000 tonnes (World Nuclear Association, 2016).

Table 4: Legal instruments governing the various energy sub-sectors

Sub-Sector	Legal Instrument
Biomass	▪ Forest Act ▪ Environmental Protection and Pollution Control Act ▪ Energy Regulation Act
Electricity	▪ Electricity Act ▪ Rural Electrification Act ▪ Environmental Protection and Pollution Control Act ▪ Energy Regulation Act
Petroleum	▪ Petroleum Act ▪ Petroleum Production and Exploration Act ▪ Energy Regulation Act ▪ Environmental Protection and Pollution Control Act
Coal	▪ Mines and Mineral Development Act ▪ Energy Regulation Act ▪ Environmental Protection and Pollution Control Act
Renewable Energy	▪ Electricity Act ▪ Rural Electrification Act ▪ Energy Regulation Act

Source: GRZ (2008)

Table 5: Estimated Uranium Resource in Zambia

Project	Company	Estimated Resource (tonnes)	Status	Comment
Mutanga	GoviEx Uranium Inc	75.5 Million	Mining licence granted	-Include 10.3 million tonnes measured and indicated resource. The rest is inferred -Project originally owned by Omega Corp, Denison then finally acquired by GoviEx
Chirundu	African Energy Resources	18.7 Million	Mining licence granted	-11.3 million tonnes measured and indicated
Lumwana	Lumwana Mining Copany	6.370 Million	Mining licence granted	Uranium being stockpiled as waste

Data source: (GoviEx Uranium Inc, N.D, African Energy Resources, N.D, World Nuclear Association, 2016)

3. Generating Power from Uranium

In nuclear plants, energy is produced by fission. Uranium ore is mined from the natural environment where significant concentration occurs to qualify as ore. The essential uranium ore mineral is uraninite (U_3O_8) or pitchblende. Other uranium ore minerals include coffinite, brannerite, davidite, thucholite and many others (Cornelis and Hurlbut, 1985). Uranium has two isotopes uranium 238 (U-238) which is the more abundant one (about 99.3% of the uranium in the earth's crust) and uranium 235 (U-235) accounting for the remaining 0.7%.

Depending on the depth of the ore body, uranium can be mined by underground or open pit methods. Uranium is recovered from ore by treating it with either acid (sulphuric or less conventional nitric) or a carbonate (Sodium bicarbonate, ammonium carbonate or dissolved carbon dioxide). Uranium can also be recovered from the ground by in situ leaching (ISL).

Approximately 45% of world uranium production is by ISL mostly in Australia, China, Russia, United States of America and Uzbekistan (Nuclear Energy Agency and International Atomic Energy Agency, 2014). Milling, leaching with sulphuric acid, drying and filtering of uranium ore produces a yellow powder called yellowcake (U_3O_8). ***Yellowcake is not weapon grade uranium.*** However, it is the first step toward uranium enrichment (Koerner, 2003). Zambian uranium projects are equally expected to produce yellowcake as a final product which will be sold to the international market.

Yellowcake undergoes a series of enrichment processes before it can be used in the reactor as fuel to generate electricity. For the reactor grade, the yellowcake uranium- 235 is enriched from 0.7% to between 3% and 5% converting it into a gas uranium hexafluoride (UF_6). Gaseous diffusion or gas centrifuge process separates the heavier U-238 from U-235. Weapon grade uranium is more than 90% U-235 enriched (Ulmer-Scholle, 2016). After the enrichment, UF_6 is converted into uranium dioxide (UO_2). UO_2 is formed into fuel pellets which are used in nuclear fuel rods in the core of the reactor (World Nuclear Association, 2014). Depending on the type of the reactor, Massachusetts Institute of Technology (2011), estimates 200 metric tonnes of uranium ore is required to produce a Gigawatt of electricity per year. From the measured and indicated resources reported at each project, Zambia has potential to produce excess nuclear power for many years.

4. Cost for Nuclear Power Plants

New nuclear power plants have enormous capital costs which make nuclear energy not economically competitive with other sources of energy (Jong et al., 2016). However, in the long –run, costs have a tendency to decrease for subsequent plants built. Fuel, operational and maintenance cost are reasonably negligible constituents of the total cost. Despite the provision of enormous government subsidies and support, nuclear plants in most developed countries are hit by construction delays, cost overruns, plant cancellations and safety issues (Broomby, 2009, Kanter, 2009a, Kanter, 2009b). For example, from the period 2002 to 2008, the cost projections for the construction of a new nuclear plant rose between US$2 billion and US$4 billion to US$ 9 billion per plant(UCS, 2009).

Following the nuclear disaster at Fukushima Daiichi power plant in Japan in 2011, both operation for existing power plants and construction costs of new nuclear power plants went up because of the requirements for onsite waste management and improved designs on threat basis (Massachusetts Institute of Technology, 2011). Immediately after the Fukushima disaster, Germany temporarily shut down its seven old nuclear power plants and announced plans to close all the seventeen plants by 2022 permanently. Elsewhere in Europe, Austria, Greece, Ireland, Latvia, Lichtenstein, Luxembourg, and Malta formed an anti –nuclear coalition(Fertl, 2011). However, depending on the local consent and judicial ruling, the Institute of Energy Economics is considering to restart seven and twelve nuclear power reactors by the end of March 2017 and end of March 2018 respectively. The decision to restart nuclear power plants was taken due to escalation in electricity costs(World Nuclear News, 2016).

In East Africa, , Kenya recently announced plans to start constructing its first 1,000MW nuclear power plant at a cost of US$5 billion by 2021 to be completed in 2027. Through collaboration with the government of South Korean on design, construction, and operation. Kenya further wants to construct a 4,000MW nuclear power plant by 2033 (Wanjala, 2016).

The USA Energy Information Administration analyzed statistics of the 2014 Annual Energy Outlook report and found out that the levelized energy cost (LEC) of nuclear power was US$0.095 and US$0.125 for solar PV (Table 6). Geothermal energy was the cheapest with LEC of US$0.05 followed by Hydro at US$0.08 (Renewable-Energy Sources, 2016). At US¢6.02/KWh, the scaling solar PV project being implemented in Zambia by the Industrial Development Corporation (IDC) is one of the cheapest in the world (IFC, 2016).

Table 6: Levelized Energy Cost for Power Plants Type

Power Plant Type	**Cost $/KWh**
Coal	$0.095- 0.15
Natural Gas	$0.07-0.14
Nuclear	$0.095
Wind	$0.07-0.20
Solar PV	$0.125
Solar Thermal	$0.24
Geothermal	$0.05
Biomass	$0.10
Hydro	$0.08

Source: Renewable-Energy Sources (2016)

5. Public Opinion

Despite being a source of cleaner energy, nuclear power evokes the apocalyptic images of Hiroshima and Nagasaki caused by a three metres atomic bombs that fell on Hiroshima and Nagasaki in Japan killing thousands of people. Under the Manhattan Project, the United States of America sourced much of the uranium that was used as raw material in the atomic bombs from a King Leopold II of Belgian –owned Shinkolobwe mine in the Democratic Republic of Congo. Shinkolobwe mine was primarily a radium mine which at that time was being sold for US$175,000 per gram (Zoellner, 2009). Worse still, the Fukushima Daichi nuclear disaster (Japan 2011), the Chernobyl disaster (Ukraine 1986), the Three Mile Island disaster (USA 1979) and the SL-1 prototype accident (USA 1961) would sway public opinion on the use of nuclear power as a source of clean energy (Time.com, 2009).

With nuclear power, the public is mostly concerned of:

(a) Radiation discharge to the environment during the normal operation of the power plant;

(b) The apocalyptic possibility of a large-scale accident; and

(c) The proliferation of nuclear power plant operational by-products such as plutonium for potential military use.

The Council of Churches in Zambia (CCZ) intoned concerns when the developers of one of the projects in Southern Province of Zambia announced their plans in 2009 to commerce uranium mining once the price can sustain costs. CCZ requested the government of Zambia to put in place a strict safety policy to guide uranium mining in the country(WISE, n.d). The Zambian projects would produce yellowcake as the final product. Scientists have largely reached a consensus that if yellowcake is handled carefully, it does not pose any risk to human health. Yellowcake emits alpha particles which can be stopped by human skin and it is not dangerous unless it is ingested or inhaled (Petersen, 2013). Therefore, the concerns raised by stakeholders such as the Council of Churches in Zambia (Nkhuwa and Musiwa, 2010) regarding uranium mining add to the controversial and often divisive nuclear power debate. Uranium mining licence holders should probably do more on stakeholder engagement especially in the communities where the projects are located.

To the contrary, supporters of nuclear energy (Table 7) argue that it is a cost competitive low-carbon emission source of energy which should not be neglected if the United Nations Framework Convention on Climate Change (an international environmental treaty) is to achieve its objective of holding global temperature below 2 degrees Celsius. The supporters have further estimated that the cost of nuclear electricity is between 22% and 40% lower than wind and solar sources (Birol, 2016, Blue & Green Tomorrow, 2016). Sooner or later, continued research and technological advancement will make nuclear fuel handling safer. Students at Idaho State University in the United States of America (USA) have designed a robot to handle nuclear fuel (Hekkinen, 2016). The USA president Donald Trump has been viewed most as pro nuclear energy. Following the Fukushima Daichi nuclear disaster, President Trump said “I am in favour of nuclear energy, very strongly in favor of nuclear energy. If a plane goes down, people keep flying. If you get into an auto crash, people keep driving”(Kanaval, 2016).

5.1 Nuclear Waste Management

The generic concern with nuclear power plants has always been regarding safety particularly with disposal of nuclear waste. However, technology has evolved so much that this is not a challenge anymore. Nuclear waste is classified as high –level, intermediate- level and low –level waste. Nuclear power plants produce high-level waste. The waste is handled and stored safely by trained workers who are shielded from radiation by a dense material such as concrete, steel or by a few metres of water. Water cools the used fuel and also shields workers from radiation. Hence, at a reactor, used fuel is removed underwater and transferred to a storage pool where it can be stored for several years or after five years, the waste can be transfer in ventilated concrete containers(World Nuclear Association, n.d).

According to Ali (2011), nuclear waste at the production site can be provisionally treated by some methods which may include vitrification, or ion exchange or synroc(a ceramic consisting of stable natural titanate minerals that can immobilize uranium or thorium for billions of years). Long-term waste management options being looked at are geological disposal, transmutation, waste re-use and space disposal. The world Nuclear Association estimate the cost of managing and disposing of nuclear waste produced from the nuclear power plant to 5 % of the total cost of electricity generated.

Table 7: Arguments for and against use of nuclear power

ANTI- NUCLEAR POWER	PRO- NUCLEAR POWER
1. NUCLEAR POWER IS UNSAFE AND EXPENSIVE ▪ The 2011 Japanese Fukushima nuclear and the 1986 Ukraine Chernobyl nuclear disasters ▪ Costly to build and decommission ▪ Cost of storing nuclear waste indefinitely ▪ Huge investment can be used on renewables	**1. NUCLEAR POWER IS SAFE** ▪ Nuclear technology is safe, and it's getting safer ▪ Fukushima Daiichi was an old plant and new generation of reactors are not likely to meltdown ▪ Fukushima was caused by an earthquake and a tsunami. Countries that are not prone to earthquakes are safe
2. RENEWABLES ▪ If subsidies for fossil fuels and nuclear cut , 100% of the energy can be produced from renewables	**2. CLIMATE CHANGE** ▪ All available energy sources need to be used ▪ Coal and natural gas which are used as alternative to nuclear are polluting and more damaging over a long -run
3. Nuclear –Free world ▪ Nuclear power plants could be used by rogue regimes to develop nuclear weapons thereby making the world unsafe	**3. Potential** ▪ Nuclear power would potentially meet the global clean energy demand

Source: Debating Europe (n.d)

6. World Nuclear Power Trend

The European Nuclear Society (ENS) has indicated that there are 450 nuclear reactors around the world as at November 2016 being used for electricity generation. There are 60 nuclear power plants under construction in 15 different countries (European Nuclear Society, 2016).

France and the USA have the largest number of operating nuclear power plants with 58 (net electricity output of 63.13GW) and 98 (net electricity output of 98.868GW), respectively. Nuclear power accounted for approximately 11% (391.915GW) of the world electricity production and 76% of France's electricity in 2015. China and Russia have each 36 operational reactors and have 7 and 20 reactors under construction respectively (Nuclear Energy Institute, 2016). In Africa, only South Africa has two nuclear power plants with a capacity of 1.860GW. So far, six other African countries Ghana, Kenya, Morocco, Nigeria, Uganda and Senegal have shown interest to develop nuclear power. IAEA will offer technical advice to these countries on international best practices and standards in generating nuclear electricity (Luke, 2015).

7. Conclusion

As the Zambian economy continues to grow in tandem with the population, the demand for power will continue to surge. For Zambia to meet its future power needs, a diversified source of energy is required. As evidenced by the power outages the country is experiencing, Zambia cannot afford to rely on hydropower for much of its power. From the measured and indicated resources of uranium mineralization reported by different companies, Zambia has the potential of generating excess nuclear energy that can be added to the national grid for many years. Therefore, policy makers should consider adding nuclear energy sub-sector to Zambia's power source in the National Energy Policy. The signing of an over 15 year period US$10 billion Memorandum of Understanding (MoU) by the Zambian and Russian governments to make Zambia a nuclear science centre in Southern Africa for peaceful uses (Mushota, 2016) may help to formulate a nuclear energy sub-sector policy.

Power outages have greater negative economic impacts on businesses thereby affecting the economy of any country. The loss to the Zambian economy as a result of power cuts is enormous than the cost of a nuclear plant in the long-run. In some instances, Zambia's biggest mining houses, manufacturing companies have had to suspend production and small businesses experience disruptions due to power cuts (Bariyo, 2015, Jeffrey, 2015). Adding nuclear energy to the Zambian energy mix can be one of the keys to stabilise power in the country.

Nuclear energy will help breathe life into the uranium projects in the country that are currently on care and maintenance due to the depressed price of uranium on the international market. The uranium mined from the projects can be used as fuel in the nuclear power plants. The mining and processing of the uranium ore will create employment, business opportunities and accelerate infrastructure development in these remote parts of Zambia. Zambia has a long history of mining and has adequate legislation in place to regulate the mining sector. Uranium mining is further regulated by the Ionization and Radiation Protection Act, No 16 of 2005 (GRZ, 2005).

References

AFRICAN ENERGY RESOURCES. N.D. *Chirundu Project* [Online]. African Energy Resources. Available: http://africanenergyresources.com/display/index/chirundu-project [Accessed 1 November 2016].

ALI, S. 2011. *Nuclear Waste Disposal Methods* [Online]. Stanford University. Available: http://large.stanford.edu/courses/2011/ph241/ali2/ [Accessed 5 march 2017].

BARIYO, N. 2015. *Zambia Copper Producer Halts Production Over Power Shortages* [Online]. The Wall Street Journal. Available: http://www.wsj.com/articles/zambia-copper-producer-halts-production-over-power-shortages-1438613847 [Accessed 10 December 2016].

BIROL, F. 2016. *IEA Executive Director delivers keynote address at World Nuclear Exhibition* [Online]. International Energy Agency. Available: http://www.iea.org/newsroom/news/2016/june/iea-executive-director-delivers-keynote-address-at-world-nuclear-exhibition.html [Accessed 7 December 2016].

BLUE & GREEN TOMORROW. 2016. *IEA Report Suggests Nuclear Energy Is Vital For Clean Energy Future* [Online]. Blue & Green Tomorrow. Available: https://blueandgreentomorrow.com/news/iea-report-suggests-nuclear-energy-vital-clean-energy-future/ [Accessed 7 December 2016].

BROOMBY, R. 2009. *Nuclear dawn delayed in Finland* [Online]. BBC News. Available: http://news.bbc.co.uk/2/hi/europe/8138869.stm [Accessed 3 December 2016].

CORNELIS, K. & HURLBUT, C. S. 1985. *Manual of Mineralogy,* New York, John Wiley & Sons,.

DEBATING EUROPE. n.d. *Arguments for and against nuclear power* [Online]. Debating Europe,. Available: http://www.debatingeurope.eu/focus/infobox-arguments-for-and-against-nuclear/#.WLuv9fI_YZM [Accessed 4 March 2017].

ERB. 2015. *Itezhi Tezhi Power Corporation and ZESCO Power Purchase Agreement* [Online]. Energy Regulation Board. Available: http://www.erb.org.zm/viewpage.php?page=ndtls&nid=72 [Accessed 19 October 2016].

EUROPEAN NUCLEAR SOCIETY. 2016. *Nuclear power plants, world-wide* [Online]. European Nuclear Society,. Available: https://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm [Accessed 9 December 2016].

FERTL, D. 2011. *Germany: Nuclear power to be phased out by 2022* [Online]. Greenleft. Available: https://www.greenleft.org.au/content/germany-nuclear-power-be-phased-out-2022 [Accessed 5 December 2016].

GOVIEX URANIUM INC. N.D. *GoviEx Projects* [Online]. GoviEx Uranium. Available: http://www.goviex.com/projects.php [Accessed 1 November 2016].

GRZ. 2005. *Ionising and Radiation Protection ACT, 2005* [Online]. Zambia Legal Information Institute. Available: http://www.zambialii.org/zm/legislation/consolidated_act/311 [Accessed 10 December 2016].

GRZ 2008. Zambia National Energy Policy. *In:* DEVELOPMENT, M. O. E. A. W. (ed.). Lusaka: Government Printers of Zambia.

HEKKINEN, N. 2016. *Students Designed a Robot to Handle Nuclear Fuel* [Online]. US Department of Energy. Available: http://energy.gov/articles/students-designed-robot-handle-nuclear-fuel [Accessed 7 December 2016].

IFC. 2016. *Scaling Solar delivers low-cost clean energy for Zambia*

[Online]. International Finance Corporation. Available: http://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/scaling+solar+delivers+low+cost+clean+energy+for+zambia [Accessed 12 December 2016].

INTERNATIONAL ATOMIC ENERGY AGENCY. 1979. *Uranium Deposits in Africa: Geology and Exploration* [Online]. Vienna: International Atomic Energy Agency. Available: www.iaea.org/inis/collection/NCLCollectionStore/_Public/12/599/12599259.pdf [Accessed 15 November 2016].

JEFFREY, J. 2015. *Zambian businesses pummelled by power cuts* [Online]. BBC News. Available: http://www.bbc.com/news/business-34844357 [Accessed 10 December 2016].

JONG, K. P. D., RAGAUSKAS, A. J., EHRHARDT-MARTINEZ, K. & RAMANA, M. V. 2016. *The frontiers of energy* [Online]. Research Gate. Available: https://www.researchgate.net/publication/290185896_The_frontiers_of_energy [Accessed 29 November 2 2016].

KANAVAL, S. L. 2016. *GoviEx Uranium (TSX.V: GXU): Will Trump bring a surge in Uranium Pricing?* [Online]. Equities News. Available: https://www.equities.com/news/goviex-uranium-tsx-v-gxu-will-trump-bring-a-surge-in-uranium-pricing [Accessed 11 December 2016].

KANTER, J. 2009a. *In Finland, Nuclear Renaissance Runs Into Trouble* [Online]. The New York Times. Available: http://www.nytimes.com/2009/05/29/business/energy-environment/29nuke.html?ref=global-home [Accessed 3 December 2016].

KANTER, J. 2009b. *Is the Nuclear Renaissance Fizzling?* [Online]. The New York Times. Available: http://green.blogs.nytimes.com//2009/05/29/is-the-nuclear-renaissance-fizzling/ [Accessed 3 December 2016].

KOERNER, B. 2003. *What Is Yellowcake, Anyway?* [Online]. Slate. Available: http://www.slate.com/articles/news_and_politics/explainer/2003/07/what_is_yellowcake_anyway.html [Accessed 15 December 2016].

LUKE, R. 2015. *Africa Banking on Nuclear Power* [Online]. Oil Price. Available: http://oilprice.com/Alternative-Energy/Nuclear-Power/Africa-Banking-On-Nuclear-Power.html [Accessed 10 December 2016].

MASSACHUSETTS INSTITUTE OF TECHNOLOGY. 2011. *The Future of Nuclear Fuel Cycle* [Online]. Massachusetts Institute of Technology. Available: https://energy.mit.edu/wp.../2011/04/MITEI-The-Future-of-the-Nuclear-Fuel-Cycle.pdf [Accessed 4 December 2016].

MUSHOTA, R. 2016. *Zambia: Nuclear Deal Inked* [Online]. Times of Zambia. Available: f http://www.times.co.zm/?p=90503 [Accessed 10 December 2016].

NKHUWA, D. C. & MUSIWA, S. 2010. *Prosperity unto Death : Is Zambia ready for Uranium Mining?* [Online]. The Council of Churches in Zambia. Available: http://www.uranium-network.org/Mali%20Konferenz/start_htm_files/start_htm_files/Prosperity-unto-Death-2010.pdf. [Accessed 5 December 2016].

NUCLEAR ENERGY AGENCY & INTERNATIONAL ATOMIC ENERGY AGENCY. 2014. *Uranium 2014: Resources, Production and Demand* [Online]. International Atomic Agency. Available: https://www.oecd-nea.org/ndd/pubs/2014/7209-uranium-2014.pdf [Accessed 30 November 2016].

NUCLEAR ENERGY INSTITUTE. 2016. *Nuclear Energy Around the World* [Online]. Nuclear Energy Institute. Available: http://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics [Accessed 9 December 2016].

PETERSEN, J. 2013. *What are dangers of transporting yellowcake?* [Online]. Rapid City Journal. Available: http://rapidcityjournal.com/news/opinion/forum-what-are-dangers-of-transporting-yellowcake/article_17dbda2a-1953-533f-8004-5d1e88a017fc.html [Accessed 5 December 2016].

PHYS ORG. 2016. *Drought caused by El Nino threatening southern Africa: UN* [Online]. Available: http://phys.org/news/2016-02-drought-el-nino-threatening-southern.html [Accessed 21 October 2016].

RENEWABLE-ENERGY SOURCES. 2016. *Cost Comparison of Energy Sources 2016* [Online]. Renewable-energysources. Available: http://www.renewable-energysources.com/ [Accessed 12 December 2016].

REVEE, W. H. 1963. *The Geology and Mineral Resources of Northern Rhodesia,* Lusaka, The Government Printer.

SOUTHERN AFRICA POWER POOL. 2015. *Southern African Power Pool Annual Report* [Online]. Harare , Zimbambwe: Southern African Power Pool. Available: http://www.sapp.co.zw/areports.html [Accessed 12 October 2016].

TIME.COM. 2009. *The Worst Nuclear Disasters* [Online]. Time.com. Available: http://content.time.com/time/photogallery/0,29307,1887705_2255451,00.html [Accessed 5 December 2016].

UCS. 2009. *Nuclear Power Cost* [Online]. Union of Concerned Scientist. Available: http://www.ucsusa.org/nuclear-power/cost-nuclear-power#.WEWHMX3g8hQ [Accessed 5 Dcember 2016].

ULMER-SCHOLLE, D. S. 2016. *Uranium Enrichment* [Online]. New Mexico Bureau of Geology and Mineral Resources. Available: https://geoinfo.nmt.edu/resources/uranium/enrichment.html [Accessed 12 December 2016].

WANJALA, C. 2016. *Kenya Plans First Nuclear Power Plant at $5 Billion Cost* [Online]. Bloomberg. Available: https://www.bloomberg.com/news/articles/2016-11-30/kenya-plans-first-nuclear-power-plant-by-2027-at-5-billion-cost+&cd=1&hl=en&ct=clnk&gl=zm [Accessed 10 December 2016].

WISE. n.d. *New Uranium Mining Projects - Zambia* [Online]. World Information Service Energy. Available: http://www.wise-uranium.org/upzm.html [Accessed 5 December 2016].

WORLD NUCLEAR ASSOCIATION. 2014. *What is Uranium? How Does it Work?* [Online]. World Nuclear Association. Available: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/what-is-uranium-how-does-it-work.aspx [Accessed 30 November 2016].

WORLD NUCLEAR ASSOCIATION. 2016. *Uranium in Africa* [Online]. Available: http://www.world-nuclear.org/information-library/country-profiles/others/uranium-in-africa.aspx#ECSArticleLink13 [Accessed 31 October 2016].

WORLD NUCLEAR ASSOCIATION. n.d. *What are nuclear wastes and how are they managed?* [Online]. World Nuclear Association. Available: http://www.world-nuclear.org/nuclear-basics/what-are-nuclear-wastes.aspx [Accessed 5 March 2017].

WORLD NUCLEAR NEWS. 2016. *Japanese institute sees 19 reactor restarts by March 2018* [Online]. World Nuclear News. Available: http://www.world-nuclear-news.org/NP-Japanese-institute-sees-19-reactor-restarts-by-March-2018-2807164.html [Accessed 5 March 2017].

ZAMBIA DEVELOPMENT AGENCY. 2014. *Energy Sector Profile* [Online]. Lusaka: Zambia Development Agency. Available: http://www.zda.org.zm/?q=download/file/fid/55. [Accessed 19 October 2016].

ZAMBIA INVEST. 2016. *Zambia Energy* [Online]. Zambia Invest. Available: http://www.zambiainvest.com/energy [Accessed 6 December 2016].

ZESCO. 2015. *Installed Generation Capacity* [Online]. Zambia Electricity Supply Corporation. Available: http://www.zesco.co.zm/ourBusiness/generation [Accessed 5 December 2016].

ZOELLNER, T. 2009. *Uranium* [Online]. The Economist. Available: http://www.economist.com/media/management/uranium-zoellner-e.pdf [Accessed 30 October 2016].

Agro-Processing for Economic Development in Zambia

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Abstract

The agro-processing sector in Zambia has been growing in recent years, a trend also observed with non-traditional exports. This paper draws its data from both secondary and primary data sources, for data analysis atlas.ti computer software was used. The paper highlights that agro-processing has the capacity to contribute to economic development and poverty reduction in Zambia. In order to significantly contribute to economic development and poverty reduction, Zambia is required to invest in infrastructure development, there is also need for the Zambian government to accelerate the development of partnerships with other stakeholders, the need to promote value chain linkages and finally to build capacity of various stakeholders in the economy.

Key Words: Agro-processing, Development, poverty reduction, Zambia

1. Introduction

Over the past decade, Zambia has recorded steady economic growth, surpassing the regional average. Its average growth rate in the last five years was over 6 percent, which is above the regional average for the countries of the Sub-Saharan Development Community (SADC) at 4 percent (Economic Commission for Africa, 2016), since mid-2015, Zambia has faced tough global and domestic conditions with real GDP growing at 2.9% in 2015 (World Bank, 2016). Growth has mainly been dictated by copper prices as well as increased Chinese demand for copper products.

An appreciation of the structure of Zambia's economy inevitably begins with emphasis upon the dominant position occupied by the copper industry. Civil Society for Poverty Reduction (CSPR) (2016), observes that, although Zambia has had over 300% rise in mineral output from 2000 to 2015, there has been little or even total lack of trickle down effects, in some cases, on the country's development.

As indicated above it can clearly be understood that despite being a major contributor to economic growth, copper production has not contributed towards significant poverty reduction and employment creation. For this reason, "the agriculture sector and the agro-industry are key priority sectors in attaining broad-based economic growth, food security and poverty reduction not only because they are labour intensive, but also because they have stronger linkages to the rest of the economy" (Oluyele, 2012). The growth of agriculture has often been constrained and its' potential has been over shadowed by lack of a large well-functioning manufacturing base to absorb produce from the agriculture sector.

Strategies of poverty reduction and economic development are often discussed among policy makers, policy analysts and many more development practitioners but there is yet to be an ultimate solution to the poverty challenge around the world especially in developing countries. However, despite Africa's large untapped land and many policy documents already suggesting on the need to focus on the agriculture sector, there is need for developing countries to concentrate more on the development of the agro-processing industry.

The agro-sector here is defined as the subset of the manufacturing sector that processes raw materials and intermediate products derived from the agriculture, fishery and forestry. Thus, the

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agro-industrial sector is taken to include manufacturing of food, beverages and tobacco, textiles and clothing, wood products and furniture, paper, paper products and printing, and rubber and rubber products (Silva et al, 2009).

Traditionally, the agriculture sector has played a major part in the development of emerging economies and has acted as a significant job creation. However, as economies advance and per capita incomes increase, the role of agriculture changes and the demand for value-added and processed food products increase, shifting the focus away from pure primary agriculture towards agro-processing.

In an effort to understand how Zambia could improve its economic development. This paper will briefly suggest the need to develop the agro-processing sector, looking at the challenges faced in the sector and suggesting ways that could help grow the sector. As such the paper will give some measures that Zambia may need to prioritize in the quest for the development of the agro-processing sector.

2. Background

Africa's growth accelerated from 3.7% in 2013 to 3.9% in 2014 (UNECA, 2015), East and South Asia was the only region that grew faster than Africa at 5.9 % (UNECA, 2015). The strong economic performance was largely due to favourable terms of trade, higher commodity prices and strong global demand for natural resources (Adesina, 2015)

However, despite the impressive economic growth, it is noticeable that the majorities are still living in absolute poverty and depend on agriculture as a major source of food and income. It is worth noting that the region has continually lagged behind in agro-processing led productivity.

The agriculture sector has in many cases operated in isolation with the agro-processing industry remaining relatively small to consume agricultural products before processing them to the next level in the value chain. However, the agro-processing industry is characterized by backward, forward linkages that have the potential to and have been responsible for stimulating increased production and value addition in primary agriculture commodities. In some countries, it has been pivotal for export diversification, boosting employment and fostering economic growth.

However, it is worth-noting that some emerging economies such as South-Africa have a well-developed, sophisticated agro-processing sector that competes in world markets (McCarthy et al, 2012). This represents a function of the level of the economic development in South Africa, and in this sense the South-African situation differs markedly from the less developed African countries. One of best recorded features of economic growth and development, also reflected in South African economic development experience, is the structural change characterized by an increase in the manufacturing activity, accompanied by a fall in the primary production in agriculture and mining (McCarthy et al, 2012).

The general trend for most economic indicators shows that the agro-processing industry makes a significant contribution to the manufacturing sector in South-Africa. On average its contribution to the output and value added of the manufacturing sector was 29.3% and 21% respectively, during 2006-2010. Its contribution to domestic fixed investment and export was also 28.5% and 13.6% respectively, during the same period. The trend also shows that despite shedding more jobs during 2006-2010, the agro-processing industry was still the largest employer in the manufacturing sector (40% of the total manufacturing employment 2006-2010) (McCarthy et al, 2012).

The Agro-industry holds strong ties with the agriculture sector, in essence the agriculture sector is the main source of input in agro-industries with the raw materials mainly being agriculture products. Therefore, a well-functioning agriculture sector has the potential to increase agro-processing output, and vice versa as farmers would be able to produce more due to readily available markets.

3. Agro-Processing In Zambia

Zambia is a landlocked country with abundant natural resources for agriculture, although 58% of the land in Zambia (75 million hectares) is classified as having medium to high potential for agriculture, only about 14% of arable land is cultivated (World Bank, 2009).

From 2001 to 2011 Zambia grew at an annual average of 6% GDP, rising from -2% in 1975 and 1995 (Ministry of Agriculture, 2013). The positive rate was triggered by high global copper prices and robust investments in sectors such as telecommunication, construction, retail and manufacturing (Ministry of Agriculture, 2013). Despite the encouraging positive signs, poverty rates have remained persistently high more than 60% since (Ministry of Agriculture, 2013). The situation with rural poverty is worse, as rural poverty rates have been stuck at 77% (Ministry of Agriculture, 2013).

The agriculture sector remains of great importance to the Zambian economy, contributing about 10 percent to the country's Gross Domestic Product (GDP) (Zulu et al, 2016). The sector employs 48.8% of the total labour work force (Zulu et al, 2016). On the other hand, the mining and quarrying industry competes with agriculture sector in terms of GDP, but employs 1.4 percent of the total labour force (Zulu et al, 2016). Zambia is a mineral based economy and mainly depends on copper for foreign exchange (UNCTAD, 2016), hence overshadowing the importance of the agriculture sector in being the engine of growth. Unlike the countries of East Africa, Zambia has not really been dependent on agriculture to generate foreign exchange, albeit, it may not particularly been the case with rural populations.

Further, the mining sectors' linkage to the local manufacturing sector is very weak (CSPR, 2016), equally, other sectors in Zambia generally have very low local content supplied to the mining sector (CSPR, 2016).

In analyzing the agro-processing sector in Zambia it would be misleading to conceive the agriculture sector as a homogeneous productive unit. It is made up of three categories of farmers namely, small scale, emergent and large scale farmers (Ndadula, 2011). With the small scale farmers being the majority, mainly located in rural areas. It is worth-noting that that the majority of small scale farmers continue to live below the poverty line.

Despite government efforts to support small scale farmers through the Farmer Input Support Programme (FISP), to help them to graduate to the next level as emergent and ultimately large scale farmers, many have failed to graduate. Similarly, the Zambian government has been attempting to diversify the agriculture sector through adding more crops on FISP but the outcome has in most cases not led to a significant improvement to the peoples livelihoods'. Hence, taken that low production in the agriculture sector is due to limited market opportunities, this has resulted into low utilization of mechanization and production or processing tools.

Table 1 shows that the Food and Beverages industry had a biggest share of composition in manufacturing in 2015; it is worth-noting that the processed and refined foods sector is mainly dominated by Zambia Sugar Plc which is the largest sugar producer in Zambia, with an estimated market share of about 90%. In 2013, the sector's export earnings rose by 35.6 percent from US$417,386.79 in 2012 to US$565,807.81 in the year under review (ZDA, 2014). The growth in the export trend has continued to be attributed to wider market access in both regional and international markets which have continued to benefit the country especially for sugar export (ZDA, 2014).

Table 1: Percentage composition of Agro-processing in manufacturing in 2015

Commodity	**Percentage composition in manufacturing**
Food and Beverages	37.5%
Chemicals and chemical products	15.8%
Textiles	7.8%
Tobacco	6.9%

UNIDO (2016) based on authors calculations

Textiles sector started falling in 2001 following the fall of Mulungushi Textiles after the liberalization of the economy, although there has been an increase in production in the wood sector of the economy, following the increased demand in the construction sector as shown in figure 1.

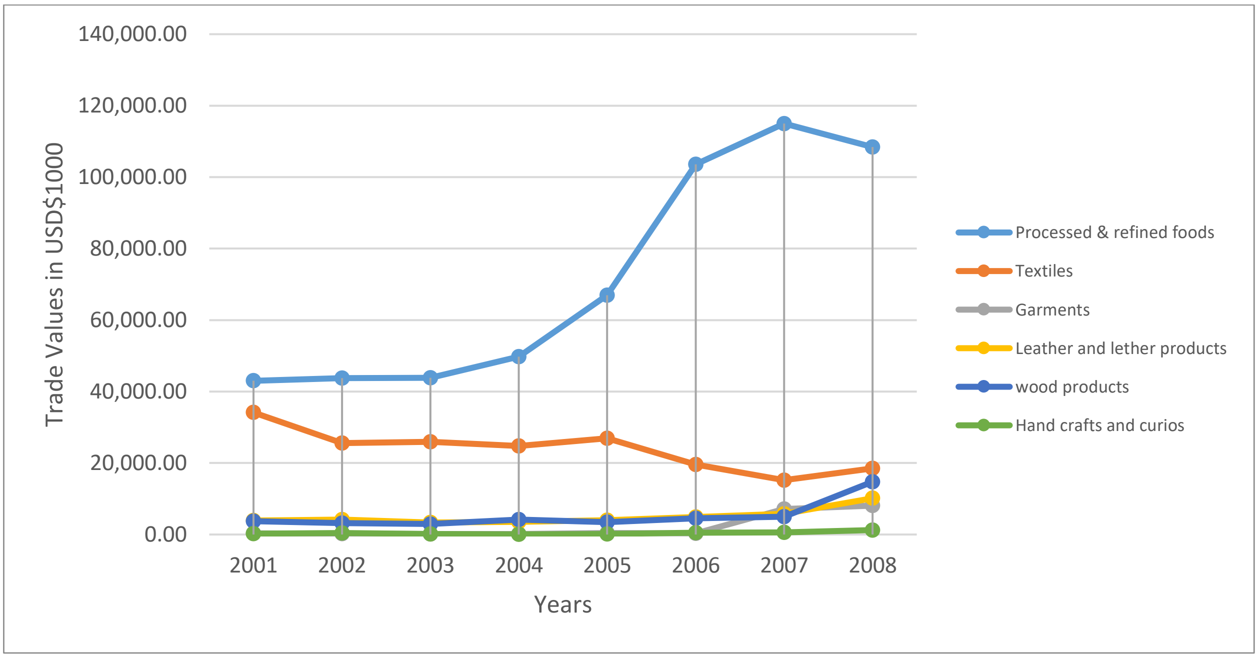

Figure 1: Exports of Agro-Processed Goods from 2001 to 2008 (Zambia Development Agency, 2009, Based on authors calculations)

Table 2 shows that Agro-based Non-Traditional Exports (NTEs) have increased over the years, having more than doubled between 2001 and 2007, driven mostly by expanded production of primary agriculture products - tobacco, cotton lint, coffee and maize but agro-processed products accounted for only 26%.

Zambia's NTEs have continued to increase over the years, in 2016 Zambia recorded an increase in NTEs at about 20% from about K1.4 billion in May to over K1.6 billion in June due to increased demand for equipment and production with maize, tobacco and cotton among the notable NTEs (Tembo, 2016). Despite the growth NTEs, the country's exports are still limited by low export volumes, low value addition in its export products and lack of competitiveness because of high production and trade costs in the domestic economy (UNCTAD, 2016).

The COMESA and SADC markets are important markets for Zambia's non-traditional exports. However, they involve several barriers like Sanitary and Phytosanitary measures (SPS), technical barriers, quotas and restrictive rules of origin and those arising from inefficient and cost-raising trade facilitation rules and procedures (UNCTAD, 2016). In addition to the challenges incurred in exports, the development of the agro-industry in Zambia today faces tough challenges including costly raw material, supply chain efficiencies and market demand constraints.

Table 2: Agro-Based Non-Traditional Exports (2001-2008)

Sector	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Primary agriculture	51,359.00	76,510.50	97,911.50	163,748.60	196,975.10	176,913.00	182,702.70	247,637.70
Floriculture	34,078.20	30,298.10	22,402.10	26,767.60	32,094.10	17,839.10	62,535.50	26,910.10
Horticulture	36,383.90	44,907.10	42,969.00	35,851.30	20,507.70	23,024.10	37,252.00	36,349.51
Animal products	3,062.50	5,192.00	3,593.20	1,992.10	2,130.90	2,305.80	5,177.70	7,861.60
Sub Total	124,883.60	156,907.70	169, 875.5	228,359.50	253,712.80	222,088.00	289,674.90	318,758.90
Processed & refined foods	43,008.20	43,747.20	43,883.60	49,802.20	66,933.30	103,573.30	114,997.60	108,419.40
Textiles	34,144.20	25,622.40	25,981.30	24,746.40	26,937.30	19,583.80	15,221.70	18,518.30
Garments	331.10	219.20	162.70	143.80	445.40	315.30	7,176.90	8,083.30
Leather and leather products	3,916.50	4,140.00	3,354.20	3,532.50	3,959.60	4,854.10	5,828.90	10,143.30
wood products	3,761.50	3,167.10	2,957.20	4,176.60	3,467.70	4,502.60	5,016.90	14,762.60
Hand crafts and curios	227.07	379.00	145.10	41.80	183.90	547.40	588.80	1,248.30
Total agro-processed products	85,051.90	77,274.90	76,484.00	82,443.30	101,927.20	133,376.40	148,830.80	153,091.60

Zambia Development Agency, 2009

Discussions on agro-processing are often linked to infrastructure development. It is worth-noting that infrastructure serves a central delivery mechanism in achieving sustainable economic development and the generation of quality social-economic development in the country. However, transport costs in Zambia are high, they are said to be five times higher than those in industrial country markets and account for about 60% of the total cost of goods (World Bank, 2008).

Poor infrastructure is a problem that affects production as well as distribution of agriculture commodities, hence putting a strain on the value chain. It has been observed that agriculture infrastructure has suffered neglect compared to urban infrastructure development in Zambia just like many other developing countries. However, there is need to be dedicated to a balanced infrastructure development, as infrastructure development is critical in the growth of the sector.

It is worth-noting that, strategic infrastructure is the backbone that interconnects modern economies. The most strategic investments are functional and create the greatest impact in terms of economic growth, social uplift and sustainability. Investment in strategic infrastructure forms the basis for economic growth by facilitating productivity and allowing a region to attract private sector investment (Gauteng department of agriculture and rural development, 2015).

The provision of appropriate, well-maintained and strategic infrastructure is critical to the growth of the agro-processing sector. As a catalyst for development, it is, therefore, necessary for government to contribute towards and facilitate investment in specific infrastructure in support of value adding activities. Infrastructure of high quality allows firms to better compete on the market, as inputs costs, accessibility and productivity is improved. In contrast, inadequate infrastructure could have cost and time implications for investors, which may see investors seeking to rather invest in areas where greater infrastructure benefits are on offer. Furthermore, investment by government creates confidence among private sector investors that government is committed to the well-being of the industry and long term growth of the economy (Gauteng department of agriculture and rural development, 2015).

Zambia's need to invest in infrastructure development is core to creating an enabling environment for the growth of agro-processing entrepreneurship. However, it is understood that Zambia has been undertaking road projects around the country in recent years with the aim of opening up from its land locked status to being land linked.

Hence, in so doing there is need to prioritise roads of higher economic value by identifying roads that may open up rural areas and ultimately lead to attraction of investment by the private sector in rural areas.

There is need for the government to enter into partnerships with other non-governmental partners, who will all come with different attributes that could benefit the economy as a whole in what are known as Public-Private Partnerships (PPPs). The PPPs require that a public sector authority and private sector be signatories of a contract that will direct the operations of the relationship.

Successful cases of agriculture transformation have shown that creating an enabling environment for the farmers and the private sector to invest in agriculture is a fundamental prerequisite. Such an enabling environment is likely to encourage farmers to invest in their own land, especially in activities that protect the land from soil erosion such as; terracing, mulching, adding rock or soil bunds, and in activities that enhance productivity (Zulu et al, 2016).

In addition, interactions of the private sector and the public sector in Zambia are not new, yet the level is very low. Hence, government could take advantage of PPPs for value-addition purposes and infrastructure development. It is interesting to note that partnerships will enable government to significantly share risks with the private sector, in a holistic and integrated manner, therefore leading to a reduction of interfaces for the public sector.

Further, with partnerships between public and private sectors, the strengths of both the sectors are leveraged (Ayyappan, 2007). On the one hand, the public sector has highly skilled and efficient manpower and on the other hand, the private sector has excellent managerial resources (Ayyappan, 2007).

There is also need for collaboration between various government entities and departments at national, provincial and local level playing a role in the agriculture and agro-processing space, each with own intervention programmes, incentives and budgets. Lacking cooperation and collaboration between such entities can lead to divergent objectives, often leading to duplication, conflicting priorities and counterproductive implementation of development initiatives, hampering the effective growth of the industry.

It is very important that in the early years of the partnership, government should play a central role in the creation of the partnerships, but in the latter stages government may be required to play more of a facilitative role.

Following many challenges affecting the agriculture sector, the Zambian government developed the Zambia National Agriculture Investment Plan (NAIP) 2014-2018, under the Comprehensive Africa Agriculture Development Programme (CAADP) seeks to sustain agriculture productivity, production and value-addition of major crops, livestock, forest and fisheries by comparative advantage in different agro-ecological regions in the country (Ministry of Agriculture and Livestock, 2013). However, despite the drafting of policy papers significantly indicating government will, there is need to effectively implement the documents.

Value addition of agriculture products has in most cases gone hand in hand with an efficient market strategy. In their natural state agriculture products are often not marketable or not purchased by consumers due to their highly perishable nature, henceforth, they have to be transformed into other products of higher value. The value added products are usually of higher demand on the market.

Henceforth, there is need to adopt a value chain approach in the provision of government support. Support to primary producers must be likened to downstream opportunities in agro-processing. In addition, government may be required to ensure a deliberate balance between interventions and investments at upstream levels of the value-chain with those at the downstream levels. One of the instruments that could be used in ensuring that support towards various value chains is dealt with in a balanced manner is that of value chain round tables. Value chain round tables provide a platform for value chain role players to articulate and discuss issues that require interventions by government and its stakeholders in the non government sector throughout the value chain.

Agro-processing capacity building and capacity building has also been a major topic of debate among different development commentators. However, if it is to make meaningful contribution and remain relevant, the major forces shaping development of the sector need to be identified and assessed.

A range of skills in the broad agriculture sector are of often lacking (Chatterjee, 2014), from practical training to farmers through agricultural extension services to academic education for full-time university students or agribusiness executives (Chatterjee, 2014).

In so doing, there is need to place different qualified stakeholders into clusters so that the training is of particular relevance in their field of work. It is worth-noting that all individual skills programmes that add to the development of the industry as well as economic growth need to be taken into consideration.

In improving the capabilities of the agro-industry to produce and market their commodities, there is need for a deliberate policy to support local production. Hence, this implies the increased exploitation of local materials and resources, application of local processing technology in cases where producers are unable to afford other forms of technology and connect the producers to the markets. However, it is worth-noting that capacity building programmes should not only be limited to the public sector but should also seek to improve the capabilities of the private sector counterparts, especially the emerging industry.

The strategy of capacity building should consist of at least the following:

- There is need to increase the investment in Research and Development, as well as dissemination of the research outcomes with intended beneficiaries.
- All development projects may be required to allocate at least 15% of the budget to capacity-building.
- Intensify apprenticeship programs.

4. Conclusion

There has always been divided opinions on whether agro-processing is a major driver of economic development in the developing countries, however, many people in developing countries support their livelihoods on the agriculture sector. Hence, raising a viable basis for the need to develop the agro-processing sector due to its strong linkages with the agriculture sector.

In Zambia the majority of farmers are small scale and poverty is a key feature among them. Hence, investing in agro-processing will be beneficial for employment creation as well as providing backward and forward linkages with not only the agriculture sector but also other sectors in the economy.

Therefore, Zambia needs to invest in agro-processing, paying particular attention to the whole value chain. The agro industry has the potential to drive economic growth and to contribute to significant poverty reduction, as well as to meet the global and domestic demand for agro-products. Despite, the high risks in agriculture production, Zambia has huge agricultural potential and could consequently take advantage of the regional demand for agro-products.

Challenges such as poor infrastructure development, low productivity, weak sector linkages among others, need to be effectively addressed as well as looking into building capacity of stakeholders in the value chain.

References

Adesina A. (2015). Building the successes of the African Development Bank and positioning to effectively address emerging challenges (available on https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Akinwumi_A._ADESINA_Vision_Statement.pdf [accessed on 09/03/2017]

Ayyappan S, Chandra P and Tandon S.K (2007). Agriculture Transformation through public-private partnerships: An interface, New Delhi; Indian Council for Agriculture Research

Chatterjee C.S (2014). Agricultural value chains in Sub-Saharan Africa: from a development challenge to a business opportunity. …..: Deustsche Bank

Economic Commission for Africa (2016). Zambia: 2015 Country profile.pp.1, Addis Abba:UNECA

Gauteng department of agriculture and rural development (2015). Gauteng agro-processing strategy.pp.36, Johannesburg: Gauteng department of agriculture and rural development

McCarthy C. Theron N. and Eeden J.V and Gebrehiwet Y. (2012). Economic profile of the agro-processing industry in South-Africa 1970-2010.pp. 245, Pretoria: Agro-processing support

Ministry of Agriculture and Livestock (2013) National Agriculture Investment plan (NAIP) 2014-2018.pp.12, Lusaka: Ministry of Agriculture and Livestock

Ndadula M.S.M (2011). Pathways to Technology Adoption: Understanding smallholder diary farmers in Southern Zambia. Kortenaerkade 12: ISS

Oluyele A. (2012). Agribusiness for Africa's prosperity: Country case studies working paper. second edition. pp. 281, Vienna: UNIDO

Silva C.A, Baker D, Shepard A.W, Jenane C, Miranda C.S. (ed) (2009). Agro-industries for development.pp.11, Rome: CAB international and FAO

Tembo T (2016), Non Traditional Exports increase. Available at https://www.daily-mail.co.zm/?p=74872 [accessed on 9/03/2017]

World Bank (2008). "Zambia: Trade Brief". April 2008. Washington D.C: World Bank

World Bank (2009). Commercial value-chains in Zambian agriculture: Do small holders benefit? Pp.2 Washington DC; World Bank

UNCTAD (2016). Zambia: Harnessing the potential for trade and sustainable growth in Zambia.pp.47, New York; United Nations

UNECA (2015). Industrializing through Trade: Economic Report on Africa-2015.pp.5, Addis Ababa: United Nations

World Bank (2015). Zambia Economic Brief: Powering the Zambian Economy. World Bank

World Bank (2016). Zambia Economic Brief: Raising revenue for economic recovery, issue 8 pp.8-10, Washington DC: World Bank

Zulu B.A.M, Chapoto A, Nkumbula N, Mulenga K. (2016). Economic diversification in Zambia: Agriculture leading the way, policy brief.pp.2-10, Lusaka: IAPRI

An Investigation on the Water Balance at Golden Valley Agriculture Research Trust (GART) in Chisamba

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ABSTRACT

The Agricultural Knowledge and Training Centre (AKTC) aims at contributing to the growth of Zambia's agricultural potential by communicating and conducting training on modern agricultural technology and inputs. It is therefore important to have an understanding of the water balance at the Golden Valley Agricultural Research Trust (GART) demonstration station for effective planning of water use and efficiency improvement. Evaluation of reference evapotranspiration (ET_o), which is climate driven is key to on-field assessment of water needs both at present and future times. At the 10 hectare farm for GART, AquaCrop and ET_o calculator software tools were used in the water balance study for a period of 37 years starting from 1978 to 2015. The crop under evaluation is soybean with sources of water from rainfall and irrigation from groundwater. For the seasonal (annual) water balance, rainfall volumes range from 594 mm to 1444 mm with an average of 890 mm. The net irrigation water requirements for soybean varied from 53 mm to 162.2 mm per season while the daily atmospheric ET_o demand is between 3.9 mm – 7.0 mm per day. Of the received water, the crop evapotranspiration (ET_c) is between 3.4 mm – 5 mm per day or 450 mm – 570 mm per season for a season that starts from 7th December to 4th April. Losses due to surface runoff are between 100 mm and 275 mm per season while deep percolation is within the range 150 mm – 300 mm per season. Losses resulting from direct soil evaporation vary from 150 mm to 190 mm per season. Comparison of AquaCrop predicted results to those observed in the field indicate a 23 % percent of soil fertility stress and only about 5 % of water stresses contributing to yield reduction. Under optimum growth condition simulation, AquaCrop average yield is 4.16 ton/ha while the observed yields after harvest is 3.22 ton/ha.

KEYWORDS: **Water balance, Reference evapotranspiration, Rain–runoff, Water productivity, Harvest index**

1. INTRODUCTION

Various factors and components that make up and influence a water balance of any region are well known. At farm level, a water balance is needed for planning of crop water requirements as well as allocation of water for other farm uses. Regardless of these advances, water availability is site specific as influenced by climate, crops grown and other field management aspects affecting water use efficiency. The research focuses on a water balance at the Golden Valley Agricultural

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Research Trust (GART) in Chisamba as a planning tool for the Agricultural Knowledge and Training Centre (AKTC) project. AKTC is a Bilateral Cooperation Project between the Zambian Ministry of Agriculture and Livestock and the German Federal Ministry of Food, and is established on the premises of GART to serve as a demonstration and training centre. Evapotranspiration is the combined process of evaporation of water from the soil and wet plant surfaces, and transpiration of water from within plant tissues. It is influenced by meteorological variables such as temperature, relative humidity, wind speed and solar radiation, crop characteristics, management practices, as well as field practices (Allen, *et al.,* 2007; Allen, *et al.* 1998b; Droogers and Allen, 2002; Yavuz *et al*., 2015). Raes, *et al*., (2009) states that agriculture is the world's largest water user by volume, and most of it is used by crops to transpire during photosynthesis. Huffman, *et al*., (2011) lists some of the methods used to determine evapotranspiration. Indirect estimation of evapotranspiration using climatological data generally seems less expensive compared to the other methods because there is no need for growing and maintain a living crop (Allen, *et al*., 2007). Reference evapotranspiration has been defined as a "standardized and reproducible index approximating the climatic demand for water vapour" and is the "evapotranspiration rate from an extensive surface of reference vegetation having a standardized uniform height and that is actively growing, completely shading the ground, has a dry but healthy and dense leaf surface, and is not short of water" (Allen, *et al*., 2007; Allen, *et al*., 1998). The Penman-Monteith model is recommended by the Food and Agricultural Organization (FAO) of the United Nations for estimation of ET_o (Pandey, *et al*., 2016; Allen, *et al*., 2007; Allen, *et al*., 1998) and is used as the standard. For agricultural fields, rainfall, irrigation, and capillary rise of groundwater are the sources of water for root zone, while evapotranspiration, deep percolation losses and runoff removes water from it. The amount of water transported upwards by capillary rise from the water table to the root zone depends on the soil type, the depth of the water table and the wetness of the root zone, and it can be assumed to be zero when the water table is more than about 1 m below the bottom of the root zone (Allen, *et al.,* 2007). Estimation of runoff is influenced by factors such as land cover, soil texture, soil structure, sealing and crusting of the soil surface, land slope, local land forming, soil moisture content, and rainfall intensity and duration (Allen, *et al.*, 2007). Runoff can be estimated using the USDA-NRCS curve number approach used within hydrologic, soils, and water resources communities (Huffman, *et al.*, 2011).

1.1. Motivation

Water is a key component in the growing of crops at all farming levels because the yields of crops are highly influenced by available water. Factors such as field management also influence harvestable yield, however, the interactions of local climate and water availability are the main limiting factors. For most farmers, the challenge is in accessing useful information on typical water balances for their farms or locality. Such information is needed in establishing supplemental irrigation volumes as well as timing of application (Irrigation scheduling). Therefore, efforts needed in collecting, computing and analysis of local meteorological data, soils, field management and crop growth characteristics for determination of net irrigation requirements, evapotranspiration as well as other water uses or losses.

1.2. Problem Statement

The AKTC project aims at contributing to the modernization of crop production in Zambia, by equipping farmers with state-of-the-art knowledge and skills thus efficient use of water becomes a prerequisite. The Republic of Zambia's diversification of the economy policy from mineral dependence to an agro-based one, puts more stress on the constant supply of water available for crop production. Most of the farms are small to medium size, mainly depending on rain-fed production; improvements in productivity is essential for rural food security. The study identifies ways to improve crop water productivity and other management practices at AKTC through the use of AquaCrop crop water productivity model to simulate yield, water balance and effects of management inclusive through number of scenarios.

1.3. Objectives

The study aims at establishing a water balance at GART, Chisamba on behalf of AKTC with the following specific objectives:

- Quantify water input and output (ETo–Precipitation/Irrigation) for the study area
- Identify the physical soil properties relevant to soil water availability and crop growth
- Simulate crop growth (for soybean), and compare actual yields observed in the field to those estimated by the AquaCrop model
- Determine water use efficiency at the Centre and other field management aspects

1.4. Study Area–GART Chisamba

The study area is located in Chisamba district of Zambia, central province geographically located at 14° 56' 37.00″ S and 28° 05' 11.00″ E. The research Centre is just about 60 km north of Lusaka. It is surrounded mainly by other farms except the north east boundary which is the Great North road. The farm has a total area of 1003.01 hectares but only the 10 hectare farm is considered in this research. The surface topography and slope is relatively flat. The irrigation system in use is centre pivot sprinkler system. For the 10 ha field, the only water source besides rainfall is groundwater with the water table below 24 m from ground surface. The soil belongs to the loam textural class having a pH range of 5.3 – 5.6 with an organic matter content of about 3 percent.

1.5. Reference Evapotranspiration

Evapotranspiration combines both soil evaporation and crop transpirations, it is affected by many factors among them are; weather, crop characteristics, management and environmental aspects. Evapotranspiration from a reference surface is called Reference evapotranspiration and is calculated based on FAO standard using the FAO Penman–Monteith equation. The reference surface is hypothetical and is described as an extensive surface of a green well–watered grass of uniform height actively growing and completely shading the ground (Allen, Pereira, *et al*., 1998). This then reduces ET_o to a climatic parameter that can be computed only using weather data. The equation and all the required meteorological data and other parameters as shown in equation 1.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where: ET_o is the Reference evapotranspiration [mm/day]; $R_n$is the Net radiation at the crop surface [MJ m-2 day-1]; G is the Soil heat flux density [MJ m-2 day-1]; u_2 is the Wind speed at 2 m height [m/s]; e_s is the Saturation vapour pressure [kPa]; e_a is the Actual vapour pressure [kPa]; $e_s - e_a$ is the Saturation vapour pressure deficit [kPa]; Δ is the Slope of vapour pressure curve [kPa/ oC] and γ is the Psychrometric constant [kPa/oC].

1.6. Crop Evapotranspiration

Reference ETo as described in section 1.5 often does not exist under field conditions as there are many other factors outside the standard conditions. These factors include crop characteristics that are different from the reference grass surface as well as management and environment factors. Therefore, adjustments for ETo are made using correction factors reflecting the influence of non–standard conditions through the use of a crop specific coefficient (Kc) that depends on the crop growth stage. The crop evapotranspiration (ETc) refers to evaporating demands from crops grown in relatively large fields, under optimum soil water, excellent management and environmental conditions. When management and environment conditions are not optimal further adjustments needs to be made to the calculated value of ETo symbolized as ETc adj. The adjustments are made by introducing a water stress coefficient (Ks) and /or adjusting Kc for all kinds of stresses that the crop undergoes (Allen, Pereira, et al., 1998). The calculations of crop evapotranspiration based on the FAO guidelines can be divided into two methods.

1.6.1. Single crop coefficient–Crop evapotranspiration

In the single crop coefficient method, the effective crop characteristics different from the reference grass are represented by a single coefficient (Kc) only. Under standard conditions, ETc is calculated from the single crop coefficient and reference evapotranspiration ETo as follows:

$$ET_c = K_c \times ET_o \quad (2)$$

Equation 2 is applicable for normal irrigation planning and management needs as well as water balance investigations for time steps of more than one day. For a detailed account of the calculation procedure for ET_c based on this method see (Allen, Pereira, *et al.*, 1998). In summary, the procedure consists of the following:

i. Identifying the crop growth stages, length of each growth stage and selecting an appropriate K_c coefficient from tables provided in literature;
ii. Depending on climatic conditions or irrigation wetting frequencies, the K_c selected in (i) above is adjusted to account for their effects.
iii. Construction of the coefficient curve for the entire growing period of a crop.
iv. Finally, ET_c is calculated using equation 2.

K_c is also affected by partial wetting resulting from certain types of irrigation such as trickle or furrow systems as an example such that the true irrigation depth of wetted soil fraction has to be determined.

1.6.2. Dual crop coefficient–Crop evapotranspiration

The dual crop coefficient outlines a procedure for calculating crop evapotranspiration under standard conditions as in section 1.6.1 but using two coefficients. One for crop transpiration (the basal crop coefficient Kcb) and the other for direct soil evaporation (Ke). ETc is then obtained using the equation 3:

$$ET_c = (K_{cb} + K_e)ET_o \qquad (3)$$

The use of dual crop coefficient is recommended for use when improved estimate of Kc is needed for irrigation scheduling on a daily basis. The basal crop coefficient is defined as the ratio of crop transpiration over the reference evapotranspiration (ETc/ETo) when the soil surface is dry but transpiration is occurring at a potential rate without water limitation. It represents the transpiration component of evapotranspiration process. On the other, the soil evaporation coefficient (Ke) represents the evaporation component of crop evapotranspiration. Immediately after rainfall or irrigation, Ke is at its maximum and becomes very small or even zero when the soil surface is dry. The evaporation process assumes soil water content on the surface to be at field capacity (θFC) just after a wetting event. The soil is allowed to dry to a water content that is halfway between oven dry and wilting point (θWP) so that the amount of water that can be depleted by evaporation per drying cycle is estimated using equation 4.

$$TEW = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \qquad (4)$$

Where: TEW is the total evaporable water = maximum depth of water that can be evaporated from the soil when the topsoil has been initially completely wetted [mm]; θFC is the soil water content at field capacity [m3/ m3]; θWP is the soil water content at wilting pint [m3/ m3]; and Ze is the depth of the surface soil layer that is subject to drying by way of evaporation [0.10 m – 0.15 m]. During drying, evaporation can be assumed to take place in two stages. The first stage is the energy limiting stage which happens when the soil surface is wet and evaporation is at its maximum. At some point during the drying process, soil water content in the upper soil surface becomes limiting and evaporation reduces accordingly. This change in in rate of evaporation is accounted for by the soil evaporation reduction coefficient (Kr). The cumulative depth of evaporation, De at the end of the energy limiting stage is REW (Readily evaporable water which is the maximum depth that can be evaporated from the top soil layer without restriction during this stage). The second stages is the falling rate stage. During this stage, the rate of evaporation is reducing and starts to exceed REW and the soil surface is visibly dry. This is the stage at which the reduction in evaporation is proportional to the amount of water remaining in the surface soil layer.

$$K_r = \frac{TEW - D_{e,i-1}}{TEW - REW} \qquad for\ D_{e,i-1} > REW \qquad (5)$$

Where: Kr is the dimensionless evaporation reduction coefficient dependent on the Soil water depletion (cumulative depth of evaporation) from the topsoil layer (Kr = 1 when $D_{e,i-1} \leq$ REW); D is the cumulative depth of evaporation (depletion) from the soil surface layer at the end of day i-1 (the previous day) [mm]; TEW is the maximum cumulative depth of evaporation (depletion) from soil surface layer when Kr = 0 (TEW = total evaporable water) [mm]; and REW is the cumulative depth of evaporation (depletion) at the end of energy limiting stage (REW = readily evaporable water) [mm]

1.7. Energy Balance

For evaporation to take place, some relatively large amount of energy is required either through sensible heating or the use of radiant energy. This energy exchange for evapotranspiration is limited mainly by the amount of energy received considering all energy fluxes. Thus the energy equation for an evaporating surface can be written as:

$$R_n - G - \lambda ET - H = 0 \quad (6)$$

Where: R_n is the net radiation; H is sensible heat; G is the soil heat flux; and λET is the latent heat flux. The terms in equation 6 can either be positive or negative with positive Rn and G supplying energy to the surface while λET and H remove energy from the surface.

1.8. Soil Water Balance

Assessing soil water balance involves taking account of both the incoming and outgoing water fluxes in the root zone over a time period. In this regard, the root acts as a water reservoir and the water retained or depleted in the root zone can be determined at any moment during the crop growing cycle. When all fluxes except evapotranspiration are known, evapotranspiration can be determined from the changes in soil water content storage within the root zone by applying equation 7:

$$ET = I + P - RO - DP - CR \pm \Delta SF \mp \Delta SW \quad (7)$$

Where: ET = is evapotranspiration, I = irrigation, P = rainfall, RO = surface runoff, DP = deep percolation, CR = capillary rise, SF = subsurface flow (In or Out) ΔSW = change in soil water content.

2. MATERIALS AND METHODS

The use of computer models to estimate evapotranspiration, and crop growth, yields, environmental conditions and other water balance components to facilitate planning becomes inevitable in limited time and resources. A prerequisite is to have all model input data in place, within statistically acceptable record length and homogeneity. AquaCrop was used to simulate crop yield response to water and water balance analysis while the ETo Calculator to compute reference evapotranspiration. The ETo calculator follows FAO standards and this method has been selected by FAO as the reference because it closely approximates grass ETo regardless of geographical location, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Similarly, AquaCrop simplifies the complexity of crop response to water and makes use of empirical production relationships as the most practical option to assess crop yield response to water. It includes the soil, with its water balance; the plant, with its development, growth and yield processes; and the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. Additionally, some management aspects are explicitly considered such as irrigation, soil fertility and field practices as they affect soil water balance, crop development and consequently yields. Figure 1 shows a flow chart of the methods employed during the investigation.

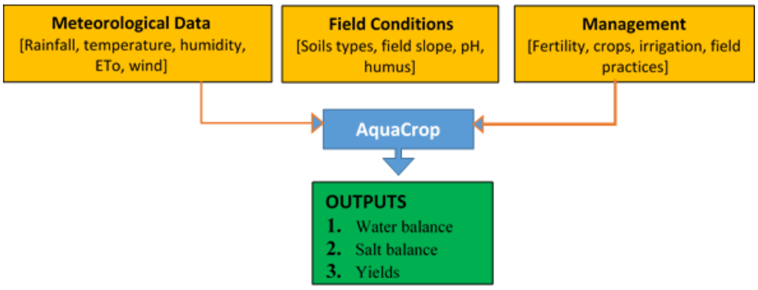

Figure 1: Methodological flow chart

2.1. Meteorological data

The main inputs into AquaCrop model are meteorological data for the computation of ETc, and as input into the soil profile for water balance analysis. This makes collection of available climatic data a first step in the development of the model.

2.1.1. Rainfall

Daily rainfall records for a 37 year period were obtained from the Metrological (MET) Office in Lusaka. This record as shown in Figure 2 (a) is for the town of Kabwe. Kabwe was used because it had the most consistence long period record as well as near enough to the study area and with similar climatic patterns.

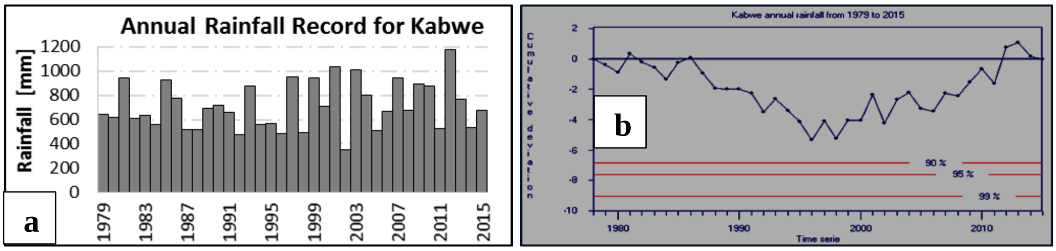

Figure 2: (a) Kabwe 37 year rainfall record and (b) its homogeneity test (residual mass curve) in rainbow software

Statistical test for homogeneity to determine the consistence of the rainfall record were performed using the Rainbow software (Raes, *et al.*, 2006) based on the cumulative deviation of the mean (residual mass curve). The results shown in Figure 2 (b) are acceptable since the cumulative residuals fluctuate around zero and are far from the rejection lines of 90 %, 95 % and 99 % respectively. For 37 year rainfall record, the mean annual rainfall is 890 mm, minimum record of 594 mm and a maximum of 1444 mm. As estimated by the Rainbow software, the region will experience dry conditions (80 % probability of exceedance) when annual rainfall is below 545 mm. A wet season is experienced (*20 % exceedance probability*) when average annual rainfall is 862 mm. The area has a sample standard deviation of 194 mm. Graphical representation of the fitted log 10 transformed rainfall data on the normal distribution is shown in Figure 3 (a) and has a coefficient of determination (R^2) of 0.97 on the fitted cumulative density function (red line in figure 3 b).

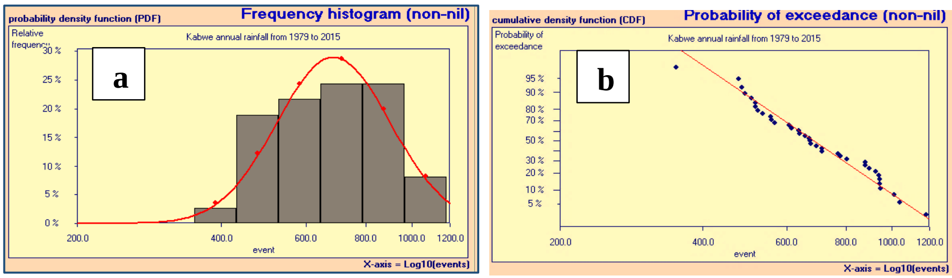

Figure 3: (a) Frequency histogram of the log transformed rainfall record and (b) probability of exceedance plot

2.1.2. Temperature

Temperature is another climate input required for use in both AquaCrop and the ETo calculator. In AquaCrop, temperature is used to determine the growing degree days (GDD) and describe crop growth, phenology and adjustments of biomass production during damaging cold periods (Raes, et al., 2009a). Growing degree days are calculated using:

$$GDD = T_{avg} - T_{base} \tag{7}$$

Where Tbase is the base temperature below which crop development does not progress, and Tavg is average air. An upper temperature threshold is also considered, beyond which crop development no longer increases with increase in air temperature for a given crop. Figure 4 gives average annual minimum and maximum temperature distribution.

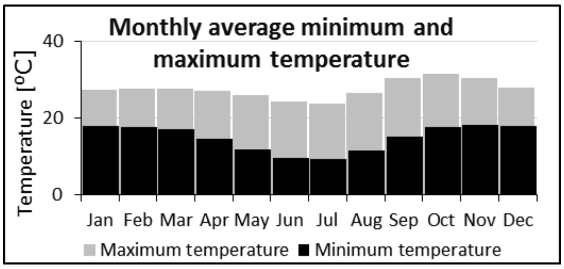

Figure 4: Monthly average minimum and maximum temperature for Kabwe

2.1.3. Relative Humidity and Wind Speed

Relative humidity is needed for calculation of ET_o in equation 1. Figure 5 (a) shows monthly average relative humidity values for Kabwe for period of 19 years (1995–2013) from Meteorological Department checked against those provided by Faoclim 2 agro–climatic data base of FAO for consistence. Wind Speed record for the same period is shown in Figure 5 (b).

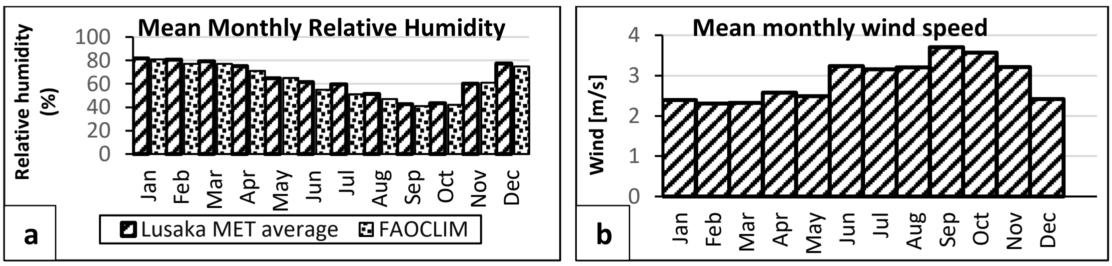

Figure 5: (a) Annual average relative humidity and (b) average wind speed for Kabwe

2.1.4. Solar Radiation and Carbon Dioxide concentration

A 12 year Faoclim 2 record of monthly average values shown in Figure 6 (a) was used.

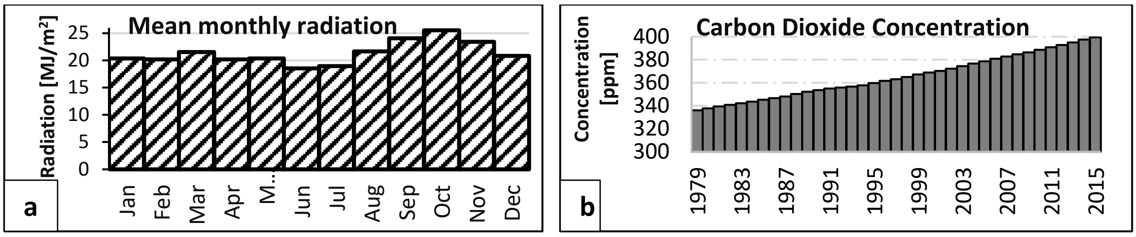

Figure 6: (a) Annual distribution of solar radiation for Kabwe and (b) carbon dioxide concentration as measured and projected at Mauna Loa Observatory in Hawaii

No records of carbon dioxide concentrations measurements were available. For this reason, historical and projected carbon dioxide (CO_2) concentration values as observed at Mauna Loa Observatory in Hawaii were used as shown in Figure 6 (b). CO_2 concentrations are used in AquaCrop model to simulate crop water productivity (WP) as it is normalized for both CO_2 concentrations and climate (ET_o). WP is expressed as the above ground dry weight of biomass (g or kg) produced per land area (m^2 or ha). Normalization for CO_2 concentration is by considering the reference concentration of 369.41 (Raes, *et al.*, 2012).

2.2. Soils

The soil under consideration falls in the loam soil category and composed of 36 % sand, 39 % silt and 25 % clay on mass basis while the organic matter content of the soil is the in range 2.72–2.96 %. The soil pH is in the range 5.3 to 5.6. Soil physical properties were calculated using the Soil Water Characteristics Model (Saxton & Rawls, 2006). The soil horizon was considered up to a depth of 2.5 m beyond which soybean roots can't reach. Because the water table is 24 m below ground surface, the soil water is lost as deep percolation and no capillary rise is considered. The estimated moisture content by volume at permanent wilting point (PWP), field capacity (FC), saturation (SAT) are 16.4 %, 30.8 %, and 46.4 % respectively while the saturated hydraulic conductivity is at 240 mm/day. Under existing field management, the curve number (CN) for modelling of surface runoff was estimated at 72. In addition, readily evaporable water was limited to 9 mm with an evaporating surface layer up to a maximum depth of 4 cm (Allen, Pereira, et al., 1998).

2.3. Crops

The crop under cultivation was soybeans. Hence its physical characteristics were obtained and estimated from field observation planted on 7th December, 2015 and reaching maturity on 4th April 2016 after 120 days. These characteristics as put in AquaCrop are shown in Table 1.

Table 1: Calendar description of soybean growing stages under optimal conditions

Growth stage from day one after sowing to:	Length (days)	Date
Emergence	7	14 December
Maximum canopy cover	60	5 February
Start of canopy senescence	90	7 March
Maturity	120	5 April
Flowering	60	5 February
Length building HI	60	End 6 April
Duration of flowering	21	End 26 February

Plant density was estimated at 350,000 plants per hectare. Crop yield is then modelled through the response of crops to water using the empirical relationship:

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\left(1-\frac{ET_a}{ET_c}\right) \tag{8}$$

Where, Y_a is the actual yield and Y_m is the maximum possible yield for a given management condition, ETa is the actual crop evapotranspiration and ETc is the crop evapotranspiration for non-water stressed conditions. AquaCrop separates actual evapotranspiration into soil evaporation and crop transpiration and eliminates the non-productive consumptive use of evaporated soil water, the final yield is also separated into biomass (B) and harvest index (HI) (Raes, *et al.*, 2009b). The above ground biomass is obtained as accumulation of daily biomass production using equation

$$B = WP \times \sum Tr \tag{9}$$

Where Tr is transpiration (mm) and WP is the water productivity (kg of biomass per m^2 and per mm of cumulated water transpired). From the calculated above ground biomass, the yield (Y) is obtained using the reference harvest index (HIo):

$$Y = f_{HI} \times HI_o \times B \tag{10}$$

Where f_{HI} is a multiplier that takes into account of stresses that reduce HIo from the reference value.

2.4. Observed irrigation Events

Besides surface treatment methods and soil fertility water supplied under irrigation is also a management issue. Table 2 gives observed irrigation events during the 2015–2016 growing season.

Table 2: Observed irrigation events showing depth and day of application from the date of planting

Event	Date	Day No.	Depth (mm)
1	4, January	29	30
2	7, January	32	30
3	10, January	35	30
4	13, January	38	30
5	26, January	51	30

2.5. Simulations

Simulations in AquaCrop encompass the whole soil–plant–atmosphere continuum. Gradual model development started with the most optimal conditions for crop growth, comparing the simulated yields with those obtaining on the ground. Three scenarios were developed based on possible existing field:

i. **Scenario 1**: In this scenario all conditions were at optimum with the soil fertility set to non–limiting and the field without any water stress (*optimum irrigation based on net water requirement for the crop to supplement rainfall*).
ii. **Scenario 2**: for this scenario, soil fertility was equally at optimum. The source of water was rainfall but instead of net irrigation, observed irrigation events were applied in the field as in Table 2.
iii. **Scenario 3**: In scenario three, soil fertility was set to non-optimal conditions with levels of soil fertility estimated from field test report from which soil fertility was set at 80 %. As in scenario 2, water application was as observed in the field, combining rainfall and irrigation events of Table 2.

In all simulations, daily rainfall values were used and monthly averages for temperature, wind speed, solar radiation, relative humidity data, and ET_o.

3. RESULTS AND DISCUSSION

3.1. Determination of ET_o

The calculated annual distribution of ET_o values imported into AquaCrop are shown in Figure 7 (a) for daily ETo. Figure 7 (b) compares monthly rainfall and ET_o values. The highest ET_o values are in October while the lowest are in June.

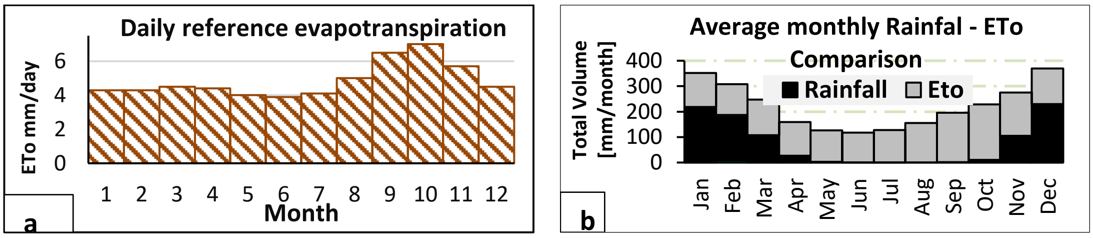

Figure 7: (a) Daily reference evapotranspiration and (b) stacked comparison of monthly rainfall and ETo for GART

Generally, ET_o demands are higher than received rainfall depths and thus supplemental irrigation is inevitable. However, for December, January and February enough rainfall is received to meet respective ET_o demands while in March and November more than half of the ET_o demand can be provided by rainfall and the deficit by irrigation. The maximum ET_o deficit of 206 mm/month or 6.87 mm/day occurs in October.

3.2. Water and Yield Analysis for Soybean

The water inputs and outputs in the field is considered including the inter–play between water, soil fertility and yield formation for soybean using the three scenarios mentioned in section 2.5. The results from all scenarios are compared so as to understand the main factors influencing field observations.

3.2.1. Net Irrigation Requirements

Under water stress-free production of scenario 1, net irrigation requirements were determined to augment rainfall with an average annual water input of 818.8 mm and average losses of 431.2 mm representing an average field loss of 51.3 % ± 5 %. Thus soybean uses an average of 427.8 mm to transpire. Table 3 shows expected seasonal values of rainfall and net irrigation requirements for dry, normal and wet weather conditions giving typical range for planning purposes. A guide on the distribution of these net irrigation requirements per 10 day interval is as shown in Figure 8.

Table 3: Seasonal water inputs from rainfall and irrigation for a dry, normal and wet year

Weather Condition	Annual Rainfall (mm)	Seasonal Net Irrigation Requirements (mm)
Dry	545.2	162.2
Normal	685.4	109.8
Wet	861.8	53.0

Table 4 shows possible maximum 10 day net irrigation requirements. The maximum that can be applied in one decade is about 50 mm only. The bulk of the water demand is needed just after the mid–season till when the crop has reached maturity. For this reason care has to be made to avoid water stresses at such a stage.

Table 4: 37 year return period 10 day net irrigation requirements under optimal growing for soybean

	Dec			Jan			Feb			Mar		
Decade	1	2	3	1	2	3	1	2	3	1	2	3
37 year return period net irrigation (mm)	19.8	29.9	23.4	36.7	47.6	38.5	44.1	30.6	47.6	47.1	49.1	21.3

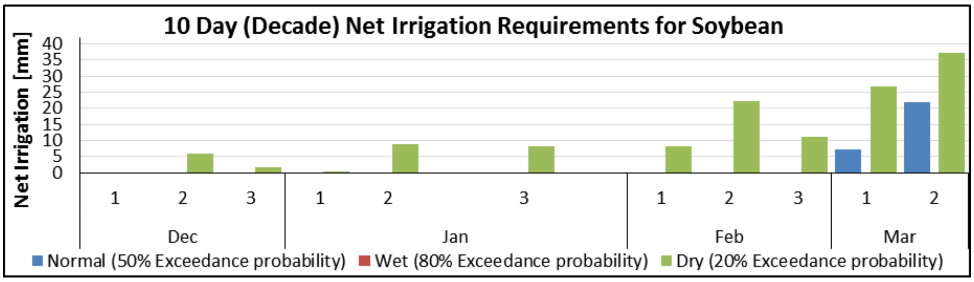

Figure 8: 10 day (decades) of net irrigation requirements for the dry, normal and wet weather conditions

Comparing actual irrigation events of Table 2 to model results under ideal conditions of scenario 1, all the five events occurred between the first and third decade of January indicating a dry year for that period for the year in question. A 30 mm depth at an interval of 3 days implies that available soil water is above the crop's allowable depletion factor and thus not fully depleted before the next application even during peak ET_o demands. Therefore, the interval of application is not optimal. The application depth of 30 mm when compared to Table 4 has a return period of 37 years, but applied in a year that is not the driest within the record. This depth is too high when compared to the statistical range of 10 mm to 22.5 mm of Figure 8.

3.2.2. Water Balance comparison between scenarios

Figure 9 (a) show scenario 1 having lowest percolation losses because irrigation is at optimum with respect to depth and scheduling thus minimizing losses due to deep percolation. Crop growth is equally modelled at optimal soil fertility, thereby making use of available water for both biomass and yield formation. Scenario 2 and 3 have percolation losses higher than in scenario 1 because irrigation depth and intervals are not optimized. In Figure 9 (b) scenario 3 has much higher direct soil evaporation losses than both scenario 1 and 2 whose evaporation losses have identical trends as a result of poor soil fertility level predicted at a fertility stress of 23 % by AquaCrop. Poor fertility resulted in poor canopy development and thus exposing large proportion of the field to direct sun and wind. Effects of poor canopy cover is notable in Figure 10(a) were transpiration for scenario 3 is lowest.

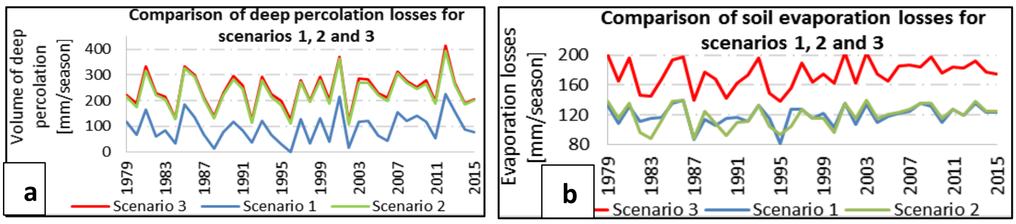

Figure 9: (a) Comparison of Seasonal deep percolation losses and (b) direct soil evaporation losses between scenarios 1, 2 and 3

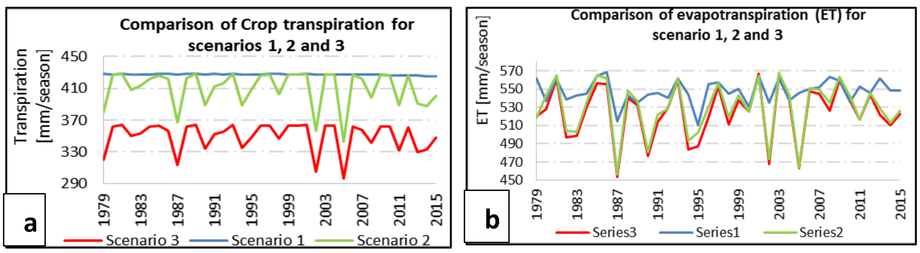

Figure 10: (a) Seasonal crop transpiration and (b) evapotranspiration between scenarios.

Transpiration in scenarios 2 and 3 is influenced by available water from both rainfall and irrigation. As for scenario 1, seasonal transpiration is constant during simulation as water is always available in right quantities. Scenario 3 transpires much less than scenarios 1 and 2 because of low fertility that inhibit crop water use through reduced biomass formation. Combining both evaporation and transpiration, scenario 1 has relatively higher values but with a transpiration to evapotranspiration ratio of over 78 %. This implies a better WP for the same crop on a dry yield basis and Scenario 3 has the lowest ratio of 67 %. Evolution of evapotranspiration is shown in Figure 11(a). Three regions have been identified, region 1; between days 10 – 20 were scenarios I and 2 exhibits possibility of water stresses in the vegetative stage of the crop cycle. Region 2; between days 25 and 40 were actual application of irrigation events is taking place in scenarios 2 and 3 and suddenly increases ET values from about 4.25 mm/day to over 4.8 mm/day as result of excessive soil evaporation from heavy irrigation and not crop transpiration as seen in scenario 1 where the increase is gradual with crop development. Region 3; 90 days from planting have higher ETo in scenario 1 when compared to the other two scenarios. The difference comes from unnecessary higher crop transpiration towards crop maturity and should be avoided without affecting yields (Less than 5% yield difference between scenario 1 and 2 in Figure 12).

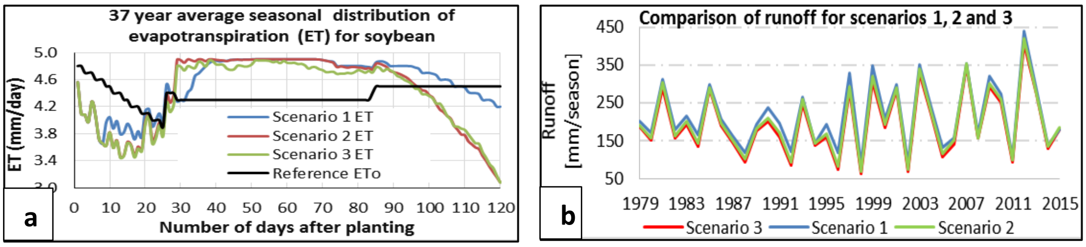

Figure 11: (a) 37 year average distribution of soybean evapotranspiration within a growing season [from 7th December to 5th April] and, (b) seasonal runoff volumes for scenarios 1, 2 and 3

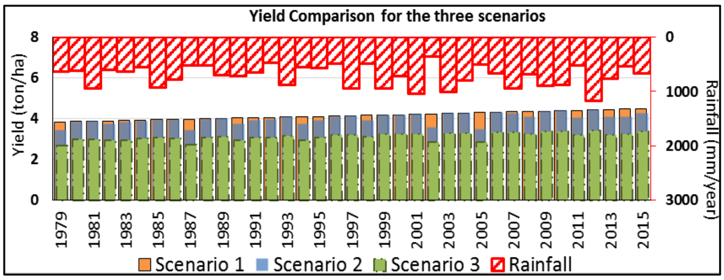

Figure 12: 37 year seasonal yields for scenario 1, 2 and 3.

In Figure 11(b) there is no significant differences in runoff between all three scenarios due to the fact that runoff processes are influenced by constant field conditions in all scenarios such as soil type, field slope, type of crop and field management. Similarly, reduced evaporation in scenario 1 due to good canopy cover slightly increases the amount of volume available for runoff.

3.2.3. AquaCrop prediction Vs actual yields

Average observed yield was 3.22 ton/ha of soybean but under ideal crop growing conditions, AquaCrop gave an average of 4.16 ton/ha while under actual applied irrigation the average reduced to 4.00 ton/ha. Observed water stresses were below 5 % while soil fertility stresses reduced average yield to 3.12 ton/ha with a maximum of 3.42 ton/ha and a minimum of 2.70 ton/ha. The seasonal yields for all three scenarios are shown in Figure 12.

4. CONCLUSION AND RECOMMENDATIONS

Analysis of seasonal water requirements indicates that current field irrigation practices do not significantly affect crop yield and simulations recorded water stresses less than 5 %. Irrigation is required from the initial stages up to the flowering and yield formation stages in dry weather conditions. Estimated 10 day irrigation scheduling is shown in Figure 8 for all weather conditions. Practically no irrigation is required under wet weather conditions. Evapotranspiration crop water requirements at daily time steps is between 3.4 mm/day to 5 mm/day and 450 mm to 570 mm per season. Rainfall average is 890 mm per year while irrigation needs varies from 53 mm to 162.2 mm per season for soybean. About half of inflow water fluxes are lost through evaporation, runoff and deep percolation. Evaporation losses range between 150 mm and 190 mm on a seasonal basis for scenario 3. For this reason, methods that avoid evaporation losses should be employed. Surface runoff ranges from 100 mm to 275 mm while deep percolation losses range from an average minimum of 150 mm to a maximum of 300 mm. Emphasis should be given to soil fertility as it is the main reason for discrepancy between AquaCrop predicted yields and those observed. The crop suffered a 23 % fertility stress, corresponding to a 23 % yield reduction. Results also depend on quality of meteorological data used in instances were monthly values are used as daily micro–climate conditions affecting crop ET and ETo maybe misrepresented. The difficult in getting field values of moisture content and carbon dioxide concentration and the use of estimated values also contributes to uncertainty of the results.

ACKNOWLEDGEMENT

The works of this report have been possible with support from The University of Zambia (UNZA) and the Agricultural Knowledge and Training Centre (AKTC) through a Memorandum of Understanding (MoU). The authors are grateful for the support given by both institutions especially on the provision of resources for the collection of field crop and meteorological data by the AKTC team and the support from the research group in Water and Soil Conservation in the Department of Agricultural Engineering. We acknowledge the assistance offered by the Meteorological Department of the Government of Zambia in Lusaka through provision of meteorological information. Our gratitude goes to Dr. E. Phiri and the staff in the Department of Soil Science at UNZA for their help with the analysis of soil samples. Special thanks go to Dr. J. M. Chileshe and Mr. H. Anschutz for spearheading and coordinating the partnership between UNZA and AKTC.

REFERENCES

Allen, Richard G., L. S. Pereira, D. Raes, and M. Smith. 1998a. "FAO Irrigation and Drainage Paper No. 56." *Rome: Food and Agriculture Organization of the United Nations* 56: 97–156.

Allen, Richard G., L.S. Pereira, D. Raes, and M. Smith. 1998b. "Crop Evapotranspiration: Guidelines for Computing Crop Requirements." *Irrigation and Drainage Paper No. 56, FAO*, no. 56: 300.

Allen, Richard G., Luis Santos Pereira, Dirk Raes, and Martin Smith. 1998c. *FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration*. *FAO*.

Allen, Richard G., James L. Wright, William O. Pruitt, Luis S. Pereira, and Marvin E. Jensen. 2007. "Water Requirements." In *Design and Operation of Farm Irrigation Systems*, 208–88.

Droogers, Peter, and Richard G. Allen. 2002. “Estimating Reference Evapotranspiration Under Inaccurate Data Conditions.” *Irrigation and Drainage Systems* 16 (1): 33–45.

Huffman, Rodney L., Delmar D. Fangmeier, William J. Elliot, Stephen R. Workman, and Glenn O. Schwab. 2011. *Soil and Water Conservation Engineering*. 6th ed. American Society of Agricultural and Biological Engineers.

Pandey, Pankaj K, Parmendra P Dabral, and Vanita Pandey. 2016. “International Soil and Water Conservation Research Evaluation of Reference Evapotranspiration Methods for the Northeastern Region of India.” *International Soil and Water Conservation Research* 4 (1). Elsevier: 52–63.

Raes, Dirk, Pasquale Steduto, Theodore C. Hsiao, and Elias Fereres. 2009. “AquaCropThe FAO Crop Model to Simulate Yield Response to Water: II. Main Algorithms and Software Description.” *Agronomy Journal* 101 (3): 438.

Raes, Dirk, Pasquale Steduto, Theodore C. Hsiao, and Elias Fereres. 2012. “AquaCrop Version 4.0 Reference Manual”. FAO, Land and Water Division Rome, Italy.

Raes, Dirk, Patrick Willems, and Félix Gbaguidi. 2006. “RAINBOW–A Software Package for Hydrometeorological Frequency Analysis and Testing the Homogeneity of Historical Data Sets.” In *Proceedings of the 4th International Workshop on Sustainable Management of Marginal Drylands. Islamabad, Pakistan*. Vol. 2731.

Saxton, K. E., and W. J. Rawls. 2006. “Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions.” *Soil Science Society of America Journal* 70 (5): 1569.

Steduto, Pasquale, Theodore C. Hsiao, Dirk Raes, and Elias Fereres. 2009. “AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: I. Concepts and Underlying Principles.” *Agronomy Journal* 101 (3): 426.

Yavuz, Duran, Nurcan Yavuz, and Musa Seymen. 2015. “Evapotranspiration, Crop Coefficient and Seed Yield of Drip Irrigated Pumpkin Under Semi-arid Conditions.” *Scientia Horticulturae* 197. Elsevier B.V. 33–40.

Assessment of Key Risks in Airport Construction Projects in Zambia: A Case Study of the Expansion and Upgrading of Kenneth Kaunda International Airport

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Abstract

Airport construction projects are large, complex, and expensive ventures that often involve political, economic, social, technical, environmental and legal (PESTEL) challenges. Despite these challenges, large sums of money are invested in airport projects that run high risks of being over budget and not within schedule. Though some degree of cost, schedule and quality risks are considered during planning, an understanding of how risks impact on the performance of the project still remains a challenge for project managers and stakeholders. Past experience from similar projects indicate that there was a lack of tools to identify and assess risks in airport construction effectively. In seeking to address these problems, this research aimed at identifying and analyzing the key PESTEL risks associated with the development of airport construction projects in Zambia. The expansion and upgrading of Kenneth Kaunda International Airport (KKIA) was used as a case study. Due to time constraints, the research was conducted during the construction phase only. Through interviews, the study established that there was lack of in-depth understanding and knowledge of the inherent PESTEL risk issues and their impact in airport construction. There was also no standard and effective technique or practice specifically targeted for assessing risks in airport construction projects. Based on a review of literature and a self-administered structured questionnaire, risks were identified and a comprehensive assessment of the probability of these risks as well as their impact on project objectives was carried out. Using the risk significance and identification score (RSIS), the study identified and ranked 20 key PESTEL risk factors as having a significant impact on project delivery. Among them "Unforeseen modification to project" was recognized to influence project objectives mostly, followed by "Stakeholders' pressure", and "Material price changes". It was concluded that project stakeholders must work collaboratively during the construction phase to address potential PESTEL risks in time to ensure the successful delivery of the project within time, without cost overruns and to the expected quality.

Keywords: Risks, airport construction projects, PESTEL, KKIA, Zambia

1. Background

The construction process, especially in the context of airport construction projects, is complex and has significant risks built into its structure (Ashley, 1977, Mohammad *et al.*, 1991) which influence the project from initiation through to the completion stages (Flyvbjerg *et al.*, 2003). For example, variable site conditions, subcontractor delays and uncertainty about changes in weather conditions are some of the common risk variables that exist in every construction project. Risk management is therefore paramount during construction for successful delivery of the project. Project Managers who do not interact attentively with the environment of these projects usually face challenges during planning and execution of their projects (Ali-Mohammed, 2010). Evidence

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suggests that such projects are usually money pits and funds are simply ‘swallowed up’ without achieving the required project objectives. This is as a result of the lack of information in assessing risks and uncertainties, and not taking corrective actions to mitigate the identified risks. For example, Anthony (2012) asserted that airport projects more often fly off course than other types of infrastructure construction because they are more complicated and involve more uncertainty. Project costs and completion time is often grossly underestimated.

It is generally accepted that not all risks can be removed but it is also accepted that identification of risks and their proactive management can decrease the probability of occurrence, and in the event that they do occur, their severity can be minimized with robust control processes and mitigation in place. The delivery of KKIA therefore, presents Zambia Airports Corporation Limited (ZACL) with a challenge in respect of airport construction risks. The key factors contributing to this are: $365 million project financed through contracted loan from the Bank of China; the scale of project not undertaken previously by ZACL; and ambitious technical challenges to be delivered in an airport environment. The objectives are to deliver on time, within budget, compliant with specifications that are safe while meeting customer needs and expectations.

Against this background, the main objective of this research was to determine the key PESTEL risks which affect project delivery in airport construction and recommend adequate risk management strategies in order to improve their implementation. In order to achieve the main objective, the following specific objectives were devised:

a) to identify and describe the significant risks associated with PESTEL problems for airport construction projects;

b) to quantify the qualitative PESTEL risk effects on project objectives and rank them in relation to their influence on project objectives; and

c) to determine the key PESTEL risks having a significant impact on project delivery.

2. Literature review and the conceptual framework

2.1 Characteristics of airport projects

An airport industry is a very large investment with a high level of impact on a region’s economic values and development. Airport projects developments in the relevant body of literature are noted to be characterized by sizeable risks during construction. The common perception is that airport projects often exhibit typical managerial problems that make them complex technologies when initiated and developed. Figure 1 illustrates the features of an airport construction environment, which distinguish it from any other construction sector.

2.1.1 Size, scope and cost

One characteristic of airport projects is the wide range of their costs. Airport projects cover a wide variety consisting of both horizontal and vertical projects ranging in cost from few thousand dollars to hundreds of millions of dollars (ACRP, 2009).

2.1.2 Security

Another important attribute of airport projects is security considerations. Airport area is usually divided into two parts: air-side which comprises runways and other facilities beyond the terminals and land-side which includes an airport’s interface with ground transportation (Reid 2007). The air-side is a secured non-public portion of an airport where movement of the construction personnel and equipment is controlled. On the other hand, the land-side excluding terminals is the non-restricted area which includes area and buildings that both travelling passengers and the non-travelling public have unlimited access to. Construction in secured zone of airports involves difficulties in providing the security which is time-consuming and costly. Based on studies, it has been found that the cost of construction in areas beyond the security checkpoints is 15 to 25 percent more than similar projects which are outside the secured area (Adrem *et. al.,* 2006). This cost difference has numerous reasons among them; workers must be issued special security badges to enter the secure air-side/terminal regions. This requires completion of a security clearance process which takes time; all vehicles and drivers must get special licences; also, because of the existence of the expensive aircraft and flammable material in the air-side, the contractor must take into account the various safety regulations which are not necessary in the land-side projects. All of these issues reduce the daily production rate of construction adding time and money to the airport project.

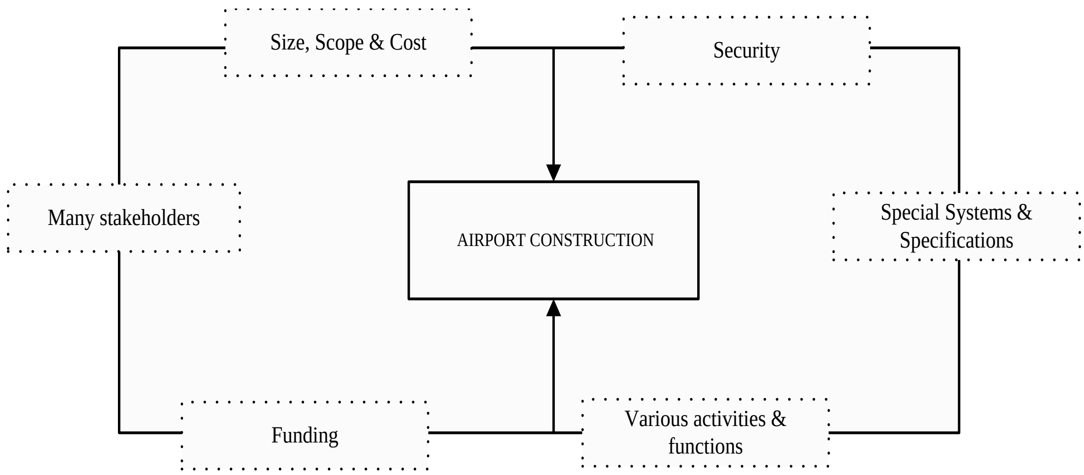

Fig. 1: Characteristics of airport construction projects (Nasser, 2013 & Ahmad, 2015 (modified))

2.1.3 Special systems and specifications

"*Airport projects have a whole series of special systems which are seen nowhere else, on an enormous scale*." (ENR, Dec 2003). These systems add to the complexity of airport projects. Some experts compare an airport to a body with multiple systems of interdependent organs; a failure in one system can shut down the entire terminal. Also, airports usually undergo additional or removal of the existing facilities instead of building a new one. This process causes many problems like establishing the terms of contract (allocation of responsibilities to project participants especially the contractors) and ensuring that the new additions are designed in a compatible way with the existing facilities in terms of style and material. The challenge is how to integrate the new and old facilities which should be accomplished in an effective manner (Adrem *et. al,* 2006).

2.1.4 **Various activities and functions**

Various activities and functions within airports require the design outline and specification to be established and prepared by an airport operator/administrator prior to involvement of construction practitioners (Adrem *et. al*, 2006). Consequently, designers' and contractors' responsibility levels for design and/or functional quality can be reduced. It may also limit the advantages of their knowledge and technical experiences.

2.1.5 Funding

Airport construction projects are usually funded by government or public and private partnerships. In the conventional approach to project development, government is the project promoter and financier while private firms who actually conduct the project are intended to do the best-case feasibility studies, produce the designs, and earn additional profits. Thus, these projects must be delivered within budget and expected quality to get public and political support for much-needed airport infrastructure.

2.1.6 Many stakeholders

Due to various activities conducted in the airport and the far-reaching effect of some airport projects (such as construction of new or expansion of existing runways), there are many different stakeholders in the construction project. All stakeholders want to optimize the design based on their concerns that are sometimes conflicting. For instance, entities interested in the commercial aspects of the airport operation may prefer a design that exposes the passengers to as many stores as possible, while entities concerned with terminal operations may prefer that passengers take the shortest possible route throughout the airport. This causes challenges for those in charge of the project to reach an agreement that may increase the development phase of the project (Adrem *et al.*, 2006).

2.2 Typical problems associated with construction projects

Constructing an airport facility takes a long time and usually involves a large capital investment. Airport projects are often portrayed in literature to experience typical problems such as cost overrun, schedule slippage and the failure to meet stakeholders' needs or to deliver the intended outcome (Gould, 2002). Ahmed *et al*., (2002), emphasized that delay on construction projects are a universal phenomenon and are usually accompanied by cost overruns. These have a debilitating effect on contractors and consultants in terms of growth in adversarial relationships, mistrust, litigation, arbitration, cash-flow problems, and a general feeling of trepidation towards other stakeholders. Several studies have been undertaken on factors causing project time overruns (delay), cost overruns, quality deficiency. and other specific risks in different types of airport project development. These studies usually focus on specific aspects of project performance.

2.2.1 Review of delays in construction projects

According to Pickavance (2005) the word "delay'' in construction refers to something happening at a later time than expected, planned, specified in a contract or beyond the date that the parties agreed upon for the delivery of a project. On the other hand, Lo *et al.* (2006) defined delay as the slowing down of work without stopping construction completely and that can lead to time overrun either beyond the contract date or beyond the date that the parties have agreed upon for the delivery of the project. Delay can lead to many negative effects such as disputes and legal actions between project owners and contractors, project cost overruns, loss of productivity and revenue, and contract termination. While schedule delays seem to be embedded in all projects, subsequent delay-related disputes can be avoided by identifying the main causes and preventing these problems from occurring. Increasingly, realistic 'construction time' has become important because it serves as a crucial benchmark for assessing the performance of a project and the efficiency of the contractor (Chan and Kumaraswamy, 2002). A consolidated literature review was therefore carried for the better understanding of the overall picture of the issues.

A study carried out by the World Bank (2009) reported that the overrun for many projects varied between 50% - 80%. In the United Kingdom, 70% of government construction projects were delivered late as reported by the National Audit Office (2001). The Building Cost Information Service [BCIS], (2012) conducted a similar research and found that nearly 40% of all studied projects had overrun the contract period. These delays were mainly caused by factors related to financial and payment problems, insufficient experience, improper planning, shortage of materials and equipment, and poor site management as pointed out in a study by Safer *et al.*, (2012). In a study conducted in Hong Kong region, Tommy *et al.*, (2006) revealed that natural ground conditions, poor communication, manpower problem and insufficient knowledge on work are the delay related risks in construction projects. The construction of the King Abdul Aziz and Riyadh International Airports, and Araar Domestic Airport in the Kingdom of Saudi Arabia are other airport projects that have faced schedule overruns (Ahmad, 2015). Jyh-Bin *et al.*, (2010) concluded that delays in construction are universal phenomena and always accompanied by cost and time overruns and it is thus essential to identify the actual causes of delay. This will minimize and avoid delays and their corresponding expenses.

2.2.2 Review of cost overruns in construction projects

Since Biblical times, cost overruns have been a fact of life as seen in (Luke, 14:28-NIV, 2005), *"Suppose one of you wants to build a tower. Will he not first sit down and estimate the cost to see if he has enough money to complete it?"* cost overruns are a worldwide phenomenon. They are normally a source of conflict among clients, consultants and contractors on the issue of project cost variation and create a significant financial risk to clients. The history of the construction industry, however, is full of projects that were completed with significant cost overruns despite the risks involved (Garry, 2005). In a study by Flyvbjerg *et. al*., (2002, 2006 and 2009), nine out of ten projects had cost overruns in transport projects. The average overrun was found to be 45%, 34% and 20% for rail projects, bridges and tunnels, and road projects, respectively across 20 nations and five continents. On the Danish Great Belt rail tunnel, Flyvbjerg, (2009) found that the cost of construction was about 120% over budget and was only made possible by revenues from a nearby motorway bridge. This tunnel was opened in 1998 and happened to be the second-longest underwater rail tunnel in Europe (Flyvberg, 2009).

In the Boston's "Big Dig" project (also known as "Central Artery/Tunnel Project"), cost was estimated in 1985 at US$6.0 billion from an originally proposed cost of $2.2 Billion. By 2006, the project costs rose to US$15 Billion (143% cost escalation), with 73% of the cost being subsidized by taxpayers (Murphy, 2008). The purpose of the project was to build a 3 kilometer stretch of underground highway through the heart of Boston, replace the existing highway above-ground with green space, and build a tunnel from Boston beneath the Boston Harbour to Logan International Airport in East Boston.

The Denver International Airport in Germany, cost the city $560 million over budget, and performed just a fraction of its original goals according to a study by Ashley (2014).

The above examples clearly indicate that the construction cost and time estimating on airport infrastructure projects still remain a challenge. According to Flyvbjerg *et al*. (2002), new ideas and techniques are needed to develop and improve this area where there is knowledge gab. One of the main reasons for airport construction cost and time overruns in Flyvbjerg's study was that "*risk is simply disregarded in feasibility studies by assuming what the World Bank calls the EGAP principle: Everything Goes According to Plan*." This approach, however, has resulted in delays, litigation and budget overruns (Hayes *et al*., 1986). According to Leung and Chuah (1998**)**, an effective risk management can help project managers to identify and assess potential risk factors and take suitable actions in order to achieve the desired project objectives. However, many project stakeholders' analyze and assess risk based on experience and intuition (AI-Bahar, 1988).

2.3 Risk management process

The BS 31100:2011 recognizes the risk management process as "*an essential part of good management*" and defines it as the "*effect of uncertainty upon objectives*". The risk management process has five phases which include initiation, identification, analysis, response planning and control as stated by Del Cano and de-La Cruz (2002). They (Del Cano and de-La Cruz, 2002) also established that these five phases were also recognized by leading project risk management guides such as the Project Risks Analysis and Management Guide (PRAM) and the Project Management

Body of Knowledge (PMBOK). Figure 2 indicates a simplified version of a systematic risk management process obtained from ISO 31000:2009 which has been adopted in this research.

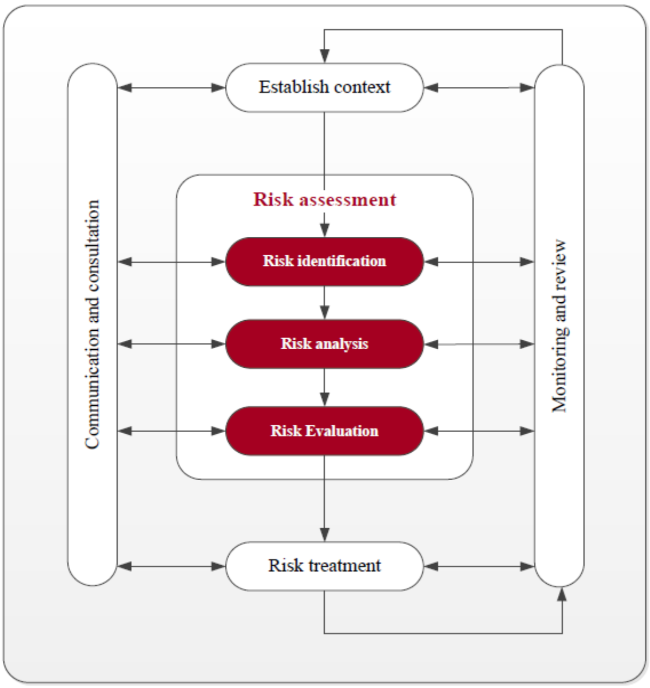

Fig. 2: Risk Management Process (ISO 31000, 2009)

2.4 Conceptual framework

Figure 3 is a representation of the conceptual framework for the applications of risk management in airport construction projects based on literature and theories of past researchers. The problem at hand is the project risk factors (PESTEL risk factors) which affect project cost, time and quality objectives. The framework placed risk management in the context of project decision making while considering the over-lapping contexts of behavioral responses, organization structure, and technology. The project objectives and construction risk management objectives should clearly be established within the context of project decision-making, and will be governed largely by the attitude of project stakeholders towards risk. The framework for risk management provides an effective and systematic way for quantitatively identifying, analyzing, and responding to risk in airport construction projects. In this framework, emphasis is placed on how to identify and manage PESTEL risks before, rather than after, they materialize into losses or claims.

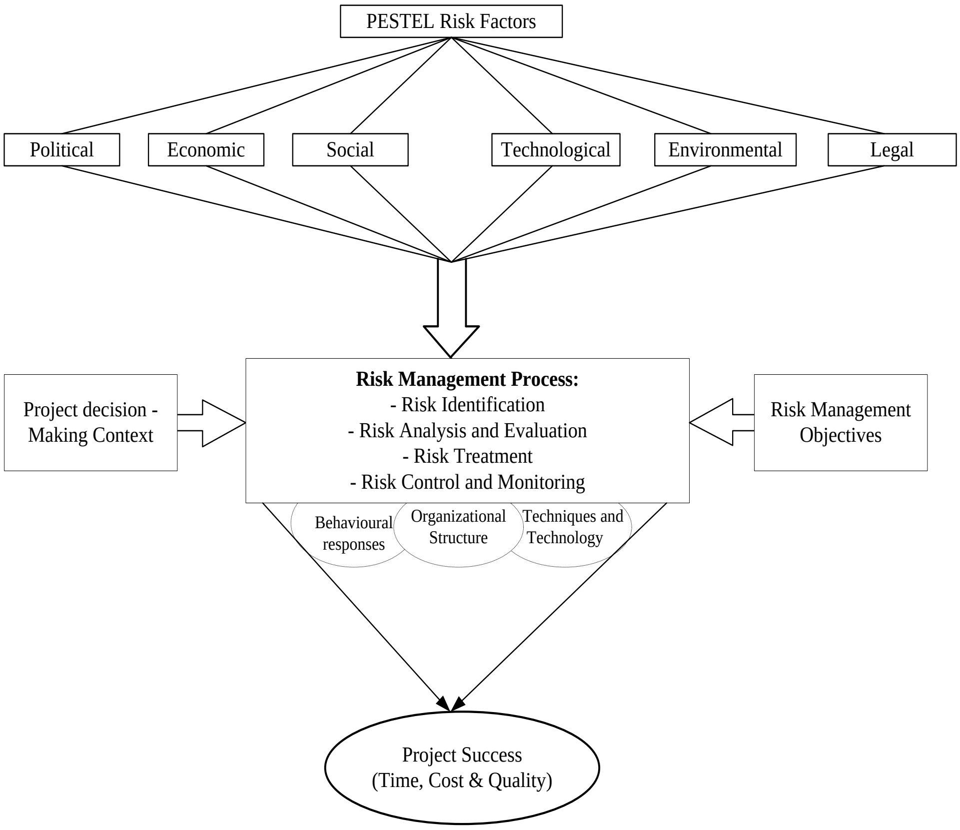

Figure 3: Conceptual framework of risk management in airport construction projects (Author, 2016)

3. Research methodology

3.1 Research design

In addressing the key research objectives, it was important to adopt an appropriate approach, which would enable appropriate data collection, analysis and interpretation of the findings for the benefit of practitioners and researchers. Consequently, the study commenced with an extensive literature review which provided profound opportunity to enable the author to understand related subjects of risks management in construction projects and to identify an appropriate theoretical framework for the study. Following the literature review, a post positivism research paradigm was adopted to reflect the methodological approach involved. To this effect, qualitative and quantitative approaches which included interviews and a structured questionnaire survey were used in eliciting the main data using the expansion and upgrading of KKIA project as a case study.

3.2 Data analysis method

The survey feedback included three groups of data, the identification, the likelihood of occurrence of each risk and its level of impact on project objectives. The risk significance index developed by Shen *et al*. (2001) was used to assess the relative significance among risks identified. Equation (1) below was used to calculate the significance score for each risk assessed by each respondent with respect to the impact on project objectives.

$$r_{ij} = \alpha_{ij}\beta_{ij} \quad (1)$$

Where r_{ij} = significance score assessed by respondent j for risk i; α_{ij} = probability of occurrence of risk i, assessed by respondent j; and β_{ij} = degree of impact of risk i assessed by respondent j. The RSIS which is used to rank risks is obtained by averaging the significance scores for each risk as shown in Equation (2).

$$RSIS_i = \frac{1}{n}\sum_{j=1}^{n} \alpha_{ij}\beta_{ij} = \frac{1}{n}\sum_{j=1}^{n} r_{ij} \quad (2)$$

Where; *RSIS* = risk significance index score for risk i on project objectives and n = total number of valid feedbacks to risk i.

The three-point scales for α (highly likely, likely and less likely) and β (high level of impact, medium level of impact and low level of impact) need to be converted into numerical scales. According to Shen *et al*. (2001) and Wang and Liu (2004), "high" or "highly" takes a value of 1, "medium" takes a value of 0.5, and "less" or "low" takes a value of 0.1. The matrix presented in Table 1 shows the calculation of the risk significance index.

Table 1: Matrix for the calculation of the risk significance index (Shen et al. (2001) and Wang and Liu (2004))

β / α	**High level of impact (1.0)**	**Medium level of impact (0.5)**	**Low level of impact (0.1)**
Highly likely (1.0)	1.00	0.50	0.10
Likely (0.5)	0.50	0.25	0.05
Less likely (0.1)	0.10	0.05	0.01

4. Results

4.1 Data collected from interviews

In all, 11 experienced respondents, who were involved in the expansion and upgrading of KKIA, were interviewed. Respondents had extensive experience in the construction industry ranging from 7 years to more than 15 years. The total professional experience of the 11 respondents was 147 years giving an average of 13.36 years and had enough technical background and experience in dealing with risk issues in airport development at the construction phase. In summary, the interview results showed that there was no standard and effective technique or practice specifically targeted for assessing risks in airport construction projects. However, there was a variety of techniques and practices existing to identify and assess risks that occur on the project during construction. The results further revealed that few project participants had a complete understanding of the generic risks that happen on the project, especially at the construction phase. As such, categorizing risks occurred only when participants identify, assess and/or manage risks using a specific perspective.

For a project like the expansion and upgrading of KKIA, contracts and contract language were often viewed as the most important method to control and allocate project risks, however only few project participants understood how risks should be allocated by contract. Misconceptions and assumptions about who owns and controls the risk also seemed to be common on this project.

As a result, respondents were receptive to the development of a structured risk identification, assessment, and management process that gives consideration to the entire life cycle of airport construction.

4.2 Results from the questionnaire survey

The survey instruments were distributed manually to construction professionals working on the expansion and upgrading of KKIA. Out of the 35 research questionnaires intended for the survey, only about 30 fully addressed instruments, were successfully distributed due to lack of adequate number of target groups on the case study project. It turned out that some of the potential respondents (Contractors, Engineers, Project managers and Client's representatives), albeit on the KKIA list used in drawing up the sampling frame, did not want to participate in the survey for reasons unknown by the researcher. A period of up to four weeks was allowed for the fieldwork and all completed survey questionnaires were retrieved and put together as indicate in Table 2 for analysis.

Table 2: Response rate (Author, 2016)

Parameters	Frequency	Percentage
Number of invalid responses	3	10%
Number of valid responses	20	66.67%
Did not respond	7	23.33%
Total	**30**	**100%**

Out of the 30 instruments delivered, 23 completed questionnaires were successfully retrieved. Of the 23 completed research instruments, three were partially answered and as a result, were screened out for data analysis. Hence, 20 were actually used in the assessment of key PESTEL risk in airport construction projects representing a valid response rate of 66.67% which according to Rubin and Babbie (2009) is considered adequate for analysis and reporting.
To generate confidence in the credibility of data collected, Table 3 was produced to indicate the general information about the participants in the survey.

Table 3: Summary of descriptive results and analysis for the questionnaire survey (Author, 2016)

Parameter	Frequency	Percentage (%)	Cumulative
Types of works			
Infrastructure	11	55.0	55.0
Utility diversion	7	35.0	90.0
Others (Administrative support)	2	10.0	100.0
Years of experience			
Less than 1 year	2	10.0	10.0
1 – 2 years	5	25.0	35.0
3 – 5 years	4	20.0	55.0
More than 5 years	9	45.0	100.0

All of this information summarized in Table 3 indicates that respondents were competent enough and capable of participating in the survey. A plausible conclusion therefore is that the respondents were sufficiently well vested in the construction of the case study project to provide data which was credible.

4.2.1 PESTEL Risk classification impact on airport construction projects in Zambia

Respondents were asked to state which of the PESTEL risk classification had the greatest impact on airport construction projects in Zambia. Table 4 shows the results of this analysis. The responses depicts that technical risks is what prevailed mostly and affects the delivery of airport projects in Zambia. This implied that airport projects are exposed to technical risks and this can be attributed to the complexity nature of airport construction projects.

Table 4: Response for PESTEL risk classification (Author, 2016)

Risk Category	Frequency	Percentage (%)	Rank
Political	13	65	3
Economic	15	75	2
Social	7	35	5
Technical	17	85	1
Environmental	12	60	4
Legal	6	30	6

4.2.2 Risk Identification

Section two of the questionnaire sought to identify risks according to the PESTEL risks set under desk top study. Under each category, possible problems were listed and respondents were asked whether they considered them as potential risks that could hinder implementation of projects.

During the analysis, if the number of respondents that “agreed” to the identified risks exceeded 50% or more, then the risk was considered significant and was further considered for the next stage of the analysis (risk probability and impact assessment). The cut off percentage of fifty was good enough considering that the other half was shared amongst the remaining two responses on the questionnaire, otherwise, the risk was considered insignificant. Table 5 gives a summary of identified risks in each category.

Table 5: Summary of identified risks (Author, 2016)

	Risk category	Identified risks
P	**Political**	✈ delay in obtaining consent ✈ delay in obtaining temporary work permits ✈ political indecision
E	**Economic**	✈ Wage inflation ✈ Foreign exchange ✈ Material price changes ✈ Energy price changes
S	**Social**	✈ Multi-player/level decision making ✈ Disputes ✈ Stakeholders' pressure
T	**Technical**	✈ Technical difficulties in utilities diversion ✈ Ambiguity of project scope ✈ Ground condition on given project sites ✈ Inadequate project complexity analysis ✈ Unforeseen modification to project ✈ Incorrect project cost estimate ✈ Incorrect project time estimate
E	**Environmental**	✈ Environmental issues from works e.g. Pollution (air, water, soil, noise, and dust) ✈ Unfavorable climate conditions heat waves, drought , heavy rainfall, and temperature)
L	**Legal**	✈ Legal disputes during construction

4.2.3 Risk probability and impact assessment

The respondents were requested to state the probability and impact of each of the identified risks using the three-point scale in Table 1. The results were used to determine the RSIS. The RSIS represent the relative importance of a risk. It was used to rank risks in relation to their impact on project performance. The results of this analysis are shown in Table 6.

Table 6: Risks ranked as per their significance in each category (Author, 2016)

	Risk category	Identified risks	Abb.	RSIS
P	**Political**	✈ delay in obtaining temporary work permits	DOT	0.48
		✈ delay in obtaining consent	DOC	0.42
		✈ political indecision	PI	0.25
E	**Economic**	✈ Material price changes	MP	0.54
		✈ Energy price changes	EPC	0.44
		✈ Foreign exchange	FE	0.42
		✈ Wage inflation	WI	0.37
S	**Social**	✈ Stakeholders' pressure	SP	0.55
		✈ Multi-player/level decision-making	MPDM	0.37
		✈ Disputes	DISP	0.25
T	**Technical**	✈ Unforeseen modification to project	UM	0.67
		✈ Incorrect project cost estimate	IPC	0.48
		✈ Ground condition on given project sites	GC	0.48
		✈ Incorrect project time estimate	IPT	0.42
		✈ Ambiguity of project scope	APS	0.37
		✈ Technical difficulties in utilities diversion	TDU	0.25
		✈ Inadequate project complexity analysis	IPCA	0.25
E	**Environmental**	✈ Environmental issues from works e.g. Pollution (air, water, soil, noise, dust, waste generation)	EI	0.42
		✈ Unfavorable climate conditions e.g. Drought, Heavy rainfall, Temperature etc...)	UC	0.37
L	**Legal**	✈ Legal disputes during construction	LD	0.54

4.2.4 Graphical presentation of the key risks

An alteration of Table 6 is presented in Figure 4 which is a graphical presentation of the key PESTEL risks in relation to project objectives. This helps to compare the magnitude of the significance of different risks on project objectives. An average significance index score of 0.25 with respect to the magnitude of the risk significance can be regarded as high (AS/NZS4360, 2004). As can be seen from Figure 4, most index scores are located above 0.25 with only four scores distributed within the circle of 0.25. This implies that the identification of the 20 key PESTEL risks was valid.

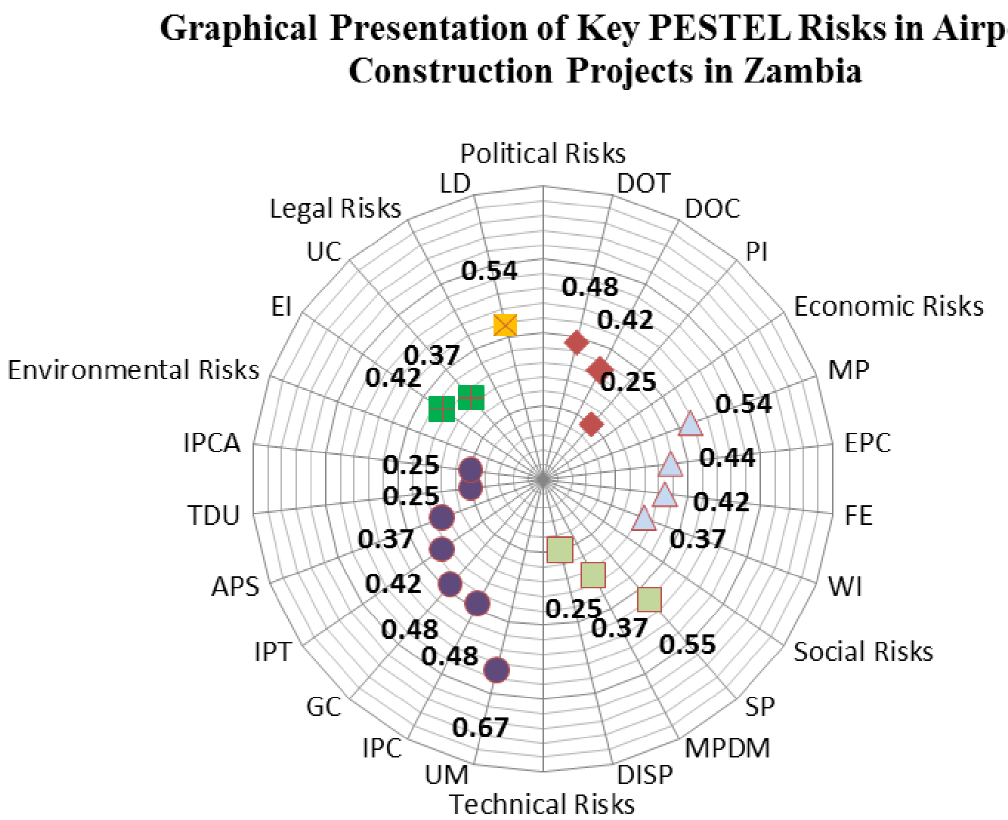

Figure 4: Graphical presentation of Key PESTEL risks in airport construction projects (Author, 2016)

5. Conclusion and recommendations

5.1 Conclusion

The theoretical foundation of this study was risks in construction. The study successfully addressed an important research topic in the risk assessment literature; PESTEL risk factors during airport development in the construction phase. While most research has focused on some aspects of construction management, this research endeavored to identify key risks associated with the achievement of airport construction project objectives in terms of cost, time and quality. On the basis of a survey with industry practitioners owning robust experience and knowledge of airport construction projects, 20 key risks were highlighted on a comprehensive assessment of their likelihood of occurrence and level of impacts on project objectives. "Unforeseen modification to project" was found to have significant impact on the project objectives. Project stakeholders should work cooperatively during the construction phase to address potential risks effectively and in time; contractors and subcontractors with robust construction and management knowledge must make sound preparation for carrying out safe, efficient and quality construction activities.

5.2 Recommendations

This research showed that there was a lack of knowledge of risks that affect airport construction projects in Zambia and rarely do project stakeholders apply risk management procedures. Risk management is more often based on intuition and experience. In light of this finding it is important to enlighten the stakeholders on risk management procedures and strategies to improve their capacity. Based on the foregoing, the researcher made the following recommendations which would guide the actions of stakeholders to effectively develop and implement risk management in airport construction projects in Zambia.

- Risk analysis and management in airport construction should be deployed during the construction phase and project stakeholders must strive to identify all potential risks and adopt strategies to mitigate their effects.

- Stakeholders involved in airport construction and development must have properly structured risk identification, analysis and mitigation processes or options to moderate the risks associated with airport construction projects.

- Project stakeholders must endeavor to plan and coordinate airport construction projects well to avoid risk. In instances where they cannot avoid the risks, the necessary tools or mitigants should be put in place to insulate the project against all possible risks.

- Risk management documentation is very critical. Project stakeholders should therefore document and properly record the identification, analysis, and risk mitigation plans and results for risk elements. This allows for lessons to be learnt and actions to be taken if necessary.

- Lastly, it is recommended that risk management should be incorporated into the academic curriculum of tertiary institution who undertakes engineering biased courses so that graduates are introduced to the subject before practicing after school.

5.3 Recommendations for further research

a) Due to varying limitations encountered during the study, the researcher acknowledges that adequate investigations were not conducted into identification of PESTEL risks in the project life cycle. The researcher therefore recommends a further study into this area to investigate PESTEL risks and impact on project performance in the total lifecycle of airport development. Different risk factors influence construction projects at different development stages with varying probability and consequences.

b) This research identified the key PESTEL risks that influence airport construction and delivery in Zambia. Future research should establish how best stakeholders should respond to these risks and how best to allocate or share them among the project stakeholders.

Acknowledgment

First and foremost, all thanks are due to the bounteous giver of all good – GOD. As this humble work comes to an end, it is a special pleasure to acknowledge the persons that have helped make it happen. My personal debts begin with Mr. Jones Kalyongwe for the immense assistance provided in terms of guidance and suggestions throughout the research process. Very special thanks to my fiancée, Ms. Trisha Njobvu for her understanding, love and support. The study benefitted from valuable comments and suggestions from KKIA project stakeholders, engineers, technical services, project manager, and contractors. Subsequently, I must acknowledge individuals who took part in the research survey and interviews, without their help this research would not have been possible.

References

Adrem, A., Schneiderbaur, D., Meyer, E., and Majdalani, F. (2006). “Managing Airports Construction Projects”, Booz/Allen/Hamilton Inc.

Ahmad, B. & Mohammed, K., 2015. Saudi Arabian aviation construction projects: Identification of risks and their consequences: Creative Construction Conference 2015 (CCC2015)

Ahmed, S., Azher, S., Castillo, M., & Kappagantula, P. (2002) Construction delays in Florida: an empirical study, *Final report submitted to the state of Florida, Department of Community Affairs*.

AI-Bahar, J. F. (1998) '*Risk management in construction projects: A systematic analytical approach for contractors',* PhD dissertation, Department of Civil Engineering, Berkeley: University of California

Ali-Mohammed, B.A. (2010) *Risk and Stakeholder Management in Mega Projects beyond the Realms of Theory* (online), Ministry of Works and Housing, Kingdom of Bahrain, available: www.works.gov.bh/media/Researchs/pw04p06.pdf (accessed May, 2016).

AS/NZS 4360 (2004) *Australian / New Zealand Standard on Risk Management*, Standards Australia and Standards New Zealand.

Ashley, D. B. (1977) *'Construction project risk-sharing',* Technical Report No. 220, Department of Civil Engineering, Stanford University, Stanford, CA, 1977.

BCIS, (2012) '*BIS Construction Price and Cost Indices',* Available: http://www.bcis.co.uk: Building Cost Information Services, UK.

Chan, W.M.C. and Kumaraswamy, M.M. (2002) 'Compressing construction durations: lessons learned from Hong Kong building projects', *International Journal of Project Management, 20, 23-35.*

Chau, K. C. (1995) 'The 3 Gorges Project of China - Resettlement Prospects and problems', *Ambio*, 24(2) 98-102.

Del-Caño, A. and De-La Cruz, M. P. (2002) 'Integrated Methodology For Project Risk Management', Canadian Journal Of Civil Engineering, 35(5) pp. 473 – 485.

Flyvbjerg, B. (2006) 'From Nobel Prize to Project Management: Getting Risks Right', Project *Management Journal,* 37(3), 5-15.

Flyvbjerg, B. **(**2009) 'Survival of the unfit test: why the worst infrastructure gets built-and what we can do about It.*'*, *Oxford Review of Economic Policy*, 25(3), 344-367.

Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2003). *Megaprojects and risk: An anatomy of ambition*. Cambridge University Press.

Flyvbjerg, B., Holm, M. K. S. and Buhl, S. L. (2002) 'Cost underestimation in public works projects: error or lie?' *Journal of the American Planning Association,* 68(3), 279-295.

Garry, G. (2005) *'Risk Factors Leading to Cost Overrun in Highway Projects'*, Queensland University of Technology, Australia.

Gould, F. E. (2002) *'Managing the construction process: Estimating, scheduling, and project control',* Upper Saddle River, NJ: Prentice Hall.

Hayes, R.H. & Wheelwright, S.C. (1986). Restoring our competitive edge; Competing through manufacturing. New York: Wiley.

ISO, (2009) *BS/ISO31000:2009 - Risk Management Principles and Guidelines*, International Organization for Standardization.

Jyh-Bin Y. (2010) 'Causes of Delay in the Planning and Design Phases for Construction Projects', *Journal of Architectural Engineering,* pp.80-83.

Lor, P. (2011) 'Preparing for research: meta-theoretical considerations [online], available: http://pjlor.files.wordpress.com/2010/06/chapter-4-draft-2011-04-152.pdf. [accessed November 2013]

Luke (14:28) *The Holy Bible, New International Version (NIV, 1982).* Thomas Nelson, Inc.

Mohammad, A., Mustafa, Z. M. and Jamal, F. A. (1991) 'Project Risk Analytic Assessment Using the Hierarchy Process', *Transactions on Engineering Management*, 38 (1).

Murphy, S. and Salzman, J. (2008) *More Big Dig charges brought*, Boston Globe.

National Audit Office. (2001). Modern policy making: Ensuring policies deliver value for money. HC289, November 2001. London: TSO

Pickavance, K. (2005) '*Delay and disruption in construction contracts'*, 3rd edition, Informa-Legal Publishing, UK.

Reid, R. L. (2007). "Logan's Smooth Landing", *Journal of Civil Engineering*, March, pp. 44-55.

Rubin, A., & Babbie, E. (2009). Research methods for social work (4th ed.). Pacific Grove, CA: Brooks/Cole.

Safer Ali et al (2012) 'Time waste and delay in construction projects', NICMAR-journal of construction management, 27(4), 64-75.

Shen, L.Y., Wu, G.W.C. and Ng, C.S.K. (2001) Risk Assessment for Construction Joint Ventures in China, Journal of Construction Engineering and Management, 127(1), 76-81.

Tommy, Y. Lo et al (2006) 'Construction Delays in Hong Kong Civil Engineering Projects', *Journal of Construction Engineering and Management*, 132(6), 636-649.

Wang, S. Q., Dulaimi, M. F., & Agura, M.Y. (2004). Risk management framework for construction projects in developing countries. *Construction Management and Economic* 22, 237-252.

World Bank, (2009) '*Publishing Information on Public Construction Projects'*, mimeo: World Bank.

Biomass Resource Potential and Enabling Environment for Bioenergy Production in Zambia

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Abstract

Zambia has abundant supplies of biomass resources, including agricultural crop residues, forest residues, animal waste, agro-industrial wastes and municipal solid wastes. These resources can be converted into useful energy such as heat, gas, electricity or fuels for transport using modern biomass conversion technologies. Currently, biomass use in Zambia is mainly in the form of charcoal and firewood. This traditional use of biomass is unsustainable and has led to high deforestation rates in the country of up to 300, 000 hectares - the highest in Africa and fifth in the world. The country has recognised the urgent need to transition from traditional to modern use of biomass in order to protect its environment and improve energy security. This paper assesses the impacts and discusses possible shortcomings of some of the efforts that government and other stakeholders in the biomass industry are making to promote the use of modern biomass energy. It also estimates the quantity of different biomass feedstock available in the country and the bioenergy production potential from these feedstocks. The assessment shows that there is good modern bioenergy production potential in Zambia. Of the four biomass resources assessed, forest residues have the highest bioenergy production potential of 102.7 PJ y^{-1} followed by agricultural residues with potential of 75 PJ y^{-1}. Livestock waste and MSW each have a bioenergy potential of 9.52 and 0.9 PJ y^{-1} respectively. Despite possessing good bioenergy production potential and an enabling environment for the promotion of modern biomass use, bioenergy application is still limited in the country. For successful utilisation of biomass resources in the country, a number of technical, environmental, social and economic constraints need to be overcome.

Key words: ***Biomass resources, bioenergy potential, enabling environment, stakeholders***

INTRODUCTION

The supply of sustainable energy is one of the main challenges that mankind will face over the coming decades, particularly because of the need to address climate change. Biomass can make a substantial contribution to meeting future energy demand in a sustainable way. It is presently the largest global contributor of renewable energy, and due to its versatility, it has significant potential

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to expand in the production of heat, electricity, and fuels for transport (World Energy Council, 2013).

The bulk of energy from biomass fuels in developing countries is consumed by households, mostly for cooking purposes - Zambia is not an exception. Biomass constitutes a major source of the energy used in Zambia, especially in the household sector where more than 80% of the cooking energy needs comes from biomass (Kasongo *et al*., 2012). About 17% of the cooking energy needs is met by electricity (Kasongo *et al*., 2012). The biomass is mainly consumed in the form of fuelwood and charcoal.This traditional use of biomass is unsustainable and has led to high deforestation rates of between 250, 000 to 300, 000 hectares in the country - the highest in Africa and fifth in the world (Lande, 2016). As expected, the use of traditional biomass (charcoal and firewood) has increased in the period from 2015 and 2016 due to load-shedding resulting from reduced electricity generation.

The Zambian government has recognised the vital role that the sustainable production and use of biomass has on not only improving the country's energy security but also contributing to reducing greenhouse gas emissions and deforestation. As such, the country has over the last decade intensified its efforts to promote the use of sustainable and modern biomass. Modern biomass energy use refers to the conversion of biomass energy to advanced fuels, namely liquid fuels, gas and electricity (Assmann *et al*., 2006). Most of these efforts are in the form of policy measures and instruments, targets, research and development support, and so on, which are aimed at creating an enabling environment for the improvement of the biomass sector.

This paper discusses the impacts and possible shortcomings of different initiatives and strategies existing in Zambia which are aimed at increasing the deployment of modern biomass technologies. It also estimates the quantity of different biomass feedstock available in the country and the bioenergy production potential. Secondary sources of data such as research reports, government reports, reference books and journal articles were used in this desktop study.

BIOMASS AND BIOENERGY PRODUCTION POTENTIAL

Biomass energy is mainly from fuelwood (charcoal and firewood), forest residues, agricultural residues, animal dung and municipal solid wastes (MSW), the availability of which is linked with forestry resources, crop production, animal population and urban waste production respectively. To determine the bioenergy potential, first the total biomass production should be estimated and then the energy potential is estimated by applying the individual recovery rate, residue to yield ratio (for agricultural residues only), moisture content and calorific value (Mondal, 2012).

Agricultural Residues (Annual Crops)

Agriculture is an important part of the economy in most of the developing countries including Zambia. Of the 752,000 square kilometres total land area of Zambia, about 43 million hectares (58%) is classified as medium to high potential for agricultural production (Republic of Zambia, 2006). Only 14% of the agricultural land is currently utilized. Besides the crop itself, large quantities of residues are generated every year from agriculture activities. The term agricultural residue is used to describe all the organic materials which are produced as by-products from agriculture activities (United Nations Environment Programme, 2013). These residues constitute a major part of the total annual production of biomass residues and are an important source of energy both for domestic as well as industrial purposes.

Gross residue amount of any crop species

Annual average yields of main crop types can be determined from the regional, country or international statistics. The corresponding field based and process based residue amounts are reached by multiplying the yields with matching residue to yield ratios (η_i^{ryr}). The residue to yield ratio indicates how much residue (mass) is generated per unit of crop products of crop type *i*. The values of η_i^{ryr} vary with several factors such as crop varieties, harvesting seasons, harvesting practices, fertiliser uses, etc. (Rahman and Paatero, 2012). The available literature shows a considerable range in the values of η_i^{ryr} for the major crops. When these ratios have been defined, gross residue $R_i(ty^{-1})$ generated annually by the crop type *i* can be obtained as Eq. (1)

$$R_i = Y_i.\ \eta_i^{ryr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $Y_i(ty^{-1})$ is the annual crop yield. The amount of residues obtained from the Eq. (1) is not entirely available; rather there are several active uses for this resource. The process residues, however, face almost no other competitors but domestic and industrial energy applications (Rahman and Paatero, 2012). To estimate the actual potentially available energy from the residues, it is necessary to establish the present utilisation pattern of the residues. Several estimations of the surplus availability factors (η^{saf}) have been presented in the literature. Moreover, all the field residues are not recoverable rather only a portion of these can be removed from the field without adverse effects on the future yields. Considering all these factors, the annual theoretical available residue amount (field or process) $R_i^{th}(ty^{-1})$ for crop type *i* can be obtained using Eq. (2)

$$R_i^{th} = R_i.\ \eta_i^{rrf}.\ \eta_i^{saf} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where η_i^{rrf} is residue recovery factor (kg kg $^{-1}$ of residue) and η_i^{saf} is surplus availability factor (kg kg $^{-1}$ of residue) for field or process based residues for crop type *i*. The field and process based residues for any crop species *i* are required to obtain separately with the same Eq. (2) considering their recovery and availability factors. Each crop species eventually gives the residue amount by summing up both the residue types *i* (field and process). Tables 1 and 2 give characteristic factors of major field based residues and process based residues respectively. Despite soybeans being one of the major crops grown in the country, the residues generated from it are not included in the table due insufficient data on its characteristic factors.

Table 1: Characteristic factors of major field based residues

Field residue	**Residue to crop yield mass ratio (η_i^{ryr})**	**Residue recovery factor kg kg^{-1} of residue (η_i^{rrf})**	**Surplus availability factor kg kg^{-1} of residue (η^{saf})**
Maize stalks	2.00	0.60	1.00
Rice straws	1.76	0.60	0.80
Cotton stalks	2.75	0.35	0.68
Groundnut straw	2.30	0.35	0.64
Millet stalks	1.75	0.35	0.5
Sorghum stalks	1.75	0.35	0.5
Sugarcane tops	0.3	0.35	0.2

Table 2: Characteristic factors of major process based residues

Field residue	Residue to crop yield mass ratio (η_i^{ryr})	Residue recovery factor kg kg-1 of residue (η_i^{rrf})	Surplus availability factor kg kg-1 of residue (η^{saf})
Maize cobs	0.27	0.8	1.00
Maize husks	0.20	1.0	0.50
Rice husks	0.267	0.8	0.46
Groundnut husks	0.47	1.0	0.50
Sugarcane bagasse	0.25	1.0	0.21

Source: Rahman and Paatero (2012)

Using calorific values for field and process based residues generated from crops grown during the 2011/12 farming season in Zambia, the annual energy production potential is determined and presented in table 3 (CSO/MAL, 2011 and Rahman and Paatero, 2012) . It should be noted that the crops under consideration were those grown by small-scale farmers only.

Table 3: Energy production potential from residues produced during 2011/12 farming season

Crop	Production (Mt y^{-1})	Residue Generated			Potential energy	
		Type	Quantity (Mt)	Calorific value (MJ.kg^{-1})	PJ	GWh
Maize	2, 731, 843	Stalks	3,278,211.60	16.95	55.57	15, 436.11
		Cobs	590,078.09	16.63	9.81	2, 725.00
		Husks	273,184.30	17.43	4.76	1, 322.22
Rice	43, 326	Straw	36,601.98	8.83	0.32	88.89
		Husks	4,257.06	12.85	0.05	13.89
Cotton	268, 902	Stalks	175,996.36	15.83	2.79	775.00
Groundnuts	108, 784	Straw	56,045.00	17.58	0.99	275.00
		Husks	25,564.01	17.89	0.46	127.78
Millet	29, 366	Stalk	8,993.34	18.00	0.16	44.44
Sorghum	17, 767	Stalk	5,441.14	18.00	0.10	27.78
Sugarcane	507	Tops	10.65	6.82	0.0001	0.03
		Bagasse	26.62	6.43	0.0002	0.06
Total					**75.0**	**1, 353.0**

Forest residues

Forest residues are generated from the forest products industry and can be divided into two categories: (1) logging residues, generated from logging operations, for example, from final fellings and (2) industrial by-products, generated by the forest industries during processing of timber, plywood, particleboard, pulp, and so on (Bhaskara and Pandey, 2015). Sawdust is one example of industrial by-products generated from about 400 sawmills in Zambia. Woodlands and forests which are sources of forest residues are estimated to cover about 50 million hectares or 66 % of Zambia's total land area (Bwalya, 2010). Currently, trees are being felled for wood fuel (charcoal and firewood production). Given the low income levels of energy consumers and the abundance of wood resources, it is foreseen that firewood and charcoal will continue to dominate Zambia’s energy consumption.

The conversion process of trees into bio-char in most developing countries is inefficient thus resulting in unsustainable use of woodfuel resources and negative environmental impacts. For instance in Zambia, the conversion efficiency of the widely used earthen charcoal-making kiln is on average as low as 6 – 10 percent on dry basis (Luwaya *et al*., 2014). However, studies have shown that any charcoal making kiln with conversion efficiency of 25% or less has potential for improvement (Luwaya *et al*., 2014). In theory this means that deforestation rates in Zambia can be reduced by up to 96% if the efficiencies of the charcoal making processes were improved to at least 25%.

Data of annual production of round and processed wood was obtained from the FAOSTAST database for the year 2015 and used to estimate the annual forest residue production. The procedure for estimating the energy potential of forest residues proposed by (Smeets and Faaij, 2007) was used. The energy potential using Eq. 3:

$$Q_{HR} = \sum_{i=1}^{n}(W_i \cdot h \cdot \rho_i \cdot LHV) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, Q_{HR} is the energy potential of logging residues and W_i is the annual production of round wood of category i, ρ_i is the bulk density of biomass of category i. Factor, h is logging residue generation ratio and was assumed to be 0.6 (Smeets and Faaij, 2007). The energy potential of wood processing residue generated was estimated using Equation (4):

$$Q_{PR} = IRW \cdot p \cdot \rho_i \cdot LHV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where, Q_{PR} is the energy potential of wood processing residues and IRW annual consumption of industrial round wood. Factor, p is wood processing residue generation ratio. It is the fraction of logs that is converted into residues during the processing of wood and depends on the efficiency of sawmills (Okello, 2013). A p factor of 70% was used for developing countries (Okello, 2013). The LHV of wood at 20% H_2O mass fraction was assumed to be 18.6 MJ kg^{-1} (M_cKendry, 2002).

Table 4 gives the bioenergy that could be potential produced from logging residues and industrial by-products generated from the forest industry in Zambia.

Table 4: Bioenergy production potential from forest residues

Forest residue source	Production of round wood (m^3)	Consumption of round wood (m^3)	Total residue (Mt y^{-1})	Energy potential (PJ y^{-1})
Logging operations	9, 867, 028	-	6, 974, 091	77.1
Wood processing	-	1, 542, 752	1, 966, 872	25.6
Total energy potential				**102.7**

Municipal solid waste (MSW)

Municipal Solid Waste (MSW) is defined as solid waste which includes all domestic refuse and non-hazardous wastes such as commercial and institutional wastes, street sweepings and construction debris (Magutu *et al.*, 2010). Generation of MSW in Zambia is on the increase due to rapid rise in population, changing life styles and popularity of fast foods and disposable utensils.

MSW can be converted into useful energy. Generally, there are four technologies that can be used to produce energy from municipal solid waste (MSW): incineration, gasification, generation of biogas and utilisation in a combined heat and power (CHP) plant, generation of biogas and conversion to transport fuel (Murphy and McKeogh 2004). The choice of technology to be implemented is depended on the composition of the MWS. The general composition of MSW generated in Zambia is shown in table 5.

Table 5: MWS composition in Zambia

Constituent	Percentage (%)
Organic	50
Paper	5
Plastic	5
Glass	2
Metal	2
Other	37

Source: World Bank (2014)

Typically the residual component of MSW (non-recyclable, non-organic) is incinerated producing electricity at an efficiency of about 20% and thermal product at an efficiency of about 55%. Gasification produces electricity at an efficiency of about 34%; this would suggest that gasification of the residual component of MSW is more advantageous than incineration where a market for thermal product does not exist. Gasification produces more electricity than incineration, requires a smaller gate fee than incineration and when thermal product is not utilised generates less greenhouse gas per kWh than incineration. Biogas may be generated by digesting the organic fraction of MSW (OFMSW). The produced biogas may be utilised for CHP production or for transport fuel production as CH_4-enriched biogas (Murphy and McKeogh 2004).

Only potential energy that can be generated through anaerobic digestion (biogas production) technology will be assessed. The potential energy will be determined for Zambia’s 10 provincial headquarters including Kitwe and Livingstone towns where MSW generation is relatively high. According to Environmental Council of Zambia (2008), the average MSW generation rate in Zambia is 0.5 kg/capita/day. Using Eq. 5, the potential energy generation from MSW in the aforementioned places can be determined:

$$E_{MSW} = \eta_{of} \cdot MSW_q \cdot B_y \cdot \eta_{vs} \quad \text{……………………..} \ (5)$$

where η_{of} is the organic fraction of the MSW generated in Zambia which is 0.5 in this case (World Bank, 2014), MWS_q is the quantity of municipal solid waste generated annually in Mt y^{-1}, B_y is the ultimate biogas yield (kJ kg^{-1} VS), and ηvs is the ratio of volatile solid to dry matter. Table 6 presents the potential energy generated through AD of MSW in 12 towns/cities of Zambia

Table 6: Potential energy through AD of MSW

Provincial headquarters	Population	MSW generation (Mt y^{-1})	Biogas generation (000' m^3 y^{-1})	Energy potential (GJ)
Lusaka	1,267,440.00	231,307.80	15,262.11	419,708.00
Ndola	394,518.00	71,999.54	4,750.66	130,643.16
Kitwe	400,915.00	73,166.99	4,827.69	132,761.50
Choma	46,746.00	8,531.15	562.90	15,479.76
Chipata	85,963.00	15,688.25	1,035.14	28,466.33
Kasama	91,056.00	16,617.72	1,096.47	30,152.85
Mongu	52,534.00	9,587.46	632.60	17,396.44
Mansa	42,277.00	7,715.55	509.09	13,999.87
Chinsali	14,015.00	2,557.74	168.76	4,641.01
Solwezi	4,846.00	884.40	58.35	1,604.73
Kitwe	202,914.00	37,031.81	2,443.43	67,194.21
Livingstone	109,203.00	19,929.55	1,314.99	36,162.16
Total			**32,662**	**898,210**

Livestock waste

Manure from cattle, poultry and pigs are the common animal wastes in Zambia. The quantity of waste produced per livestock per day varies depending on body size, type of feed and level of nutrition. The production rates are estimated by employing the number of heads and the wastes generation for the individual species (Tiwari and Mishra, 2012).

Energy production through Anaerobic Digestion

Manure produced by livestock through a process called anaerobic digestion (AD) can be converted into biogas - a combustible gas. It is composed of 50 – 70% methane (CH_4), 30 – 40% carbon dioxide (CO_2) and trace amounts of hydrogen sulphide (H_2S). Biogas can be directly used to provide heat energy for cooking and space heating, used to provide lighting or can be converted into electricity using boilers and steam turbines. AD of livestock manure takes place in airtight containers called agricultural biogas plants. The annual thermal potential E_j^h (PJ y^{-1}) of livestock j can be determined using equation Eq. 6:

$$E_j^h = 365\,(M_j \cdot \eta_j^{rcf} \cdot \eta_j^{vs} \cdot r_j^{bg} \cdot Q_{hvl}) \ldots\ldots\ldots\ldots\ldots.. (6)$$

$$M_j = N_j \cdot r_j^{rgd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (7)$$

Where M_j (ty^{-1}) which is calculated using Eq. 7 is the annual manure production of livestock species j, N_j (in thousands) is the head count of livestock type j, r_j^{rgd} is residue generation rate of dry matter (kg d^{-1}), η_j^{rcf} is residue collection factor (kg kg^{-1} of residue), η_j^{dm} is the fraction of dry matter of residues (kg kg^{-1} of residue), η_j^{vs} is the ratio of volatile solid to dry matter, r_j^{bg} is the biogas generation rate (m^3 kg^{-1} of VS) of livestock species j and Q_{hvl} (MJ m^{-3}) is lower heating value of biogas.

Table 7 shows the annual potential energy that can be generated from different species of livestock reared in Zambia.

Table 7: Potential energy production from biogas

Livestock	Head count (in thousand)	Residue generation rate kg d^{-1} dry matter	Residue collection factor kg kg^{-1} of dry matter	Ratio of volatile solid to dry matter	Biogas generation rate m3 kg^{-1} of VS	Energy generated (PJ y^{-1})
Cattle	3,038	2.52	0.5	0.93	0.20	5.46
Sheep	467	0.33	0.6	0.91	0.31	0.20
Goats	759	0.55	0.3	0.59	0.31	0.18
Pigs	812	1.13	0.9	0.61	0.70	2.70
Poultry	43, 000	0.04	0.9	0.46	0.18	0.98
Total						**9.52**

ENABLING ENVIRONMENT FOR BIOMASS DEVELOPMENT

Although Zambia has an abundance of biomass resource, the sustainable exploitation of this resource is limited due to bedevilled efforts to transform the promise of bioenergy into reality. Expanded exploitation will require several fundamental changes and policy interventions. The next sections discuss the enabling environment that exist to promote the sustainable use of biomass.

National Energy Policy

The 2008 National Energy Policy (NEP) of Zambia stipulates policy measures and strategies that are aimed at ensuring the availability of adequate supply of energy from various sources, which are dependable, at the lowest economic, financial, social and environmental cost consistent with national development goals. With regards to biomass, the policy seeks to ensure environmentally sustainable exploitation of the resource by ensuring efficiency through better management and introduction of new sources such as biofuels (MEWD, 2008). This entails shifting from traditional biomass use to modern biomass use modern biomass technologies include liquid biofuels produced from straw and wood, industrial cogeneration and bio-refineries, biogas produced through anaerobic digestion of residues, pellet heating systems and other technologies (United Nations Environment Programme, 2013).

Impact and short comings of the biomass policy measures

Despite having policy measures and strategies aimed at improving the uptake of modern biomass technology in Zambia, the biomass industry is still underdeveloped. The next subsections discuss the impact that the biomass policy measures have had on the development of the biomass industry to date. Possible shortcomings of each aforementioned policy measures and strategy are also discussed.

Provision of appropriate financial and fiscal instruments

A study by Dombrovski (2015) shows that financial and fiscal support instruments are necessary in achieving policy objectives aimed at developing Sustainable renewable energy technologies

(SRETs). It further shows that such instruments are most effective and efficient when they are focused on promoting eco-innovation (technology changes). The term ‘effective’ denotes the extent to which a policy instrument achieves policy objectives whilst the term ‘efficient’ refers to the ability of a policy instrument to reduce generation costs (Commission of the European Communities, 2008). The eco-innovation process includes three stages for SRET: invention, innovation and diffusion (European Environment Agency, 2011). An example of technology change or eco-innovation is shifting from the use of traditional biomass technology to modern biomass technologies. According to Dombrovski (2015), policy makers should be familiar with the current level of SRET development in their countries before deciding on an instrument’s (re) design, implementation or removal. In particular, they need to know the exact number of wind, solar, biomass and /or geothermal technology innovations and installation.

It is not mentioned in the Zambian energy policy whether or not promotion of eco-innovation was taken into consideration when developing the financial and fiscal instruments that is aimed at developing the biomass industry. If not, then it is very unlikely that the stipulated instruments are both effective and efficient. It is quite evident that the use of modern biomass technology is low in the country and in addition its level of use is to an extent unknown. This is in part due to a general lack of mechanisms to collect data related to RET installations. Lack of information on biomass technology installations and the possibility that eco-innovation was not taken into consideration when developing the financial and fiscal instruments could partly explain why the biomass market in Zambia is underdeveloped.

Raising public awareness on the benefits and opportunities of other modern biomass energy sources

Efforts to raise awareness on the benefits and opportunities of using improved cook stoves and anaerobic biogas plants for sustainable energy generation has been made, mainly by the non-governmental organisations (in partnership with some government agencies). As earlier mentioned, this is done in effort to improve the uptake of modern biomass technology in the country. The biomass awareness raising programmes in Zambia are mainly conducted through invitation-based workshops. Such an approach rarely targets the key stakeholders – the end-users who are usually from low income communities. According to the policy brief by European Energy Initiative and German Technical Cooperation Agency (2008), experience has shown that awareness programmes that practically demonstrate (e.g. markets, fairs or farms) the benefits of using modern biomass technologies over traditional ones are effective. The policy brief further advises that government authorities should consider providing modern biomass technologies in certain public facilities such as schools, or to include relevant information in school or university curricula. For example, in Uganda, information on biomass energy conservation and improved stoves, in combination with other energy related issues, are included in the public school curriculum. In order to raise awareness among children, the Ministry of Energy and Mineral Development and the Ministry of Education developed teaching materials for primary schools. This, along with the high acceptance of the locally marketed stoves and the support of the local leadership, contributed to dissemination rates of up to 90% in some villages (European Energy Initiative and German Technical Cooperation Agency 2008). The demand is still high.

Zambia should consider adopting the awareness strategies recommended by European Energy Initiative and German Technical Cooperation Agency (2008) as a means of improving the uptake of modern biomass technology. Currently, less than 0.25% of the population is currently using improved cook stoves that are being promoted (The Carbon Neutral Company, 2013). With regards to anaerobic biogas plants, the Netherlands Development Organisation (SNV) is actively promoting the technology through the training of biogas plant masons. As of to date, SNV has trained 40 masons around the country and this has slightly improved the number of biogas plants installed.

Development of a regulatory framework of biomass

As articulated in the first strategy of the third aforementioned policy measure, building the capacity of key stakeholders is vital for the development of the biomass sector. Stakeholders with the right capacity and clear mandates in the energy and forestry sectors allow high level deliberations to feed into new policy and regulation, and subsequent implementation. These include those actors dealing with policy and law making as well as formulation of regulations pertinent to the governance of the sector both at national and local levels. Others are mandated to implement policies and enforce laws and regulations on the ground. Yet others indulge in the scientific and technical aspects of the biomass energy sector. Equally important are those actors whose core mission is to lobby, advocate and/or finance certain biomass energy production and /or utilization. However, these have not been thoroughly identified in Zambia, thus posing challenges with regards to building capacity of the key stakeholders. To improve this situation, relevant authorities should deliberately map the above stakeholders and classify them in broader categories namely: Government or State Stakeholders; and Non-Government Stakeholders.

Efficient and coordinated ways of managing the biomass energy sector is prerequisite to the development of the sector (European Union Energy Initiative Partnership Dialogue Facility and German Federal Enterprise for International Cooperation, 2014). However, the country is currently lacking an effective mechanism that coordinates the efforts of different stakeholders in the biomass industry. As a result a lot of efforts aimed at improving modern biomass use through projects are usually duplicated and have similar outputs. Ultimately, there has been little improvement in the biomass sector due to the fact that recommended actions stemming out of these project activities are not implemented as follow up projects. In addition, due to weak linkages between research institutions and other key biomass stakeholders such as government agencies and non-governmental organisations, important findings from biomass related research are not disseminated and utilised to improve the biomass sector. According to Zyl, *et al*. (2007), firms and universities need to apply thinking strategies to their surroundings, to increase collaborations and knowledge transfer while ensuring that sufficient mutual benefits can be derived as is the case in South Africa. Thus, there is need to strengthen partnerships between universities and firms in Zambia. Efforts have been made in Zambia to strengthen such links - a notable one is the Corporate Graduate Link programme. This programme was launched in 2012 with the aim of bridging the gap between the university graduates' qualification and the needs of the industry in Zambia. It was funded by the German Federal Ministry for Economic Cooperation and Development for four years and managed by a consortium of DAAD (German Academic Exchange Service), universities in Germany and Zambia (University of Zambia and Copperbelt University), Chambers of Commerce from both countries, as well as mining companies in Zambia. This programme has continued, but due to lack of funding it has slowed down considerably with very little activities that are aimed at strengthening partnerships taking place.

The development of efficient management structures for the biomass energy sector requires coordination between stakeholders from different sectors, agreement on a shared goal, reliable sector data, awareness of trends and the development of an action plan to improve governance of the sector. This would require a genuine willingness among the relevant institutions to cooperate in developing a shared vision of the desired future for biomass energy, and to adapt their own policies and structures accordingly. Distinct roles of the different institutions and absence of competition over budgets and responsibilities help facilitate such cooperation (European Union Energy Initiative Partnership Dialogue Facility and German Federal Enterprise for International Cooperation, 2014).

Rural Electrification Programme

Rural electrification has long been identified as a vehicle to eradicate poverty by stimulating the rural economy in the Republic of Zambia (Japan International Cooperation Agency, 2009). In 1994, the Government of the Republic of Zambia (GRZ) established the Rural Electrification Fund (REF) by committing the sales tax on electricity, and has been trying to increase the electrification rate in rural areas by executing projects funded by REF. In 2003, the Rural Electrification Act was enacted to establish Rural Electrification Authority (REA) and to improve the management of REF.

In order to enhance rural electrification in Zambia, a Rural Electrification Master Plan (REMP) was prepared in 2008 with the assistance of Japan International Cooperation Agency (JICA).

Although power generation from biomass is one of the principal methods stipulated in the REMP for rural electrification, there has not been a single biomass power generation plant installed to date. However, there are plans to develop a biomass gasifier based power plant (1 MW capacity) in Kitwe by Copperbelt Energy Corporation (CEC) Company.

Apart from gasification, there are other wide ranges of power generation technologies such as combustion, pyrolysis and anaerobic digestion. To promote the uptake these technologies for rural electrification in Zambia, accurate and reliable data on the cost and performance of biomass power generation technologies needs to be collected. At the moment, this data is unavailable. Providing this information would help government agencies, policy-makers, investors and utilities make informed decisions about the role bioenergy can play in their power generation mix (International Renewable Energy Agency, 2012).

Draft Renewable Energy Strategy and Renewable Energy Feed-in Tariff Policy

In 2010, a draft Renewable Energy Strategy was developed in order to translate the objectives of the National Energy Policy into a practical implementation plan. The strategy, however, has not been adopted as of now. According to a report by the International Renewable Energy Agency (2013), the key objectives of this strategy, in line with the goals of the NEP, Fifth National Development Plan 2006 – 2010 and the Vision 2030 of Zambia are:

i. Access to modern energy services for all
ii. Meeting growing energy demand in a sustainable manner

The strategy includes long-term renewable energy targets for specific applications. In terms of electricity, the targets are to generate 100 MW from solar, 200 MW from small hydro and 100 MW from biomass by 2030 (International Renewable Energy Agency, 2013). However, the targets have been set without any thorough investigation of the economic potential of each renewable energy resource considered. In order to meet the target of generating 100 MW from biomass by 2030, a biomass resource assessment will need to be undertaken. Such an assessment can trigger a remarkable change in the perception of decision makers, in their knowledge base and awareness of the country's biomass potential and opportunities, thereby allowing them to make more informed decisions.

In 2015, the Zambian government through the Ministry of Energy and Water Development developed a Renewable Energy Feed-in Tariff (REFiT) Policy which is aimed at creating a platform for increased private sector involvement in renewable energy (RE) power generation. Feed-in tariff (FIT) is a scheme designed for electric utilities to purchase electricity generated by renewable energy plants at a tariff that is determined by the utilities and guaranteed for a specified period of time (Subbia, 2015). The eligible RE technologies stipulated in the policy include: wind, solar, geothermal, hydro and biomass.

The short-term goal of the REFiT policy is to increase the national power generation output through private sector generation investments in technologies that are able to participate at relative low tariff levels and combine this with increased grid capacity through micro-generation and thereby support the government's new generation investment programmes. During this first phase of the REFiT programme (three year period), the procurement limits per technology (in MW) will be:

a) 100 MW for hydro (maximum of 20 MW per project)
b) 50 MW for all technologies other than hydro (maximum of 20 MW per project)
c) 10 MW for micro generation

The medium – to long-term goal of is to contribute to a diversified renewable energy mix in order to create increased energy security. This is to be achieved in the second phase of the REFiT programme i.e. after phase one for another three years.

Just like in the renewable energy strategy, there is opportunity to produce power from biomass, however, the lack of biomass resource assessment again hinders the uptake of the technology. Hence the need to undertake a technical and economic potential assessment for bio-electricity generation technology. In addition, the introduction of cost-reflective tariffs for electricity (which is underway) will encourage investment and development of renewable energy electricity generation technologies including biomass power generation.

Conclusion

The energy potential of biomass resource in Zambia has been evaluated. The resources include agricultural residues, forest residues, municipal solid waste and livestock waste. According to the estimation by this method, significant amount of bio resources are available for modern energy applications in Zambia. Of the four biomass resources assessed, forest residues have the highest bioenergy potential of 102.7 PJ followed by agricultural residues with potential of 75 PJ. Livestock waste and MSW each have a bioenergy potential of 9.52 and 0.9 PJ per year respectively. Despite possessing good bioenergy production potential and an enabling environment for the promotion of modern biomass use, bioenergy application is still limited in the country. For successful utilisation of biomass residues in the country, a number of technical, environmental, social and economic constraints need to be overcome. In addition, there is need to not only quicken the process of adopting draft policies that are crucial to the development of the biomass industry but also implement biomass strategies and measures stipulated in the National Energy Policy.

References

Assmann, D., Laumanns, U. and Uh, D. (2006). *Renewable Energy: A Global Review of Technologies, Policies and Markets*, Oxfordshire: Routledge.

Bwalya, S.M. (2010). *Climate Change in Zambia: Opportunities for Adaptation and Mitigation through Africa Bio-Carbon Initiative*, Lusaka, Zambia: Peaks Environmental Management Consultants.

Bhaskara, T., and Pandey, A. (2015). *Advances in Thermochemical Conversion of Biomass*, India, Dehradun: Elsevier

Chowdhury M A I, Hasan G M J, Karanjit B and Shrestha L R. (2006).Solid Waste Management in Katmandu, Capital City of Nepal.Journal of Solid Waste Technology and Management. 32 (2): 1088-1697.

Commission of the European Communities (2008*).The support of electricity from renewable energy sources*.Commission Staff Working Document. Brussels: Commission of the European Communities, 2007.

CSO/MAL (2011). Central Statistical Office and Ministry of Agriculture and Livestock 2011 Crop Forecast Survey (CFS). Lusaka, Zambia: CSO, MAL.

Dombrovski, R. (2015). 'Effectiveness of financial and fiscal instruments for promoting sustainable renewable energy technologies', *Economic and business review,* 17(3), pp. 331.

Edema, M. O., Sichamba, V. and Ntengwe, F. (2012).Solid waste management- case study of ndola, zambia. International Journal of Plant, Animal and Environmental Sciences. ISSN 2231-4490 Available online at www.ijpaes.com

Energy Regulation Board (ERB), (2014). Energy sector report 2012 and 2013. Retrieved from: http://www.erb.org.zm/reports/EnergySectorReport2012-2013.pdf

Environmental Council of Zambia (2008) *Zambia Environment Outlook Report 3,* Lusaka: Environmental Council of Zambia.

European Environment Agency (2011). Environmental tax reform in Europe: opportunities for eco-innovation. *EEA Technical report No. 17, Copenhagen, Denmark.*

European Union Energy Initiative Partnership Dialogue Facility and German Federal Enterprise for International Cooperation (2014). *Biomass energy sector planning guide,* Germany: Schumacher. Visuelle Kommunikation.

Food and Agriculture Organization (FAO), (2014).Bioenergy and food security rapid appraisal (BEFS RA) User Manual, crop residues and livestock residues.

International Renewable Energy Agency (2013). *Zambia renewables readiness assessment 2013,* Abu dhabi: International Renewable Energy Agency.

International Renewable Energy Agency (2012). 'Biomass for power generation', *International Renewable Energy Agency,* 1(5), pp. 1

Japan International Cooperation Agency (2009). *Rural electrification master plan for Zambia 2008 - 2030,* Lusaka: Japan International Cooperation Agency.

Kasongo, C., Ilitongo, K., Ekanath, K., Felix, H., Kaoma, M. and Oppenoorth, H (2012). *Domestic Biogas Programme in Zambia*, Lusaka: Netherlands Development Organisation.

Koopmans, A., and Koppejan, J. (1997). Agricultural and Forest residues – Generation, Utilization and Availability, proceedings of the Regional Consultation on modern Applications of Biomass Energy, Kuala Lumpur, Malaysia, 6 – 10 January 1997.

Lande, J. (2016). *Zambia: The lower Zambezi community forestry project,* Available at: http://www.firstclimate.com/carbon-reduction-projects/zambia-the-lower-zambezi-community-forestry-project/ (Accessed: 28th October 2016).

Luwaya, E, (2014). A parametric analysis of conversion efficiency of earthen charcoal making kiln using a numerical method. *In Heat transfer, fluid mechanics and thermodynamics*. Orlando, Florida, 14 - 16 July 2014. Orlando, Florida: Heat transfer, fluid mechanics and thermodynamics. 241

Magutu, O.P., Mbeche, M. I., Nyamwange, M. Mwove, E. R. Ndubai, (2010). Formulation and Implementation of Operation Strategies Used in Solid Waste Management: Case Study of City Council of Nairobi" IBIMA Publishing 2010Journal of African Research in Business & Technology, 21 pages: available on-line at www.ibimapublishing.com/journals/JARBT/2010/842702/842702.pdf.

Mc Kendry, P. (2002) 'Energy production from biomass (part 1): overview of biomass', *Bioresource Technology,* 83(1), pp. 37-46

Ministry of Energy and Water Development (MEWD) (2008). *National Energy Policy*, Lusaka, Zambia: Ministry of Energy and Water Development.

Mondal, M, (2012). *Implications of renewable energy technologies in the Bangladesh power sector: Long-term planning strategies*. Doctoral. Bonn, Germany: Bonn University.

Murphy, J.D., and McKeogh, E. (2004) 'Technical, economic and environmental analysis of energy production from municipal solid waste', *Science Direct,* 29(1), pp. 1043 - 1051.

Okello, C., Pindozzi, S., Faugno, S., and Boccia, L. (2013) 'Bioenergy potential of agricultural and forest residues in Uganda', *Science Direct,* 56(1), pp. 515 - 525

Rahman, M.M. and Paatero, V.J (2012) 'A methodology approach for assessing potential of sustainable agricultural residues for electricity generation: South Asian perspective', *Biomass and Bioenergy*, 47(2012), pp. 153-163.

Republic of Zambia (2006) *Vision 2030 - A prosperous middle-income nation by 2030*, Lusaka: Republic of Zambia.

Smeets E.M.W and Faaij A.P.C. *(2007). Bioenergy potentials from forestry in 2050: an assessment of the drivers that determine the potentials. Climatic Change 81(3e4):353e90.*

Subbiah, M.(2015).Renewable Energy Feed-In-Tariff [PowerPoint Slides]. Retrieved from http://www.erb.org.zm/downloads/eregulation/refit/REFIT

The Carbon Neutral Company (2013). *Katete Improved Cookstove Project, Zambia*, Availableat:*www.carbonneutral.com/images/.../Katete_Improved_Cookstoves_Zambia_VCS.pdf* (Accessed: 17th October 2016).

Themelis, N. and Mussche, C. (2014). *2014 energy and economic value of municipal solid waste (MSW), including non-recycled plastics (NRP), currently landfilled in the fifty states*, New York, USA: Earth Engineering centre.

Themelis, N. (2006). *Energy recovery from Global Waste-to-Energy*, New York, USA: Waste-to-Energy Research and Technology Council.

Tiwari, G.N., and Mishra R.K. (2012). *Advanced Renewable Energy Sources*, London: Royal Society of Chemistry.

United Nations Environment Programme (2013). *Technologies for Converting Waste Agricultural Biomass to Energy*, Osaka: United Nations Environment Programme

World Bank (2014) *Urban Development Series – Knowledge Papers*, Available at: *http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387* (Accessed: 27th January 2017).

World Energy Council (2013). *World energy resources: bioenergy*, London: World Energy Council.

Zyl, J., Amadi-Echendu, J., and Bothma, T.J.D. (2007) 'Nine drivers of knowledge transfer between universities and industry R&D partners in South Africa ', *South African journal of information management*, 9(1), pp. 1-2.

Creating an intergraded energy and agriculture model for small scale rural farming system

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Abstract

With the recent increase in the prices of agricultural inputs and the general high cost of producing food in Zambia, there is a definite need to focus research on ways to curb the increasing cost of crop production. The purpose of this work is to establish energy and agriculture integrated model that improves the livelihoods of rural small scale famers. This model aims to bring about economic development and improved livelihoods by lowering food production costs, providing a clean sustainable energy source and utilizing waste streams. An attempt to retrieve used phosphorus from domestic, animal and plant wastes for crop fertilization purposes was found. In addition there was high potential for methane (biogas) production from the same waste.. The potential for methane production through anaerobic digestion of these wastes, means that not only can this process replace expensive fertilizer, but it can also be a sustainable energy source that can be a catalyzed for economic development in rural areas. This can be achieved through the combining phosphorus recycle and methane production on a small scale process. This paper also attempts to establish a work plan that can be used to test and possibly verify this model.

Keywords: Phosphorus, methane gas, renewable energy, small scale farming, model

1 Introduction

A quick glance at the current fertilizer prices reveals that there has been a sharp increase in fertilizer prices between the 2014/15 planting season and the 2015/16 planting season. For instance, D-Compound prices have gone up by 78% from ZMW226/50 kg in 2014/15 season to ZMW403/50 kg in the 2015/16 planting season. Similarly, the price for Urea went up by 55% from ZMW226/50 kg bag in 2014/15 season to ZMW350/50 kg bag in 2015/16 season (Union, 2016). According to a report by the Ministry of Agriculture (2016), this has been a direct result of the depreciation of the kwacha against the dollar and as the fertilizer industry is importing raw materials (such as phosphorus, nitrogen and other elements); this has led to a 77% price increment. Further, rural farmers have to take into account transportation of these fertilizers from major cities to their fields. Schemes such as the Farmer Input Support Program established in 2002/2003 to provide fertilizer and seed at heavily subsidized prices has faced difficulties amidst the high fertilizer prices. Due to this price increase, this research will aim to incorporate phosphorus retrieval in an attempt to replace expensive agricultural inputs such as fertilizers to ensure food

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security. The adaption of this process in a subsistence farming setup is key to ensure that it helps the rural farmers who are most affected by the scarcity of fertilizer inputs.

According to Rural Electrification Authority (REA), the premier provider of electricity infrastructure for rural areas, their goal is to provide electricity infrastructure to rural areas using appropriate technologies in order to contribute to the improvement of the quality of life (Enterprises, 2013). Table 1 shows that, in comparison to some of her neighbors, Zambia has a long way to go in terms of her electrification rates. The access to energy enables the population in the rural areas to establish businesses and develop small scale processing plants that will enable them to add value and store their farm produce. Therefore, addressing the energy needs for the rural areas is essential to Zambia's development and economic growth.

Table 1: Electrification rates in Zambia and some of her neighbors

Country	Population without electricity (millions)	National Electrification rate (%)	Urban electrification rate (%)	Rural electrification rate (%)
Zambia	11	26	45	4
South Africa	8	85	90	77
Botswana	1	66	75	54
Zimbabwe	8	40	80	21

Further, in an attempt to retrieve used phosphorus from domestic, animal and plant wastes, this process also has the potential to produce methane (biogas) from these wastes. The biogas produced from this process can converted to electricity using inverters and used to electrify and power the rural areas. Depending on the amount and quality of biogas production, the use of biogas can extend further than the conventional cooking and heating purposes. The potential for methane production through anaerobic digestion of these wastes, means that not only can this process replace expensive fertilizer (further, bioslurry that is a potential by-product of this process can also be used as a fertilizer), but it can also be a sustainable energy source that can be a catalyzed for economic development in rural areas. Due to the nature of the process of biogas production, this model intends to use the same reactor to recycle phosphorus and also produce biogas.

2 Literature Review

2.1 Phosphorus Recycle (Struvite production)

Current world phosphorus reserves (
Figure 1) are available in the form phosphorus rock and hence are mined and are major inputs in the fertilizer industry. This mined phosphorus is a finite resource and there is need to look at a more sustainable source of phosphorus as a shortage of phosphorus would have dire consequences on food security, especially in developing countries such as Zambia. Almost 80% of the phosphorus mined for fertilizers is lost as waste as the plant only absorbs approximately 30% of the phosphorus in the fertilizer therefore there is great potential in recycling phosphorus from our waste.

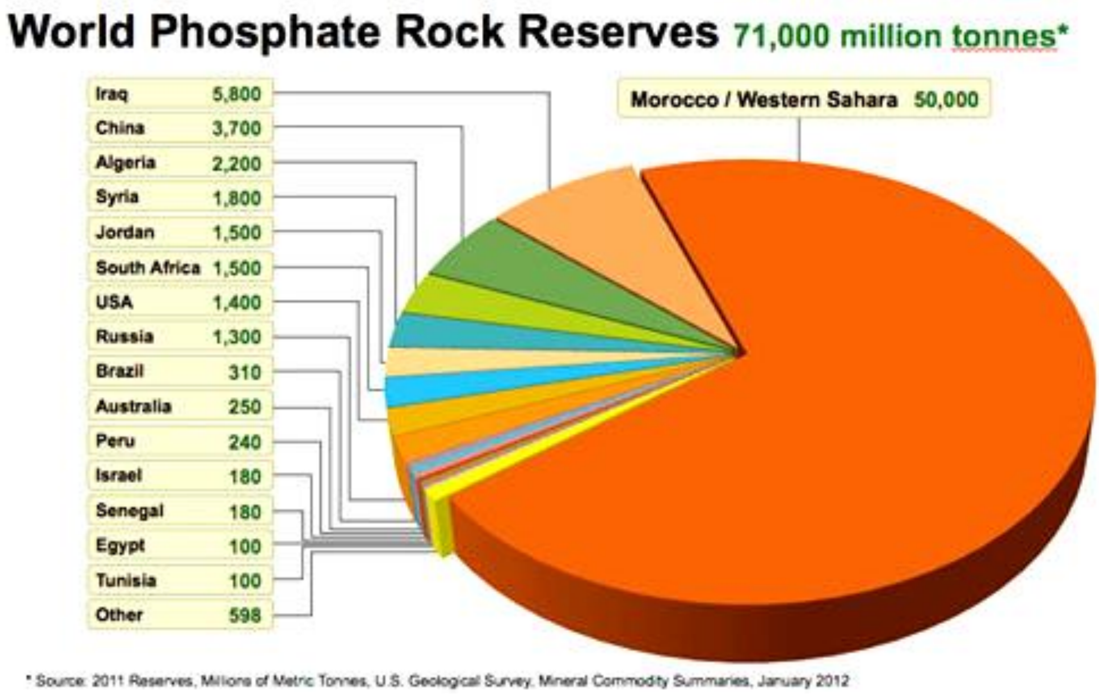

Figure 1: A schematic showing the world's phosphate reserves (Salazar, 2012)

Our use of phosphorus must be drastically reduced in the next 20-40 years if we are to ensure food security. Due to the threat of phosphorus scarcity to food security, there is an urgent need to ensure we will have sufficient phosphorus to feed humanity in the future (Crutzen, 2016).

Struvite is a crystalline mineral substance that contains magnesium ammonium and phosphate ions. The formation of struvite ($MgNH_4PO_{-4}.6H_2O$) is a result of the crystallization of high concentrations of phosphorus in waste streams with an addition of a magnesium source such as sea water, Mg-O by-products, brine and wood ash. In a study by Prabbu and Mutnuri (2014), crystallized struvite was formed from cow urine and brine in order to determine its effectiveness as an agricultural input. Results show that at room temperature, struvite was formed from a renewable source and can be used to replace conventional fertilizers (Prabbu & Mutnuri, 2014).

A technical assessment done by Sikosana, *et al* (2015) looked at the possibility of treating waste water from a Waste Water Treatment Works in Cape Town in order to recover phosphorus that can be precipitated and further used in the agriculture sector. This work highlights three main processing routes through which phosphorus can be retrieved from waste and will be used as a basis for the experimental work for this paper. Table 2 summarizes the three main routes.

Sikosana (2015) discovered that in South Africa, the selling price of struvite was significantly lower than the cost of recovering it. Further, the high capital costs and the unprofitable operations of struvite production made this process economically unviable. This project aims to focus on subsistence farmers and already existing infrastructure to make this process viable (Sikosana, Randall, & Blottnitz, 2015).

Table 2: Summary of the three main concept designs for phosphorus retrieval

	Route 1	Route 2	Route 3
Design	OSTARA installation (OSTARA, 2013)	Multiform Harvest (Bilyk, Pitt, Taylor, & Wankmuller , 2011)	Typical installations (Tetra Tech, 2013)
Technology	Crystallization: Fluidized bed reactor	Crystallization: Fluidized bed reactor	Chemical ppt: CSTR
Objective	To recover excess orthophosphate by producing high quality, crystalline struvite for sale in premium markets (potentially food production)	To recover excess orthophosphate by producing low quality, powdery struvite for sale in low end markets and processing plants	Removal and disposal of excess orthophosphates in side stream
Process summary	Use of large reactor unit with recycle for high quality crystal formation Struvite is filtered and dried (92 % DS)	Use of smaller reactors to produce low quality struvite slurry No recycling of reactor effluent Collected struvite is (20% DS)	Chemicals dosed to induce precipitation Sludge is dewatered (25% DS)

2.2 Methane (Biogas production)

The first Anaerobic Digestion (AD) plant was set up in India in 1859, today, most developed countries are now using AD to manage municipal waste and to create heat and power. Figure 2 shows the production of biogas from municipal waste water streams. This work however will be focused on providing organic waste from the crop and animal waste in order to produce biogas. Noting however that the raw materials for the phosphorus recycle reactor and the biogas production are the same and therefore this process can be combined (Cavinato, 2011).

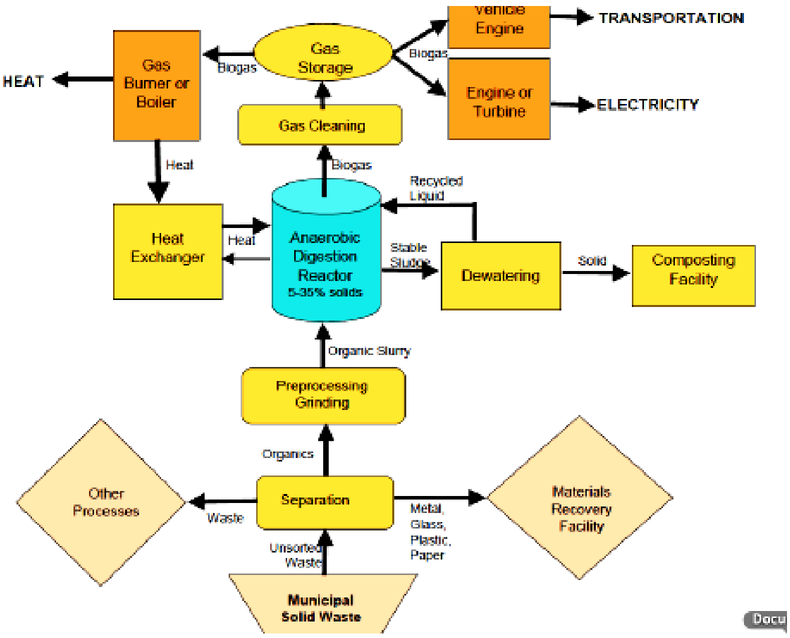

Figure 2: The process of biogas production from municipal waste water streams (Cavinato, 2011)

3 Methodology

This model will be tested and conducted in various phases. Firstly, lab/bench scale tests will be conducted in order to determine the chemical feasibility of the process. If this stage is successful, it will be followed by a pilot scale project on a selected farming area. During the lab/bench scale phase, a questionnaires and interview will be conducted amongst a sample population in a rural farming area of Zambia to determine the feasibility of a community's willingness to recycle their waste streams for fertilizer and energy production. Finally, if significant amounts of phosphorus (struvite) and methane is recycled and produced, a cost analysis will be done to determine the economic feasibility of the entire process.

3.1 Lab/bench scale tests

These tests will be conducted as a precursor to the pilot scale tests which could subsequently lead to demonstration tests. These tests are important in determining the chemical feasibility of the process. This process will require a batch stirred tank reactor with closely monitored temperature control as shown in Figure 3. (Edwards, 2013)

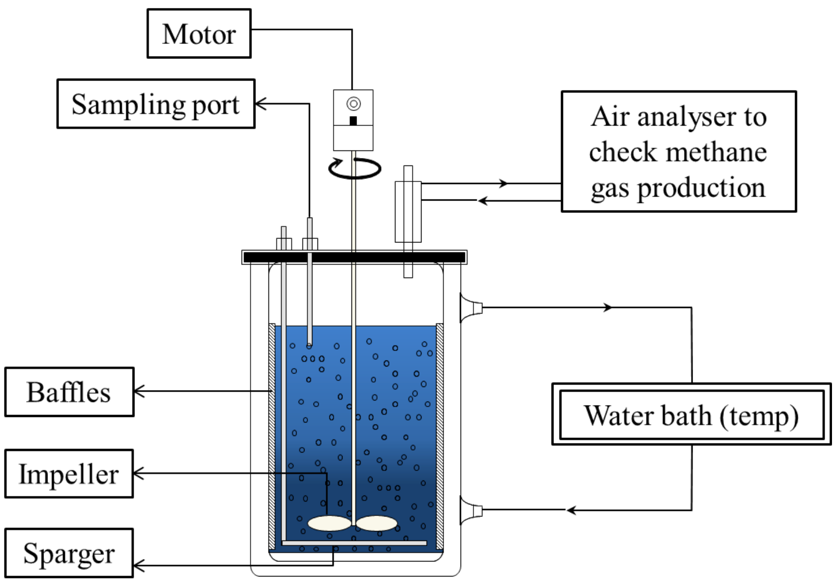

Figure 3: Proposed Continuous Stirred Tank Reactor (CSTR) for lab/bench scale tests

3.2 Pilot scale tests

These tests will be conducted after the Lab/bench scale tests. which could subsequently lead to demonstration tests. These tests are important in determining the chemical feasibility of the process. This process will be done according to Figure 3. (Sikosana, Randall, & Blottnitz, 2015).

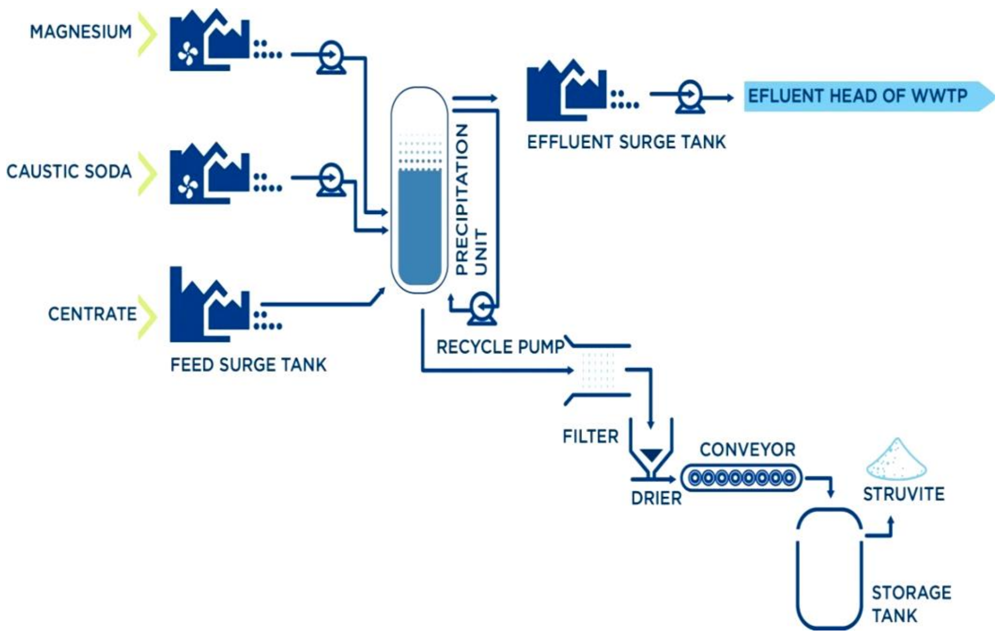

Figure 4: A schematic flow diagram of the complete struvite production process (Sikosana, Randall, & Blottnitz, 2015).

3.3 Questionnaire/interviews

This phase will require extensive interviews and handing out questionnaires to all the relevant stakeholders. These involve:

- Small scale rural farmers
- Water and sewage utility companies
- Government representation: Zambia Environmental Management Agency (ZEMA)
- Ministry of Agriculture and livestock
- Zambia National Farmers Union
- Musika
- Natural Resources Development College (NRDC)
- National Institute for Scientific and Industrial Research (NISIR)
- Wildlife and conservation Society Zambia
- Researchers: School of Mines, School of Agriculture, School of Veterinary medicine
- Public representation.

4 Conclusions

Food production levels in Zambia vary widely from year to year. Food security is fragile because subsistence farmers depend on rainfall, traditional hoe cultivation and increasingly expensive agricultural inputs, and even in years of national food surplus, many subsistence farmers or households often struggle. This paper therefore provides an alternative to expensive agricultural inputs such as phosphorus rich fertilizer by recycling phosphorus in the form of struvite from agricultural wastes.

Zambia is one of the countries with the lowest electrification rates in Sub-Saharan Africa and hence the need to electrify rural areas using cheap and sustainable energy source. Due to the common raw materials required in the phosphorus recycle process and the production of biogas, this paper has explored the feasibility of concurrently running both processes.

This paper is primarily a pre-feasibility report that explores the concept and chemical feasibility of the process. It also serves as a basis and guide for laboratory scale tests and the identification of a suitable study area and population.

References

Akcil, A., & Koldas, S. (2006). Acid Mine Drainage (AMD): causes, treatment and case studies. *Journal of Cleaner Production*, *14*, 1139-1145.

Bilyk, K., Pitt, P., Taylor, R., & Wankmuller , D. (2011). *PROCESS AND ECONOMIC BENEFITS OF SIDESTREAM TREATMENT.* Hazen and Sawyer Environmental Engineers and Scientists. Hazen and Sawyer Environmental Engineers and Scientists.

Cavinato, C. (2011, August 15-19). Anaerobic Digestion Fundamentals . Venezia, Venezia.

Company, T. M. (2013). *Phosphorus*. Retrieved April 8, 2016, from http://www.cropnutrition.com/efu-phosphorus#essential-role

Crutzen, P. P. (2016). *The phosphorus Challenge.* San Diego: GPRI.

Edwards, D. (2013). Scaling up step by step. *Biofuels Commercialisation*, 44-46.

Enterprises, A. T. (2013). *Rural Electrification Authority*. Retrieved October 31, 2016, from Who we are: http://www.rea.org.zm/index.php/contact-us

Prabbu, M., & Mutnuri, S. (2014). Cow urine as a potential source for struvite production. *International Journal Recycle Organisation Waster Agriculture*, *1*(1).

Sikosana, M., Randall, D., & Blottnitz, H. (2015). A technical and economic exploration of phosphate recovery from centralised sewage treatment. *Process Engineering*.

Tetra Tech. (2013). *Cost Estimate of phopshate removal at wastewater treatment plants.* Technical Support Document, Environmental Protection Agency.

Union, Z. N. (2016, May 19). *Zambia National Farmers Union.* Retrieved October 27, 2016, from Zambia National Farmers Union website: http://www.znfu.org.zm/article/statement-201516-maize-marketng-arrangements

Design and Fabrication of a Coin sorting machine

Mwaka Lingambe[1], Joram Donavan[2], Chella Zanga[3], Bartholomew Kalaba[4], Obed Chansa[5], and Darlington Masendeke[6]

Abstract

This paper presents the design and fabrication of a Coin sorting machine. The Coin sorting machine is aimed at sorting multiple collections of Zambian coins into their respective denominations. The design has been necessitated by the need to circumvent the challenge of sorting coins manually by Banks and shop owners. The objectives of the research were to explore various design concepts to come up with the most effective one, to design a mechanism by which coins are fed into the machine, to set the coins in vibratory motion, to sort the coins, and to design the coin collector. The Coin sorting machine design was arrived at after evaluating various design concepts based on the parameters of the coins namely, the diameters, thicknesses and weights. The design architecture consists of the vibratory motion source, the vibratory coin feeder, the sorting channels, the coin collector and the collecting tray. From this research, it has been demonstrated that coins can be sorted into their respective denominations by setting them into vibratory motion and then guiding them into cascaded sorting channels from which they are delivered into the coin collector by means of gravity.

Keywords
Coin, Sorting machine, Vibratory, Design, Fabrication

1. INTRODUCTION

A coin sorting machine is a device which sorts a random collection of coins into separate denominations [1]. Coin sorting machines are typically specific to the currency of certain countries due to different currencies often issuing similarly sized coins of different values [1]. A sorting machine usually makes no attempt at counting providing only collection of uncounted coins to be separately passed through a counter. The first coin sorting machines to be invented date as way back as the 1890s after it was found

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that banks and other business industries were finding it difficult to sort their coins [1]. With time, sophisticated and expensive coin sorting machines have been developed for use in shops and banks.

The Coin Sorting Machine , comprises a vibratory motion source, which are small electrical motors powered by either rechargeable finger-size batteries or from a 12V power supply, a vibratory coin feeder from which coins are guided into a cascaded assembly of sorting channels which can also be referred as a sorting mechanism. In the sorting channels, coins are sorted as they pass through openings on the grooves of coin sorters, depending on their diameters. The sorted coins are collected into the coin collector with compartments for the respective coin denominations. The coin collector is designed to easily slide in and out of the collecting tray for the purposes of loading and offloading coins, respectively.

Following the introduction of new coins, namely, the 5 ngwee, 10 ngwee, 50 ngwee and K1, in the year 2013, Zambian banks and shop owners are faced with a challenge of sorting multiple collections of coins into their respective denominations. As a result, more time is spent on sorting coins manually thereby reducing productivity. It is from this background that the Coin Sorting Machine was designed and fabricated. The coin sorting machine was designed to be easy to use and less costly compared to existing commercial coin sorting machines.

The cost of commercial coin sorting machines varies, depending on the sophistication and efficiency of the machine [2]. In other words, the more efficient and mechanically complex the machine is, the higher its cost [2].

Different inventions of Coin Sorting Machines are available as described in US patent: 4167949, 4172462 and 7861841, for example. Some of these inventions employ a rotary disc as means of delivering coins to a conveyor belt on which the guides have a spiral progression. These inventions are compact and work perfectly well, although their designs are quite complex. Other designs of coin sorting machines have sieves and therefore coins are sorted by shaking the sieve [3].

Some designs for sorting coins employ several trays, equal to the number of denominations being sorted. These trays are fixed on top of each other. Each tray, except the bottom one, has holes punched on its base which allow all denominations smaller than what it is designated to collect, to pass through and fall onto the next tray. In order for this to be accomplished, the upper tray collects the largest coins while the lower one collects the smallest ones, with those in between descending in that order. When the coins are placed in the upper tray, the whole assembly is shaken by hand to facilitate the sorting process [4]. The Coin Sorting Machines can also be made cheaper but effective by simplifying their designs such as the design presented here where coins are delivered by vibrations and gravity through a series of sorting channels arranged in cascade.

The scope of this research was limited to developing the design concept for the coin sorting machine, coming up with detailed drawings of the individual components and developing a working prototype of the coin sorting machine.

2. DESIGN CARRIED OUT

The design of the Coin sorting machine involved collecting the design parameters of the coins, developing the design architecture and finally developing a working prototype. The prototype was developed in accordance with the product design specifications and after evaluating various design concepts. Testing was also done on the prototype to ensure that the desired operation and results were achieved.

1.1. Design parameters

The Coin design parameters were used to develop the concepts for the coin sorting machine. The selected concept uses the differences in the diameters. The coin design parameters are as shown in **Table 1**.

Table 1*: *Coin design parameters

Denomination	**Diameter (mm)**	**Thickness (mm)**	**Weight (g)**
K1	24.00	1.73	5.00
50 ngwee	21.00	1.60	3.50
10 ngwee	20.00	1.57	3.00
5 ngwee	19.00	1.55	2.50

1.2. Design architecture

The coin sorting machine architecture is made up of the vibratory motion source, vibratory coin feeder, sorting channels, collecting tray and the coin collector as shown in Figure 1. This design architecture was developed by breaking down the function of the coin sorting machine into sub-functions such as delivering coins into the machine, moving the coins, sorting the coins, collecting the coins and offloading the coins.

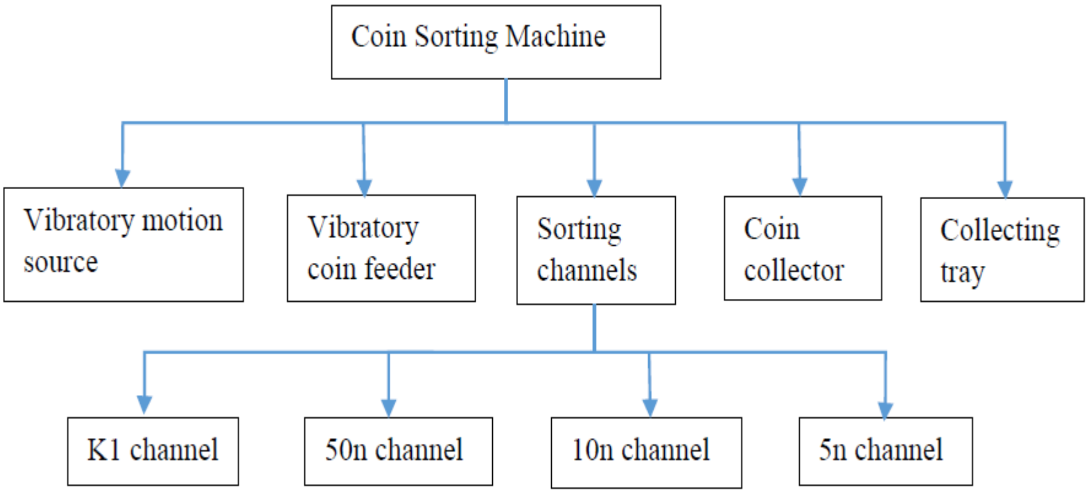

***Figure 1**: Design Architecture for the coin sorting machine*

The vibratory motion source are small motors taken from the XBOX 360 wireless game controllers. Considering the orientation of the coins, despite the incline of the feeder, it became apparent that vibratory motion will easily agitate the coins and also aids the movement of coins that might get stuck along the feeder guides. The motors can be powered via a USB port from a 12V power supply or from rechargeable finger-sized batteries connected in series and each rated at 600mAh-1.2V.

The vibratory coin feeder is made of a stainless steel wire msh joined to a sheet metal steel plate where the coins are placed. The choice of a metal feeder was based on the low damping coefficient of the steel sheet metal so as to transmit the vibratory motion of the motors to the coins effectively. The feeder is mounted at an angle to the horizontal on a stand and fitted with guides at the end that feeds the coins into the sorting channels.

The sorting channels are arranged in cascade and inclined at an angle to the horizontal. There are four channels, each designed to sort out one denomination of coins. In other words, there is a sorting channel for the K1 coins, sorting channel for 50 ngwee coins, sorting channel for 10 ngwee coins and a sorting channel for the 5 ngwee coins. Cardboard was chosen as material to make the cascaded sorting channels in order to minimize noise, reduce the weight of the machine and provide proper slip for the coins.

The coin collector has four compartments. Each compartment receives one denomination of coins. That is, as the coins from the vibratory coin feeder are delivered into the sorting channels, the K1 coins slide directly into the K1 compartment. Similarly, the 50 ngwee, 10 ngwee and 5 ngwee coins slide directly into their respective compartments. The coin collector is made of plastic material and is able to slide in and out of the collecting tray. The collecting tray is made of stainless steel wire mesh.

1.3. Prototype operation

To describe the operation of the prototype developed, reference is made to the labelled design of the coin sorting machine shown in Figure 2. The descriptions of the labels are shown in Table 2.

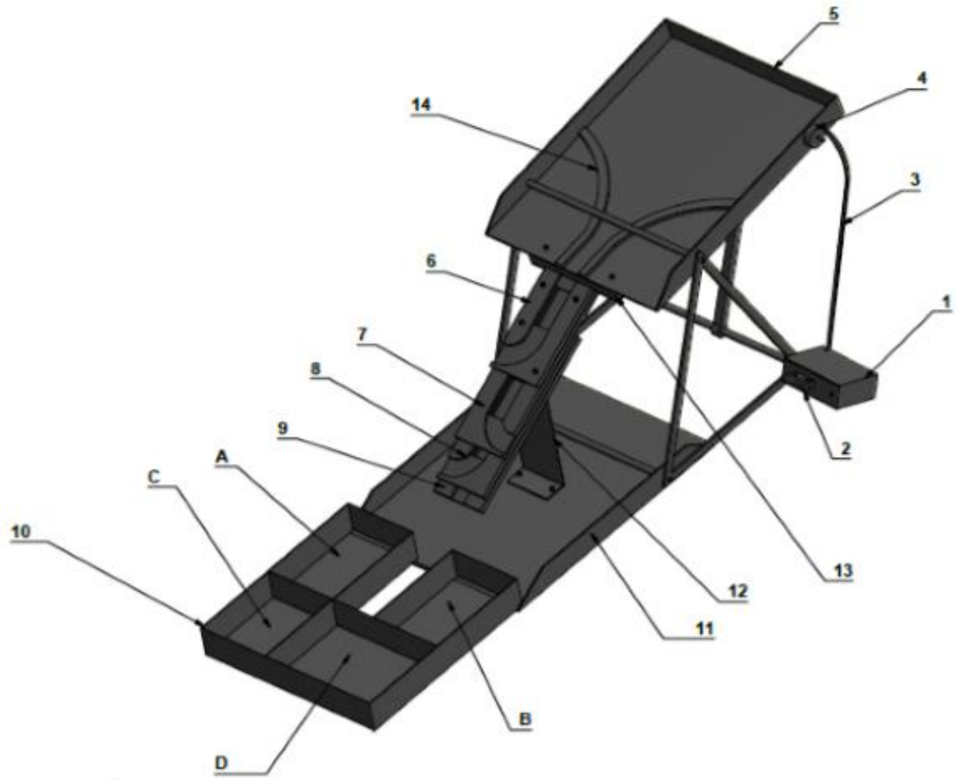

Figure 2*: *Coin sorting machine prototype

Table 2*: *Annotations to the prototype

Label	Description	Label	Description
1	Rechargeable batteries housing	10	Coin collector
2	switch	11	Collecting tray
3	Electric cable	12	Lower bracket
4	Vibratory motion source(motor)	13	Upper bracket
5	Vibratory coin feeder	14	Coin guide
6	K1 sorting channel	A	K1 compartment
7	50 ngwee sorting channel	B	50 ngwee compartment
8	10 ngwee sorting channel	C	10 ngwee compartment
9	5 ngwee sorting channel	D	5 ngwee compartment

Sorting a random collection of Zambian coins into their respective denominations in accordance with the invention is achieved by these components: vibratory motion source, vibratory coin feeder, sorting channels, collecting tray and coin collector. The coins are placed on the vibratory feeder which is fitted with coin guides. When the switch is switched ON, the vibratory motion sources, rated 600mAh-1.2V and connected to rechargeable batteries inside their housing through the cable begin to run thereby transmitting vibrations to the vibratory feeder inclined at an angle $\mathbf{22^\circ \leq \theta \leq 25^\circ}$ to the horizontal.

The vibrations set the coins in motion, causing them to slide down the vibratory coin feeder and between the coin guides. As the coins approach the straight part of the coin guides, they are set in a single file and delivered to the sorting channels. The sorting channels each have a thickness of 8 mm and groove-depth of 4 mm. The grooves on sorting channels have openings with different widths but same length of 50 mm.

As the coins approach the first sorting channel, the K1 coins are sorted and delivered to compartment **A** by means of a chute to guide the coins from the groove while the rest of the coins proceed to the second sorting channel where the 50 ngwee coins are sorted and delivered to compartment **B** while the rest of the coins proceed to the third sorting channel where the 10 ngwee coins are sorted and delivered to compartment **C** while the rest of the coins proceed to the last sorting channel where the 5 ngwee coins are received, being the last coins to be sorted. The 5 ngwee coins are delivered to compartment **D**.

The assembly of sorting channels, is supported by means of two brackets, namely the upper bracket mounted on the vibratory feeder and the lower bracket mounted on the collecting tray. The sorting channels are arranged in cascade to ensure that the coins are successively sorted as they make transitions from one sorting channel to the other.

When the sorted coins have been delivered to the coin collector, they can be offloaded by sliding the coin collector out of the collecting tray. The coin collector is then slid into the collecting tray in readiness to receive the sorted coins from the next sorting session.

1.4. Tests and findings

Tests were carried out to establish the suitable angles of inclinations of the vibratory coin feeder and the sorting channels with the horizontal surface. This test was an important task in the design because a large inclination of the feeder would cause coins to pile up as they are being fed into the sorting channels and this is very undesirable since the coins should be fed one at a time. The inclination of the sorting channels, ought to be large enough to allow the coins to slide into their designated channels and slots, and eventually into the coin collector. The angles were determined by means of an inclinometer. The inclination angles for the vibratory coin feeder and the sorting channels were found to be in the range of $\mathbf{22^\circ \leq \theta \leq 25^\circ}$ and $\mathbf{28^\circ \leq \theta \leq 32^\circ}$**,** respectively.

The other tests were carried out to check for smooth transition of coins on the channels. It was found out that some coins were getting trapped along the channels and at the point of exit from the channels due to uneven surfaces and sharp turns, respectively. This problem was circumvented by smoothening of uneven surfaces and making smooth exit turns at angles greater than 90°.

3. CONCLUSION

This paper shows that a cheap and easily operated coin sorting machine was successfully designed and fabricated. The materials used were readily available on the market at a low cost and could be easily modified to fit the design. Therefore, if the coin sorting machine is commercialized, banks and shop owners will easily afford it. The design architecture consisted of the vibratory motion source, the vibratory coin feeder, the sorting channels, the coin collector and the collecting tray. The design concepts for the coin sorting machine were developed using the parameters of the coins namely, the diameters, thicknesses and the weights. The selected concept for the design was based on the differences in diameters.

From this research, it has been demonstrated that coins can be sorted into their respective denominations by setting them into vibratory motion and then guiding them into cascaded sorting channels from which they are delivered into the coin collector by means of gravity. Proper motion of the coins was achieved by establishing suitable angles of inclination for both the vibratory coin feeder and the cascaded coin channels.

4. REFERENCES

[1] Wikipedia, the free encyclopedia [Online]. Available: https://en.wikipedia.org/wiki/Currency-counting_machine (Accessed on 8 November, 2016).

[2] (Online source), Klopp Coin, Inc., 2012, "Coin sorters", Florida. Available: http://kloppcoin.com/products/coin-sorters/

[3] N. Duong, D. Trung, B. Thanh, L. Ann and L. Trung (2004), "Coin Sorter Machine, design and development", Asian institute of Technology, [Online]. Available: http://www.faculty.ait.ac.th/pisut/PDD/PDD04/CoinGroup1.pdf (Accessed on 8 November, 2016).

[4] J. Johnson, "How a coin sorter works", [Online]. Available: http://www.ehow.com/how-does_5006488_how-coin-sorter-works.html

Determination of air quantity requirements in view of increased heat load for Mindola deep section, Mopani, Zambia.

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Abstract

Temperatures and humidity at Mindola Sub-Vertical (MSV) shaft have been rising with increase in mining depth. This rise in temperature has been catalysed by a number of factors notably: the increase in use of diesel equipment; geothermal gradient (increase of temperature with mine depth); auto compression and other sources of heat. As the mine get deeper and ventilation requirements become more complex, the mine needs to adapt better ventilation systems to meet new demands of keeping an acceptable mine environment for both workers and machinery.

Therefore, this study was aimed at determining the ventilation requirements for the new Mindola Sub-Vertical shaft in view of increased heat levels. The study involved identifying major sources of heat and quantifying the same using heat determination methods (Heat Loads and Air- Tonnage Ratio). The air volume required to remove or reduce heat and other mine pollutants like dust and gases was also determined.

The study has established that the total quantity of heat generated in the mine is 32,033.21kW and the quantity of air required to dilute this heat is 826.45m^3/s. The said quantity is however, 202.24m^3/s more than the current down casted air of 624.00m^3/s.

***Keywords**: Temperature, Mine Heat Sources, Heat Loads, Air- Tonnage ratio.*

1.0 Introduction

Nkana mine operates four (4) underground shafts, a number of open pits across the Nkana oxide cap, a concentrator and a cobalt plant. Mindola Sub- Vertical Shaft (MSV), where the study was undertaken from is one of the four underground shafts found at Nkana mine. The other shafts are Central shaft, South Ore Body shaft (SOB) and North Shaft. MSV is the largest and deepest shaft at Nkana mine.

One of the challenges currently facing the Mindola Sub-vertical Shaft is the difficulty in maintenance of a conducive mine environment as the shaft deepens where workers can work safely. Other than the provision of right quantities of fresh air, to dilute dust and gases, heat and humidity have become a major concern as the shaft deepens. At the current depth of more 1,550m,

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MSV is experiencing high dry and wet bulb temperatures of about 35.0°C and 32.5°C respectively.

2.0 Description of existing Ventilation system

2.1 Up-Cast Ventilation shafts:

The shaft is saved by three (3) principal main up-cast fans namely, V10, V5 and V9 saving the southern, central and the northern part of the mine respectively and two down cast shafts namely 1and 2 as shown in Figure 1. The current total up-cast quantity of air measured is 657.m³/s at 1.2 kg/m³ while the total mass flow rate is 778kg/m³ at static pressure of 11.9kPa.

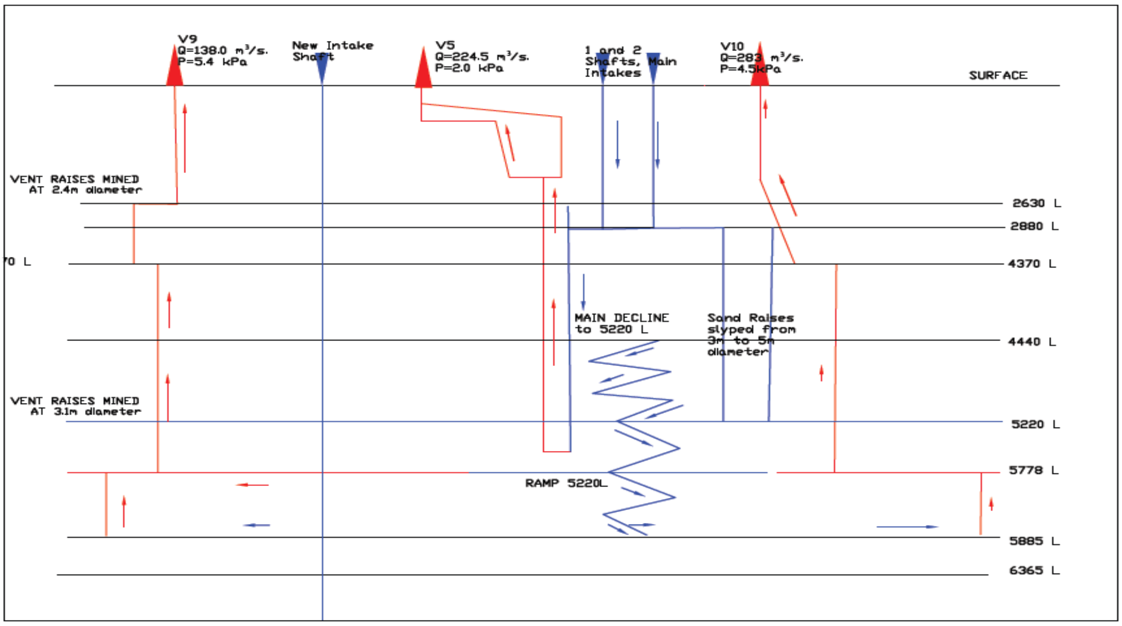

Figure 1: Ventilation system of Mindola SV Shaft

2.2 V 9 Upcast shaft

The shaft consists of a single inlet, centrifugal fan of a backward curved aerofoil bladed impeller with a duty of 5.4kPa static pressure handling air quantity of 138.0m³/s. The Shaft represents 21% of the total up cast quantity. The drive is directly coupled with nominal power of 1500kW, sitting on the 5.5m diameter shaft. The V9 Shaft serves the northern part of the mine running through various levels and raises up to 5045L.

2.3 V5 Upcast shaft

The shaft consists of an axial flow fan with a duty of 2.0kPa static pressure handling air quantity of 236.5m³/s. The shaft represents 36% of the total upcast quantity. The drive is directly coupled with nominal power of 1500kW, sitting on the 4.9m diameter shaft. The shaft runs through center of ore body strike length and serves the shaft complex areas.V5 extends down to the shaft bottom (5660L).

2.4 V10 Upcast shaft

V10 shaft consists of a centrifugal fan of a backward curved aerofoil bladed impeller with a duty of 4.5kPa static pressure handling air quantity of 283.0m³/s representing 43% of the total upcast quantity. The drive is direct coupled with nominal power of 1500kW, sitting on the 4.9m diameter shaft. The shaft extends up to 4370L on the southern part of the mine. Table 1 shows the pressure and volumetric measurement on the main upcast fans at Mindola sub vertical shaft.

Table 1: Measurements on Main Upcast Fans

Fan	Static Pressure (kPa)		Air Volume Measurement (m^3/s)			
	Design Duty	Actual	Design Duty	Actual	U/G point	Level
V10	5.0	4.5	354.0	283.0	244.8	3920
V9	6.5	5.4	150.0	138.0	134.4	3920
V5	3.1	2.0	307.0	224.5	224.7	2380

2.5 Downcast shafts

MSV has two surface downcast namely number 1 and 2 shafts. The intake air splits at 2630L and 2880L, with former further splitting through three air haulages (trunks) handling a total 369m³/s on its available cross section area of 51.7m². The remainder of 255m³/s goes through the cross section area of 24.5m² at 2880L main crosscut to Sub-vertical Shaft (SV). From 2880L, the SV shaft is mined at 7.1m diameter with available area for ventilation estimated at 70% i.e. 27.7m². The sand raises being slipped from 1.8m to 5.0m diameter from 2880L to 4440L will give a total area of 39.3m²

3.0 Materials and Methods

Techniques used to gather information for the study included: detailed literature review and collection of field data from the mine. Structural interviews using logic modeling were also conducted with selected mining officials from Mine planning and Mine ventilation departments.

3.1 Instruments

Instruments for measurements of ventilation parameters included: Whirling hygrometer; vane anemometer; stop watch and measuring tape. The whirling hygrometer was used to determine the wet and dry bulb temperatures while the vane anemometer was used to determine air speed. Pressures were captured using the barometer.

4.0 Determination of heat loads and air flow requirement

The following generally accepted Equations [1] to [8] were used to determine head load from different section of the mine. Air requirements based on heat load were then computed by using the Physchrometric Chart shown in Figure 2.

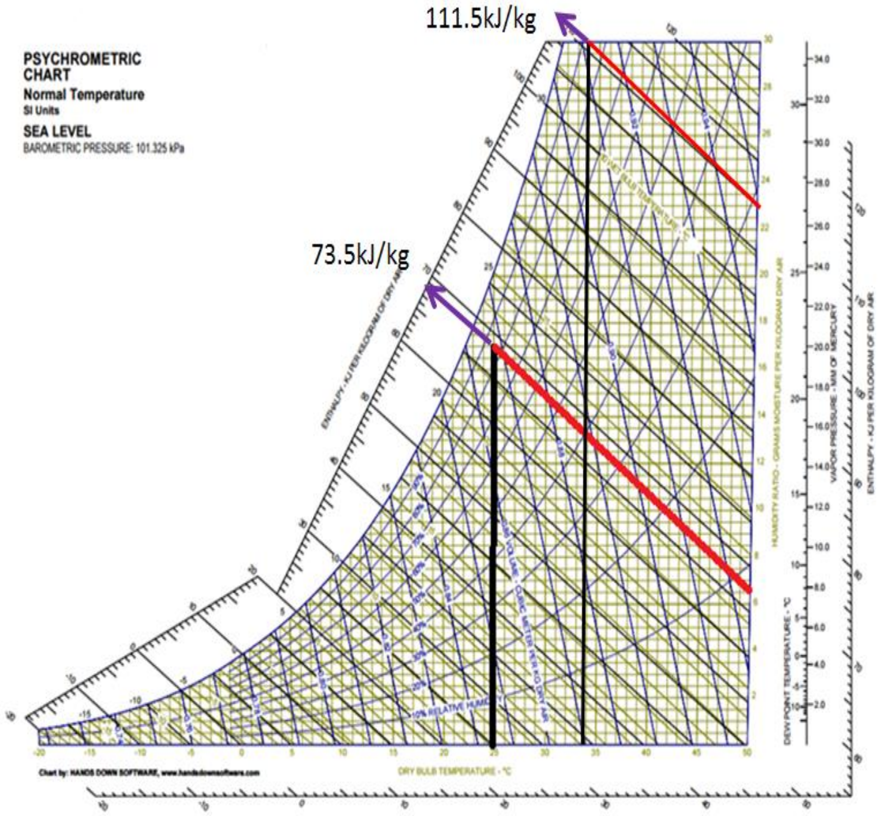

Figure 2: Psychometric Chart (A. Barenberg, 1974)

(a) Heat from Rock Strata

$q = 3.35LK^{0.854}(VRT - \theta)/1000$ (McPherson, 2012) [1]

Where;
L = Total length of all the haulages (m)
K = Conductivity of quartzite (5.74W/m ºC) (Cornelis, 2016)
VRT =Average Virgin Rock Temperature (ºC)

(b) Heat of Auto-Compression

$H_2 - H_1 = g(Z_1 - Z_2)/1000$ (Hartman, 1997)
$S = H_2 - H_1$
$S = 9.79 \times \Delta Z/1000$ kJ/kg
$M = Q \times w$ (kg/s) (Burrows, 1974)

$q = S \times M$ (kW) [2]

Where:
$H_2 - H_1$ = Change in enthalpy
Q = Quantity of the down cast air (m^3/s)
w = Density of the ambient air (kg/m^3)
ΔZ = Difference in elevation

S = Sigma heat at below surface
M = Mass flow of the down cast air (kg/s)
g= acceleration due to gravity ($9.81 m/s^2$)

(c) Heat from Fissure Water

$$q = (M \times C \times (W_F - \theta)/t \quad (kW) \qquad [3]$$

(Ramsden, F. von Glenn, 2012)

Where:
q = heat from water fissures
M = mass of the water fissures pumped out of the mine per day (kg)
W_F = water fissure temperature (^0C)
θ =Air temperature (^0C)
C= Specific heat of water
t= seconds in one month

(d) Electrical Equipment

$q = P \times I$ (McPherson, 1993) [4]

Where:
P = Power consumption (kW)
I = Mopani domestic inefficiency (%)
q = heat (kW)

(e) Diesel Units

$q = R_e$ (Stinnette & De Souza, 2013) [5]

Where:
R_e = Total input power rating for all the diesel units (kW)
q = Heat load from diesel units (kW)

(f) Heat from Men

$$q = N \times A \times R_M \qquad [6]$$

$A = 0.202\ Mt^{0.425}\ Ht^{0.725}$ (m^2) (McPherson, 2012)

Where:

Mt = Mass of a miner (kg)
Ht = Height of man (m)
N = Number of men
A = Area of a miner (m^2)
R_M = Metabolic heat rate (W/m^2)

(g) Heat from Broken Rock

q = M× K× (VRT – θ)/t (Le Roux, 1990) [7]

Where:
M = Mass of rock broken per month (kg)
K= Thermal Capacity of the rock (kJ/kg ^{0}C)

(h) Heat from Explosives

q = (0.6× M ×H)/t [8]

Where;
M = Mass explosives used by the mine (kg)
H = Heat content of the explosives (kJ/kg)

4.1 Determination of air flow requirement based on Air – tonnage ratio (ATR)

For the purpose of ventilation planning, the factor of air quantity per tonne of broken ore has considerable significance. Based on experience on many mines in which rock temperatures are high, Lambrecht and Barcza (1958) devised an empirical relationship which has continued to be used to date. Air requirement for a mine is defined by the production rate. This rate in addition to the rock and ore characteristics depends on the type and size of mining equipment used. On average the flow requirement is about 2.985 or 3m3/s of air per 1000 tonnes of ore extracted. Table 2 shows typical air quantity and tonnages for different mines from 1940 to 1971.

Table 2: Air Quantities and tonnages 1940-71 (after Burrows, 1974)

Year	Total Air	Air/man	Air/Tonnes	No. of Mines
	Quantity m^3/s	$m^3/s/man$	$m^3/s/1000t$	
1940	8348	0.0314	1.27	41
1950	11145	0.049	1.87	46
1960	17158	0.059	2.18	52
1970	24307	0.085	2.91	46
1971	24548	0.087	2.985 (3)	44

5.0 Results and Discussion

5.1 Calculation parameters for Heat Loads

Below are parameters used for heat load and air volume calculation for the mine?

a. KJ/s is equivalent to kW. (Le Roux, 2009)
b. Density of quartzite rock is 2690 kg/m^3 (Cornelis, 2016)

c. Thermal capacity (C) and conductivity (K) of quartzite are 837kJ/kg ºC and 5.74W/m ºC respectively. (Cornelis, 2016)
d. Standard density of air is 1.2kg/m^3
e. Quantity of down cast air is (shaft 1 and 2= 369.0 + 255.0) = 624m3/s
f. Level of consideration is 1,726m (5660L)
g. Mopani domestic efficiency is about 75%
h. Average Virgin Rock Temperature (VRT) is 42.0ºC
i. Ambient temperatures (θ) are 24.0 /25.0ºC. Maximum desirable temperature are 31.0/34.0ºC
j. For maximum air volume calculation assume that all the diesel units are operating in one room at efficiency 80%
k. Considering 26 working days in one month

5.2 Determination of Heat Loads for air requirements

(a) Heat from Rock Strata

Total length of the entire main mine openings is 13,200 m. Using Equation 1, heat generated is;

$$=3.35 \times 13{,}200 \times 5.74^{0.854}(42.0-25.0)/1000$$
$$= \mathbf{3343.32\ kW}$$

(b) Advancing End of the Heading

- Daily face advance (DFA) is 1.8 m x 2= 3.6m
- Length of the advancing end of the heading is 3,600m

$$q = 6K\ (L+4DFA)\ (VRT-\theta)$$
$$= 6 \times 5.74(3600+ (4 \times 3.6))\ (42.0 - 25.0)/1000$$
$$= \mathbf{2116.16\ kW}$$

Where:

L = Length of the advancing end (m)

DFA = Daily face advance (m)

$$= 3343.32\ kW + 2116.16\ kW$$
$$= \mathbf{5459.48\ kW}$$

(c) Heat of Auto-Compression

- Depth of the mine level of consideration is 1,726m (5660L)
- Down cast quantity (shaft 1 and 2= 369.0 + 255.0) = 624m3/s
- Assuming Ambient density of 1.2 kg/m^3
- Taking the increase in sigma heat per 1000m as 9.79kJ/kg

$$S = 9.79 \times \Delta Z/1000 kJ/kg$$
$$= (9.79 \times 1726)/1000$$
$$= 16.90\ KJ/kg$$

$$M = Q \times w = 624 \times 1.2= 748.80\ kg/s$$

$$q = S \times M\ (kW)= 16.90 \times 748.8$$
$$= \mathbf{12{,}654.7\ kW}$$

(d) Heat from Fissure Water

- Average volume of water measured from the boreholes is 35,577.75m^3/day.
- Taking 1Litres = 1Kg and 1000Litres = 1m^3
- Average water fissure temperature is 33.5 ºC.

Using Equation 3, heat generated is;

$$= [(35577.75 \times 1000 \times 4.187 \times (33.5-25)] / (24 \times 30 \times 3600)$$

$$= \mathbf{977.00\ kW}$$

(e) Electrical Equipment

Electrical power consumption for Mindola Sub vertical shaft for 12 months is given as 187,666.4/12. The average consumption can be calculated as shown below:

Average power consumption =Total/12

=187,666.4/12

=15,638.87kW

Using Mopani domestic efficiency to be 75 %, the heat from Electrical consumption is given as:

=15,638.87kW ×0.25

= 3,909.7 kW

(f) Diesel Units

Taking the total input power rating of the diesel units as = 7,492Kw

$$q = R_e$$

$$= \mathbf{7{,}492 kW}$$

(g) Heat from Men

The average number of men working at Mindola SV in a day is 496. Taking the average mass and height of a miner to be 60.5kg and 1.688m respectively and using Equation 6, the total amount of heat generated is:

$$q = N \times A \times R_M$$

$$= 496 \times 1.814 \times 260$$

$$= \mathbf{234\ kW}$$

Where

$$A = 0.202\ (60.5^{0.425})\ (1.688^{0.725}) = 1.814 m^2$$

(h) Heat from Broken Rock

According to production schedule average rock broken per month at 20% waste inclusion is 200,000t/m tones. Using Equation 7, heat generated from broken rock is:

$$= (200{,}000\ kg \times 1000 \times 0.837 \times (42.0-25.0)) / (26 \times 24 \times 3600)$$

$$= \mathbf{1266.83\ kW}$$

(i) Heat from Explosives

Monthly explosive consumption for the period of 1st to 30th April, 2015 was 1549 cases. Provided each bag and case weighs 25kg, the total monthly consumption in kg was;

= 25kg×1549.0
= 38,727kg
60 % of the heat from the explosives is returned to the rock

Heat content of ANFO explosives is 3820kJ/kg; Using the formula from Equation 8, Heat from explosive is:

= (0.6×38,727 ×3820)/ (26×24×3600)
=39.5kW

Table 3 shows summary of total heat loads from various sources, while Figure 3 shows mean temperatures for 12 months at Mindola Sub vertical shaft.

Table 3: Summary of total heat loads

Heat Source	**Quantity (kW)**
Rock Strata	5,459.48
Auto-Compression	12,654.70
Fissure water	977.00
Electrical Equipment	3,909.70
Diesel Units	7,492.00
Men	234.00
Broken Rock	1,266.83
Explosive	39.50
Total	**32,033.21**

Taking the Barometric pressure at 1,726m (5660L) as 107.3kPa; using the 101.325kPa Psychometric chart in Figure 3, the sigma heat at the ambient temperatures of 24.0/25.0^{0}C is 73.5kJ/kg and at maximum allowable temperatures of 32.0/34.0^{0}C is 111.5kJ/kg. The Density of air, at the maximum allowable temperatures and pressure of 107.3Kpa is 1.02kg/m^3. The Quantity of air required to dilute total heat load is determined by using the following Equation:

$Q = q/ (p \times (S_1 – S_2))$ (m^3/s) (McPherson, 2012) [9]
= (kJ/s) / (kg/m^3 × kJ/kg)
= 32,033.21/ [1.02 × (111.5-73.5)]
= **826.45m^3/s**

Where:

q = total heat load (kW)
P = density of air at the maximum temperature (kg/m^3)
S= sigma heat (kJ/kg)
Q= quantity required to dilute the heat load (m^3/s)

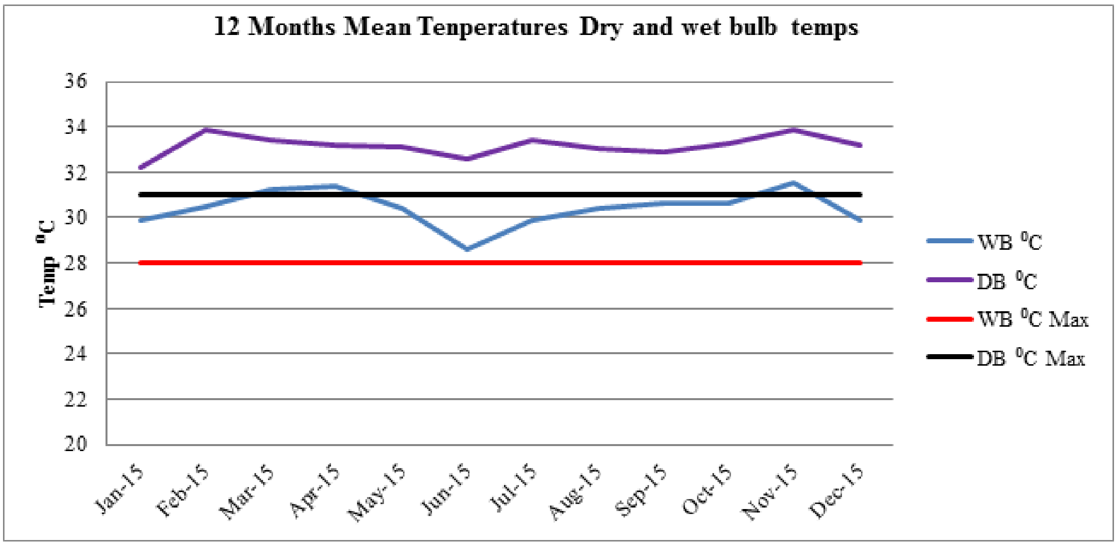

Figure 3: Mean Temperatures for 12 months

5.3 Determination of Air requirements based on Air Tonnage Ratio

Beyond the year 2017, according to Mopani Copper mines Management Report (2015), mining operations at the mine will concentrate below the 5220L at an annual rate of 2.0 million tonnes of ore. Therefore, using 2 million tonnes/ year and $3m^3/s/1000t/month$, air required is:

$$Q = \frac{(3 \, X \, 2000000)}{12 * 1000}$$

$$= 500 m^3/s$$

From air quantity calculations, it is evident that determination of air requirement based on total heat load had the highest value and as such air quantity of 826.45 m^3/s was adopted.

6.0 Conclusion

The study has established that the total quantity of heat generated in the mine is 32,033.21kW and the quantity of air required to dilute this heat is $826.45m^3/s$. The said quantity is $202.24m^3/s$ more than the current down casted air of $624.00m^3/s$.

Acknowledgements

Great thanks goes to Mopani Copper Mines Plc (MCM) for allowing this research to be carried at the mine. Special thanks also go to Mr. Niven Kalima, Section, ventilation officer, MCM) for his help during data collection.

References

Barenberg. A. W. T, (1974), “Psychrometry and Psychrometric charts”, Chamber of Mines of South Africa, 3rd Edition, Printed by Cape and Transvaal (Ptv), Cape Town, South Africa.

Burrows J, (1974), “The Ventilation of South African Gold Mines’’, 1st Edition, Printed By Cape and Transvaal (Ptv), Cape Town, South Africa.

Cornelis Klein, (2016), encyclopedia Britannica, Rock –Geology)

Howard L. Hartman, Jan M. Mutmansky, Raja V. Ramani, Y. J. Wang, (2012), “Mine Ventilation and Air Conditioning”, John Wiley & Sons

Le Roux W.L, (1990) “Mine Environmental Control,” 4th Edition (1990), Printed By the Cape and Transvaal Printers, Cape Town, South Africa.

McPherson M.J, (2012), ‘’Subsurface Ventilation and Environmental Engineering’’, 3rd Edition Printed by Cambridge Press, Cambridge, Britain.

Ramsden R. and Von Glehn F., (2012), “Guidelines for selecting equipment in cooling systems equipment in cooling systems’’, 14th U.S / North American Mine Ventilation Symposium.

Stinnette J. D. & De Souza E, (2013),“Establishing Total Airflow Requirements For Underground Metal/Nonmetal Mines With Tier Iv Diesel Equipment”, Mine Ventilation Services

Bandopadhyay S. & Ganguli R., (2004), “Mine Ventilation: Proceedings of the 10th US / North American Mine Ventilation Symposium”, Anchorage, Alaska, USA.

Mopani Copper mines Management Report (2015), Kitwe, Zambia.

Evaluation of Stress Grades for Zambian Pine Timber

Gilson Ngoma[1], Nathan Chilukwa[2] and Katongo Mwansa[3]

Abstract

To adequately design a structure using timber, it is important to know the physical and mechanical properties of the timber. This study was conducted to determine the strength properties for the Pine; one of Zambia's most widely used commercial timber species. Two of the most common species of Zambian Pine were evaluated, viz; *Pinus oocarpa* and *Pinus kesiya*. Strength tests conducted included bending and compression parallel and perpendicular to grains. The tests were conducted in accordance with procedures espoused in ASTM D143 and BS 373 standards. Results of the tests showed the bending strengths of *Pinus oocarpa* averaged about 92.6 MPa while that of *Pinus kesiya* averaged 77.7 MPa. Compression parallel to the grains varied from 49.4 MPa to 77.6 MPa and 39.9 MPa to 50.5 MPa for *Pinus oocarpa* and *Pinus kesiya* respectively while compression perpendicular to the grains varied from 1.4 MPa to 4.0 MPa for *Pinus oocarpa* and 1.2 MPa to 3.6 MPa for *Pinus kesiya*. The modulus of elasticity varied from 7,703.7 MPa to 15, 720 MPa for *Pinus oocarpa* and 7,383.7 MPa to 10,854.4 MPa for *Pinus kesiya*. The two Pine species were also compared in terms of strength. This was done to aid timber selection. It was found from the tests that the mean bending strength of clear *Pinus oocarpa* was higher than that of clear *Pinus kesiya* by almost 19%. The determination of the strength properties of the timbers was done with a view to kick-start the development of a new code of practice for structural use of locally grown timber species in Zambia as the existing standard (ZS 032:1986) has since been withdrawn.

Keywords: Pinus oocarpa, Pinus kesiya, Bending Strength, Compression strength, Classification

1. Introduction

Timber is one of the oldest construction material in Zambia. It has various uses from furniture making to structural use in buildings. Timber is a natural material, therefore, when it is produced at the sawmill in the form of planks, the strength among the pieces of the same size and species varies greatly owing to differences in density of the material, seasoning and the presence, to a greater or lesser extent, of defects such as knots and sloping grain. With this variability in strength, efficient use of timber as a structural material is greatly affected. To specify timber for structural use, timber is graded into classes based on its strength. This process is referred to as

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stress grading. When the stress grading has been done, the timber can then be correctly specified for structural design applications.

The most common timber used for construction in Zambia is the Pine. According to the forestry department, the two most common Pine species in the country are *Pinus kesiya* and *Pinus oocarpa;* mostly plantation grown on the Copperbelt. Other plantation grown species (on a smaller scale) are *Pinus merkusii* and *Pinus michoacana.*

The existing code of practice for structural use of locally grown timber species in Zambia (ZS 032), developed in 1986 has since been withdrawn. In a phone interview, Zambia Bureau of Standards officer Kapaya C. confirmed the withdrawal stating that even though the standard has been withdrawn, it is yet to be replaced/superseded by any other. Therefore, the objective of this study was to determine the strength properties of two of Zambia's Pine species with a view to kick-start the development of a new code of practice to replace the withdrawn code ZS 032: 1986.

1.1. Materials and Test Methods

Materials for this study consisted of the two species of Zambian Pine; Pinus kesiya and Pinus oocarpa. The Pinus kesiya was acquired from a saw mill in the industrial area of Kitwe while the Pinus oocarpa was acquired from Rainlands timber processing company in Kamfinsa area of Kitwe along the Kitwe-Ndola dual carriageway. In total, three 150×50mm cross section by 5m length and two 75×75mm cross section by 5m length timber pieces were acquired for each of the two species, all sawn from different trees. The timbers were selected in such a manner as to accommodate the different rates of growth so as to avoid biased sampling. All the processes from air-drying to planning were conducted at Rainlands Timber Processing Company

The acquired timber was put in a shade and allowed to air dry from about 25% moisture content to approximately 12% moisture content. The seasoning process took between two to three weeks and the moisture content monitoring was done with the aid of a moisture tester. The timber pieces were then roughly cut to sizes slightly larger than the final specimen sizes using saw cutting machines (Plate 1) and then finally planed to the exact various specimen sizes using a planning machine (Plate 2). All pieces were cut bearing in mind the grain direction.

Plate 1: Saw cutting of the timber pieces

Plate 2: Planning of the Timber Pieces

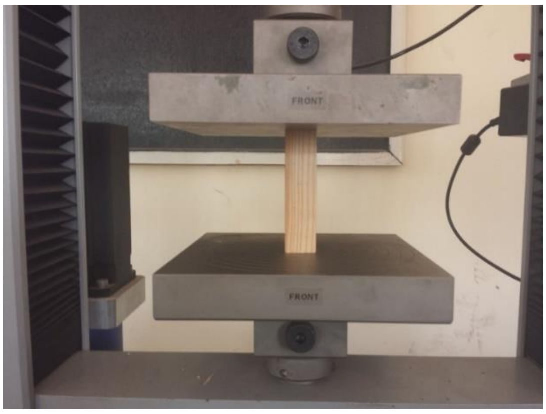
1.1.1. Three Point Bending Test

The three-point bending test was conducted in accordance with BS 337: 1957-Methods of testing small clear specimens of timber. A total of 60 specimens; 30 specimens for each species of timber, with each specimen measuring 20×20×300mm and supported between knife edges with bearing plates and rollers at a loading span length of 280mm, were each subjected to a continuous centre load. The load was applied through a bearing block to the tangential surface of the specimen nearest to the pith at a rate of motion of 1.3mm/min as shown in Plate 3.

Plate 3: Three-Point Bending Test

1.1.2. Compression parallel to grain

The compression parallel to the grains test was conducted in conformity with ASTM D143-Standard methods of testing small clear specimens of timber. In this test, a total of 59 specimens were tested: 29 specimens for Pinus oocarpa and 30 specimens for Pinus kesiya. Specimens measuring 25 x 25 x100mm height were each subjected to a continuous load by a moving platen applied at a rate of 0.6mm/min parallel to the grains of the timber specimen until failure had occurred (Plates 4 & 5).



Plates 4: Loading of specimen

Plate 5: Specimen after failure

1.1.3. Compression perpendicular to the grain

The compression perpendicular to the grains test was conducted on a 50mm cubic specimen as shown in Plate 7. The cross sectional area of load application was in conformity with ASTM D143 as well as BS337. In this test, a total of 20 specimens of each of the two species of pine were tested by applying a continuous load perpendicular to the grain at a rate of 0.305mm/min up until the specimen had undergone a strain of about 0.05 (2.5mm compression).

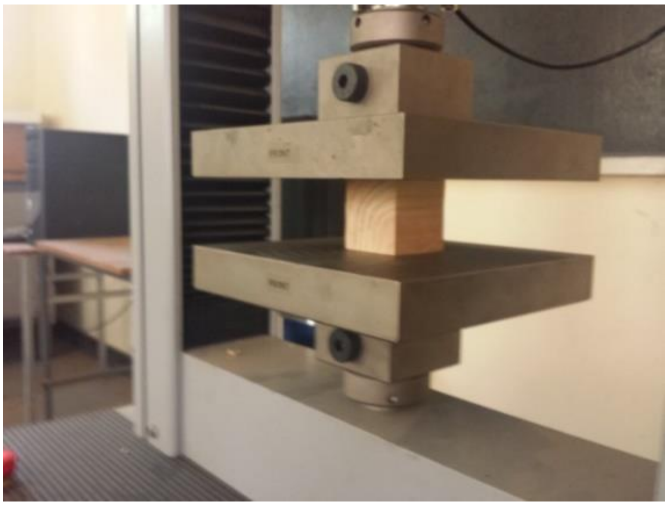


Plate 7: Compression perpendicular to grains

1.1.4. Moisture content test

As the strength of timber depends on the moisture content, the moisture content test was carried out on the specimens immediately after the strength tests so as to determine the approximate moisture contents during the time of the strength testing. Moisture content is determined as the water present in the timber divided by the mass of timber with all the water removed, expressed as a percentage. The withdrawn ZS 032: 1986 recommended that timber to be used for structural purposes should have moisture content of about 15% while that used for doors and windows should have moisture content of about 12%. The British Standard however, recommends a moisture content of about 12% for structural timber, further suggesting adjustments in strength for timber with moisture content varying from 12% but within 10 % to 18%.

To determine the moisture content of each specimen, all loose splinters on the specimen created from the failure of the piece during the time of strength testing were first removed. This was done to avoid the possibility of a reduction in weight of the specimen caused by the breaking away of the loose splinters from the specimen during the time of moisture testing, which would result in wrong results.

Each sample was then weighed on the mass balance to obtain its weight before oven drying (Wt). The samples were then put in an oven and dried to constant weight at a temperature of 105°C for 24hrs and then re-weighed to obtain the oven-dry weight (Wd). The moisture content for each sample was then computed by the use of equation 1: Average moisture contents of the specimen is given in Table 7.

$$MC = \frac{\text{Wt} - \text{Wd}}{\text{Wd}} \times 100 \quad (1)$$

where;

MC =Moisture Content (%)

Wt =Weight before oven drying (g)

Wd =Weight after oven drying (g)

2. Results and Discussion

2.1. Three-Point Bending Strength

Results of the three-point bending test for the first 10 specimens of Pinus oocarpa and Pinus kesiya are shown in Figure 1 and Figure 2, respectively. The results show the peak force against deflection of the specimens. The peak force was used to determine the bending strength of the timber using equation 2. Results of the calculated bending strengths for Pinus oocarpa and Pinus kesiya are given in Tables 1 and 2, respectively.

$$\sigma = \frac{3\text{FL}}{2\text{bd}^2} \quad (2)$$

where;

σ =bending strength (N/mm^2)

F=Force at peak (N)

L=Loading span of specimen (mm)

b=Breadth of specimen cross section (mm)

d=Depth of specimen cross section (mm)

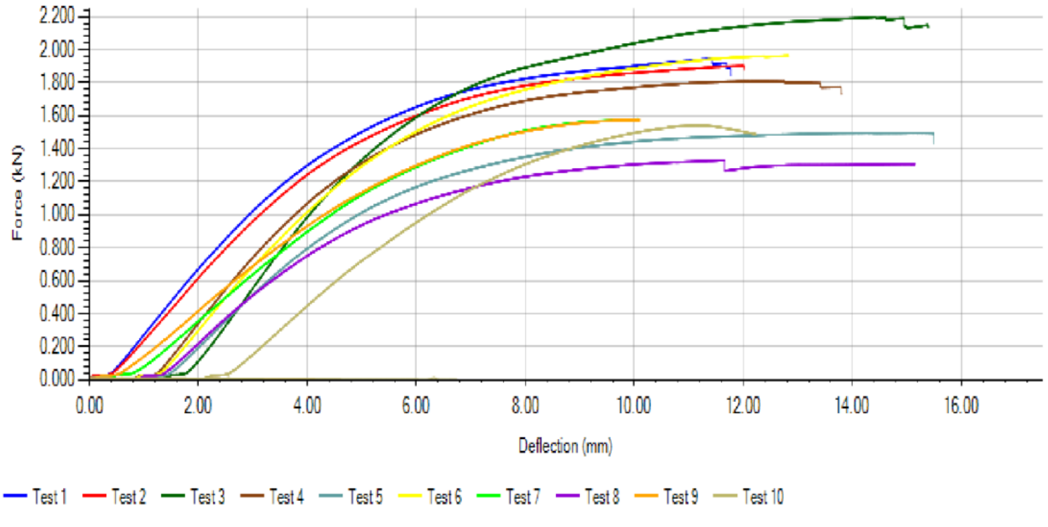


Figure 1: Force vs Deflection results for first 10 specimens of Pinus oocarpa

Figures 1 and 2 show some slip or slight deflection immediately before application of force. This is probably as a result of the first sitting/positioning of the centre load.

The results show that the specimens of Pinus oocarpa tested have average bending strength of 92.6 MPa with a standard deviation of 13.036 while the bending strength of Pinus kesiya was lower than that of Pinus oocarpa averaging 77.7 MPa with a standard deviation of 8.438.

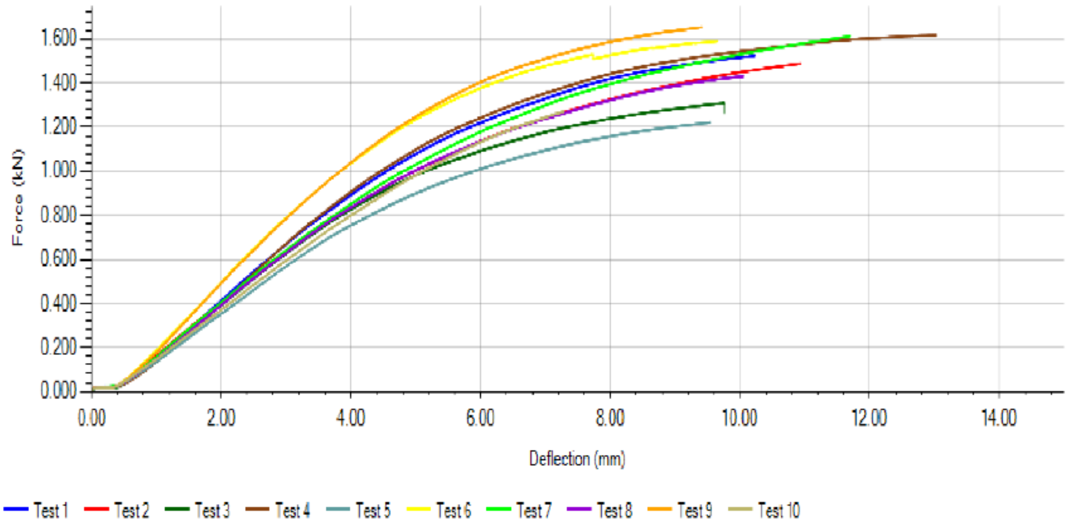


Figure 2: Force vs Deflection results for first 10 specimens of Pinus kesiya

Table 1: Bending Strengths of Pinus oocarpa

Specimen No	Peak force (N)	Bending strength (N/mm^2)	Specimen No	Peak force (N)	Bending strength (N/mm^2)
1	1,946.00	102.165	16	1405	73.763
2	1,903.00	99.908	17	1912	100.38
3	2,198.00	115.395	18	1727	90.668
4	1,811.00	95.077	19	1432	75.18
5	1,496.00	78.54	20	1444	75.81
6	1,965.00	103.163	21	1751	91.928
7	1,581.00	83.002	22	1625	85.313
8	1,331.00	69.877	23	2023	106.208
9	1,575.00	82.688	24	1954	102.585
10	1,544.00	81.06	25	2073	108.833
11	1,463.00	76.808	26	1749	91.823
12	2,193.00	115.133	27	1789	93.923
13	1,698.00	89.145	28	2111	110.828
14	1,843.00	96.758	29	2038	106.995
15	1,521.00	79.853	30	1827	95.918
Results Mean		92.624			
Standard deviation		13.036			
C of V		14.074			

Table 2: Bending Strengths of Pinus kesiya

Specimen No	Peak force (N)	Bending strength (N/mm^2)	Specimen No	Peak force (N)	Bending strength (N/mm^2)
1	1,606.00	84.315	16	1,591.00	83.528
2	1,398.00	73.395	17	1,614.00	84.735
3	1,271.00	66.728	18	1,433.00	75.233
4	1,704.00	89.46	19	1,657.00	86.993
5	1,525.00	80.063	20	1,272.00	66.78
6	1,620.00	85.05	21	1,507.00	79.117
7	1,380.00	72.45	22	1,340.00	70.35
8	1,253.00	65.783	23	1,592.00	83.58

Specimen No	Peak force (N)	Bending strength (N/mm²)	Specimen No	Peak force (N)	Bending strength (N/mm²)
9	1,454.00	76.335	24	1,412.00	74.13
10	1,276.00	66.99	25	1,668.00	87.57
11	1,526.00	80.115	26	1,665.00	87.412
12	1,491.00	78.278	27	1,409.00	73.973
13	1,312.00	68.88	28	1,472.00	77.28
14	1,618.00	84.945	29	1,271.00	66.728
15	1,222.00	64.155	30	1,838.00	96.495
Results Mean		77.695			
Standard deviation		8.438			
C of V		10.86			

2.2. Modulus of Elasticity analysis

The modulus of elasticity for each specimen under three-point bending was calculated using equation 3.

$$E = \alpha k \qquad (3)$$

where $\boldsymbol{\alpha}$ is a geometric parameter equal to; $\frac{L^3}{4bd^3}$

L=Loading span of specimen
b=Breadth of specimen cross section
d=Depth of specimen cross section
k=Slope of the elastic portion of the Force-Deflection graph

A summary of the results of the Modulus of Elasticity for Pinus oocarpa and Pinus kesiya is given in Tables 3 and 4 respectively.

Table 3: Summary of Modulus of Elasticity of Pinus oocarpa

Property	Minimum	Maximum	Standard deviation	Mean	Coefficient of variation
Bending strength (N/mm²)	69.877	115.395	13.036	92.624	14.074
Modulus of Elasticity (N/mm²)	7,703.739	15,719.796	2,125.182	11,965.479	17.761

Table 3: Summary of Modulus of Elasticity of Pinus kesiya

Property	Minimum	Maximum	Standard deviation	Mean	Coefficient of variation
Bending strength (N/mm²)	64.155	96.495	8.438	77.695	10.860
Modulus of Elasticity (N/mm²)	7,383.771	10,854.352	1,031.246	8,910.296	11.574

The modulus of elasticity is a measure of a material's resistance to being deformed elastically when a force is applied to it. The results of the tests conducted show that Pinus oocarpa has an average modulus of elasticity of just over 11,900 MPa while that of Pinus kesiya averaged around 8,900 MPa. The average modulus of elasticity of Pinus kesiya is comparable with what was specified in ZS 032:1986 which is 9 250 MPa.

2.3. Compression Parallel to grain strength

This test was done to measure the timbers' strength parallel to the grains. The compressive strength was obtained by peak force by the cross sectional area of the timber piece as indicated in equation 4. Results of the test and calculated compressive strengths for Pinus oocarpa and Pinus kesiya are given in Tables 4 and 5.

$$\sigma_{//} = \frac{F}{A} \tag{4}$$

Where;

$\sigma_{//}$ = Compressive strength parallel to grain(N/mm^2)

F =Force at peak (N)

A=Cross sectional area of specimen (mm^2)

Table 4: Compressive strength parallel to the grains for Pinus oocarpa

Specimen No	Force at peak (N)	Area (mm^2)	Stress at peak (N/mm^2)	Specimen No	Force at peak (N)	Area (mm^2)	Stress at peak (N/mm^2)
1	41,710.00	625	66.736	16	39,400.00	625	63.04
2	39,310.00	625	62.896	17	44,880.00	625	71.808
3	40,310.00	625	64.496	18	40,750.00	625	65.2
4	39,380.00	625	63.008	19	30,880.00	625	49.408
5	40,230.00	625	64.368	20	39,980.00	625	63.968
6	39,710.00	625	63.536	21	44,790.00	625	71.664
7	38,870.00	625	62.192	22	48,260.00	625	77.216
8	40,140.00	625	64.224	23	41,580.00	625	66.528
9	37,490.00	625	59.984	24	39,410.00	625	63.056
10	40,770.00	625	65.232	25	41,690.00	625	66.704
11	35,620.00	625	56.992	26	44,870.00	625	71.792
12	37,720.00	625	60.352	27	37,400.00	625	59.84
13	38,710.00	625	61.936	28	48,530.00	625	77.648
14	47,490.00	625	75.984	29	38,610.00	625	61.776
15	40,470.00	625	64.752				
Minimum		49.408					
Mean		65.046					
Maximum		77.648					
Standard deviation		5.988					
Coefficient of Variation		9.205					

Table 4: Compressive strength parallel to the grains for Pinus kesiya

Specimen No	Force at peak (N)	Area (mm^2)	Stress at peak (N/mm^2)	Specimen No	Force at peak (N)	Area (mm^2)	Stress at peak (N/mm^2)
1	27,490.00	625	43.984	16	27,000.00	625	43.2
2	26,100.00	625	41.76	17	26,730.00	625	42.768
3	25,200.00	625	40.32	18	31,400.00	625	50.24
4	26,770.00	625	42.832	19	28,620.00	625	45.792
5	26,670.00	625	42.672	20	29,790.00	625	47.664
6	25,360.00	625	40.576	21	31,000.00	625	49.6
7	26,480.00	625	42.368	22	27,780.00	625	44.448
8	27,300.00	625	43.68	23	25,220.00	625	40.352
9	27,820.00	625	44.512	24	27,250.00	625	43.6
10	31,130.00	625	49.808	25	26,250.00	625	42
11	28,740.00	625	45.984	26	30,280.00	625	48.448
12	24,950.00	625	39.92	27	31,570.00	625	50.512
13	29,680.00	625	47.488	28	31,160.00	625	49.856
14	25,610.00	625	40.976	29	30,390.00	625	48.624
15	27,770.00	625	44.432	30	26,700.00	625	42.72
Minimum		39.920					
Mean		44.705					
Maximum		50.512					
Standard deviation		3.341					
Coefficient of Variation		7.473					

The results show that the compressive strength parallel to the grains of Pinus oocarpa ranged from 49.4 to 77.6 MPa with an average of 65 MPa. For Pinus kesiya, the compressive strength parallel to the grains averaged, 44.7 MPa.

2.4. Compression Perpendicular to grain strength

The compression perpendicular to grain test was carried out to determine the compression perpendicular to grain strengths for the small specimens of timber. The compressive stresses were determined as the stresses at the limit of proportionality (L.O.P) as there was no clearly defined ultimate stress for this property as can be seen in Figure 3. The compression strengths (at L.O.P) for the specimens were deduced from equation 5.

$$\sigma_{\perp} = \frac{F}{A} \tag{5}$$

where;

$\sigma_{\perp}$ = Compressive strength perpendicular to grain (at L.O.P) in N/mm^2
F = Force at L.O.P
A = Cross sectional area of specimen (mm^2)

The results show that the compression perpendicular to the grains of Pinus kesiya ranged from 1.2 MPa to about 3.6 MPa with an average of about 2.6 MPa. This is comparable with what was specified for select grade Pinus kesiya in ZS 032: 1986. The results also showed that the compression perpendicular to the grains of Pinus oocarpa was comparable to that of Pinus kesiya.

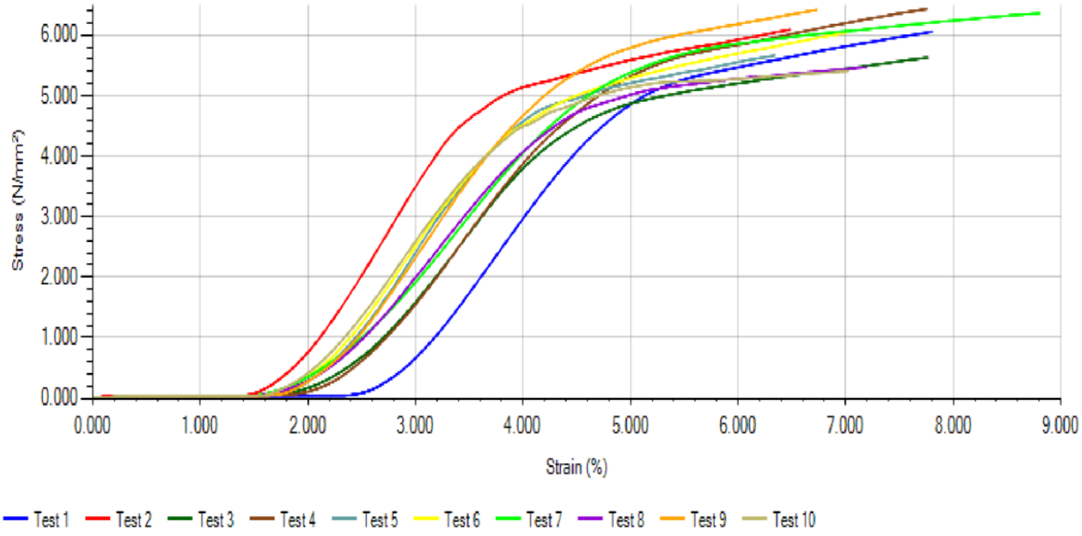


Figure 3: Stress vs Strain for Pinus oocarpa

Table 5: Compression of Pinus oocarpa

Specimen No	Force at L.O.P (N)	Area (mm^2)	Stress at L.O.P
1	8,470.00	2,500	3.388
2	10,024.00	2,500	4.01
3	3,500.00	2,500	1.4
4	9,402.00	2,500	3.761
5	8,345.00	2,500	3.338
6	7,898.00	2,500	3.159
7	4,263.00	2,500	1.705
8	8,933.00	2,500	3.573
9	5,261.00	2,500	2.104
10	3,783.00	2,500	1.513
11	7,770.00	2,500	3.108
12	4,434.00	2,500	1.774
13	4,080.00	2,500	1.632
14	8,095.00	2,500	3.238
15	8,744.00	2,500	3.498
16	8,847.00	2,500	3.539
17	4,002.00	2,500	1.601
18	8,126.00	2,500	3.25
19	6,872.00	2,500	2.749
20	7,412.00	2,500	2.965
Mean	2.765		
Standard deviation	0.872		
C of V	31.517		

Table 6: Compression of Pinus kesiya

Specimen No	Force at L.O.P (N)	Area (mm^2)	Stress at L.O.P
1	8,379.00	2,500	3.352
2	8,389.00	2,500	3.356
3	5,694.00	2,500	2.278
4	8,877.00	2,500	3.551
5	7,887.00	2,500	3.155
6	8,969.00	2,500	3.588
7	6,938.00	2,500	2.775
8	5,401.00	2,500	2.16
9	7,764.00	2,500	3.106
10	2,909.00	2,500	1.164
11	8,173.00	2,500	3.269
12	3,479.00	2,500	1.392
13	8,708.00	2,500	3.483
14	7,848.00	2,500	3.139
15	3,968.00	2,500	1.587
16	3,228.00	2,500	1.291
17	7,967.00	2,500	3.187
18	3,426.00	2,500	1.37
19	7,551.00	2,500	3.02
20	3,434.00	2,500	1.374
Mean	2.58		
Standard deviation	0.895		
C of V	34.689		

2.5. Mean Strength Adjustment

Moisture content affects the strength of timber. According to BS EN 384: 2004 timber should normally be strength tested at approximately 12% moisture content, the equilibrium moisture content (EMC) for most timbers i.e. the moisture content at which the timber is neither gaining nor losing moisture to the surroundings.

The moisture content test was carried out on all the samples of timber immediately after the strength test so as to determine the moisture content at time of strength testing. The moisture content was determined using equation 1.

Table 7: Adjustment of mean strength values depending on moisture content

Strength Property	Mean moisture content for sample (%)	Mean strength before adjustment (N/mm^2)	Mean strength after adjustment (N/mm^2)
Bending strength: Pinus oocarpa	12.1	92.624	92.624
Bending strength: Pinus kesiya	10.6	77.695	77.695
Compression parallel: Pinus oocarpa	10.5	65.046	62.148
Compression parallel: Pinus kesiya	10.1	44.705	42.193
Compression perpendicular: Pinus oocarpa	12.2	2.765	2.765
Compression perpendicular: Pinus kesiya	12.0	2.580	2.580
Modulus of elasticity: Pinus oocarpa	12.1	11,965.479	11,965.479
Modulus of elasticity: Pinus kesiya	10.6	8,910.296	8,662.233

Strength property value adjustments were done on samples whose mean moisture contents had deviated by more than 1% from the standard 12% moisture content value but occurring within the range 10-18%. These adjustments were made according to BS EN 384-2004. According to this standard;

- For bending: no adjustment.
- For compression parallel to grain strength: 3% change for every percentage point difference in moisture content.
- For modulus of elasticity: 2% change for every percentage point difference in moisture content.

The adjustments were carried out in such a manner that the property values increased if the data was adjusted from higher moisture content, and vice versa. Table 7 shows the adjusted mean strength values.

2.6. Mean Strength Comparison

Small clear specimens of two species of Zambian pine; i.e. Pinus kesiya and Pinus oocarpa were tested for their bending strength, compressive strength parallel to the grain as well as compressive strength perpendicular to the grain. The results are summarized in Figure 4.

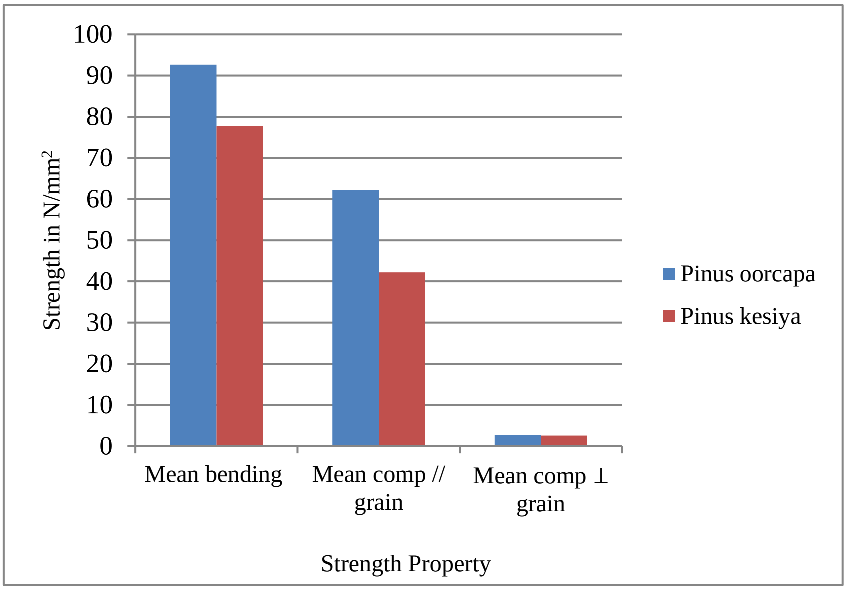


Figure 4: Mean strength values for the two Pine timber species.

The results show that Pinus oocarpa generally has higher strength properties than Pinus kesiya. The mean bending strength for Pinus oocarpa was about 19% higher than that of Pinus kesiya whilst the compression parallel was about 47% higher. The compression perpendicular to the grains (at the L.O.P) for Pinus oocarpa was approximately 7% higher than that of Pinus kesiya.

3. Conclusion and recommendations

It was determined from the results of the study that strength of timber along the grains is far greater than perpendicular to the grains. This is consistent with the findings of Adeyemi *et al*. (2016) who reviewed mechanical properties of eight different timber species. It was also noted that the results obtained are relatively high when compared to those found in timber structural design standards and codes of practice such as BS EN 338 and ZS 032. This can be attributed to the fact that the characteristic values of timbers in timber standards are either based on structural sized timbers or small specimens that have undergone further downgrading. The downgrading can be as a result of application of size effect adjustments as well as effects brought about as a result of the presence of strength reducing characteristics such as timber defects by visual grading. From literature, small clear specimens generally exhibit higher strength properties as compared to structural sized timber. One study conducted by Zziwa (2009), suggested that the bending strength of structural sized timber could be estimated at 20% of the bending strength of small clear specimens. On the other hand, the modulus of elasticity, which is also an important property in the grading of timber, was found to be lower in clear specimens when compared to structural sized specimens. This again is supported by literature. Studies by Wahab *et al*. (2013) as well as Isopescu *et al*. (2012) both found that the modulus of elasticity of small specimens is lower compared to that of structural size timber, in the latter case, a difference of about 300 MPa. However, the difference is less significant when compared with the difference that the bending strength exhibits.

The Zambian standard code of practice for structural use of locally grown timber, ZS 032: 1986 has been withdrawn. Therefore, until a new code is developed, designers will have to rely on foreign codes such as the British standards for design. Therefore, the two timber pine species; Pinus oocarpa and Pinus kesiya were assigned strength classes according to the BS EN 338: 2003. The code (BS) suggests that a timber can be assigned to a particular strength class provided the mean Modulus of Elasticity of that timber is equal to or 95% of the mean MOE value in that class.

Table 8: Characteristic strength properties for C18 and C30 timber

Strength class	Bending strength (N/mm^2)	Tension parallel to grain (N/mm^2)	Tension perpendicular to grain (N/mm^2)	Compression parallel to grain (N/mm^2)	Compression perpendicular to grain (N/mm^2)	Shear parallel to grain (N/mm^2)	Mean modulus of elasticity (kN/mm^2)
C18	18	11	0.5	18	2.2	2.0	9
C30	30	18	0.6	23	2.7	3.0	12

Thus, it was found that Pinus oocarpa with a mean MOE value of 11,965.5 N/mm^2 can be classified as a C30 timber while Pinus kesiya with a mean MOE value of 8,662.2 N/mm^2 can be classified as a C18 timber. According to the standard, the characteristic strength values under the strength classes (Table 8) can be used for design purposes.

Whilst it makes it convenient for design purposes to group structural timber in assigned strength classes, the characteristic strengths in those classes should be as representative of the timber species as possible. Therefore, the assignment of the two timber species to the British code should be viewed as a short-term solution and more experimentation on locally grown plantation timber species should be conducted in order to develop a new code of practice for the country.

Acknowledgements

Rainlands Timber Processing Company

References

Adeyemi F.O., Jimoh A.A., and Wilson U.N., (2016) "A review of Mechanical Strength properties of some selected Timbers in Nigeria" *The International Journal of Science and Technoledge*

ASTM D 143 -94, (2000). "Standard Test Methods for Small Clear Specimens of Timber". *ASTM International*

B.S. 373 (1957). "Method of testing small clear specimens of timber". *British Standards Institution, London*

B.S. EN 338, (2003). "Structural Timber: Strength Classes". *European Committee for Standardisation, CEN, 2003, Brussels, Belgium.*

Isopescu, D., Stanila O., and Astanei I., (2012) "Analysis of wood bending properties on standardized samples and structural size beams tests", *"Gheorghe Asachi" Technical University of Iaşi.*

Wahab M., Jumaat M., Khaidzir O., (2013) “Strength assessment of Malaysian Timbers in Structural Size”. *Proceedings of the International Civil and Infrastructure Conference*

ZS 032, (1986) “Zambian Standard of Practice for Structural use of locally grown Timber”, *Zambia Bureau of Standards*

Zziwa A., (2009) “Strength Characterisation of Timbers for Building Construction in Uganda”. *Dissertation for Doctor of Philosophy, Makerere University.*

Evaluation of the Zambia Air Traffic Management Radar (ZATM-Radar) project

Daniel Chileshe Musantu[1]

Abstract

Over the last decade, the world at large has experienced growth of air traffic. And this has resulted into operational and procedural complexities and negative environmental effects. Our Zambian air space has experienced growth of air traffic which has resulted in operational challenges. This traffic increase has resulted in rise of air traffic incidents which are indicators of possible future accidents. Zambia Air ports Corporation Limited (ZACL) under air navigation services commercial section has projected a rapid increase in traffic levels. And this increase requires an advanced Air Traffic Management (ATM) system. In the past Zambian air traffic controllers have used procedural type of controlling where they rely on voice communication with the pilots. This procedure compromises air traffic safety in an environment with high traffic levels. It is for this reason the ZACL Communication Navigation and Surveillance (CNS) engineers and air traffic controllers recommended installation of ATM Surveillance System. The completion of the Zambia Air Traffic Management Radar (ZATM) project has enhanced safety, security and efficiency in the Zambian air space. This paper will discuss the performance and benefits of the ATM surveillance radar systems in Zambia. The following performance key indicators will be considered: Safety, Security, Efficiency, Capacity and Environmental effects.

Keywords*:* ATM, Radar, Safety, Efficiency, and Air Traffic.

1. Introduction

Air transport today plays a major role in driving sustainable economic and social development. It directly and indirectly supports the employment of 56.6 million people, contributes over $2.2 trillion to global Gross Domestic Product (GDP), and carries over 2.9 billion passengers and $5.3 trillion worth of cargo annually. But even as air transport's speed and efficiency significantly facilitate economic progress, its growth under certain circumstances can be a double-edged sword. Though a sure sign of increased living standards, social mobility and generalized prosperity on the one hand, unmanaged air traffic growth can also lead to increased safety risks in those circumstances when it outpaces the regulatory and infrastructure developments needed to support it. (International Civil Aviation

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Organization, 2013). This increase of air traffic and its effects has affected the Southern African region including Zambia.

1.1 Zambian Air Space Traffic Growth

In recent past air traffic trend has shown a steady increase of traffic levels in the Zambian air space. This increase requires a more effective and reliable Air Traffic management (ATM) system to enhance safety, efficiency and environmental protection. Table 1 shows recent past air craft movement in the Zambian air space (ZACL, n.d.).

Table 1: Air Craft movements *(ZACL, n.d.)*

PERIOD	ACTUAL MOVEMENTS	PLANNED MOVEMENTS	VARIANCE	% GROWTH OR
YEAR		**(PROJECTED)**		**REDUCTION**
2011 - 2012	77,707	116,284	(38,577)	(33.2)
2012 - 2013	79,915	119,242	(39,327)	(33.0)
2013 - 2014	81,770	121,536	(39,766)	(32.7)
2014 - 2015	86,052	124,288	(38,236)	(30.8)
2015 - 2016	77,792	129,470	(51,678)	(39.9)
TOTAL	**403,236**	**610,820**	**(207,584)**	**(34.0)**

Zambia Airports Corporation Limited (ZACL) has projected growth in air traffic movement in Zambia. Table 2 shows the air traffic projections, indicating an increase of about 4% per annum at Kenneth Kaunda International Airport (Anon., 2009 September).

Table 2: Historical and High Case Forecast Aircraft Operations Lusaka International Airport (Anon., 2009 September)

Year	Passenger		Other	Total
	Internat-ional	Domest-ic		
Historical				
2007	11,164	12,106	12,985	36,255
2008	11,284	17,323	16,648	45,255
Forecast				
2009	9,700	12,000	17,300	39,000
2010	10,000	12,800	18,000	40,800
2011	10,600	13,600	18,800	43,000
2012	11,300	14,400	19,500	45,200
2015	13,100	16,600	22,000	51,700
2020	17,100	20,500	26,800	64,400
2030	26,700	28,500	39,600	94,800
CAGR	Average annual growth			
2009-2020	5.3%	5.0%	4.1%	4.7%
2020-2030	4.6	3.3	4.0	3.9
2009-2030	4.9	4.2	4.0	4.3

An increase in air traffic movement translates into increased number of air traffic incidents.

1.1.1 Air Traffic Incidents

ZACL Air Traffic Standards Office has recorded an increase is the number of incidents mainly attributed to increased air traffic movement (Anon., 2016). Figure 1 shows the graphical analysis of air traffic incidents over a period of 5 years. The analysis showed that the increase in traffic movements is direct proportional to the number of air traffic incidents.

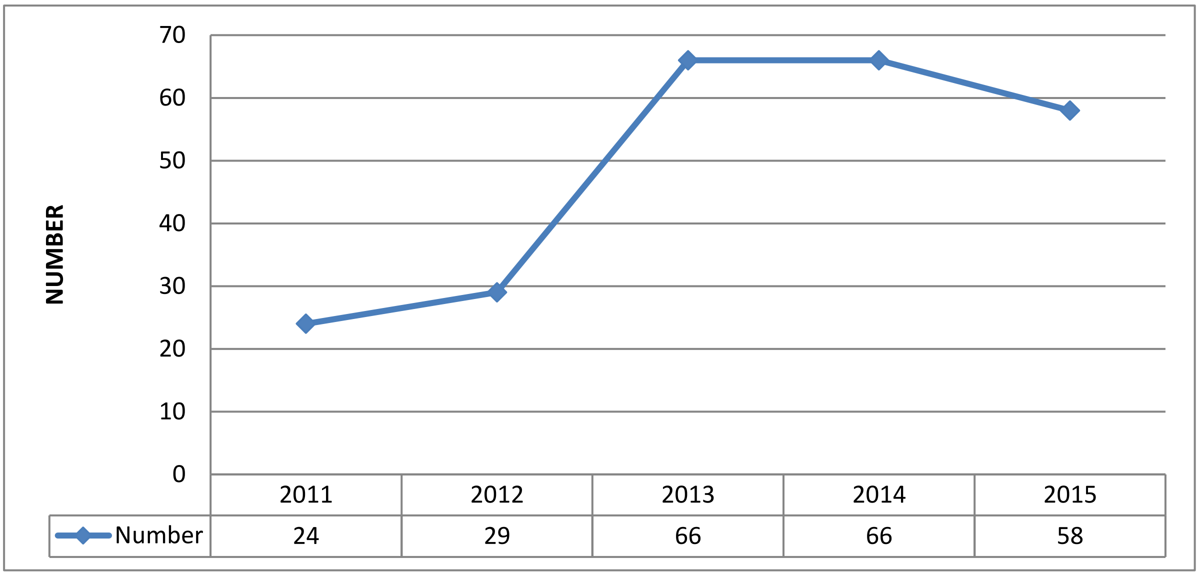

Figure 1 ZACL Air Traffic Incidents Analysis Graph

To ensure safety, efficiency, security, environmental protection and increase capacity an advanced ATM system was required. In the past air traffic controllers have used a conventional (procedural) way in managing approaching and departing air traffic. In this system air traffic controllers depend on voice communication to manage fast moving air traffic. This type of air traffic management became stressful and challenging for air traffic controllers in an air space with high traffic levels.

It is for this reason ZACL in conjunction with the Government of the Republic of Zambia embarked on the project of installing two ATM Surveillance Radars. The contract to supply, deliver and install the two radar systems was awarded to Thales Air Systems of France. The two installations ran in parallel at Kenneth Kaunda International Airport (KKIA) in Lusaka and Harry Mwanga Nkumbula International Airport (HMNIA) in Livingstone. The decision to install the two radar systems at KKIA and HMNIA was based on the high traffic movements at the two airports as compared to other airports in the country (NACL, October 2009). The two systems were simultaneously commissioned in December 2016.The project was intended to benefit both the local and international aviation community flying into and through the Lusaka Information Region (IFR) through the provision of RADAR controlled air traffic environment.

In order to appreciate and understand the functions of the radar system we will discuss briefly its technical composition.

Air Traffic Management Radar Technical Operation

The Radar is used for surveillance and monitoring of air traffic within its coverage. It enhances the safety of the air traffic within its coverage.

The Radar comprises of the Secondary and Primary systems which are collocated, meaning the two using a single antenna system for transmissions. Figure 2 shows the combination of the secondary and primary systems.

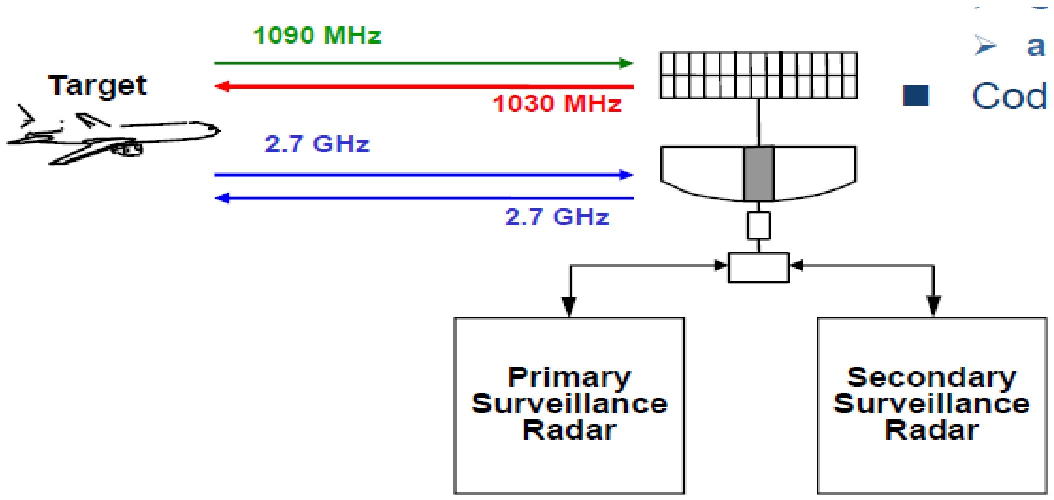

Figure 2: Primary and Secondary Surveillance Radar collocated.

1.1.2 STAR2000S-Band Primary Surveillance Radar (PSR)

Star 2000S is the type of the primary surveillance radar. This is the type of radar that uses the reflection (Echo) principle of operation as shown in figure 3. In the primary system the radar does not require an intelligent reply from a target or obstacle but just a reflected signal. It is from the reflected signal the radar is able compute the speed, direction, altitude and direction of a target. The PSR is able to pick all air crafts including those without transponders on board. And this enables air traffic controllers to detect and be aware of all aircrafts under their control. This feature enhances security by detecting unpermitted aircraft in a particular airspace.

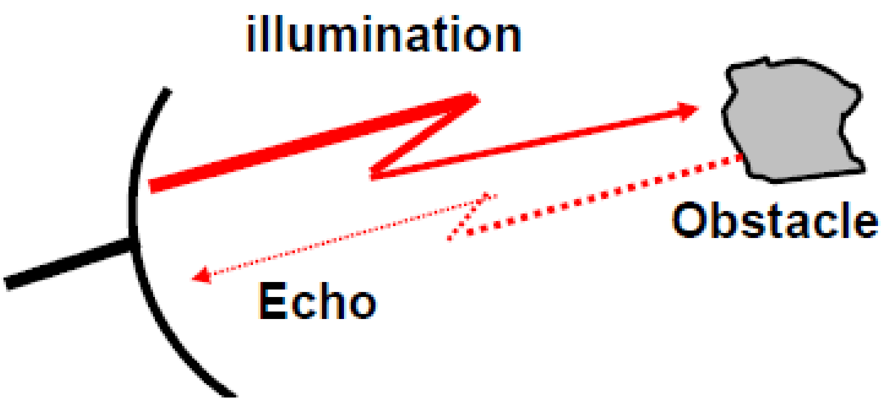

Figure 3: Primary Radar Reflection Principle of Operation

The PSR radiates a total maximum power of 16 Kilo watts (Thales, n.d.). This output power enables the primary radar to have coverage of 80 NM or 144 kilometers in radius. The PSR is incorporated with the dual weather channel used mainly to observe cloud covers and storms. This helps air traffic controllers to provide current weather conditions to pilots.

1.1.3 RSM970S Mode S Monopulse Secondary Surveillance Radar (MSSR)

The RSM970S Mode S is the type of the secondary surveillance radar used in the ZATM project. Figure: 4 shows the basic principle of operation of the secondary radar. The Secondary radar is quite complex than the primary radar it relies on a transponder from the aircraft after interrogation. It provides the following information call sign of aircraft, speed, direction, flight level, ident and type of aircraft. The coverage is a radius of 250 NM or 450 kilometers hence ensuring wide airspace coverage.

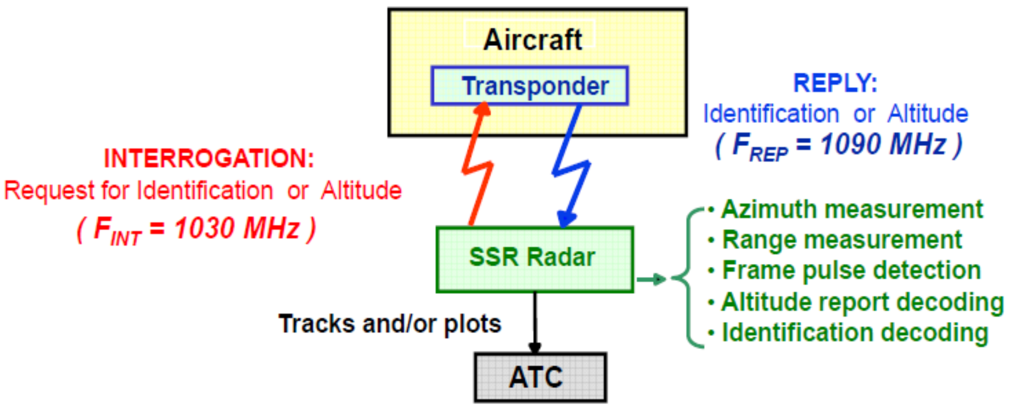

Figure 4: Secondary radar principle of operation (Thales Aviation Systems, 2014)

Figure 5 shows the Lusaka radar coverage area for both secondary and primary. The inner dotted circle shows the primary radar coverage and the outer shows the secondary radar coverage.

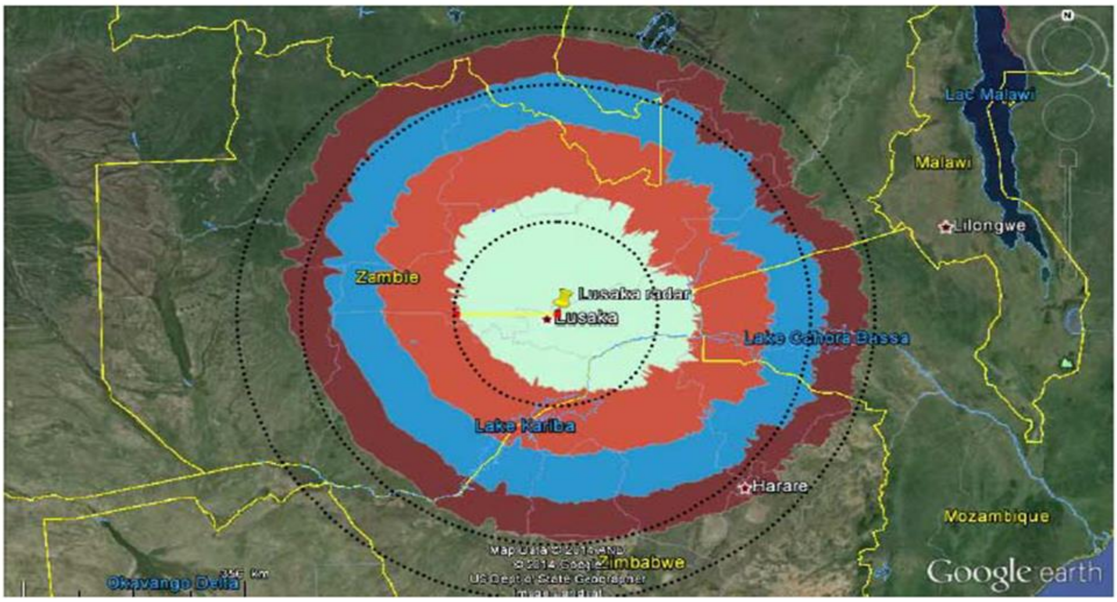

Figure 5: Lusaka Primary and Secondary radar coverage (Thales Aviation Systems, 2014)

The targets of the two radar systems are monitored by air traffic controllers on the system called TopSky.

1.1.4 Thales Topsky-ATC Display System

Topsky-ATC is the latest technology used in ATM to display the information from the radar head. It has point-to-point links with radar stations. Depending on the radar sensor type, the types of data able to be received and processed are plots, tracks, weather data and radar status. Optionally, Raw Radar Data may also be received and displayed in addition to the above. Figure 6 shows a live screen shot of Thales Topsky display on the controller work position.

Figure 6: Top-Sky display screen shot

The use of the visual display by air traffic controllers enhances efficiency. Since air traffic controllers are able to see traffic in the air space under their control, air traffic management is improved. And operational most errors are eliminated hence air safety enhancement.

Upon discussing the technical composition and operation of the ATM radar system we can now discuss the key performance indicators.

Key performance indicator analysis

In order to evaluate the performance of the ZATM radar project the key performance indicators are to be analyzed. These key performance indicators are safety, efficiency, capacity and environmental effects.

1.2 Safety

Under procedural control an air traffic controller is highly dependent on the information given by the pilot via radio communication. This information includes the speed, direction, altitude and position of aircraft. And the controller has to make critical decisions in a very short period of time based on this radio communicated information. This means controllers have to strain their mental abilities in figuring out the position and direction of calling aircrafts. And this results in a lot of mental stress and fatigue especially at peak hours. Hence compromising on the required aviation safety and operating standards. In the radar environment there is more situation awareness because controllers are able to see the traffic on the screen. They are able to see direction, position, type and speed of the calling aircraft. This enables controllers to manage traffic and make decisions easily. Controllers at both KKIA and HMNIA have confirmed the reduction in stress and fatigue under the radar environment. A study is in progress to evaluate the reduction of the actual air traffic incidents from the time of ATM radar implementation.

By the use of the weather channel, controllers are able to advise pilots of potentially dangerous weather changes, such as storms. This feature has definitely reduced weather related incidents as noted by air traffic controllers.

1.3 Capacity

In procedural air traffic management the longitudinal separation is 20 nautical miles (ICAO, 2015) as compared to radar procedures which is 5nautical miles. Figure 7 shows the comparison of longitudinal separation distances between procedural and radar procedures.

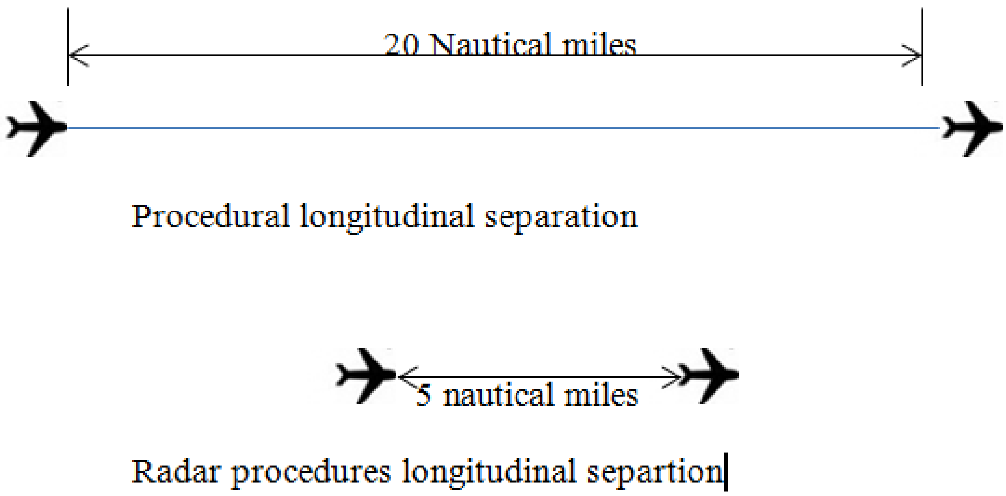

Figure 7: Radar procedures separation vs procedural separation

Because of longer separation in procedural air traffic control the lading rate is 7 aircrafts per hour, in comparison to radar procedures where the landing rate is about 14 aircrafts per hour. The controllers are now able to land more air crafts within a short period hence possibilities of handling high volume of projected air traffic in Zambia.

1.4 Efficiency

With procedural air traffic managements air crafts are held for longer periods because of procedures involved. Aircrafts take longer periods from the reporting point to the time they touch down. As for radar procedures the holding time is reduced tremendously which results in high efficiency for both the airline operators and air traffic controllers. Since controllers are using visual (Radar) coupled with radio communication they are more effective in their job execution. As table 3 shows controller spend less time to land aircrafts in comparison to procedural control. This has resulted in a lot of efficiency by the air traffic controllers.

Table 3: Radar Vs Procedural Air Traffic Control

KKIA Approach Air Traffic Control Centre (Date: 03/03/2017)

Type of Aircraft	Reporting point (EST VLS)	Procedural Approach Estimated Arrival Time	Radar Approach Actual Arrival Time	Time Gained
Jetstream 32	08:10 UTC	08:18 UTC	08:13 UTC	5 Min
Embraer 135	06:31 UTC	06:39 UTC	06:34 UTC	5 Min
Jetstream 41	07:43 UTC	07:51 UTC	07:50 UTC	1 Min

1.5 Environmental

There is high fuel consumption for air traffic in a procedural environment because of longer holding periods. This results into high CO_2 emissions causing damage to the environment like global warming. So introduction of the two ATM radar systems in the Zambian air space will improve the negative effects caused by air traffic emissions.

1.6 Security

The two ATM radars will greatly contribute to the security of the Zambian air space in terms of detecting unpermitted air crafts. Controllers will have the ability to see all air crafts and upon seeing any suspicious air craft they will be able to notify the national security wing.

1.7 Search and Rescue operations

In case of the missing aircraft search and rescue operations becomes very difficult under procedural control. But with the introduction of radar it will be easy for the search and rescue team to find the location of missing aircrafts. This is because controllers are able to see the actual coordinates or the position of the aircraft on the screen.

The above key indicators show the major improvements that the ATM Radars have brought to the air traffic management in Zambia.

Conclusion

The purpose of this paper was to evaluate and review the impact of the installation of the two ATM radar systems on the Zambian Air Space. Based on the equipment performance and air traffic controllers' feedback, the ATM radar system has enhanced the air traffic management in Zambia. Table 4 shows the summary of the key performance indicators of the ZATM radar project.

Table 4: ZATM Radar Project Evaluation Table

Type of Control	Key Performance indicators				
	Safety	**Efficiency**	**Capacity**	**Environmental Negative Effects**	**Security**
Procedural	Compromised during high traffic levels	Reduced	Low due to big vertical and longitudinal separations	High due to long holding periods causing a lot of CO_2 emissions	Low
Radar	Increased due to increased controller's situation awareness	Increased	Increased due to less vertical and longitudinal separations	Reduced due to short holding periods	High

Surveillance radar installation in Zambia has directly contributed to the enhancement of air space safety, capacity, security, efficiency and environmental protection. Based on this evaluation and research there is need to cover the entire Zambian air space with radar surveillance, with the view of considering Automatic Direction Surveillance Broadcast (ADS-B) technology. This is the latest surveillance system which can be interfaced with the two Zambian ATM radar systems in order to increase radar coverage country wide. Lastly the high safety levels caused by the ZATM radar project will attract a lot of airlines to the Zambian air space hence improving the national economy.

References

Technical Manuals

International Civil Aviation Organization, 2013. Global Air Navigation Plan. p. Executive summary.

Africa, I. E. a. S., 2012. *PBN/GNSS.* Nairobi, ICAO.

Anon., 2009 September. *Historical and High case Forecast Aircraft Operations-Lusaka Inter Airport,* Lusaka: Jacobs Consultancy.

Anon., 2016. *ATC Occurences Analysis,* Lusaka: Zambia Airports Corportation Limited, Air Traffic Services.

Civil Air Navigation Services organisation, 2015. Performance Based Navigation.

IATA, n.d. *Introduction To PBN.* s.l., s.n.

ICAO, 2011. *ICAO Fuel Saving Estimaton Tool User Guide.*

ICAO, 2015. Manual of Air Traffic Services. In: *Manual of Air Traffic Services part 1.* s.l.:ICAO, p. 101.

NACL, October 2009. *Forecast of Passenger and Air Cargo Demend,* Lusaka: Jacobs consultancy.

Thales Aviation Systems, 2014. *Radar Fundamentals volume 3.* s.l.:Thales.

Thales, n.d. STT2000A. In: *Thales Technical Manual.* s.l.:Thales, p. 25.

ZACL, n.d. Lusaka: Zambia Airports Corporation limited, Air Navigation Services Commercial Section.

Zambia Airport Corporation Limited, 2015. *Annual Reports,* Lusaka: Commercial office.

Feasibility studies on the implementation of bioleaching technology in Zambia Mining Industry: Case study of Konkola Copper Mines plc (KCM), Kalumbila Mineral Limited and Kansanshi Copper Mines.

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Abstract

Bioleaching is a process that involves living micro-organisms to extract valuable metals from low grade sulphide ores. Bioleaching is an emerging technology with significant potential to add value to the mining industry so as to deliver attractive environmental and economic benefits. This technology processes low grade ores in the range of 0.5-2% total copper. From literature, low grade secondary copper sulphide ores are easily processed using this technology. And the geology and mineralization of Zambian Copper Mines have revealed that Zambia has substantial amount of copper sulphide ores.

This study examines the feasibility of implementing bioleaching technology on low grade copper sulphide mineral ores in Zambia. This case study includes Konkola Copper Mines Plc (KCM), Kalumbila Mineral Ltd and Kansanshi Copper Mine. The survey instrument used to examine the feasibility of implementing bioleaching technology was a questionnaire which was availed to Konkola Copper Mines Plc (KCM), Kansanshi Copper Mines and Kalumbila Mineral Ltd.

The results obtained from the questionnaires showed that all the three mining companies are not fully aware of this technology and they use flotation as a method of mineral recovery to process the various low grade copper sulphide ores mined. KCM processes copper sulphide ores of 0.5-1.5% total copper, Kalumbila ores of grade percentage 0.2-1.0% whilst Kansanshi ores of grade percentage 0.2-0.3% total copper. The grade percentage of ores mined at the surveyed mines showed that this technology can be implemented.

Currently, there are fluctuating copper prices on the world market, high cost of production coupled with the depletion of high grade ores. The three mines are poised to economical and environmental benefits when this technology is implemented.

Keywords: Bioleaching, micro-organisms, low grade ores, Environment, Mineralization of Zambia Copper Mines

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1. Introduction

The world demand for copper is growing and there is a high rate of depletion of high-grade copper ores, hence the minerals processing industry is faced with the challenges to process low-grade ores and retreatment of tailings from current mining operations. Zambia, in spite of being endured with vast mineral deposits, still remains on the same position in terms of copper production. Lately, the Democratic Republic of Congo surpassed Zambia in annual copper production (African Business Magazine, 30th May, 2014). This is because of the old conversion technology being used in most mines in Zambia. This is attributed to the fact that most of high grade mineral deposits have been depleted leading to some mines being closed or reduction in the output levels. Therefore, this technology will help Zambian mines to process even low grade mineral deposits and abandoned tailings of these mines to put Zambia on the world market once more as the leading producers of copper and hence boost its foreign currency income.

It is therefore, very important to fully understand this technology in terms of its benefits to the Zambian mining industry before implementing it. Bioleaching is a process that uses living micro-organisms to extract valuable metals from low grade sulphide ores. This process is well illustrated by various authors (Bosecker, 1997, Rawlings, 2002) as a process that involves both the oxidation and dissolution of the sulphide ores. Bioleaching of copper ores has occurred naturally since many centuries ago. In Roman Empire, copper was recovered from acidic mine waters more than 2000 years ago (Colmer and Hinkle, 1947). It was seen as a natural degradation. This extraction could have been possibly by the involvement of microorganisms, and at that particular time, there were no conventional methods such as those used in pyro- hydrometallurgical Techniques. Nevertheless, the process of bioleaching was not recognized as such until about 50 years ago (Bosecker, 1997) , when it was discovered that microorganisms were mainly responsible for the enrichment of the metals in water from ore deposits. This important process takes place naturally whenever the microorganisms meet suitable conditions (Colmer and Hinkle, 1947).

The involvement of the microbial activities in the dissolution of sulphides ore can be traced back to the Rio Tinto River in Spain which got its name by its red colour, obtained from the high concentration of the ferric-iron (Fe^{3+}) dissolved in it. The dissolved iron and the dissolved copper (in small quantities) were due to the presence of microorganism activities around the area. The Rio Tinto has been recognized as a river devoid of fish and drinkable water, due to this astonishing scenario (Shannon, 1976).

Bioleaching is as well applied in the pre-treatment of refractory gold ores before they are subjected to the cyanidation process. This technique is also applied in the recovery of copper from secondary copper sulphide ores (Brierley and Brierley, 2001, Watling, 2006). This process is facilitated by microbial action, mostly of bacteria and archaea. Bioleaching is presently under development for the extraction of metals such as zinc, lead, arsenic, antimony, nickel and cobalt from the low grade ores. Being of low grade, economical bioleaching necessitates the application of low-cost technology. Currently, the technologies of choice are heap or dump leaching, both of which have been commercialized on very large scale for the leaching of copper sulphide ores but historically, in situ bioleaching have received considerable attention for the extraction of copper and uranium from their ores.

Bioleaching can involve numerous ferrous iron and sulphur oxidizing bacteria. The bioleaching process proceeds in three sub-processes, one of which is driven by microorganisms, a sub-process known as the ferrous-iron oxidation process. In this process, microorganisms oxidize the ferrous-iron (Fe^{2+}) to ferric-iron (Fe^{3+}). The Fe^{3+} is the main oxidizing agent in the chemical oxidative dissolution of sulphide ores. However, the chemical oxidative dissolution of the sulphide ores reduces the Fe^{3+} to Fe^{2+}. This sub-process explains the importance of the microorganisms in the generation and regeneration of solutions with relatively high redox potentials that leach sulphide ores. On the other hand, the sulphur oxidising bacteria converts the sulphur moieties to sulphur and the sulphuric acids which sustain the bioleaching process (Boon *et al*., 1999, Sand *et al*., 1995, Schippers and Sand, 1999). Fig. 1 (a) shows an ore before and after bioleaching and Fig. 1 (b) a bioleaching of chalcopyrite in a laboratory

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(a) (b)

Fig.1: (a): An ore, before bioleaching (left) and after bioleaching (right) (Rawlings and Johnson, 2007a);(b) a bioleaching of chalcopyrite in a laboratory (fermsre.oxfordjournal.org)

The process of bioleaching is conducted in different methods such as in heap, stirred tank, dump and in situ of which stirred is faster compared to the other methods. This is because of the homogenous conditions prevailing inside the stirred tanks by stirring.

2. Background

The presence of microbiological techniques and molecular biology, which help to isolate and identify the species related to the extraction of minerals (Rawlings and Johnson, 2007b) have been of importance in bioleaching research. The economic extraction of copper from low-grade ores requires low-cost processing methods such as in situ, dump and heap leaching. Bacterially assisted heap leaching of low grade copper from secondary copper sulphides is a developing technology that has been applied successfully for the extraction of copper from secondary sulphide minerals such as chalcocite, chalcolite, covellite in bulk at a number of operations worldwide (Watling, 2006). Chile being one of the countries where the technology has been implemented. Heap bioleaching is one of the techniques used in the bioleaching process, which involves treatment of bulk and irregular shaped crushed mineral sulphide ores using the leaching solution enriched with microorganisms in order to extract the desired metals.

Bioleaching is a more environmentally friendly process compared to conventional extraction methods like smelting, flotation in that there are no sulphur dioxide emissions, carbon monoxide, water vapour and other gases as in smelters, less land degradation, recycle of the liquor that contains bacteria. Bioleaching takes place in an acidic environment (sulphuric acid is formed in the process) for the survival of the bacteria and for the extraction of the desired metal from the ore, sulphuric acid and H^+ ions that have been formed in the process can leak into the ground and surface water turning it acidic, causing environmental damage. Heavy ions such as iron and zinc leak during acid mine drainage. For these reasons, a setup of bioleaching must be carefully planned. However, this impact is minimal as compared to the convention methods.

3. The Micrororganisms Used in the Bioleaching Process

The microorganisms are important in the bioleaching process; this is because they control reaction kinetics within the bioleaching processes. They are acidophilic in nature meaning they operate under acidic conditions or under low pH conditions. This is why they are more advantageous because they can work within any micro-processes because of their nature of their acidic environment. There is also no need to sterilize the environment from other competitive organisms. These microorganisms are classified as mesophiles which operate at temperatures in the range of 25°C to 40°C and under pH range of 1.5 and 2.5 as their optimum condition and example of such strains is *Thiobacillus ferrooxidans* (Das and Ayyappan, 1999). The moderate thermophiles works well at elevated temperature of between 50°C and 60°C for example *Ferroplasma thermophilum* and extreme thermophiles which operate at much elevated temperature of above 80°C, example of *sulfolobus*. Their performance is enhanced by certain factors such as temperature; pH, carbon dioxide, nutrients, oxygen, particle size and mineral substrate for further review refer to (Acevedo, 2002, Wanjiya, 2013).

4. Bioleaching Mechanisms

Bioleaching mechanisms explain the importance of the microorganisms in this technology. The role of the bacteria is to re-oxidize the ferrous iron back to the ferric form and oxidizing the elemental Sulphur formed. The ferric iron then chemically oxidizes the sulphide minerals producing ferrous iron. The bacteria only have a catalytic function because they accelerate the re-oxidation of ferrous iron to ferric iron which takes place very slowly in the absence of bacteria. Bioleaching can involve numerous ferrous iron and sulphur oxidizing bacteria, including *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thioxidans*. As a general principle, ferric-irons (Fe^{3+}) are used to oxidize the ore. This step is entirely independent of microbes. The role of the bacteria is further oxidation of the ore, but also the regeneration of the chemical oxidant ferric-irons (Fe^{3+}) from ferrous- irons (Fe^{2+}). The leaching rate is driven by ferric-iron (Fe^{3+}) availability. Therefore, the role of microorganisms in the bioleaching process can never be underestimated due to the fact that they generate and regenerate the ferric-iron and thereby maintaining a constant supply of the ferric iron which defines the degree of the extraction rate of the desired metal recovery as shown in the Figure 2 below.

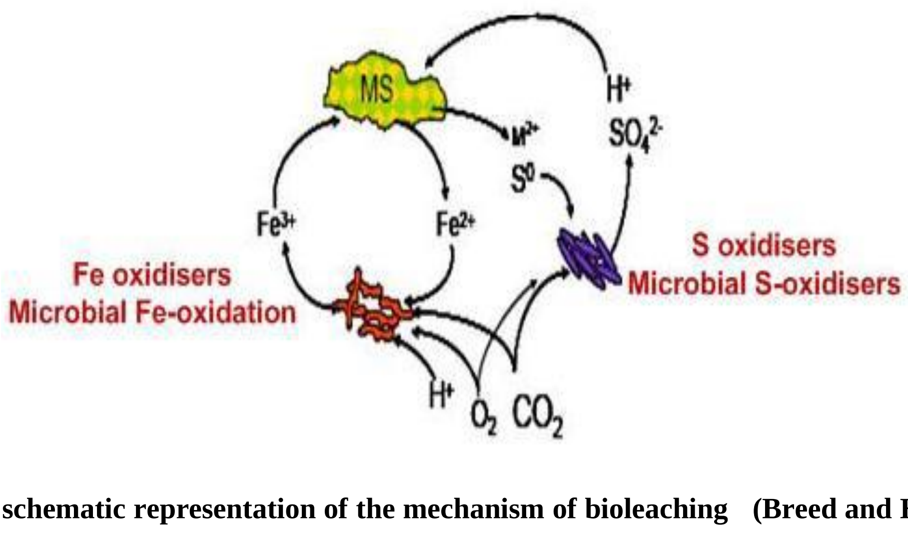

Fig.2: A schematic representation of the mechanism of bioleaching (Breed and Hansford, 1999)

$$Me + 2Fe^{3+} \rightarrow Me^{2+} + 2Fe^{2+} + S^o \quad (1)$$

$$4Fe^{2+} + O_2 + 4H^+ \xrightarrow{Bacteria} 4Fe^{3+} + 2H_2O \quad (2)$$

$$2S^O + 3O_2 + 2H_2O \xrightarrow{Bacteria} 2SO_4^{2-} + 4H^+ \quad (3)$$

The microbial oxidation process occurs at the cell membrane of the bacteria. The electrons pass into the cells and are used in biochemical processes to produce the energy for the bacteria while reducing oxygen to water. The critical reaction is the oxidation of ferrous iron to ferric iron. The main role of bacteria is the regeneration of this reactant.

5. Geology and Mineralization of the Zambian Copperbelt

The geology and mineralization of the Zambian Copperbelt the geology of the surveyed mines is cardinal for bioleaching to be implemented.

The Central African Copperbelt (CACB) is well known for its world class stratiform and stratabound copper-cobalt deposits. These deposits are located in the Democratic Republic of Congo (DRC) and Zambia. They are hosted within Neoproterozoic sedimentary rocks of the Katangan Super group, deposited in a series of intra continental rift basins. During Pan African Lufilian orogeny, the Katanga rocks underwent a long tectonic history producing over 500 km east West arcuate fold-and-thrust belt known as the Lufilian or Katanga belt Fig.3. A less deformed plateau molasses were syn-tectonically deposited in the Northern Katangan foreland basin, it consists of the uppermost member of the Katangan super group (Kundelungu group); (Batumike *et al*., 2007a, Batumike *et al.*, 2007b, Groves *et al*., 2010). The sedimentary rock-hosted stratiform copper or sedimentary copper deposits are important sources of copper, cobalt and silver (Gustafson and Williams, 1981, Selley *et al*., 2005) , accounting for ~ 15% of the world's copper resource. The CACB is the world's largest and highest-grade sedimentary copper province with close to 200 Mt of copper produced or in resources and the world's largest reserves of cobalt (Lydall and Auchterlonie, 2011) .The CACB has produced copper for more than 4000 years and in the 1960s and 70s was a leading global copper producer. A recent resurgence to privatization of the industry in 1995 and 2003 in Zambia and DRC, respectively led to its once again becoming a world leader in metal production (Lydall and Auchterlonie, 2011).

Since the discovery of the Central African Copperbelt in early 1900's several exploration techniques including remote sensing, geological mapping, trenching, geochemical and geophysical surveys, and drilling has been used to delineate deposits. These deposits display different style, texture and associated alteration, and occur within different lithology (conglomerate, schists, arenites, shale, carbonates, diamicite) at several stratigraphic levels (Groves et al., 2010). The mineralization is either or both fine grained dissemination or vein-hosted coarse grained sulphides. Highly carbonaceous shales tend to be low grade or barren but may contain economic amounts if copper sulphides where veining is prominent. The most typical sulphides assemblage in all of Zambian Copperbelt deposits is chalcopyrite.

The Zambian Copperbelt accounts for approximately 46% of the production and reserves of the Central African Copperbelt. Zambia's vast potential for mineral resources is due to its unique geographic location with combined production and reserves or resources totalling approximately 100Mt copper (Selley *et al*., 2005). Though a wide range of minerals occur in the country, the mining industry has been dominated by copper mining which has overshadowed the exploitation of other potential mineral resources. In the Zambian Copperbelt several exploration techniques including soil geochemistry, aerial photography, and electrical self-potential were used in Zambia to detect mineralization and subsequently ore bodies. The Zambian Copperbelt deposits are located in the Southeastern part of the Lufilian belt, and they represent a cluster of deposits (Konkola-Musoshi, Nchanga-Chingola, Nkana-Mindolo, Mufulira, Luanshya-Baluba and Chambeshi) and almost 20 smaller deposits, not all of which have been mined. Mines in Zambian Copperbelt include large open pits and a number of underground operations. Copper resources have also been found in the thrust zones of north-western Zambia which represent zones of detachment between basement and Katanga sequence. Mineralization in the Zambian Copperbelt is dominantly sulphide, comprising of chalcopyrite, bornite and chalcocite variably accompanied by pyrite and pyrrhotite, carollite, covellite and diginite (Selley et al., 2005). Ore grades are commonly around 3% to 4% copper and 0.1% to 0.2% cobalt. Huge low grade copper deposits (~0.67% Cu) which are dominantly sulphides (chalcopyrite) were discovered in Lumwana area in the north-western Zambia (Bernau, 2007).

5.1 Geology and Mineralization at Kansanshi Copper Mine

The deposit at Kansanshi occurs within a broad, northwest trending, north-west closing antiform, which can be traced for approximately 12 kilometres. Kansanshi is a vein deposit developed within a tectonised rock sequence and, as such, constitutes a major mineralization control. Copper mineralization at Kansanshi occurs as vein-specific mineralization within and immediately adjacent to mesoscopic veins (Torrealday *et al*., 2000). Primary copper sulphide mineralization is dominated by chalcopyrite, with very minor bornite, accompanied by relatively minor pyrite and pyrrhotite. Oxide mineralization is dominated by chrysocolla with malachite, limonite and cupriferous goethite. The mixed zone includes both oxide and primary mineralization but also carries significant chalcocite, minor native copper and tenorite. Some copper appears to be carried in clay and mica minerals, where it is essentially refractory. Copper sulphide mineral ore grades mined at Kansanshi Mine are around 0.2 to 0.3% total Copper.

5.2 Geology and Mineralization at Kalumbila Mineral Ltd

The sentinel or Kalumbila copper-nickel-cobalt deposit is located on the flanks of Kabompo structural dome, 55km west of the Lumwana mine and is located approximately 150km west of Solwezi in north-west province of Zambia. Base metal mineralization is hosted in a carbonaceous phyllite, sericite-quartz rock. The sentinel phyllite hosts the mineralization and is structurally bound by a large recumbent fold. The Sentinel deposit includes extensive low grade copper mineralization and subsidiary Nickel and Cobalt hosted in metasedimendary carbonaceous phylite (Steven and Armstrong, 2003). Copper sulphides mineral ore grades mined at Kalumbila Mineral Ltd are around 0.2-1% copper.

5.3 Geology and Mineralization at Konkola Copper Mine Plc (KCM)

The Konkola deposit is a high grade stratiform copper-cobalt ore deposit in the eastern part of Zambian Copperbelt. Economic mineralization is confined to the ore shale formation, part of the Neoproterozoic metasedimentary rocks of the Katanga Supergroup. Petrographic study reveals that the copper-cobalt ore minerals are disseminated within the host rock, sometimes concentrated along bedding planes, often associated with dolomitic bands or clustered in cemented lenses and in layer-parallel and irregular veins. The hypogenesulphide mineralogy consists predominantly of chalcopyrite, bornite and chalcolite (Sweeney et al., 1986) Copper sulphide mineral ore grades processed at KCM are in the range of 0.5-1.5% total copper.

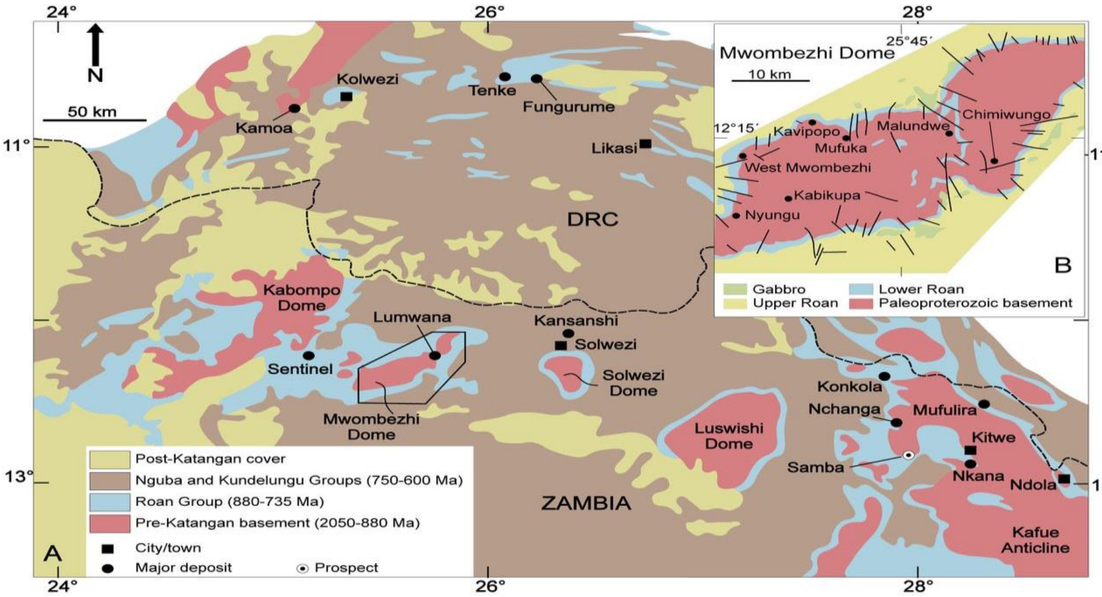

Fig.3: Geological map of the Central African Copperbelt and major copper deposits in black dots (www.economicgeology.org)

6. Methodology

For this study, three mines namely Konkola Copper Mine plc (KCM), Kalumbila and Kansanshi were chosen out of a number of mines that are currently operating in Zambia that process copper sulphide mineral ores or that possess tailings dumps that have not been re-processed. A descriptive research methodology was used for this study. A questionnaire was designed by the researcher as a survey instrument to assess the possibility of implementation of Bioleaching Technology, what was also cardinal was the analysis of Zambian mineralogy and grade percentages of the mined ores at the individual mines which were selected for this project.

The designed questionnaire was availed to the mentioned companies. From the completed questionnaires, the results were obtained and analyzed.

The survey addressed four key factors;

i) To examine whether the mines know about bioleaching technology and about its benefits economically and environmentally.
ii) To examine whether the mines process low grade copper sulphide ores that can be processed using bioleaching.
iii) To know the mineralogy of the surveyed mines for this particular project.
iv) To examine whether it is feasible to implement bioleaching technology at the mines under this particular survey.

7. Results

The results obtained from the surveying process conducted at KCM, Kalumbila and Kansanshi Mines on the possibility of implementing bioleaching technology at these mines are presented below.

7.1 Konkola Copper Mines Plc (KCM)

KCM processes low grade sulphide mineral ores of grade percentage 0.5-1.5% total copper and method of mineral recovery used is flotation, this is because this technology has proven to be most feasible and economical (high recoveries, high grade concentrates, clean concentrates).

The company is aware of the bioleaching process in terms of its economic (sustainability, low capital investment, conservation of energy etc) and environmental benefits (less landscape damage, less SO_2, CO_2 emissions) but does not know the benefits that this new technology would offer by changing from flotation to bioleaching.

The mine is interested in bioleaching and it is eager to carry out a research undertaking through collaboration with the Copperbelt University research unit under chemical engineering department by carrying out pilot plant on this technology. The minerals found at KCM are shown in the Table 1 below.

Table 1: Mineral ores mined at KCM

Mineral	Mineral formula
Chalcopyrite	$CuFeS_2$
Bornite	Cu_5FeS_4
Chalcocite	Cu_2S
Chrysocolla	$(Cu, Al)_2H_2Si_2O_5(OH)4.nH2O$
Malachite	$CuCO_3(OH)_2$
Pseudomalachite	$Cu_2(CO_3)(OH)_2$

7.2 Kalumbila Mineral Limited

The mine processes low grade sulphide ores of grade percentage 0.2-1% total copper using floatation as a mineral recovery method because it is most feasible and economical. The mine has knowledge about bioleaching regarding its benefits environmentally and economically, even so, this mine does not know the benefits of changing from flotation to bioleaching. Kalumbila Mineral Ltd is not interested in the technology. The minerals found at Kalumbila are shown in the Table 2 below.

Table 2 : Mineral ores mined at Kalumbila mine

Mineral	Mineral formula
Chalcopyrite	$CuFeS_2$
Bornite	Cu_5FeS_4
Covellite	CuS
Digenite	Cu_9S_5
Chalcocite	Cu_2S

7.3 Kansanshi Copper Mine

Kansanshi Copper Mine processes low grade copper ores of grade percentage 0.2-0.3% total copper using flotation as a method of mineral recovery. Kansanshi Copper Mine knows about bioleaching but does not know its benefits economically and environmentally but unlike Kalumbila and KCM mines, Kansanshi is aware of the benefit of changing from flotation to bioleaching, that is, it could be cheaper but slower. The company isn't interested in the new technology but there is a possibility of implementing it using pilot plant and the company is ready to collaborate with The Copperbelt University for experimental studies.

Table 3: Mineral ores mined at Kansanshi

Mineral	Mineral formula
Chalcopyrite	$CuFeS_2$
Bornite	Cu_5FeS_4
Covellite	CuS
Digenite	Cu_9S_5
Chalcolite	Cu_2S
Malachite	$CuCO_3(OH)_2$
Azurite	$Cu_2(CO_3)_2.Cu(OH)_2$
Cuprite	Cu_2O
Tenorite	CuO
Chrysocolla	$(Cu, Al)_2H_2Si_2O_5(OH)4.nH2O$
Native copper	Cu

8. Discussion

The results obtained for Konkola Copper Mine (KCM) according to Table 1, have revealed that the mineral composition for this mine is mostly sulphide ores. Previous research (Rossi, 1990) which has shown that the common and most abundant secondary sulphide mineral ores in nature are easier to bioleach. Mineralogy composition of ores mined at KCM are of grade 0.5-1.5% total copper which are within the range according to the literature, (Gentina and Acevedo, 1985). This technology will give enormous economical and environmental benefits to KCM in terms of emissions coming from the smelter plants. The possibilities of setting up a research unit in bioleaching at the Copperbelt University will not only benefit the company but will enhance the research unit of the institution in this particular area of research such that it may become a centre of Bioleaching Research Unit benefit Zambia and the entire Southern Africa region.

Kalumbila Mineral Ltd processes a variety of low grade sulphide mineral ores, as shown above on Table 2, the mineralogical composition of this mine is ores of grade percentage 0.2-1% copper which falls within the range of bioleaching minerals. Even though, the Kalumbila Mineral Ltd is not interested in this technology, the benefit can be so enormous. Once Kalumbila is availed with the enormous benefit of this technology as revealed in the above literature review, it will change it perception on their view on this technology. Bioleaching can offer some long term solutions to this mine in terms of low capital investment, because the mine can process bulky low grade mineral ores with minimal operating costs.

Kansanshi Copper Mine processes a variety of copper mineral ores that are of low grade. However, the majority do contain the sulphide except for some such as chrysocolla, malachite, Azurite as shown in Table 3 above. The grade percentage of the copper mined is in the range of 0.2-0.3% total copper. The mine processes copper sulphide ores using flotation as a method of mineral recovery. This method is used because the infrastructure is available. Even the company is concerned on time it taken by this technology as compared to the convention method, the benefits are huge under this technology in a long run. The mine will be able to process bulk mineral concentrate at low capital investment and low environmental challenges.

There are tailing dumps in Kitwe, Luanshya, Chingola and other areas around the Copperbelt, these can be processed using bioleaching. The outcome from processing tailings could generate a lot of income for these mines and clear the land from possible pollution emerging from these dumps which can affect the ground water with dissolved heavy metals. Heavy metals have the potential to cause cancer and any other diseases to human beings.

9. Conclusions

This present study was undertaken to examine the feasibility of implementing bioleaching technology on low-grade copper sulphide mineral ores in Zambia at Konkola Copper Mines (KCM), Kalumbila Mineral Ltd and Kansanshi Copper Mine. The study has shown that it is feasible to implement Bioleaching Technology at the surveyed mines. The grade percentages and the ores mined at the mines as shown in Tables 1, 2 and 3 shows that this technology can be implemented.

The study has shown that bioleaching is not known at the surveyed mines and some of the reasons this technology has not been implemented in Zambia are listed below;

- Due to the lack of information on this technology
- Some mines process mineral ores that are high grade,
- Most mines are comfortable with the conventional method (flotation, smelting) currently being used as proven technologies.
- The sustainability of bioleaching technology has not been compared with that of the conventional method,
- This technology has not been implemented anywhere in Zambia using pilot plant to prove its feasibility.

Zambia can fully benefit from this technology once implemented and gain its lost status of the highest producer of copper in Africa and the second in the world from Chile. Most mines in Zambia are relying on the old technologies of mineral processing techniques which process low grade ores at high operating cost and low valuable mineral recovery. Therefore, this new technology to Zambia will achieve high valuable metal recovery because it is able to process large capacities of low grade minerals at low operating costs and negative environmental impacts. It can recover valuable metals from the abandon tailings such as the black mountain in Nkana West and tailings in Nkana East in Kitwe. These lands can later be used as land for residential or industrial development, an example being the Nkana East tailings once cleared that land can be of great use. Other mines which have been closed down due to depletion of high grade copper ore will be revamped using this technology as well as other mines not covered in this research study will benefit. The pollution of ground water will be minimal and hence save human being from possible illnesses such as cancer ,etc (Türkdoğan *et al.*, 2003). Fluctuating copper prices on the world market, high cost of production coupled with the depletion of high grade copper ores, Zambia is paused to benefit from this technology once implemented.

10. ACKNOWLEDGEMENT

1. Mr Kenny Nyirenda, for the contribution to the data from geological point of view towards the success of this paper.

2. Konkola Copper Mines Plc, Kansanshi Copper Mines and Kalumbila Mineral Ltd senior metallurgists for the availing of data which was used in the research paper

3. The Copperbelt University, School of Mines and Mineral Sciences for enabling environment to conduct research

11. REFERENCES

Acevedo, F. (2002.) Present and future of bioleaching in developing countries. *Electronic journal of biotechnology,* 5**,** 18-19.

Africa Business Magazine (2014), Dr CongoPlots $700m Mining Sector Investiment. (available online http://www.africanbusinessmagazine.com/sectors/commondities/dr-Congo-plots-700m-sector-investiment.

Batumike, J., O'Reilly, S., Griffin, W. and Belousova, E. (2007a.) U–Pb and Hf-isotope analyses of zircon from the Kundelungu Kimberlites, DR Congo: implications for crustal evolution. *Precambrian Research,* 156**,** 195-225.

Batumike, M., Caileux, J. & Kampunzu, A. (2007b.). Lithostratigraphy, basin development, base metal deposits, and regional correlations of the Neoproterozoic Nguba and Kundelungu rock successions, central African Copperbelt. *Gondwana Research,* 11**,** 432-447.

Bernou, R. (2007). The geology and geochemistry of the Lumwana Basement hosted copper-cobalt (uranium) deposits, NW Zambia. University of Southampton.

Boon, M., Meeder, T., Thone, C., Ras, C. and Heijen, J. (1999). The ferrous iron oxidation kinetics of *Thiobacillus ferrooxidans* in continuous cultures. *Applied microbiology and biotechnology,* 51**,** 820-826.

Bosecker, K. (1997). Bioleaching: metal solubilization by microorganisms. *FEMS Microbiology reviews,* 20**,** 591-604.

Breed, A. and Hansford, G. (1999). Studies on the mechanism and kinetics of bioleaching. *Minerals engineering,* 12**,** 383-392.

Brierley, J. and Brierley, C. (2001). Present and future commercial applications of biohydrometallurgy. *Hydrometallurgy,* 59**,** 233-239.

Colmer, A. R. and Hinkle, M. (1947). The role of microorganisms in acid mine drainage: a preliminary report. *Science,* 106**,** 253-256.

Das, T. and Ayyappan, S. (1999). Factors affecting bioleaching kinetics of sulfide ores using acidophilic micro-organisms. *BioMetals,* 12**,** 1-10.

Gentina, J. C. and Acevedo, F. (1985). Microbial ore leaching in developing countries. *Trends in Biotechnology,* 3**,** 86-89.

Groves, D. I., Bierlein, F. P., Meinert, L. D. & Hitzam, M. W. (2010). Iron oxide copper-gold (IOCG) deposits through Earth history: Implications for origin, lithospheric setting, and distinction from other epigenetic iron oxide deposits. *Economic Geology,* 105**,** 641-654.

Gustafson, L. B. and Williams, N. (1981). Sediment-hosted stratiform deposits of copper, lead, and zinc. *Economic Geology,* 75**,** 139-178.

Lydall, M. and Auchterlonie, A. (2011). The Democratic Republic of Congo and Zambia: a growing global 'hotspot'for copper-cobalt mineral investment and exploitation. *In:* 6th Southern Africa Base Metals Conference, Phalaborwa, . 18-20.

Rawlings, D. E. (2002). Heavy metal mining using microbes 1. *Annual Reviews in Microbiology,* 56**,** 65-91.

Rawlings, D. E. and Johnson, D. B. (2007a). *Biomining*, Springer.

Rawlings, D. E. and Johnson, D. B. (2007b). The microbiology of biomining: development and optimization of mineral-oxidizing microbial consortia. *Microbiology,* 153**,** 315-324.

Rossi, G. (1990). *Biohydrometallurgy*, McGraw-Hill.

Sand, W., Gerke, T., Hallmann, R. and Schippers, A. (1995). Sulfur chemistry, biofilm, and the (in) direct attack mechanism—a critical evaluation of bacterial leaching. *Applied microbiology and biotechnology,* 43**,** 961-966.

Schippers, A. and Sand, W. (1999). Bacterial leaching of metal sulfides proceeds by two indirect mechanisms via thiosulfate or via polysulfides and sulfur. *Applied and environmental microbiology,* 65**,** 319-321.

Selley, D., Broughton, D., Scott, R., Hitzman, M., Bull, S., Large, R., Mcgoldrick, P., Croaker, M., Pollington, N. and Barra, F. (2005). A new look at the geology of the Zambian Copperbelt. *Economic Geology 100th Anniversary Volume,* 29**,** 965-1000.

Shannon, R. T. (1976). Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Crystallographica Section A: Crystal Physics, Diffraction, Theoretical and General Crystallography,* 32**,** 751-767.

STeven, N. and Armstrong, R. (2003). A metamorphosed proterozoic carbonaceous shale-hosted Co-Ni-Cu deposit at Kalumbila, Kabompo Dome: the Copperbelt ore shale in northwestern Zambia. *Economic Geology,* 98**,** 893-909.

Sweeney, M., Turner, P. and Vaughan, D. (1986). Stable isotope and geochemical studies in the role of early diagenesis in ore formation, Konkola Basin, Zambian copper belt. *Economic Geology,* 81**,** 1838-1852.

Torrealdaay, H. I., Hitzman, M. W., STein, H. J., Markley, R. J., Armstrong, R. and Broughton, D. (2000). Re-Os and U-Pb dating of the vein-hosted mineralization at the Kansanshi copper deposit, northern Zambia. *Economic Geology,* 95**,** 1165-1170.

Turkdogan, M. K., Kilicel, F., Kara, K., Tuncer, I. and Uygan, I.(2003). Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region of Turkey. *Environmental toxicology and pharmacology,* 13**,** 175-179.

Wanjiya, M. (2013). Investigation of bacterial ferrous iron oxidation kinetics in a novel packed-column reactor: pH and jarosite management. MTech. Thesis,Cape Peninsula University of Technology, South Africa.

Watling, H. (2006). The bioleaching of sulphide minerals with emphasis on copper sulphides—a review. *Hydrometallurgy,* 84**,** 81-108.

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Foundry localisation strategy implementation as a vehicle to South African industrialisation: MCTS contribution

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Abstract

Localisation strategy is one of the South Africa government strategies aimed at promoting economic growth and re-industrialization of the country through local content programme. The foundry sector is one of the foundation stones for metal related manufacturing and fortunately has been selected as one of the focus industries for localisation programme. However the economic sustainability of South Africa foundries have been in dramatic decline, South Africa had about 450 foundries in the 1980s, just over 200 were found in 2003 and about 170 were left in 2014. This dismal decline in foundries is due to years of underinvestment, a widening skills gap and import leakage. The South African government through its state departments had introduced localisation strategy initiative to promote procurement of local content produced locally for use in government initiated projects such as State Owned Enterprises (SOE) Infrastructure programme as a means of supporting local foundries' competitiveness. This paper highlighted the role of the MCTS in the broader South Africa Industrialisation strategy such as; human capital development, technology transfer, product and process improvement.

Keywords: Localisation strategy, Foundries, State Owned Enterprises.

1. Introduction

South Africa's socio-economic challenges have escalated in recent years, with the unemployment rate reaching 25% higher (Writer, 2015). The manufacturing's sector contribution to the Growth Domestic Products (GDP) had fallen from 20% in 1994 to 11% in 2015 (Viviers, 2016). This can be significantly attributed to the importation of high value added products into South Africa by from countries like China and India, therefore the need for more vigorous economic diversification and job creation fields has come into focus on the national agenda. The revitalisation of the manufacturing sector is one of the cornerstones of government's various economic policies and strategies (Viviers, 2016) The manufacturing sector provides a locus for stimulating the growth and achieving specific outcomes, such as job-creation and economic empowerment, thus accelerating the country's growth and development (Maponya, 2015).

The South African government has instituted two key national strategies that promote industrialisation and support the growth and diversification of South Africa manufacturing

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industry. The New Growth Path (NGP) and the Industrial Policy Action Plan (IPAP) to achieve high GDP and employment growth in South Africa through direct and indirect employment in the manufacturing sector. (The dti, 2013).

The New Growth Path (NGP) is a framework that seeks to address the issues surrounding unemployment, inequality, and poverty, through strategy implementation relating to job creation by attempting to restructure the South African economy to improve performance in relation to labour intensive and an improved growth rate (Government Communications, 2010). The Industrial Policy Action Plan (IPAP) on the other hand is a good step towards transforming South Africa's manufacturing sector which aims to ensure that stronger cohesion exists between macro and micro economic policies that relate to exchange and interest rates, inflation and trade balance requirements which is guided by the vision of National of National Industrial Policy Framework (Framework (NIPF) (Maponya, 2015).

The manufacturing sector revitalisation has also received support through the Preferential Procurement Policy Framework Act (PPPFA) changes, together with the NGP and IPAP II, which empowers the Department of Trade and Industry (DTI) to designate sectors and products that government departments and State-owned Enterprises (SOEs) should procure from local producers ,which with sets an aspirational target for government and large firms to buy goods and services from local industry (Makube, 2013) .

In a bid to increase the competiveness of local foundries, the Metal Casting Technology Station (MCTS) within its mandate had been engaged with foundries and other key stakeholders in various activities such as Human capacity development, Technology Innovation and Process and product development. This paper will discuss the outcomes of the MCTS contribution toward improving the competiveness of foundry to gain advantage on the localisation programme which will stimulate industrialisation and economic growth.

2. Current status of local foundry industry

The State Owned Enterprises (SOEs) are on the roll –out of large - scale infrastructure recapitalisation and expansion programmes. The Infrastructure programmes includes bulk freight transportation (port, rail and pipelines) by Transnet, electricity generation and distribution by Eskom on the new power infrastructure (DST, 2008). The two entities had committed to adherence of PPPFA and support of the development of the local supplier industries under the Customer Supplier Development Programme (CSDP) initiated by the Department of Public Enterprise (DPE). The SOEs had not built any major infrastructure in recent in a decade and the local supplying industry has not adequately invested in plant and technology to meet the SOEs latest requirements. The CSDP aimed at increasing the competiveness, capacity and capability of the local supply base to optimise the development of competitive supplier industries and where possible build export capabilities (DPE, 2007).

The foundry sector is one of the foundation stones for metal related manufacturing and fortunately has been identified as one of the focus industries for localisation programme. However the economic sustainability of South Africa foundries have been in dramatic decline, South Africa had about 450 foundries in the 1980s, just over 200 were found in 2003 and about 170 were left in 2014 (Davies, 2015). This decline is due to high volume of import products, rapidly rising energy costs and energy inefficiency; the cost of compliance with environmental regulation, a widening skills gap (Mbanjwa, 2015).

The industry produces approximately 375 000 tons of ferrous and nonferrous products in 2014, and created direct and indirect employment of estimated 13100 (Davies, 2015). Most of the foundry industry is geographically located in Gauteng with more than 65% of those located in Ekurhuleni Municipality and the market share of the industry mainly serves the mining, automotive and general sector, with above 50% accounting between mining and automotive as shown in figure 1, (Davies, 2015).

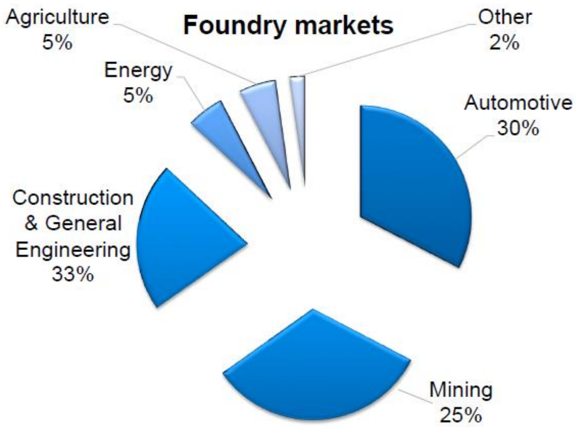

Figure 1: Shows the South African Foundry market share (Davies, 2015)

Foundries are mainly classified as tier 2 or 3 supplier in typical supply chain structure. With the Original Equipment Supply (OEM) being the tier 1 supplier. The tier 1 suppliers are direct suppliers of fit for purpose equipment and Second and third tier supplier are manufactures of assemblies and sub –assemblies or key maintenance/testing services (DST, 2008), However strategic approach will be to focus on tier 1 suppliers using its direct sphere of control to align the OEMs with appropriate tier 2 and recommend that tier 2 participate in supplier benchmarking as part of their commitment to continuous improvement. This process is aimed at developing the ability to deliver through leveraging of productive and technological capabilities according to specifications and the ability to provided total life cycle support, as reflected in figure 2 (DST, 2008).

In 2009, foundry industry assessment and benchmarking analysis was conducted to evaluate the competiveness and capabilities of the foundries. The foundry industry assessment and benchmarking analysis was conducted based on the review of various previous report from studies conducted in the industry as well as interviews of the key industry stakeholders (Decipher Consulting, 2009). The benchmarking provides details review of companies capabilities against buyer requirements and indicate performance gap to addressed and migrate to world class competiveness.

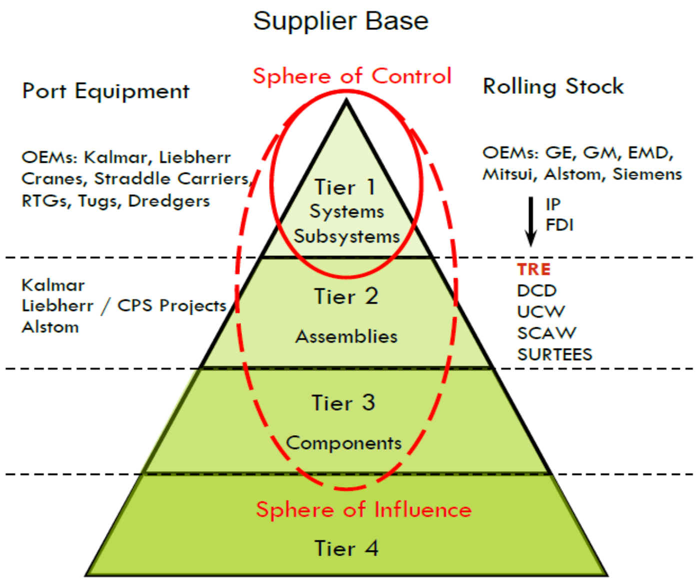

Figure 2: Show Typical supplier base (source: DST, 2008)

The benchmarking report highlighted that foundry industry requires technological upgrades and human capital development to improve their production processes, to produce within OEMs specifications. (Decipher Consulting, 2009).

3. Metal Casting Technology Station Contributions.

The MCTS mandates is to support the foundry industry with technology transfer and skills development through human resources and capacity development to improve the competiveness of the foundries. In a bid to increase the competiveness of local foundries, the Metal Casting Technology Station (MCTS) within its mandate had been engaged with foundries and other key stakeholders in various activities such as Human capacity development, Technology Innovation and Process and product development. The MCTS is an initiative of Department of Science and Technology (DST) managed through Technology Innovation Agency (TIA), hosted by University of Johannesburg under the Faculty of Engineering and the Built Environment (FEBE).

The MCTS assisted over 50 foundries with various interventions in a collaborative approach with number of stakeholder such as National Foundry Technology Network (NFTN, South Africa Institute of Foundryman (SAIF) and Technology Localisation Unit (TLIU).

3.1 Human capital development

The MCTS's main objective in addressing human capital in foundries is skills development aimed at closing the gap left by aging man power and years of neglect in training and upskilling shop floor operators by the foundry industry. This was implemented using three strategic initiatives, which are: internship, post graduate training and career path frame work. To create career path framework which was aimed at re-design the draft foundry qualifications (NQF Level 2 – 4) in accordance with the newly developed qualification design model and allow school leaver to be trained in three main areas of foundry operations, namely melting, moulding and pattern making processes, the MCTS collaborated with SAIF and NFTN. The MCTS supported SAIF with the establishment and commissioning of Gauteng Foundry Training Centre (GFTC) at Ekurhuleni East College which aimed at training moulder, melter and pattern maker using artisan training programme.

The MCTS participated in the implementation of the internship programme sponsored by the DST and managed by TIA. The internship programme was aimed at placing foundry metallurgy students at different foundries to assist student to gain work experience while creating capacity of young engineer in the foundry industry. The programme manage to place over 90 students within the foundries with an average of 60% being retained by the industry.

The MCTS collaborates with Freiberg University in Germany. The collaboration had resulted in 4 University of Johannesburg students being trained at Freiberg University at a Master degree level, 3 students from Freiberg visited MCTS under students exchange programme and 3 Freiberg university staff members came to work with MCTS staff on various projects to provide knowledge transfer.

3.2 Technology and Innovation

The MCTS objective with regards to technology and innovation transfer is to provide specialised knowledge and new technology to the foundry industry through technology demonstration and collaborations. The MCTS together with SAIF and NFTN organised the 1ST Metal Casting Conference in 2013, with more than 200 international and local delegates in attendance with over 20 papers presented by academics, industry and government institutions. This provided local foundries with opportunities to network, sharing information with international expertise and having an overview of the global market trends of foundry industries .The MCTS participated in Improvement of Energy, Material Efficiency and Recycling in South African Foundries which was titled EffSAfound.The project was funded by Germany Ministry and NFTN, was implemented by the German Institute of Foundry Technology (IfG). The research project was aimed at improving the material and energy efficiency of the South Africa foundries. The MCTS is technology partner with AMV solutions from Spain on ALEA software. The ALEA software is a raw material charge optimiser to reduce the cost of raw material inputs, quality and competiveness of the foundry on inputs materials. The MCTS is a satellite site for Casting Simulation Network (CSN). The CSN is implemented by TLIU with aim of promoting access to casting simulation software to South Africa industry with the benefits of reduction of trials, reduction of scrap, cost reduction, improved product development cycle and improved product optimisation.

3.3 Product and Process Improvements

Here the objective is to enhance quality of products through continuous process and product improvement. The MCTS had conducted over 10 product and process improvements with various foundries. The projects range from sand reclamation, sand defects reductions, development of heat-treatment process and energy management. In Addition more than 100 tests have been conducted for foundries and supplier using state of the art equipment. One of the case studies of Product improvement is showed in Figure 3.

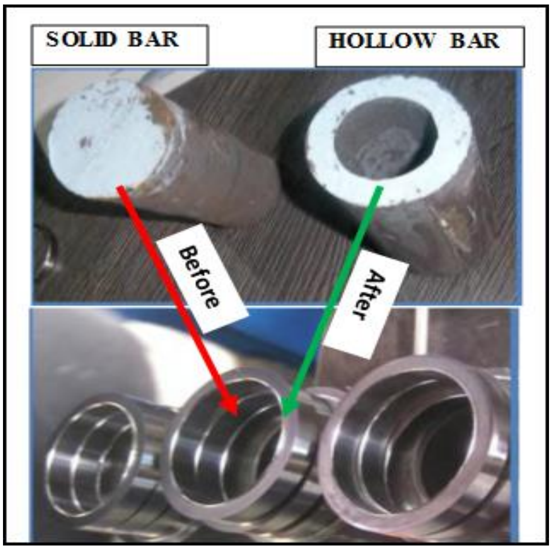

Fig.3: Solid and hollow bar for manufacturing valve seats

The foundry before the intervention was producing a solid bar to make valve seats. The MCTS with various stakeholder collaborated to assist the foundry with products improvement. The outcomes of the projects showed 37% material reduction, 33% reduction in operational cost. The outcomes provided the opportunity for the foundry to revised pricing and increase competiveness.

This section in my view is the most important of the paper as it highlights the various contributions of the MCTS to the foundry localisation strategy. That is in line with title of the paper. Authors should outline mandate of the MCTS clearly in the first place.

Here MCTS has highlighted three main areas of contribution; (i) human capital development, (ii) technology and innovation and (iii) product and process improvement. Under each sub-section, the authors could start by stating the main objective (s) and followed by strategies to be employed to achieve the stated objectives. That can improve focus of the whole section. In addition figures on financial savings where possible can be included to convey a bigger story.

4. Conclusion

- Through the technology localisation and technical skills-knowledge transfer strategies, over 50 Foundries in South Africa had benefited from a wide range of interventions provided by the Metal Casting.

- In one of the interventions 37 % reduction in material cost and 33 % reduction in operational cost was achieved

- 90 students were placed in various foundries with an average of 60 % retention by industry.

- 4 masters students were trained and graduated in a Germany University and are now employed in different foundries as technology transfer agents.

- One international conference where 20 conference papers were presented in with over 200 delegates in attendance was organised in 2013.

5. Acknowledgements

The authors are thankful to the University Of Johannesburg, the Department of Science and Technology and the Technology Innovation Agency for the financial support. The important assistance received by the Metal Casting Technology Station from the South African Institute of Foundrymen, the National Foundry Technology Network Technology Localisation Unit and the foundry industry as a whole is here acknowledged.

6. References

Davies, J., 2015. *South African Foundry Industry: 2nd vamcosa foundries workshop,* Johannesburg: www.foundries.org.za.

Decipher Consulting, 2009. *Industry Assessment and Benchmarking Report,* Pretoria: DST.

Department of Public Enterprises: Republic of South Africa, 2007. *Competitive Supplier Development Programme,* Pretoria:

Department of Science and Technology, 2008. *Technology Localisation Plan a Framework for Engagement in National Technology Localisation Actions,* Pretoria:

Government Communications, 2010. *Cabinet statement on the new growth path,* Pretoria: s.n.

Makube, T., 2013. *Procurement and Localisation - Designation of Sectors,* Pretoria: The Department of Trade and Industry.

Maponya, C., 2015. *http://www.sanews.gov.za.* [Online] Available at: http://www.sanews.gov.za/south-africa/manufacturing-sector-can-drive-south-africa%E2%80%99s-global-competitiveness

Mbanjwa, X., 2015. Tough times ahead for foundries. 23 August.

The dti, 2013. *Industrial Policy Action Plan,* Pretoria: the dti.

Viviers, W., 2016. *Paving the way for South Africa's (re)industrialisation, including the 'local content' vs. the 'local spend' debate,* North-West: NWU - TRADE.

Writer, S, 2015. [Online] Available at:http://businesstech.co.za/news/general/77737/south-africa-unemployment-1994-2015/

Identifying the appropriate flocculant and addition rate to obtaining optimum settling rates of solids and best overflow clarity at Lumwana Concentrator.

L. K. Witika[1] and J. Silolezya[2]

Abstract.

In a quest to take advantage of the currently prevailing high metal prices on the world major metal exchange market, Lumwana Copper Mines Plc (LMC) has embarked on a campaign to increase its total production capacity in all areas. Currently, LMC's Process Plant which was designed to operate on a throughput of 2400 Tonnes per hour (tph) is now operating on a throughput of an average 3800 tph. This increase in the throughput, without plant expansion has reduced the slurry's residence time in the unit processes of the treatment plants, consequently there is more concentrates reporting to the concentrates thickener overflow resulting in poor overflow clarity.

Therefore, this work was suggested to determine the appropriate flocculant addition rates to the concentrates thickener (TH001) in an effort to attain optimum settling rates to achieve best overflow clarity.

LMCs' traditional flocculants; Savofloc P3155, Floxit 9020 and Magnafloc 155 were used to determine the best flocculant products by optimizing their dosage in relation to the settling rates of copper concentrate fine particles give best overflow clarity. The laboratory test-works aimed at assessing the flocculants efficiencies for settling rates, clarity of overflow water and determination of the optimum flocculants dosages.

The results showed that the optimum dosage for Savofloc P3155 and Floxit 9020 were 30g/t and Magnafloc 155, 20g/t respectively. At these dosages, the flocculants gave high settling rates and best overflow clarity. Of the three, Magnafloc 155 was the best flocculant product, as, at its optimum dosage, gave the highest settling rate and best overflow clarity and was the most economical.

Keywords: Lumwana, flocculants, thickener, overflow, dosage.

1. Introduction.

Lumwana Mining Company (LMC) Plc is owned by Barrick Gold Cooperation, whose head offices are in Toronto, Canada. LMC is located in the Zambian North-Western province, 300 km west of the Copperbelt and 95 km south-west of the provincial capital, Solwezi, has two ore deposits, Malundwe and the recently opened Chimiwungo copper-cobalt ore deposit, with an estimated 37 years production life. The Concentrator uses three traditional flocculants, Savofloc P3155, Floxit 9020 and Magnafloc 155 which are in use alternatively on both the concentrates thickener and the tailings thickener to enhance the solid-liquid separation in the dewatering

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section. Recently, LMC has embarked on a campaign to increase its total production capacity by increasing its throughput at the concentrator from 2400 tph to an average of 3800 tph without any plant expansion. This increase has reduced the residence time of the slurry in the subsequent unit processes, and has led to more of the fine concentrate particles to reporting to the overflow of the concentrates thickener, resulting in poor overflow clarity.

This work, was therefore, suggested to determine the best flocculant and the appropriate flocculant addition rates to attain the optimum settling rates and reduce on the loss of fine copper concentrate in the overflow. Flocculants are very expensive reagents, hence the need to optimize their consumption and consequently reduce on production expenses.

2. Literature Review.

In mineral processing, solid-liquid separation stages such as thickening of flotation concentrates, recovery of pregnant leach liquors and dewatering of tailings are unavoidable. In most cases, solid-liquid separation is slow and incomplete. The rate of settling of any given particle is dependent upon its size, its density relative to that of the suspending medium, the viscosity of the medium and the interactive forces between this and other suspended particles. To improve the settling rate of finer particles, high molecular weight organic polymers (flocculants) are used to aggregate the suspended particles and cause the efficient separation of the solids from the aqueous suspending medium.

Flocculation can be induced by lowering the surface potential of the particles to be flocculated (Wills; 1988). Increasing the surface potential of the particles induces dispersion. All this can be achieved by adjustment of the pH and by specific ion adsorption. The rate of flocculation is dependent upon the frequency at which the particles encounter one another and upon the probability that their kinetic energy is sufficient to overcome the repulsive electrical energy barrier upon such encounters.

A flocculant may be highly effective on a certain pulp and ineffective on another (Cytec Industries Inc.; 2002). The proper addition rate is also very important to achieve the desired results, hence all flocculants and their addition rates must first be tested.

There are three main types of flocculants, namely; Inorganic flocculants which include compounds such as lime and alum, Natural organic flocculants such as organic compounds like starch and glue and Synthetic organic flocculants which are widely and include synthetic organics such as poly-acrylamides. The flocculants used at LMC are a synthetic long chain poly-acrylamide molecule.

Flocculation using Poly-acrylamide molecules probably takes place in two stages, involving absorption of polymer molecules onto individual suspended particles and results in either the end of the chain being left dangling or loops of the unabsorbed segments sticking out from the particle surface into the medium. In the second stage of process the free ends or loops of the polymer chains contact and absorb onto other suspended particles forming particle aggregates or flocs. Clearly, bridging can only take place with polymers of very high molecular weight which need not carry a charge opposite in sign to that of the suspended particles.

Sedimentation which generally implies the separation of dilute slurries by gravity into clear supernatant liquor and concentrated sediments provides one of the cheapest methods by which solid-liquid separation is achieved.

Sedimentation is most efficient when there is a large density difference between the component liquid and solid. This is always the case in mineral processing where the carrier liquid is water.

The process by which fine particles settle in commercial settling tanks is known as gravitational sedimentation (Enock, 2002). Gravitational sedimentation involves very low shear forces, thus providing good conditions for flocculation of fine particles. The consideration of the resistance to flow of a solid sphere as it settles in a liquid is vital for any theory on sedimentation.

The principle of thickening may be studied on an aqueous suspension of solids in a measuring cylinder. After some time we observe four different layers, practically clear water, a diluted suspension, a more concentrated suspension, and an almost solid cake. We distinguish thickening mechanisms as; Free settling - which refers to the sinking of particles in a volume of fluid which is large, relative to the volume of the particle, hence particle crowding is negligible, Hindered settling - where the effect of particle crowding becomes more apparent and the falling rate of the particles decrease as the system behaves as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid and rejection of water - which leaves an almost solid cake. Hence, the solids concentration in a thickener varies from that of the clear overflow to that of thickened underflow being discharged. In the hindered settling region, the flocs settle to form a loose bed. As the height and weight of this bed increases, water which had been present within flocs, is excluded and oozes upward through the bed. After all the solids have settled by free and hindered settling, further compression of the bed takes place by water exudation, and the volume water content of the bed decreases.

3. Experimental Methodology

The test-works to identify the best flocculant product was conducted on laboratory scale on the Lumwana concentrate, using the three LMC traditional flocculants, Magnafloc 155, Floxit 9020, and Savofloc P3155 from the company.

All Concentrate samples were taken at the same time and stored in tightly shut 10 litre buckets to avoid evaporation and segregation from the final concentrate line before being fed to the concentrates thickener. Part of the samples were put into the oven to dry overnight. A full sieve analysis was done to determine the particle size distribution in the concentrate sample. The pulp density (% solids in slurry) of the sample was determined to be 15% solids using the pulp density scale.

After the samples had been dried overnight, they were subjected to wet screen

0.1 % solution strength for all the given flocculants, a 0.5 grams of each flocculant was weighed and a mixing beaker containing about 200mls of water was prepared. The addition and mixing of the flocculant and water was done in intervals, little by little in such a way that by the time the water reached the 500mls mark, all the flocculant had also been added. This process of flocculant preparation was accompanied with continuous thorough stirring using a magnetic stirrer to aid the dissolution of the flocculant in water. Lastly but not the least, the settling tests were done using 500mls measuring cylinders. The cylinder was calibrated with a seal tape from which the mudline height was obtained in centimeters. The pulp in the cylinder was first homogenized by turning the cylinder up-side-down, 8 times to eliminate segregation of the slurry. The prepared 0.1% flocculant solution was then quickly added to the pulp in the cylinder and the suspension agitated by turning the cylinder up-side-down 3 times. The suspension was then put to settle and the stop watch started simultaneously. The mudline height was noted at different time intervals.

The above settling procedure was repeated for all the flocculants at the various dosages of 10, 15, 20, 30 and 40g/t.

The effects of the flocculation characteristics of solids suspended in a medium, such as pH of the suspension, temperature, pulp density (% solids), viscosity of the medium were all kept constant and only the flocculant type and the dosages were varied.

4. Results and Data Analysis

4.1 Sieve Analysis Results

Figure 1 shows the relationship between cumulative % passing and sieve size.

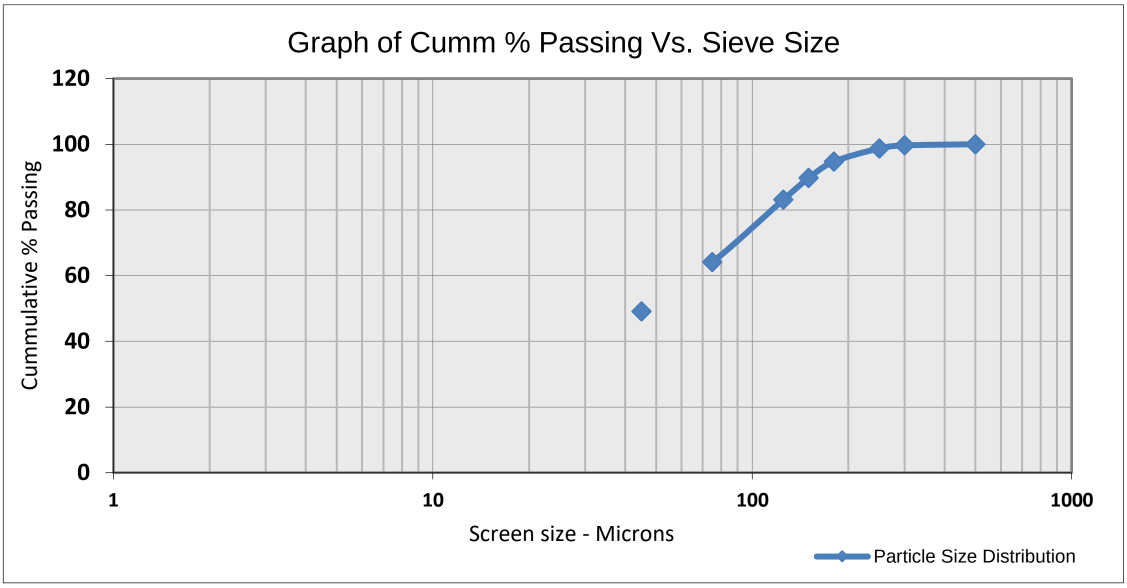

Figure 1: Particle size distribution of the concentrates thickener feed.

The particle size distribution of the concentrates thickener feed was wide, ranging from slightly above 300 µm to below 45 µm and giving was observed that 80% of the thickener feed passed at 125 µm sieve size (P_{80} of 125 µm).

4.2 Graphs Showing Settling Characteristics

From the numerical data collected and recorded in the laboratory, graphs of mudline height (cm) against time (sec) were drawn as shown below. Detailed tables of results are listed in the appendix.

4.3 Optimization of Savofloc P3155

From Figure 2 above, it can be observed that from 15g/t onwards, as the dosage of Savofloc P3155 increases there is no improvement in the settling characteristics. Therefore 15g/t dosage of Savofloc P3155 is the optimum settling dosage. But even though the settling characteristics were optimum at 15g/t, the clarity of the liquid was still very poor.

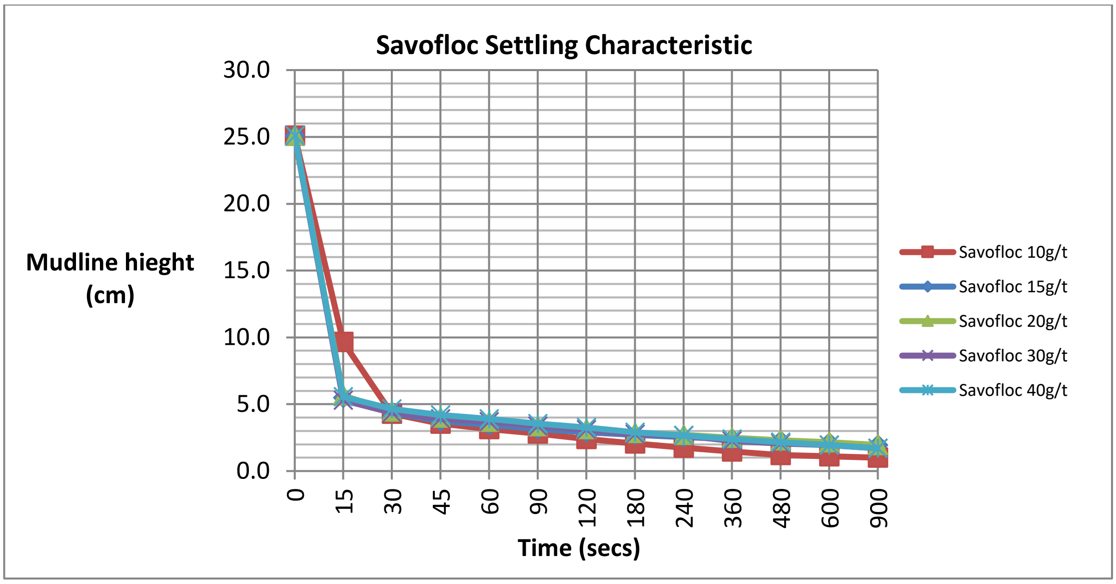

Figure 2: Effect of Savofloc P3155 on the settling characteristics of the concentrate.

4.4 Optimization of Floxit 9020

From Figure 3 above, again it can be seen that from 15g/t, any increase in the flocculant dosage results in no improvement in the settling characteristics of the concentrate. Therefore Floxit 9020 has an optimum settling dosage of 15g/t. The clarity of the liquid at the dosage was still not good enough.

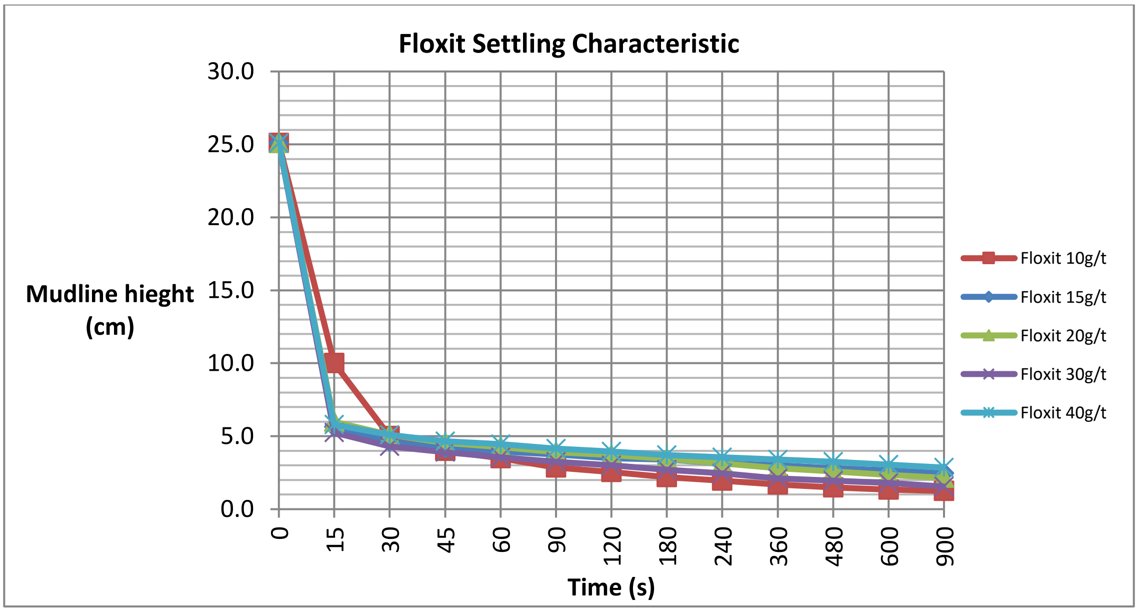

Figure 3: Effect of Floxit 9020 on the settling characteristics of the concentrate.

4.5 Optimization of Magnafloc 155

In the Figure 4, the settling characteristic of the concentrate does not improve after the 20g/t dosage of Magnafloc 155. Therefore the optimum settling dosage of Magnafloc 155 is determined to be 20g/t. It was also observed that at this dosage Magnafloc exhibited high levels of clarity of the supernatant liquid.

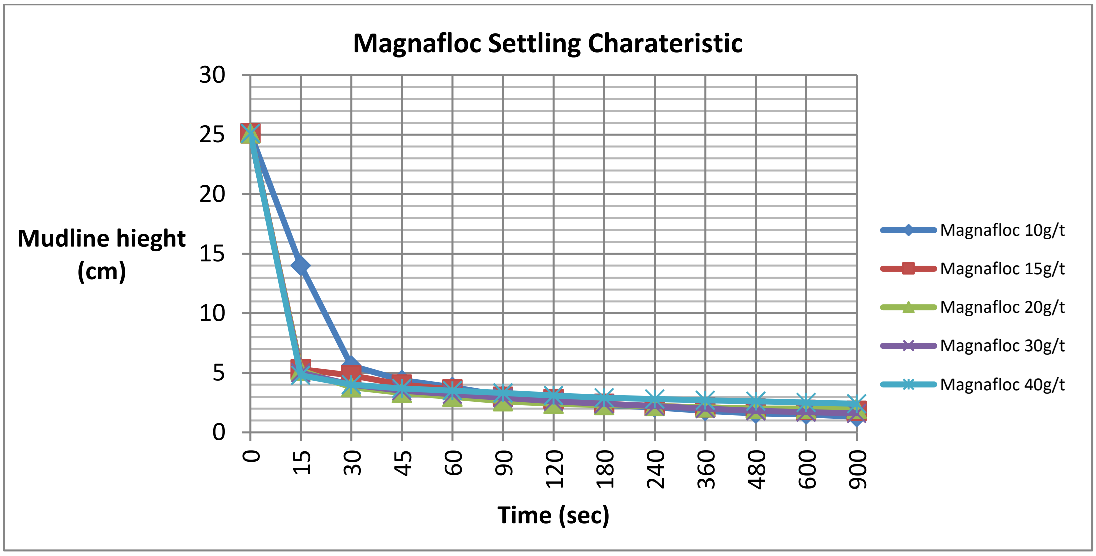

Figure 4: Effect of Magnafloc 155 on the settling characteristics of the concentrate.

4.6 Determination of Optimum Settling Dosages

From the graphs presented in the preceding sections, the optimum settling dosages of the different flocculant products was determined and can be summarized in one graph as shown below.

From the nature of the curves in Figure 5, it can be seen that Magnafloc 155 gave the most optimum settling characteristics of the concentrate.

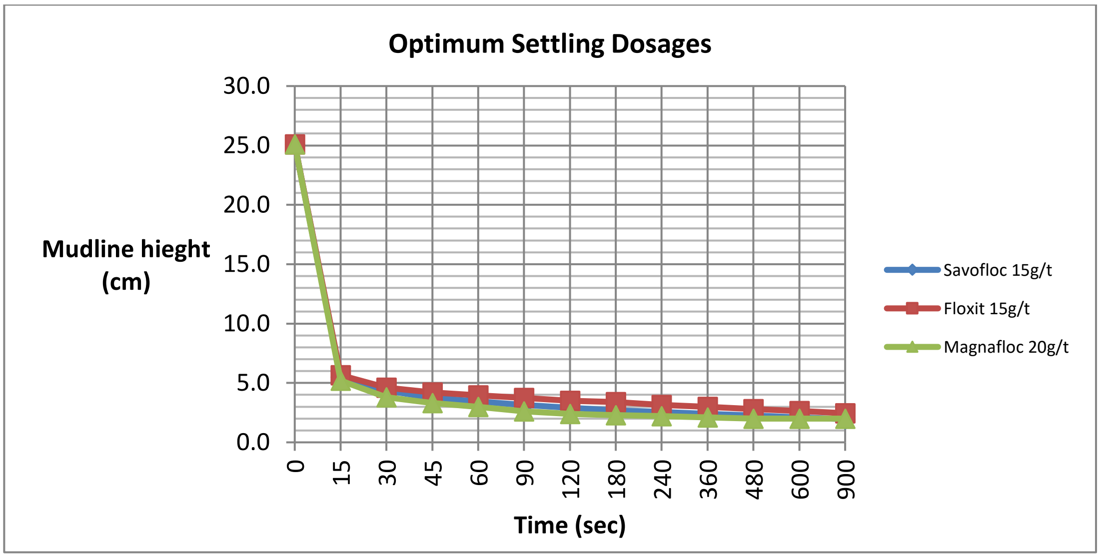

Figure 5: Settling characteristics of the concentrate at the optimum settling dosages of the three flocculant product.

4.7 Determination of Optimum Clarity Dosages

Figure 6 gives photographic figures showing the clarity of the supernatant liquid obtained after settling of the particles flocculated at the optimum settling dosages.

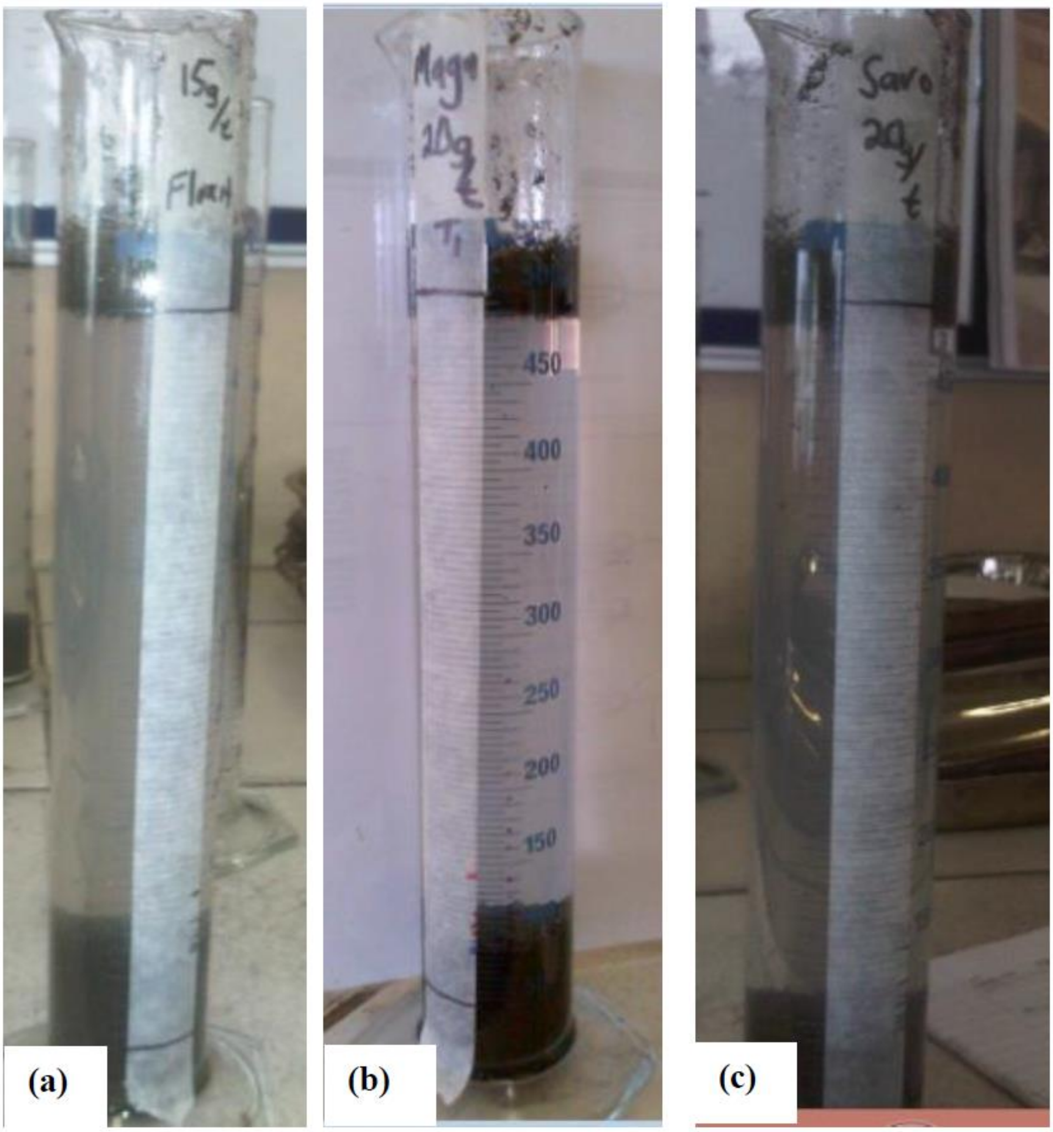

Figure 6: Clarity profiles of the supernatant liquid at the Optimum settling dosages. (a) 15g/t of Floxit, (b) 20g/t of Magnafloc and (c) 15g/t of Savofloc

It was observed that at the optimum settling dosage, only Magnafloc 155 exhibited a good clarity of the supernatant water. Savofloc P3155 and Floxit 9020 had poor clarity of the supernatant water at the optimum settling dosages.

Figure 7 shows another set of cylinders indicating clarity obtained at different dosages of which by inspection, were established to be the optimum dosages with reference to clarity. The method of inspection was adopted to determine best clarity because the equipment for the determination of clarity using the Total Suspended Solids (TSS) method was not operational.

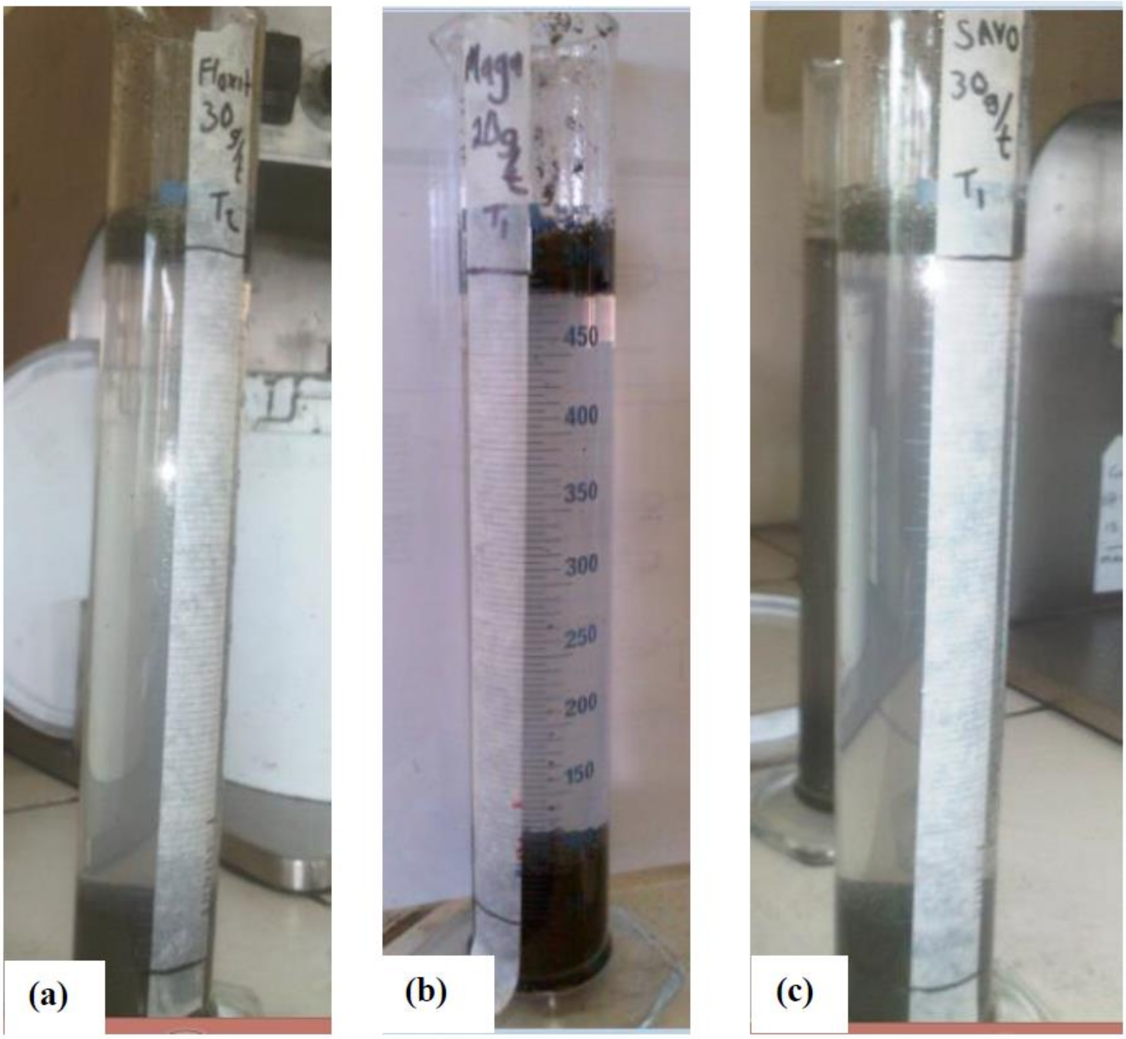

Figure 7: Clarity profiles of the supernatant liquid at optimum clarity dosages. (a) 30g/t of Floxit, (b) 20g/t of Magnafloc and (c) 30g/t of Savofloc

Best clarity of the supernatant water was obtained at dosages of 30 g/t for Savofloc P3155 and Floxit 9020. Magnafloc 155 showed best clarity at 20 g/t. These were established as the optimum clarity dosages.

4.8 Cost Analysis

The different types of flocculants had different costs associated with each of them. Table 1 shows the relative costs of the three flocculants.

Table 1: Relative Costs of the different Flocculants

Flocculant Type	**Cost (ZR/tonne)**
Savofloc P3155	19,661.20
Floxit 9020	16,302.00
Magnafloc 155	20,739.84

During the time of doing this work, LMC concentrator was operating at an average plant throughput of 3800 tph. Taking this a reference throughput, the concentrates thickener operated at a throughput of 3648 tph (96 % of plant throughput).

4.9 Costs In Relation To Optimum Settling Dosages

Figure 8 below shows the relative consumptions and costs of flocculant per month of operation if the plant operated at the optimum settling dosages of 15 g/t for Savofloc P3155 and Floxit 9020, and 20 g/t for Magnafloc 155 respectively.

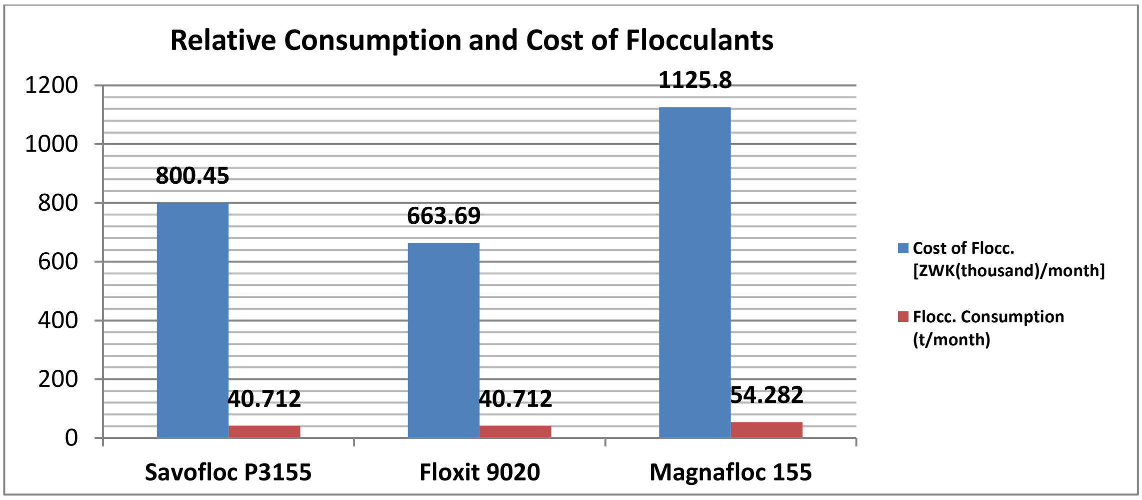

Figure 8: Relative Consumptions and Costs at Optimum Settling Dosages

From Figure 8 above it can be seen that the monthly consumption of 54.282 tonnes for Magnafloc 155 would relatively be higher than that for Savofloc P3155 and Floxit 9020, both of which would be consumed at 40.712 tonnes per month.

4.10 Cost In Relation to Optimum Clarity Dosages.

Figure 9 shows the relative consumptions and costs of flocculant per month of operation, if the plant ran at the optimum clarity dosages 30 g/t for Savofloc P3155 and Floxit 9020, and 20 g/t for Magnafloc 155 respectively.

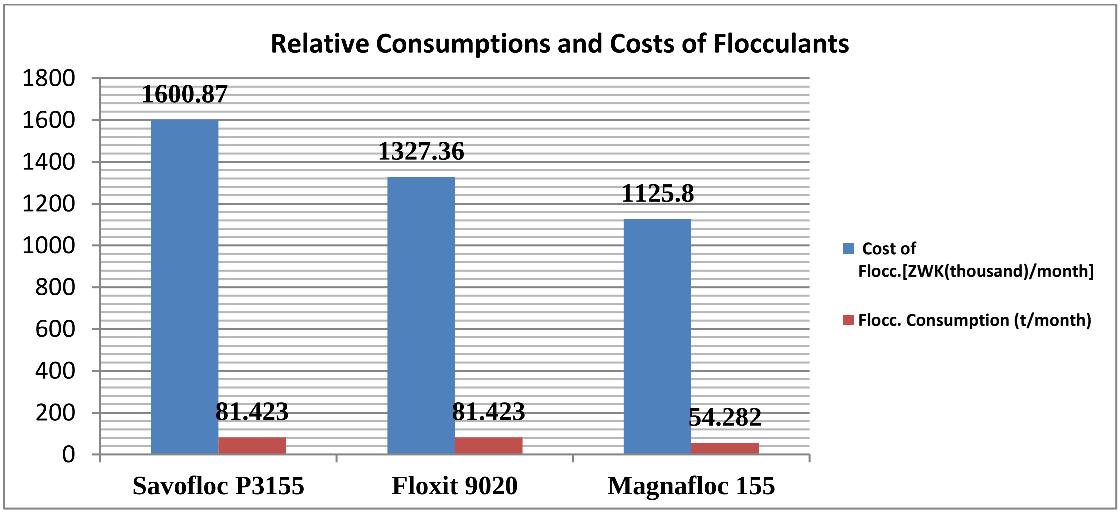

Figure 9: Relative Consumptions and Costs of Flocculants at Optimum Clarity Dosages

From Figure 9 above, it can be seen that at optimum clarity dosages, the monthly consumption of Savofloc P3155 and Floxit 9020 increases to 81.423 tonnes, surpassing that for Magnafloc 155 as 54.282 tonnes monthly.

5. Discussion.

The particle size distribution of the concentrates thickener feed was wide, with particles ranging from slightly above 300 µm to below 45 µm. Sieve analysis showed that 80% of the thickener feed passed the 125 µm sieve size (P_{80} of 125 µm). Performance of two flocculants, Savofloc P3155 and Floxit 9030 were consistent, both showing best settling characteristics at about 15 g/t dosage, though it was also observed that the clarity of supernatant liquid for both Floxit and Savofloc flocculated suspensions at this dosage was poor, as can be seen in Figure 6, (a) and (c) respectively.

In Figure 4, the settling characteristics of the suspended particles in the presence of Magnafloc 155 gave a dosage of 20 g/t for Magnafloc 155, for the best settling characteristics of the suspended solids with a fairly the good clarity of the liquid.

Furthermor, increase in the dosages of the two flocculants, Savofloc and Floxit did not enhance the settling characteristics of the flocculated suspensions, but an increase in the clarity of the liquid was observed. At 30 g/t, the best clarity of the liquid was observed for both Savofloc and Floxit, and this was comparable to the clarity of the liquid observed for Magnafloc at 20 g/t as can be seen in Figure 7.

The optimum settling dosages were found to be 15 g/t for both Savofloc P3155 and Floxit 9020, and 20 g/t for Magnafloc 155. The optimum settling dosages of the three flocculants were compared as shown in Figure 5. The settling characteristics of Magnafloc 155, was observed to be the best settling characteristics, hence was established to be the most suitable of the three flocculants in so far as settling characteristics are concerned. During the time the project was being conducted, LMC concentrator was operating at an average plant throughput of 3800 tph. Taking this throughput as a reference, we had the concentrate thickener operating at a throughput of 3648 tph (96% of plant throughput). Cost analysis of the flocculant consumptions, if the plant ran at optimum settling dosages as shown in table 2. This indicate that, employing the optimum settling dosages would give a monthly consumptions of 40.712 tonnes for Savofloc P3155 and Floxit 9020, and 54.282 tonnes per month of Magnafloc 155.

This would translate to a monthly operating cost of ZRW 800,446.77, ZWK 663,687.02 and ZWK 1,125,799.99 for Savofloc, Floxit and Magnafloc respectively. From this analysis, Floxit proved to be most economical, seconded by Savofloc and lastly Magnafloc.

But note that the clarity of the liquid, particularly for the Savofloc and Floxit flocculated suspensions leaves much to be desired, before the second specific objective can be achieved, as can be seen in Figure 6. The optimum clarity dosage for both Floxit and Savofloc was determined to be obtained at 30 g/t as can be seen in Figure 7. Magnafloc had its best clarity obtained at 20 g/t dosage.

Therefore, it was established that the overall optimum dosages of the flocculants were 30 g/t for Floxit and Savofloc, and 20 g/t for Magnafloc because at these dosages, both the settling rates of the suspended solids and the clarity of the supernatant water were optimized.

Finally, cost analysis of the flocculants' relative consumptions, if plant operated at the average throughput of 3800 tph and overall optimum dosages as shown in table 3. Monthly consumption of both Floxit and Savofloc would stand at 81.423 tonnes, translating to ZWK 1,600,873.89 and ZWK 1,327,357.75 for Savofloc and Floxit respectively. Monthly consumption of Magnafloc would still stand at 54.282 tonnes, translating to ZWK 1,125,799.99. From this analysis, Magnafloc proved to be the most economical, seconded by Floxit and lastly Savofloc.

Therefore it was established that Magnafloc 155 was the best flocculant product because at 20 g/t it exhibited the best overall settling characteristics, the best possible clarity of the supernatant liquid and was the most economical at achieving these specific objectives.

6. Conclusions

From the analysis and observations of the investigation results, it was determined that the overall optimum flocculant dosages that showed both, a high settling rate and best clarity of supernatant water for the three flocculants were 20 g/t for Magnafloc 155 and 30 g/t for both Savofloc P3155 and Floxit 9020.

It was also determined that Magnafloc 155 was the best flocculant because at it's overall optimum dosage of 20g/t, it exhibited the highest settling characteristics among the three flocculant, the best clarity of supernatant water and the lowest monthly consumption of 54,282 tonnes, as compared to 81,423 tonnes of both Savofloc P3155 and Floxit 9020. This gave the most cost effective flocculant with the lowest monthly operation cost of ZWK 1,125,799.99 as compared to ZWK 1,327,357.75 and ZWK 1,600,873.89 for Floxit 9020 and Savofloc P3155 respectively.

7. Bibliography

Enock, M. C. (2002). Investigation into Flocculants, Type and Consumption in the TLP dewatering Process.

Jain, S. K. (2001). Mineral Processing. CBS Publishers and Distributors, 2nd Edition.

Kaonda. (2011). Course Notes MM442- Hydrometallurgy. Lusaka: Department of Metallurgy and Mineral Processing.

Services, C. T. (2002). Mineral Chemicals. Cytec Industry Inc. Reversed Edition.

Siame, E. (2011). Course Notes MM441- Mineral Processing I. Lusaka: Department of Metallurgy and Mineral Processing.

Wills, B. A. (1988). Mineral Processing Technology. Pergamon Press, 4th Edition.

Witika, L. K. and E. Mwanza, (2013)Evaluation of High-Rate Thickener performance at Konkola concentrator of Konkola copper Mine, Plc. Lusaka: Abstract, School of Mines Symposium, 2013..

Innovation and Modernization of the South African Mining Industry

Steven M. Rupprecht[1] and Antoine F. Mulaba-Bafubiandi

Abstract

In June 2016, the Southern Africa Institute of Mining and Metallurgy (SAIMM) held a colloquium in Johannesburg South Africa of which the the purpose was to create a dialogue between industry, government, research institutes and academia in the area of new technology and innovation. One of the key findings presented at the colloquium was the Chamber of Mines (COM) study indicating that the South African gold reserves dependent upon conventional mining methods will be depleted by 2031 with Platinum Group Metals (PGM) reserves signaling a similar fate.

The South African industry considers mechanization, automation and continuous mining operations as critical to extend gold reserves beyond 2046 or in the case of PGMs to 2042. To date, mechanization, automation and continuous mining in the gold and platinum environments has had limited success in the South African mining industry, generally achieving lower than planned productivity at higher than budgetted costs. Thus, the development of innovative mining systems based on new technology is critical for the continuance of the South African mining industry.

This paper discusses the strategies and research initiatives required to support a mining industry beyond 2040 and investigates the role that innovation will play in sustaining a mining industry that is currently in decline.

Keywords: Mining industry, mining research and innovation, new technology

1. Introduction

Mining in general, and South African hard rock mining in particular, is associated with risk. Narrow reef mining entails risk from fall of ground, seismic events, fires, and other hazards to the mineworker via the actual mining process. However, another risk which is influencing the South African mining industry is the every apparent risk of mine closure due to economic factors or social and statutory constraints. These concerns affect the entire spectrum of employment in the mining industry from the general labourer to top management; from students just entering university studies in the field of mining to mineworkers with decades of experience; from surface operations exploiting coal and iron ore to underground gold, PGMs, chrome, and manganese operations.

In the past, labour was inexpensive and plentiful, and combined with the narrow nature of the orebodies, this led to labour-intensive mining methods (Figure 1). Many of the deposits were shallow and conducive to short travelling distances and high productivity. This is no longer the case – the reality is medium- to deep-level mining that involves travelling through two or three shaft systems with working face times often less than four hours per shift.

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The industry has attempted to mechanize the South African narrow-reef environment – in the late 20th century in the gold mines and since the 21st century for the platinum industry. The former initiative largely failing due to the increase in dilution and the subsequent reduction of the head grade and the current initiative making some progress but not conclusively successful (*e.g.* Lonmin's experience). The implementation of mechanization in the narrow-reef environment requires favourable geology with upto 50% of the mineral resources being unsuitable for mechanized mining systems (Rupprecht and Rapson, 2004) and the mechanized mining systems requiring a considerable amount of capital.

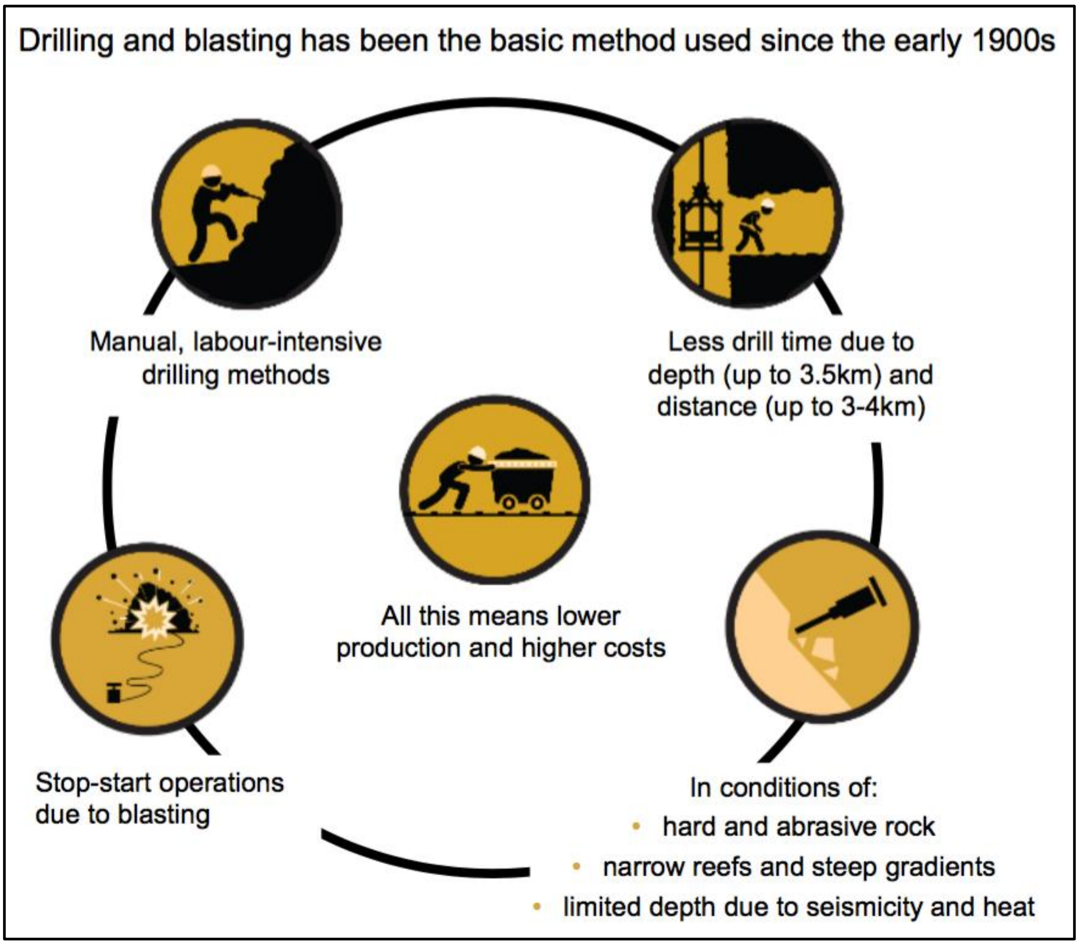

Figure 1. Traditional Conventional Mining Method (Macfarlane, 2016).

These concerns are in context with a labour force that is highly unionized with demands for significant increases in wages; a regulatory environment that is often viewed as over-zealous in regard to safety stoppages and social and community responsibility; and a business environment lacking sufficient power infrastructure, where many new mines are coming on line (for example the eastern and northern limbs of the Bushveld Complex) combined with double digit annual increases for electricity tariff and diesel for a number of years (Figure 2). All of these issues are combined with concerns such as the future availability of water and changing of the environmental regulations.

The view of the authors is that the South Africa mining industry as we now know it will be finished within the next 15 to 20 years if significant changes are not made with immediate effect. The South African mind-set must change – unfortunately, too many affected people still consider the South African mining industry as an industry provided with cheap labour, noting that labour equates to 50% to 60% of the on-mine mining costs.

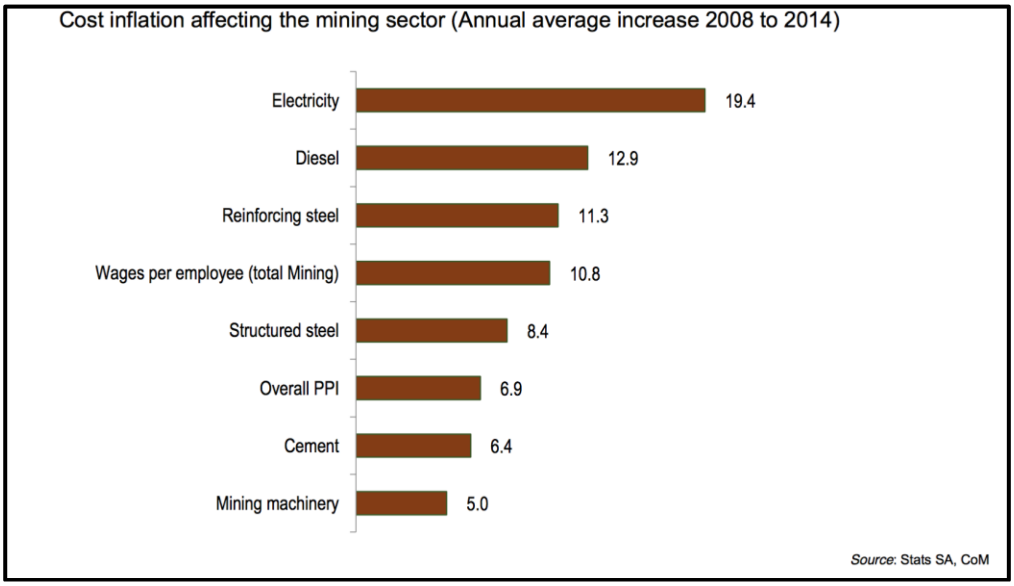

Figure 2. Cost inflation affecting the mining sector (annual average increase 2008 to 2014) (COM, 2015).

Figure 3 illustrates the decline of the South African mining industry since 1980. As can be seen, the gold industry accounted for over 60% of all mining-related employment in the early and mid-1980s. Currently, gold represents just over 20% of the employment for the South African mineral industry, with PGMs employing the larger proportion of mineworkers. More importantly, Figure 3 demonstrates the decline of the industry with direct mining-related employment steadily decreasing from 800 000 in the 1980s to 495 000 in 2014.

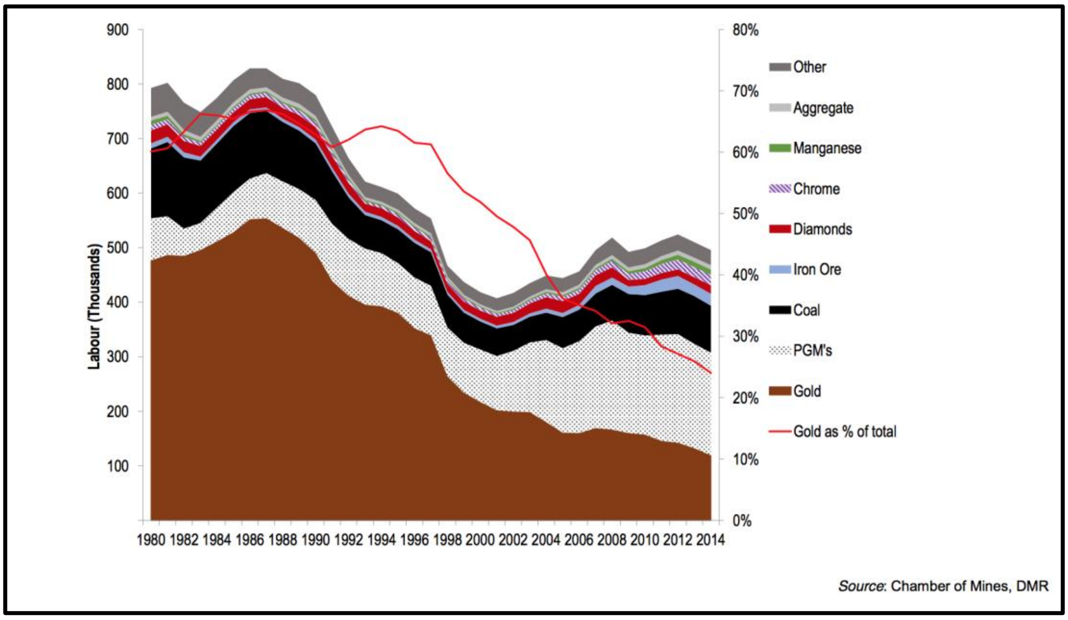

Figure 3. Direct employment in the South African mining sector (COM, 2015).

Figures 4 and Figure 5 depict the results of a recent South African Chamber of Mines study and presented by Turner indicating the tonnages to be mined from South African gold and platinum mining companies based from conventional, mechanised and continuous (24/7 mechanised) mining operationson. These figures indicate that by 2025 gold tonnage sourced from conventional mining will largely be depleted; similarily platinum tonnages sourced from conventional drill and blast operations will be exhausted in 2015. The report suggests that through the continued implementation of mechanised mining, these reserves, both gold and PGMs, can extend beyond 2035 and with continuous operations mining should be able to continue beyond 2040.

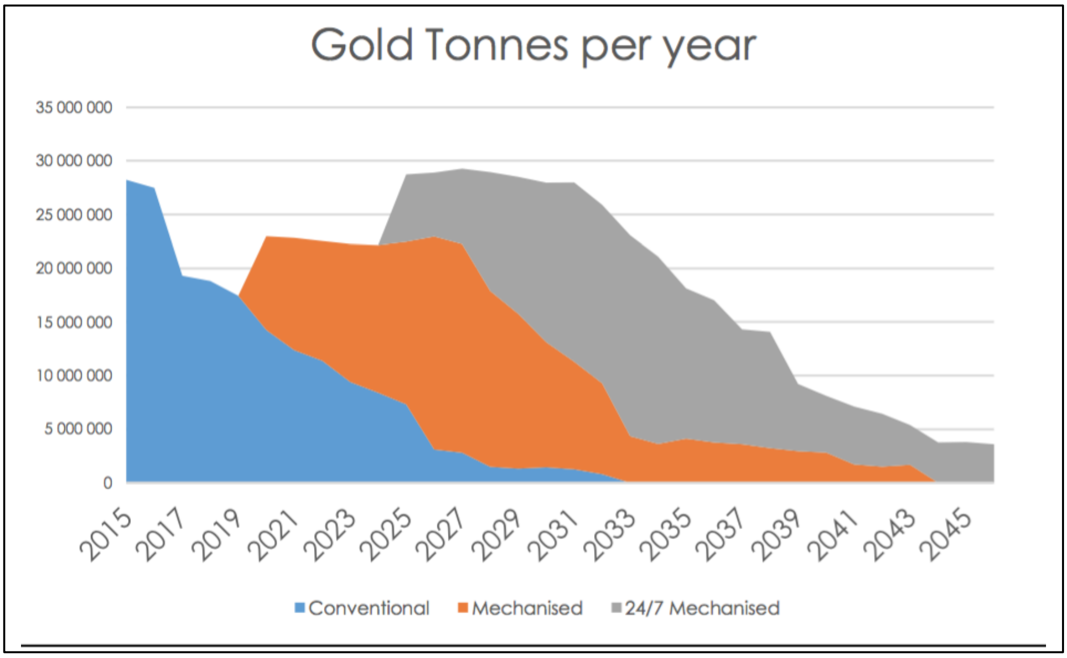

Figure 4. Gold tonnes mined per year based on mining method (Turner, 2016).

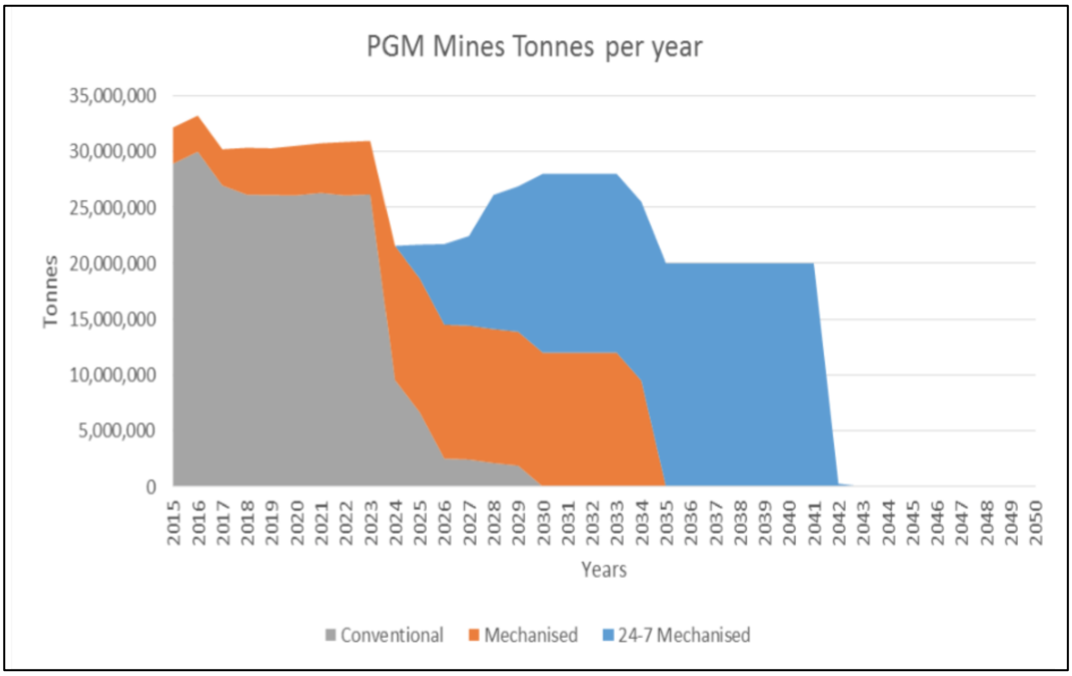

Figure 5. PGM mined tonnes per year based on mining method (Turner, 2016).

The above discussion has painted sombre picture of the mining industry. Regrettably this picture is further reinforced by the fact that productivity (gold and PGMs), as shown in Figure 6, has reduced to its 1990 levels, indicating a stagnant (2000) and even negative trend (2006) in productivity.

The picture is clear – the South African mining industry, even with the commodity boom of the early 21st century, is shrinking and does not present a picture of health or vibrancy. The data referred to does not take into account the major challenges of 2015 and 2016, where further mine closures and retrenchments have taken place in many of the South African mining commodities, for example iron ore, PGMs, manganese, and coal.

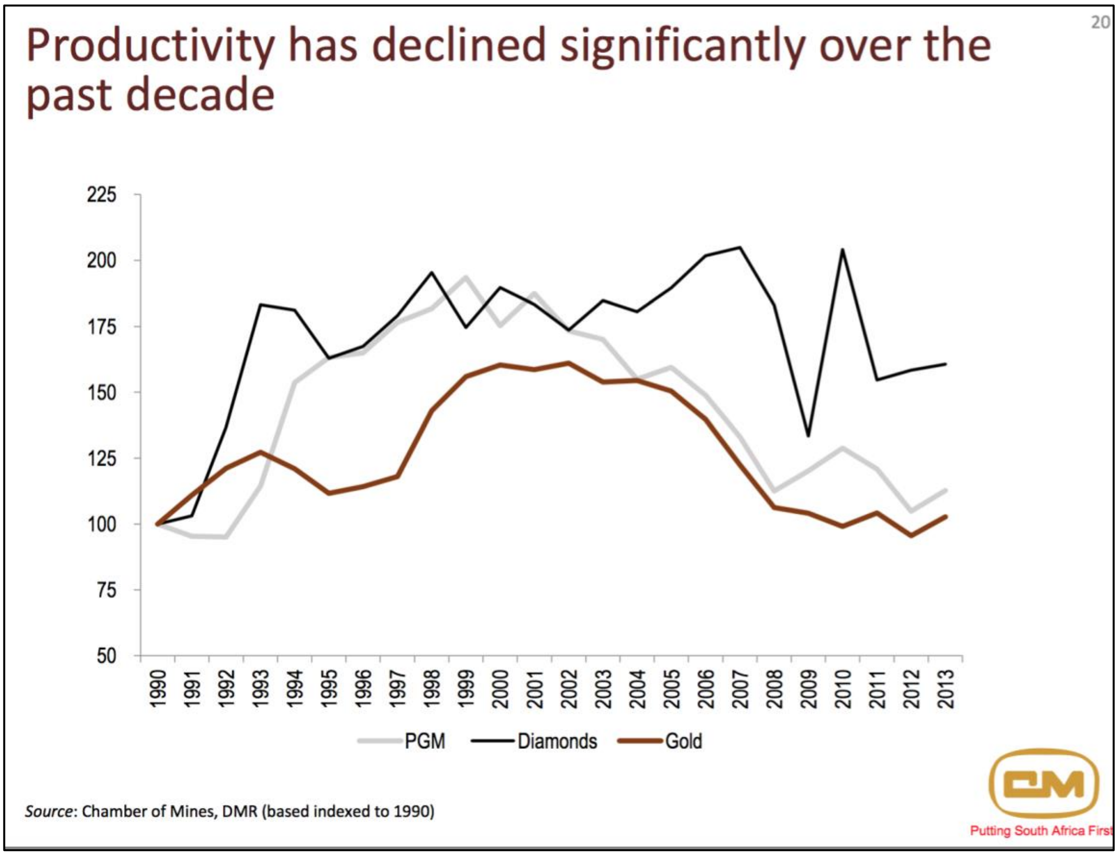

Figure 6. Productivity in the South African mining sector (COM, 2015).

2. Innovation and Modernization

2.1 Historical Background

The Witwatersrand Chamber of Mines, which subsequently became the Chamber of Mines of South Africa, was established in 1887 to create an organization that could publish information on the Witwatersrand gold mines. In 1962, the Chamber of Mines recognized that there was a need to create a centre for mining research excellence that could assist the gold mining industry. This led to the establishment of Chamber of Mines Research Organisation (COMRO) in 1964, which carried out research in a collaborative basis on behalf of gold mines that were members of the Chamber of Mines. In 1966, after the Coalbrook colliery disaster, where 435 miners died, COMRO was extended to include the South African collieries. In the late 1980s there was a reduction in funding for research, thus limiting mining-related research which ultimately lead to COMRO being taken over in 1992 by the Council of Science and Industry Research (CSIR) – the government statutory research council – and the COMRO unit was renamed Miningtek. After 1992, Miningtek undertook research for individual/group mines on an elective or needs basis, including the platinum mining industry. Also during this period much work was undertaken by Miningtek in the area of health and safety through the Safety in Mines Research Advisory Committee (SIMRAC).

1998 saw the introduction of the DeepMine Collaborative Research Programme, which was developed to investigate technologies to allow gold mining to proceed between 3000 m and 5000 m. The DeepMine Collaborative Research Programme continued until 2002 and was followed by the FutureMine Collaborative Research Programme, which investigated improvements in productivity and reduced mining costs. Based on the success of the DeepMine programme, the CoalTech 2020 and PlatMine collaborative research programmes were launched. However by 2005, with the exception of CoalTech 2020, the period of collaborative research was over.

Since the late 1980s mining research has been sporadic with much work having been done in safety and health issues (SIMRAC) with a brief period when the DeepMine Collaborative Research Programme produced over 100 reports to support deep-level gold mining. Although the DeepMine research programme strove to transfer the knowledge produced – 'research reports being the primary product of DEEPMINE' (Durrheim and Diering, 2002) – the author has observed numerous examples of mine studies and other research work duplicating work already conducted by DeepMine or the other collaborative research programmes. Regrettably, many of these mines are owned by companies that did not belonged to the colloborativeresearch programmes, and in other cases participating groups have failed to fully disseminate this knowledge to all operations and therefore research work is often being repeated.

Going forward, any new research innitiative must take stock of the current research knowledge base to ensure fundamental work is not duplicated. Furthermore, critical to the success of research iniatives is a comprehensive method of distributing the results and finding of all research.

2.2 Mechanization

Narrow reef mechanization is critical and one only needs to review the six SAIMM International Platinum Conferences from 2004 until 2014 to understand the volume of work that has gone into introducing mechanization to the southern African platinum industry (Figure 7) . One cannot raise the issue of mechanization in the platinum industry without discussing Lonmin and its 2004 vision to achieve 50% of reef production and 100% for development metres by 2010 using mechanized mining methods (Webber *et. al*., 2010). The actual level of mechanization achieved in 2010 was only 20%. The Lonmin mechanization programme failed to meet its target with equipment underperforming, difficulties in regard to labour and supervision, and mining dilution higher than planned due to the size of on-reef developmnt and the inability of the extra-low profile (XLP) equipment to handle rolls in the reef. Thus, Lonmin changed its strategy, deciding that mechanized mining utilizing the XLP equipment needed to be proved on a smaller scale before implementing it mine-wide.

Mechanization is a non-debatable area requiring further research, innovation, and development. Probably the biggest shortcoming with the development of mechanization has been the inability of the industry to manage this in a collaborative manner. There has been too much duplication between mining groups, a lack of proper documentation and a reliance on original equipment manufacturers to develop the equipment. A strong requirement is for the local manufacturing of mobile equipment, focused primarily on the southern African underground mining environment. There is a need to apply relevant industrial engineering principles to the mining industry while still being cognisant that mining is not a factory as inputs (*i.e*. the mining work environment) change on a regular basis, requiring workers and supervisors to readily adapt as and when required. Importantly, primary research must also be conducted by dedicated researchers having the proper experience and skills – this in itself offers challenges to the required change process.

2.3 Continuous operations

Continuous mining (24/7 mechanised mining) is an initiative in narrow vein stoping to achieve increased production by applying low amounts of energy to the drill hole to break rock (Figure 8). If successful, continuous mining potentially offers a quantum leap in face advance when compared with conventional mining methods. Thus, the success of a continuous mining system could have a huge impact on the South African mining industry.

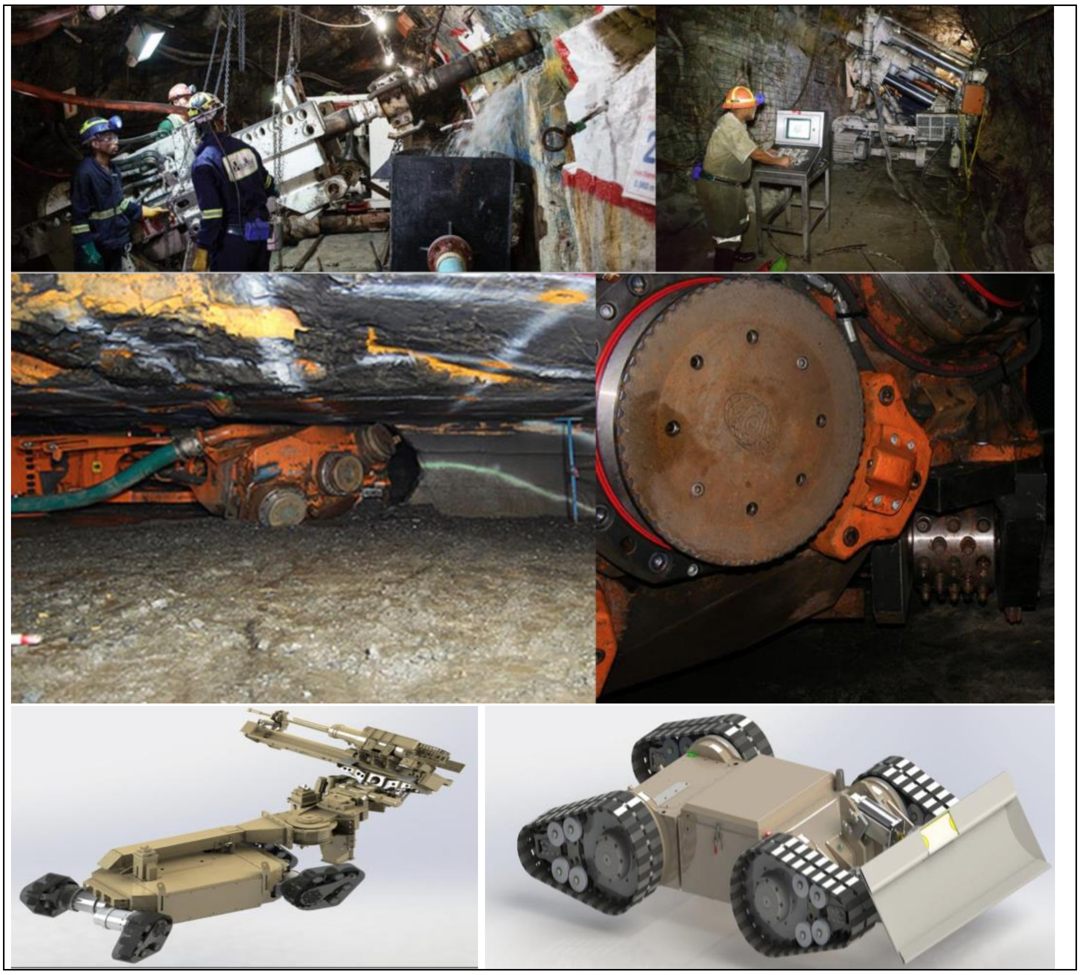

Figure 7. Examples of Current and Envisaged Mechanization.

Continuous mining offers the possibility of stoping continuously throughout the 24 hours, and monthly face advance in excess of 40 m. Traditionally research has focused on the actual breaking of the blast hole (i.e. the micro process) and achieving acceptable emission levels. At this stage continuous mining appears to be applicable to stope layouts including down dip, up dip, and breast, with mining face lengths between 30 m and 90 m. To ensure accuracy, holes should be drilled utilizing stope drill rigs with low profile dozers to remove the broken rock from the stope face (Figure 9). Research on continuous mining has largely been dormant since around 2003. At the time continuous mining failed to consistently and repeatedly break rock utilizing low energy charges. Further concerns were the levels of noxious fumes and dust generated by low energy charges. If the above technical issues can be resolved, there remains the issue of the feasibility of continuous mining as a rock breaking system, as indications are that the process is considerably more expensive than conventional blasting.

3. Conclusion

The need for change has been around for a long time combined. The COMRO conducted research on proposed change in the 1980s. Hustralid and Nilsson in 1998 discussed technology development as a function of time, with Pukkila and Sarkka (2001) illustrating the development steps towards the intelligent mine. In 1998, the South African gold mining industry (AngloGold, GoldFields and DRD) established the DeepMine Research Programme, which was followed by Futuremine, Platmine and CoalTech 2020 in the early 2000's. In 1998, Bobby Godsell, the Chief Executive Officer of AngloGold commented on the transformation of mine labour:

‘*Work structures have remained remarkably unchanged for many decades because of static technology, the impact of apartheid, and the previously closed nature - in times past - of the South African economy*.’ (Godsell, 1998).

Figure 8. Continuous Mining – Control Foam Injection (Pickering and Young, 2016)

In 2001, the implementation of new technology is explained in MacFarlane’s SAIMM Journal paper: ’The implementation of new technology in southern African mines: pain or panacea’ (MacFarlane, 2001). And some 15 years on, the mining industry is at a cross roads either to develop solutions to extend the life of mines beyond 2040 or to contiunue in its current path resulting in the South African mining transforming into a insignificant producer of gold and PGM metals.

This paper discussed the justification for the mining industry to make significant advancements in the way it conducts mining. The industry must ’leapfrog’ the current mind-set of conventional mining. Advances in technology, namely mechanization and continuous mining, are proposed as a means to extend South African gold and platinum mineral reserves beyond 2040.

Fundamental to the South African mining industry is the development of mechanised and continuous mining. Crucial to this research is the basic understanding that meaningful research takes time and it may take several years before the industry sees applicable results. A good analogy may be the growing of an olive orchard, which may take five to 12 years before first fruiting. Key to the success will be the transfer of knowledge to the mining industry.

In conclusion, the mining industry must embrace change and recognize the need for meaningful change. Only visionary thinking, hard work, and commitment from all interested and affected parties will enable the industry to navigate through these troubled times and create a sustainable industry that will continue past 2030.

References

Chamber of Mines South Africa (COM). (2015). Overview of the South African Mining Industry. Cape Town Mining Indaba, February 2015

Durrheim, R.J. and Diering, D.H. (2002). The transfer of knowledge produced by the DEEPMINE Research Programme: a critical evaluation. *Journal of the South African Institute of Mining and Metallurgy*, 102 (5), 261–267.

Godsell, B. (1998). South Africa: the world’s largest gold producer: Prospects beyond 2000. AngloGold.

HUSTRALID, W.A. and NILSSON. J.O. Automation and productivity increases at LKAB, Kiruna, Sweden; Proc. CMMI Congress, Montreal, 1998.

Macfarlane, A.S. (2001). The implementation of new technology in southern African mines: pain or panacea. *Journal of the South African Institute of Mining and Metallurgy,* 101 (3), 115.

Macfarlane, A.S. (2016). Moving to next generation mining system: A Chamber of Mines View. *New technology and innovation in the Minerals Industry Colloquium*. Southern African Institute of Mining and Metallurgy, Johannesburg. 9 -10 June 2016.

Pickering. R., and Young. C. (2016). Controlled Foam Injection: A New and Innovative Non-explosive Rockbreaking Technology to Replace 'Drilling and Blasting' in Mining. *New technology and innovation in the Minerals Industry Colloquium*. Southern African Institute of Mining and Metallurgy, Johannesburg. 9 -10 June 2016

PUKKILA, J. and SARRKA, P. Intelligent Mine Technology Program and its implementation; Proc. Massmin 2000, Brisbane 2000.

Rupprecht, S. and Rapson, G. (2004). Long hole drilling for the platinum industry – a mining perspective. *International Platinum Conference, 'Platinum adding value'.* Southern African Institute of Mining and Metallurgy, Johannesburg. Symposium Series S38

Turner. P. (2016). Value creation through moderisation of South Africa's Mining Industry. *New technology and innovation in the Minerals Industry Colloquium*. Southern African Institute of Mining and Metallurgy, Johannesburg. 9 -10 June 2016

Webber, G., Van Den Berg, A.A., Le Roux, G.G., and Hudson, J.H.K. (2010). Review of mechanization within Lonmin. *Proceedings of the 4th International Platinum Conference, Platinum in Transition 'Boom or Bust'*. Southern African Institute of Mining and Metallurgy, Johannesburg.

Lessons Learnt in the Operation and Management of Mpanta Solar Mini Grid in Samfya District

Patrick Mubanga

Abstract[1]

Rural Electrification Authority (REA) uses various technologies to electrify the rural areas such as grid extension, mini hydro and solar power. The development of the 60kW Mpanta Solar Mini Grid in Samfya District is an attempt by REA to industrialize the Mpanta Rural Growth Centre.

The sustainability of the plant in terms of operation and maintenance is currently managed by Kafita Cooperative Society which is under a 4 year MOU with the REA. The installed power capacity of the station is 60kW which is generated from an array of Photovoltaic modules to supply the Mpanta community within the catchment area of radius of 1.5km. The project was implemented at a cost of K13million over a period of two (2) years. The load centres of the power plant include 480 households, school, a clinic and 10 shops at a local market (REA, 2013).

The purpose of this paper is to provide an overview of lessons learnt over the 4 years that the plant has been operating in terms of the sustainability and efficiency of the plant. The paper therefore brings out lessons that could be used as a platform for implementation of future mini grids which are categorised under the following themes: Lighting is not the only power requirement, Appreciation of renewable energy, Prepaid meters versus load limiters, Payment models, Quality after sales service is essential, Dedicated project personnel, Beyond education, products must be designed to prevent tampering, Anchor loads, Willingness to pay, and Partnership in the management of the plant

Based on the lessons that have been learnt over the 4 year period, it is critical that a number of factors are necessary for the successful implementation of off-grid projects.

Keywords: Grid extension, Mini hydro power, Rural Growth Centre, Solar Power and Industrialisation

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1.0 INTRODUCTION

1.1 Background

The Rural Electrification Act No. 20 of 2003 established the Rural Electrification Authority (REA) and the Rural Electrification Fund (REF). According to the Act, the Authority administers and manages the REF which it uses to implement the rural electrification programme. The overall mandate of REA is to provide electricity infrastructure to rural areas using appropriate technologies such as grid extension, mini grids systems i.e. solar and hydro, stand-alone solar systems in order to increase rural electricity access rate and contribute to improved productivity and quality of life for the rural population (REA, 2013). Some of the functions of the Authority as outlined in the Act are provided as follows;

1. To administer and manage the Rural Electrification Fund (REF);

2. Develop, implement and update the Rural Electrification Master Plan (REMP);

3. Promote the utilisation of available rural electrification technology options to enhance the contribution of energy to the development of agriculture, mining, industry and other economic activities in rural areas;

4. Mobilise funds within and from outside Zambia in order to carry out rural electrification projects;

5. Offer on a competitive basis, the construction of rural electrification projects

Since 2006, REA has sought to accelerate the pace of implementation of the national electrification programme for rural areas in order to increase electricity access rate from 3.1% in 2006 to 51% by the year 2030 using various electrification methods and in accordance with the provisions of the REF and the estimated financial outlay of about US$50 million to achieve the set targets in the REMP. However, over the years, the trends in allocation of funds to the rural electrification programme have fallen far short of the REMP estimates resulting in fewer numbers of projects being implemented. According to the Central Statistics Office (CSO), 2010 Living Conditions Monitoring Survey (LCMS) Report (LCMS, 2010), the rural electricity access rate stood at about 4.5% as at 2010 for grid connected households while another 4.5% of rural households were reported to have access to electricity using solar technology. It is worth noting that the rural electricity access rate as recorded in the CSO (2015) LCMS is currently at 3.7% which could be attributed to growth in population that has not matched with the rate of electricity connections (LCMS,2015).

Therefore, the Authority has a mammoth task to achieve the targeted rural electrification of 51% by the year 2030 as set in the REMP. In order to accelerate the rural access rate, the Authority has deliberately targeted the development of solar and hydro mini grids which are used to electrify a number of villages in the rural areas. In 2012, the Authority developed the Mpanta solar mini grid which initially targeted 480 households. From the time the project was commissioned, the

Authority has been working with a Cooperative to help in the management of the plant (Mubanga,2013).

1.2 Mpanta solar mini grid

The project is designed to generate 60kW of electrical power from an array of Photovoltaic modules to supply the Mpanta community within the catchment area of radius of 1.5km. Samfya District is located 820km North of Lusaka while Mpanta is located 40km East of Samfya. The plant currently has a consumption of 50kW which is in excess of 80% of its maximum attainable power capacity (REA, 2013). The project was implemented for a period of two (2) years at an estimated cost of K13 million. Currently the plant supplies power to 480 households, school, a clinic and 10 shops at a local market. Figure 1 below show the location map of Mpanta solar project. Figures 2 shows part of the solar plant with staff house in the background while figure 3 shows part of the connection provided by the project. Figure 4 shows the network for low voltage lines.

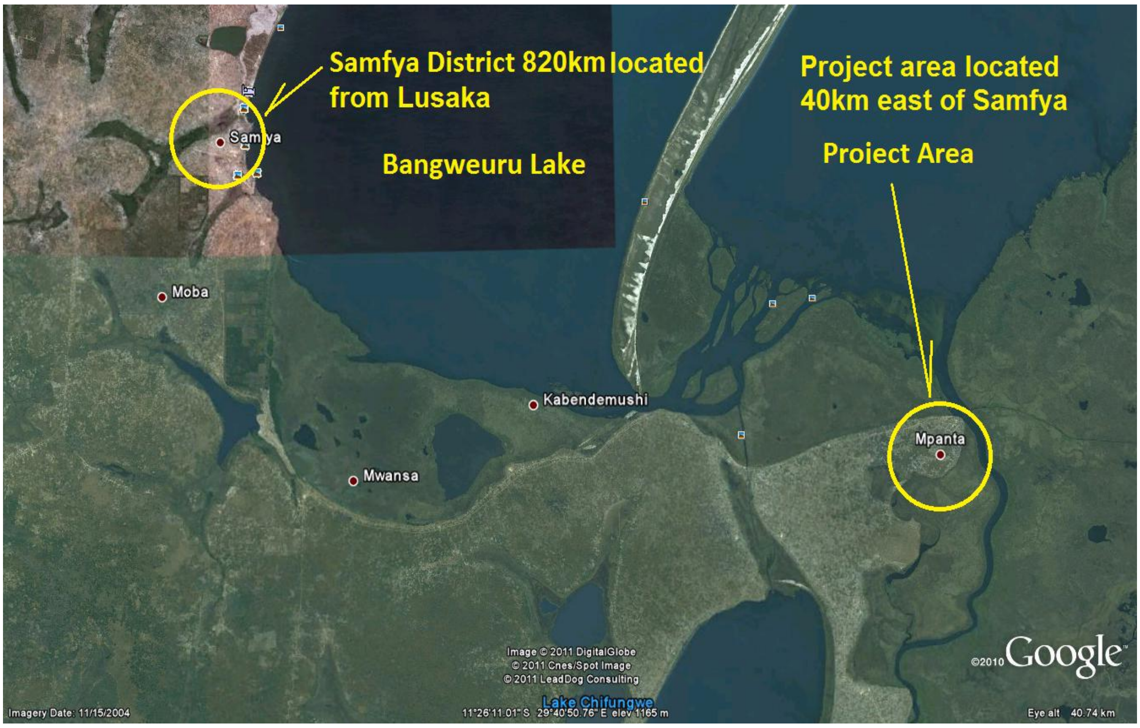

Fig.1: Map showing the location of the Mpanta solar plant

Fig. 2: Part of the solar plant with staff house in the background

Fig. 3: Part of the connection provided by the project

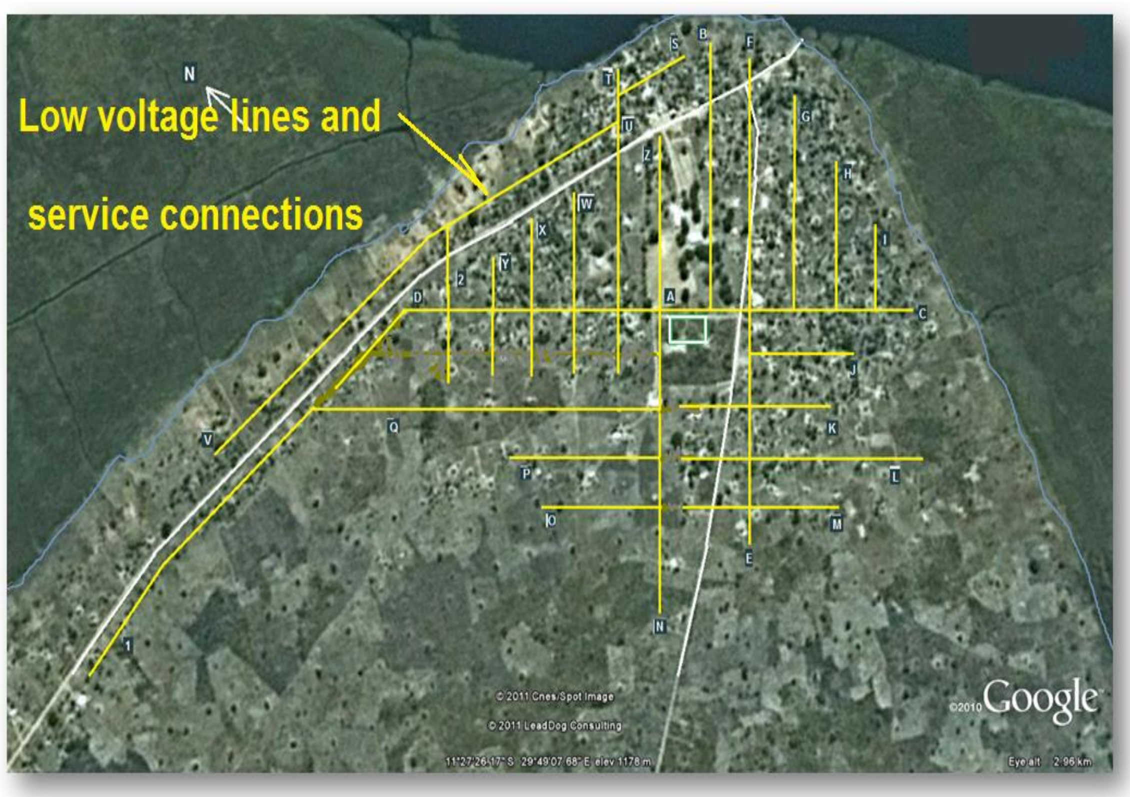

Fig. 4: Network for low voltage lines

Before the project was implemented in Mpanta, the area was not electrified and the social and economic conditions of the area were poor. In terms of lighting, the community was using candles and paraffin lantern. Based on the REA's Five Year Plan, the project was identified and the purpose of the project was to improve the social and economic conditions of the area through electrification of shops, clinic and school. Therefore before the project was implemented, a cost comparison was done between extending the grid and construction of a solar plant (REA, 2013). Based on the assessment, it was cheaper to implement the solar project than extending the grid.

The purpose of this paper is to provide an overview of lessons learnt over the 4 years that the plant has been operating in terms of the sustainability and efficiency of the plant. The paper will therefore bring out lessons that could be used as platform for implementation of future mini grids in the country.

2.0 LESSONS LEARNT

The following are the lessons that have been leant over the years that plant has been operating:

2.1 Lighting is not the only power requirement for the rural community

In designing most rural based electrification projects, project designers have mostly considered lighting as the main need of the rural people (Dadzie ,2008). In the project, we have noticed that communities have been by passing load limiters that have been provided by the project. The load limiters which act as circuit breakers manage the amount of current that is drawn by the consumers. Based on the project design, the maximum current that the consumer can draw is 6A and this translates to 7 bulbs, TV, Cell phone charger, decoder and radio/music system. Therefore if households connect prohibited appliances such as cooker plates, welding machines, grinders and other high voltage equipment by- passing limiters, then this becomes an illegal connection and on average 6 cases has been recorded over the last 4 years concerning the same. The occurrence of the illegal connections is an indicator that the community need more power to supply additional loads. One thing that is important in the village is to provide power in people's homes so that children can do homework at night and also to facilitate phone charging (Laura, 2016).

2.2 Appreciation of renewable energy technologies by the rural community

Over the last two years, the country has been experiencing load shedding due to reduced rainfall in the country and the region at large. Consequently, customers that are supplied by the National Utility ZESCO are loaded shedded for 8 hours a day. On the other hand, power supply in Mpanta is supplied for 18 hours i.e. starting 06:00hrs to 24:00hrs every day. Through community sensitization meetings that are held every month which are aimed at bring awareness on the need to pay and also reduce vandalism on the electric equipment, the local communities have been expressing appreciation of the technologies through songs and drama . The communities have been comparing themselves with customers that are supplied by ZESCO that they are much better than them considering that they have longer hours of power supply than their counterparts in town.

2.3 Prepaid meters versus load limiters

As earlier indicated, a number of cases have been reported where customers have been by passing the prepaid meters in order to use electricity minus paying for it. In addition, disconnected customers have also take advantage of the scam by reconnecting themselves to the network. On one of the strategies to manage the crisis is to install prepaid meters which prevent usage of electricity without paying and bypassing of the meters by consumers who have been disconnected. Installation of meters will help the efficient use of power, improve revenue collection and also help improve the relations with consumers as disconnections and reconnections bring a lot of disputes between staff and the clients.

2.4 Payment models

The main economic activity of the area is fishing. From December to March, the Government introduces a fish ban to allow for fish stock to bread and grow. Unfortunately the ban negatively affects the revenue base of the community in the sense that the community cannot catch or sell fish during this period. This ban also affects the revenue collection which drops to 50% on average. In order to manage this reduction in revenue, plans are underway to allow consumers pay in advance to cover for the four months. In additions, some consumers have also requested to be disconnected during this time so that bills do not accumulate. Then when the ban is removed, consumers will again request to be reconnected.

2.5 Quality after sales service is essential

The provision of electrification through off-grid solutions does not end with the construction of a power plant and connection of consumers (Dadzie ,2008). The client will require education on the use of the products and quick response to faults when they occur. Supplying efficient off grid systems without efficiently designing the after sales service will lead to a failed project. Beneficiaries must be clear on the number of days it will take for a fault to be repaired and what warranties they enjoy and this has to be provided as promised to make the project successful. Ensuring that repairs and maintenance are done correctly is key for the sustainability of the project

2.6 Dedicated project personnel are key in the effective management of the power system

The engagement of a dedicated Project Staff with technical knowledge and experience in solar PV systems enables the staff to correctly anticipate the possible challenges and find suitable solutions quickly (Dadzie, 2008). The staff at the plant has devise a system that has saved the plant from damage from lighting struck which is common during the rainy season in the area. A design was installed last year that was develop by a technician and has so far saved the plant from damage by lighting struck.

2.7 Beyond education, products must be designed to prevent tampering

In designing off-grid systems, it is necessary to consider the behaviour and the abilities of the prospective beneficiaries. Beneficiaries must be well educated on the expected performance of the systems (Dadzie ,2008). The network that is provided to the consumers is designed in such a way that only replacement of bulbs should be done by the consumers. Therefore, systems must be designed to prevent the possibility of tampering by beneficiaries.

2.8 Anchor loads

One key lesson from this project is to ensure the sustainability in terms of revenue collection. The plant should deliberately support anchor loads such as communication towers, consumers like civil servants who do not depend on the fish business. These consumers will provide a financial cushion during the time when there is a fish ban. In addition to this, other anchor loads such as cold storage facility to be run side by side with sustainable fish farming projects by the community could prove instrumental in cushioning revenue collection during the fish ban period as clients could easily manage to pay for electricity if such initiatives can be integrated. However, for these initiatives to be realised, the Energy Regulation Board has to be engaged in order to ensure that the tariffs are cost reflective (Dadzie ,2008).

2.9 Willingness to pay

The provision of electricity to remote off-grid communities is not just a business but a social intervention and therefore consumers must be screened to identify their willingness to pay. Consumers should have a mind-set of knowing that without fulfilling the obligation of paying for their bills, the plant would close up. Over the last 4years, the plant has recorded an average of about 58% monthly bills collection rate with over 80% of clients not being consistent in paying and failing to fully settle their bills on time.

2.10 Partnership in the management of the plant

According to the Act no. 20 of the Rural Electrification Act the Authority is allowed to work with strategic partners in the management of the power infrastructure that are developed by the Authority. This approach is strategic in the sense that the local communities are empowered to participate in the management of the power stations. The Mpanta Solar mini Grid Plant is currently being run by Kafita Cooperative Society under a 5 years MOU with the Rural Electrification Authority who currently retain ownership of the plant with an interim License from the Energy Regulation Board to generate and distribute power as well as replace the batteries after 4 years. The identification process is critical as the sustainability of the power plant is dependent on the type of the identified partner. The partner in the project must therefore be well screened to identify their commitment to the project. The identification process should start early enough preferably at design stage so that more time is allocated to the process. In future projects, preferably a study should be conducted to establish the type of business model that will be used and this should be done before a design is undertaken. Once model has been determined, a strategic partner can then be identified to help manage the project. With good management and financing plan, it was possible to provide electricity to remote rural dwellers using solar energy.

3.0 Conclusion

In conclusion, it is important to note that a number of factors are necessary for the successful implementation of off-grid projects. Project designers must therefore learn from other projects to avoid pit falls associated with the development of off grid projects (Dadzie ,2008).

REFERENCES

Journals:

Dadzie, F. Y. (2008) Lessons learned in implementing off-grid electrification. Africa Energy Yearbook, pp. 97-100.

Reports:

REA (2013) Mpanta Solar Mini Grid. Internal report

Mubanga, P. (2013) Electrification of Mpanta Area Using Solar Mini Grid, Lusaka:

CSO (2010) Living Condition Monitoring Survey, Lusaka

CSO (2015) Living Condition Monitoring Survey, Lusaka

Laura W. (2016) Testimonial from Avoki Omekanda: Restoring Education and Energy to the Nation of his Birth. IEEE, Piscataway.

Low Cost Solar Thermal Technologies with high potential on Rural Development in Zambia

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Abstract

Low cost solar thermal technologies have very high potential in addressing the energy related challenges in the country, especially those that the rural areas are experiencing such as indoor air pollution from the use of biomass fuels in cooking, high rate of deforestation, high postharvest losses, lack of clean drinking water and lack of hot water facilities. By using solar thermal devices such as solar cookers, solar water stills, solar water heaters and solar food dryers, the above challenges can be addressed. Fabrication of the solar devices is simple and can be done in low tech workshops equipped with welding, drilling and riveting machines. The cost of materials for making the solar devices ranges from K300 to K600. Results obtained so far are that solar cooking of rice takes 30 minutes, solar drying of mangoes can be done in a day and half, solar distilled water production can reach 2.5 litres/m^2/day; and solar water heaters can achieve water temperatures of about 60 ^oC.

Key words: Solar thermal, solar water heater, solar water still, solar food dryer

1. Introduction

The main sources of energy available in Zambia are biomass, distributed electricity, fossil fuels and renewable sources such as solar. Biomass has been the country's main source of energy accounting for more than 70 % of the consumed energy, with 97 % of rural dwellers and 57 % of urban dwellers using this resource (Central Statistical Office, 2012). For distributed electricity, the installed hydropower capacity is about 1,900 MW, while the potential is in excess of 6,000 MW. Zambia's electrification rates are very low with the current electricity supply deficit estimated at 45 % for urban and 3 % for rural areas (IRENA, 2013). Zambia lies in one of the highest solar irradiation zones in the world with solar irradiance of 5.5 kWh/m^2/day (Martin and Goswami, 2005) and so the potential for solar power is extremely high making it an ideal country for solar thermal applications such as cooking, drying, water treatment and water heating.

A comparison of solar energy with other forms of energy like fossil fuels, biomass and distributed electricity, shows that solar energy has the following benefits:

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- It does not require a distribution system as it is readily available, and is therefore suitable for many rural areas of developing countries,
- It is clean and safe,
- It is not a diminishing resource and not subject to market forces,
- It requires little maintenance.

The main applications of solar energy are in solar photovoltaic (PV) systems which produce electricity, and in solar thermal technologies for water heating, solar drying of foods, solar cooking and solar distillation and solar disinfection (Garg and Prakash, 2007). Most solar thermal devices require simple construction techniques that can be easily mastered by people with modest skills (Simate, 1999).

2. Challenges solved by Solar Thermal Applications

2.1 Indoor air pollution from the use of traditional biomass fuels

It is estimated that 2.6 billion people use firewood and charcoal for cooking and heating (DFID, 2013), leading to massive deforestation and indoor air pollution especially in developing countries. According to the World Health Organization (WHO), about 1.5 million people die prematurely every year as a result of indoor air pollution from the use of solid fuels, which work out to be more than 4,000 deaths per day with over 50 % of them being children under five years old. It is also estimated that more than 85 % of these deaths are attributable to the use of biomass in cooking, and the rest is due to the use of coal (IEA, 2006).

2.2 High Rate of Deforestation

According to the UN-REDD programme (2010), Zambia has approximately 50 million hectares of forest, with an estimated deforestation rate of 250,000 to 300,000 hectares per year. Deforestation threatens the environmental stability of the country and contributes to climate change. Deforestation is exacerbated by the current insufficient electricity supply, and practically both urban and rural populations in Zambia now heavily depend on firewood and charcoal for their daily cooking purposes. For the rural dwellers, increased deforestation in most parts of the country has resulted in people having more difficulties in collecting firewood and accessing trees for making charcoal.

2.3 High Postharvest Losses

The agricultural sector in Africa is affected by severe physical constraints. Infra-structural provisions such as roads and rail systems tend to favour farmers based in urban areas, while rural areas have generally been neglected. Thus, surplus produce from the majority of farmers cannot easily reach the market. For fruits and vegetables, the problem is compounded by their highly perishable nature, where they can keep for only a few days without refrigeration, before they rot (Arfaoui, 2006). Therefore, opportunities for growth are frustrated by high post-harvest losses which, for fruits and vegetables, are estimated at 50% of production (Studman, 1999).

Hichaambwa (2010) carried out a study on the developments in the Horticultural Supply Chains in Zambia with particular reference to Soweto market, the largest market in Zambia, and pointed out the postharvest challenges the country faced. The challenges included the following:

- Supply greatly exceeding demand during time of gluts, such that produce stayed longer on the market without refrigeration and hence reducing in quality and eventually going to waste.
- Inadequate processing facilities leading to great wastage of fruits such as guavas and mangoes when they were in season.

Hichaambwa (2010) reported that there was need to improve the processing capacity to process excess seasonal fresh produce for sale or consumption during times when the produce was not in season.

Processing is seen as a means of preserving product quality and providing opportunities for value addition and income from marketing produce in local, regional and international markets. Although there are several methods of preservation e.g. canning and freezing, simple solar drying technologies are the most appropriate for application in rural farming areas which have poor infrastructure and limited technical, financial and management resources (Axtell, 2002).

Traditionally, fruits and vegetables have been dried by simply laying them in the open air, either on mats or raised platforms under the sun. Although this is effective, there is limited control over the drying process which results in a variable product quality and a greater risk of contamination. To give more control over these aspects, solar dryers have been designed which protect the product from dirt and insects and increase the rate of drying (Fellows and Hampton, 1992). Solar food drying technology relies on the sun as its energy source. The method requires the building of a structure, often of very simple construction, to enhance the effect of the sun's energy to dry fruits and vegetables quickly and cleanly. The air temperatures generated in the solar dryer can produce dried products with low final moisture contents compared to open sun drying. This reduces the risk of spoilage during processing and in subsequent storage; the higher air temperatures attainable are also a deterrent to insect and microbial infestation. Using such an enclosed structure affords protection against dust, insects and animals (Axtell, 2002).

The main advantages of dried foodstuffs are that they can be safely stored for long periods, are cheaper to transport than fresh produce because dried foods weigh less and occupy less space and have cash value for producers. Dried fruits for example, can be eaten in a number of ways - on their own as snacks or as ingredients for food dishes. They have good nutritional qualities; dried mango, for instance, can be a rich source of vitamin A which, if given in children's diets, can greatly reduce the likelihood of child blindness. The dried fruits produced can be sold locally, regionally and internationally depending upon quality standards and market channels developed (Fodor, 2006).

2.4 Lack of Clean Drinking Water

Solar distillation uses sunlight to heat water and produce water vapour which is then condensed back into water. The basic operation of a solar still is that water to be distilled is contained in an enclosure which has the top cover made of glass or some transparent material and the cover is inclined at an angle. Direct sunlight heats up the water in the basin through the bottom of the basin and this causes the water to evaporate. The water vapour then condenses on the glass cover since the cover is in contact with the cooler outside air. The resulting liquid water runs under the glass cover and is collected. A solar still with a collection area of 1 m^2 produces 2.5 litres of clean drinking water per day in a sunny environment like Zambia (Maambo and Simate, 2016).

The utilisation of solar energy for the distillation of water has been practised for a very long time, the earliest documented work being that of some Arab alchemists in 1551. The first conventional solar still trough was designed and built in 1872 by a Swedish engineer, Charles Wilson. It was a large basin-type solar still that supplied fresh water to a mining community in Chile and was in operation for 40 years. The still had a collection area of 4700 m^2 and produced 23,000 litres of fresh drinking water per day in clear weather (SolAqua, 2008).

2.5 Lack of Hot Water Facilities

In a domestic solar hot water system, the cold water from the main supply to the house or tank is passed through the indirect storage cylinder where it is preheated by the solar system before entering the normal hot water storage cylinder (geyser) which can then add more heat by electricity as required. So this is where the saving in electricity comes in. Because the water entering the geyser is already hot from solar heating, it needs less heating by the geyser and this translates into less electricity consumed and finally reduced electricity bills. Savings can be as high as 90% in the summer months and a reasonable 50% in winter (NREL, 2011). In addition to domestic hot water system, any situation that requires hot water is ideal for solar hot water. Installations like laundries, swimming pools, boarding schools, guest houses and hotels can achieve big savings on their electricity bills. According to Cassard et al (2011) solar water heating substantially reduce energy usage, expenditures, carbon dioxide emissions and helps reduce our dependence on uncertain foreign energy supplies.

3. Work done at University of Zambia in Solar Thermal Applications

3.1 Solar cooking

A parabolic solar cooker was fabricated and tested in 2004. Recently the Department of Agricultural Engineering acquired a commercially produced parabolic cooker from Japan and it is being tested under Zambian weather conditions. It boils water in about 20 minutes and cooks rice in 30 minutes. The cooker will continue being tested on cooking other Zambian foods including Nshima. The parabolic solar cooker is shown if figure 1.

Fig. 1: Parabolic Solar cooker

The parabolic solar cooker was made of flat galvanized sheets which were cut to a certain pattern and joined together using small bolts to form the parabolic shape which reflects the light to a small point. A welded frame of square tubes was used to support the parabola and the grill for holding the pot. The materials for the construction of the solar cooker cost K300. On the other hand, the imported solar cooker was made of highly polished aluminium sheets (reflectors) and aluminium frame and its total cost was USD400.

3.2 Solar water distillation

Many types of solar stills have been designed, fabricated and tested. The solar stills produce clean drinking water from any contaminated water with average production of 3.5 litres of clean water per day (Simate, 2001). Laboratory results show that they remove virtually all the bacteria and dissolved solids of any water. Improvements in the productivity of the still have been investigated with the addition of reflectors to the still in order to capture more solar radiation (see figure 2). Table 1 shows a comparison of distillate output from a still without reflectors and that with reflectors. The percentage increase when reflectors were added ranged from 18.7% to 30.3%.

The solar stills were made of galvanized flat sheets that were bent in the required shape and then joined by brazing to form water tight joints. The bottom of the basins were painted black while the sides were insulated with styrofoam to reduce heat losses. The top cover was clear glass to allow solar radiation to enter the still. The materials for the construction of the solar still cost K400.

Fig. 2: Solar stills, one without reflectors and the other with reflectors

Table 1: Distillate output from solar stills with and without reflectors

Expt. no.	Depth of water in the still (mm)	Interval average solar radiation (W/m^2)	Distillate output (ml)		Distillate increase in output (%)
			Still without reflectors	Still with reflectors	
1	15	622	49.8	59.1	18.7
2	15	664	54.7	68.3	24.9
3	15	626	54.0	66.4	23.0
4	15	660	56.9	69.8	22.7
5	10	564	58.4	74.2	27.1
6	10	701	59.2	76.8	29.7
7	10	700	60.4	78.7	30.3

Table 2 shows selected water parameters that were tested at the environmental engineering laboratory of the University of Zambia and compared to World Health Organization (W.H.O) drinking water standards. The water produced by the still was clearly clean and safe for drinking with all the microorganisms removed.

Table 2: Typical Water quality laboratory results

Parameter	**Raw water sample**	**Distilled water from the Solar Still**	**World Health Organization drinking water standards limit**	**% Change**
pH	7.63	7.7	6.5 – 8.5	0.92
Total dissolved solids (mg/l)	354	15.2	1000	-95.71
Turbidity (NTU)	14.3	0.95	5	-93.36
Alkalinity (CaCO3 mg/l)	204	7	500	-96.57
Total Hardness (CaCO3 mg/l)	284	11	500	-96.13
Faecal Coliforms (No./100ml)	33	0	0	-100.00
Total Coliforms (No./100ml)	129	0	0	-100.00

3.3 Solar Water heating

A batch type solar water heater with a capacity of 60 litres was fabricated and has been providing hot water to a family of six. The water reaches a temperature of 60 °C and has to be diluted before bathing. Figures 3 and 4 show the solar water heater.

Fig. 3: Front view of solar water heater

Fig. 4: Side view of solar water heater

The solar water heater was made of a metal drum and a plastic drum. The drums were supported on a welded square tube frame on to which galvanized sheets were riveted. The metal drum was painted black and served as the energy absorber and water heater while the plastic tank was the cold water reservoir. The top of the heater was covered with clear glass to allow solar radiation into the device. The materials for the construction of the solar water heater cost K600.

3.4 Solar Food Drying

Many different solar dryers such as direct, indirect and mixed mode have been designed, fabricated and tested using different foods such as mangoes, pineapples, vegetables and Kapenta. These products take about a day to dry to safe moisture content suitable for storage. Dried fruits can be added to cereals whereas dried vegetables such as tomatoes can be ground into powder and added to gravies to thicken them. Figure 5 shows a natural convection solar tunnel dryer.

Fig. 5: Side view of the solar tunnel dryer

The dryer in figure 5 was made of a welded frame of square tubes on to which galvanized sheets are riveted to form a tunnel and a chimney. A uv treated greenhouse plastic of 200 µm thickness was used to cover the top of the dryer, while the inlet and outlet for air into and out of the dryer respectively, were covered with wire mesh to prevent insects from entering the dryer. The materials for the construction of the dryer cost K500.

Figure 6 shows a typical drying curve for mango in the natural convection solar tunnel dryer.

The final moisture contents of the dried mango in this study (ranging from 13 to 14 % w.b.) compare well with what has been reported previously by Dissa *et al.*, 2009 and Goyal *et al.*, 2006 of 13.79 % (w.b.) and 12 % (d.b.) respectively. Under these moisture contents, the product can be kept for longer periods of time because less moisture is available for microbial activities that cause spoilage. In this way, dried products maintain a good keeping quality acceptable for human consumption for reasonable periods of time, and therefore ensure food security and reduce postharvest losses.

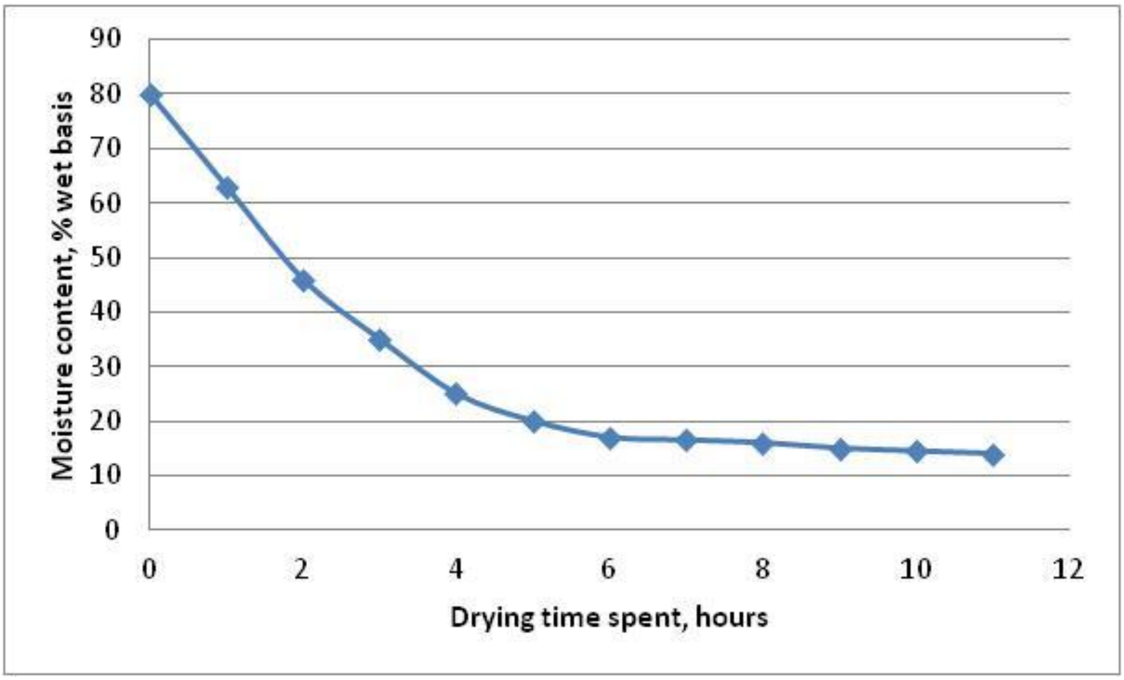

Fig. 6: Mango drying curve

4. Conclusion

Low cost solar thermal applications are capable of addressing some of the energy related challenges that citizens especially those in the rural areas of Zambia face, such as indoor air pollution from the use of biomass fuels in cooking, high rate of deforestation, high postharvest losses, lack of clean drinking water and lack of hot water facilities. The University of Zambia has demonstrated that these challenges can be addressed by simple, low cost devices that can easily be fabricated in low tech workshops. These devices include solar cookers, solar water stills, solar water heaters and solar food dryers.

References

Arfaoui Y (2006) Improving the welfare and increasing the income generation by the commercialization of sustainable energy technology - Commercialisation of Solar dryer for Agricultural Product [online], United Nations Environment Programme (UNEP) African Rural Energy Enterprise Development Initiative AREED. Available from: <http://www.areed.org> [Accessed 24 February 2007].

Axtell B (2002) Drying food for profit – A Guide for Small Businesses. London: ITDG Publishing.

Cassard H, Denholm P and Ong S (2011) Break-even Cost for Residential Solar Water Heating in the United States: Key Drivers and Sensitivities. National Energy Renewable Laboratory. Technical Report NREL/TP-6A20-48986.

Central Statistical Office of Zambia (2012) The Monthly, CSO, Zambia, www.zamstats.gov.zm

DFID (2013) UK to help girls and women access clean energy, Department for International Development. [Online]. Available at:https://www.gov.uk/government/news/uk-to-help-girls-and-women-access-clean-energy.

Dissa A, Bathiebo J, Kam S, Savadogo P, Desmorieux H and Koulidiati J (2009) Modelling and experimental validation of thin layer indirect solar drying of mango slices. *Renewable Energy,* 34**,** 1000-1008.

Fellows P J and Hampton A (1992) Small-scale Food Processing – A guide to appropriate equipment, London: Intermediate Technology Publications.

Fodor E V (2006) Solar Food Dryer: How to make and use your own low-cost, high-performance, Sun-powered food dehydrator, Gabriola Island, Canada: New Society Publishers.

Garg H P and Prakash J (2007) Solar energy - fundamentals and applications, Tata McGraw-Hill, New Delhi, India, ISBN 0-07-463631-6.

Goyal R, Kingsly A, Manikantan M and Ilyas S (2006) Thin-layer drying kinetics of raw mango slices. *Biosystems Engineering,* 95**,** 43-49.

Hichaambwa M (2010) Developments in the Horticultural Supply Chains in Zambia, *Global Horticultural Initiative video conference on Post Harvest and Transport Technologies: Reducing Losses and Improving Quality in Fruits and Vegetables in Eastern and Southern Africa*. [online], Available from: <http://www.aec.msu.edu/fs2/zambia/HortSupplyChainsInZambia_paper.pdf> [Accessed 27 February 2011].

IEA (International Energy Agency) (2006) Energy For Cooking in Developing Countries. In: *World Energy Outlook*, 2nd ed., Vol. 1, pp. 419 - 445. Paris, France: IEA.

IRENA (2013) Zambia Renewables Readiness Assessment. International Renewable Energy Agency. Available at: http://www.irena.org/documentdownloads/publications/rra_zambia.pdf. Accessed 10 August, 2016.

Maambo H and Simate IN (2016) Performance Improvement of Solar Water Stills by Using Reflectors. *Journal of Humanitarian Engineering, Vol. 4, No. 2, Engineers Without Borders Australia 2016.*

Martin C L and Goswami B Y (2005) Solar Energy Pocket Reference. International Solar Energy Society. ISBN 0-9771282-0-2. Germany.

NREL (2011) Break-even Cost for Residential Solar Water Heating in the United States: Key Drivers and Sensitivities, National Renewable Energy Laboratory, Colorado, USA. Available at: http://www.osti.gov/bridge, Accessed 10 August, 2016.

Simate IN (1999) Mixed mode solar drying, PhD Thesis, University of Newcastle upon Tyne, U.K.

Simate I N (2001) *Solar water distillation – Zambian perspective*. Proceedings of the 27th Water Engineering and Development Centre (WEDC) International Conference, Mulungushi International Conference Centre, Lusaka, Zambia, 20th – 24th August, 2001 pp310 – 312.

SolAqua (2008) Pure Drinking Water through Solar Distillation. Available at: www.solaqua.com/solwtdis1.html, Accessed 10 August, 2016.

Studman C J (1999) Fruit and Vegetable Postharvest Systems in the Tropics, pp 380-393. In ed; F.W. Bakker-Arkema, CIGR Handbook of Agricultural Engineering, Volume IV, Agro-Processing Engineering. St. Joseph, USA: American Society of Agricultural Engineering.

UN-REDD programme (2010) Zambia Quick Start Initiative. Available at: mptf.undp.org/factsheet/project/00074834. Accessed 10 August 2016.

Machine-to-Machine (M2M) Communication and the Internet of Things (IoT): Pillars of Industrialization

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Abstract

With industrialization at the top of most developing countries' development agenda, ways of making industrial processes as efficient as possible, and ensuring a positive impact is had, on the surrounding communities, are key to ensuring the survival of these industries. The potential of Machine-to-Machine (M2M) communication and the Internet of Things (IoT), if well harnessed, can provide a foundation on which these ways can be achieved, while ensuring sustainability and efficiency. This paper discusses M2M and IoT and the potential they have for industrialization, by presenting examples of their application in various industries and spheres of life. It also serves to break the ground for interested readers by presenting a collection of references on the two research paradigms.

Keywords: Machine-to-Machine, Internet of Things, Industrialization, Efficiency.

1. Introduction

Developing countries have prioritized industrialization as a key driver of sustainable economic growth and development. This is apparent as industrialization is top on the development agenda in Africa, where there are a lot of such countries. Despite this push towards industrialization, Africa continues to lag behind (Marti & Ssenkubuge 2009). This is evidenced by the extent to which most countries in Africa are not modernized when industrialization is a key facet of modernization. Modernization is a process that is a combination of science, economics, and politics (Lewis 2007). Hence for industrialization to drive sustainable economic growth and development, it has to systematically embrace these tenets (of science, economics, and politics).

The implication is that industrialization has to be heavily pushed by government or policy makers and heavily propelled by scientific and economic advancements. However, to the government or policy makers, it is but one of the many competing public policy priorities and national development needs. Hence it is imperative that the push towards industrialization appears to uplift

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the wellbeing of the citizenry, who these governments or policy makers see as central in every decision.

One element about industrialization is that it tends to spur technological advancement and innovation (Marti & Ssenkubuge 2009). Hence as the industrial agenda is being pursued, the community around the industry can reap the benefits of these technological advancements and innovations that come with industrialization. It is, therefore, imperative that the operations in industries must be done in an eco-friendly manner, and using resources efficiently and sustainably while leveraging these benefits. This will inevitably lead to industries being seen to be adding value to society. Which, unfortunately, is rarely the case (Globescan 2013).

Since industrialization involves extensive application of science and technology (Kaplinsky 1998), this paper seeks to highlight two Information and Communication Technology (ICT) research paradigms that will [are] potentially propel industrialization to unprecedented levels of efficiency (through automation and analytics) and sustainability. They will lead to the execution of everyday processes in ways that society can visibly perceive the positive impact of industrialization. These technologies are Machine-to-Machine (M2M) communication and the Internet of Things (IoT). This paper discusses what these research paradigms are and highlights their visions and place in industry. Furthermore, examples of their application are given to illustrate how their adoption can lead to efficiency and improvement in the general quality of life for the workers and general population around the industries.

The paper is organized as follows: section II presents a discussion on what M2M and IoT are, and the implication they have on the Engineering landscape. Section III presents examples of areas where these paradigms have received adoption and serves to ignite the readers' imagination process on the possibilities of these paradigms, while the conclusion of the paper is presented in section IV.

2. Machine-to-Machine (M2M) Communication and the Internet of Things (IoT)

Due to the increasing affordability of ICTs, there has been a drive to connect everything to the communication infrastructure (Pticek et al. 2016). This, coupled with the development of new types of sensors with better perceptual abilities than humans, has propelled the popularity of M2M and IoT. M2M and IoT enable the monitoring, control, and automation processes of industrial processes. M2M (communication) is the exchange of information between two or more smart devices/ machines over a communication infrastructure independent of human intervention. It establishes conditions that allow devices to exchange information with business applications via a communication network (figure 1), as a foundation for automation (Boswarthick et al. 2012a).

Its initial vision was an automated communications process by which measurements and other data were collected at remote or inaccessible points and transmitted to receiving equipment for monitoring purposes. However, it has grown into a myriad of new devices, largely unnoticed by humans, working together to expand the footprint of end-user services. Most M2M applications create new ways to care for safety or comfort, optimizing a variety of goods delivery mechanisms, enabling efficiency in resource tracking, and creating new value.

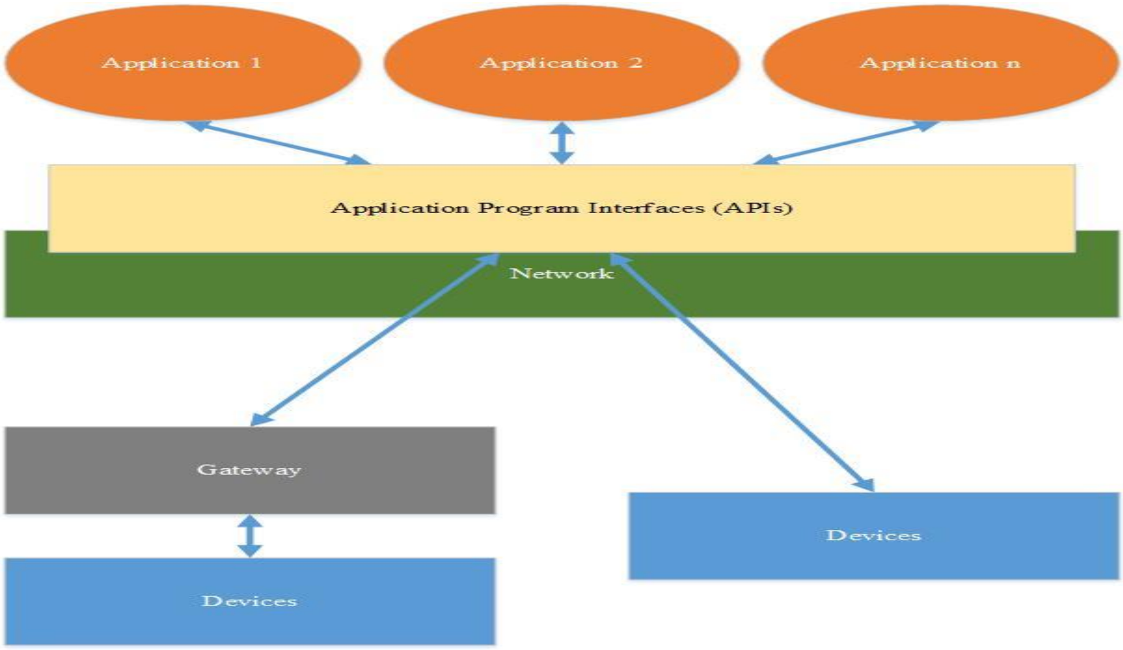

Fig 1: M2M interaction topology

According to Pticek et al. (2016), M2M is motivated by the fact that a networked machine is more valuable than an isolated machine. Furthermore, an interconnection of multiple machines enables development of more autonomous and intelligent applications. Hence central to the M2M vision is value addition. The largest present use of M2M is in car/ vehicle telematics (Holler et al. 2014).

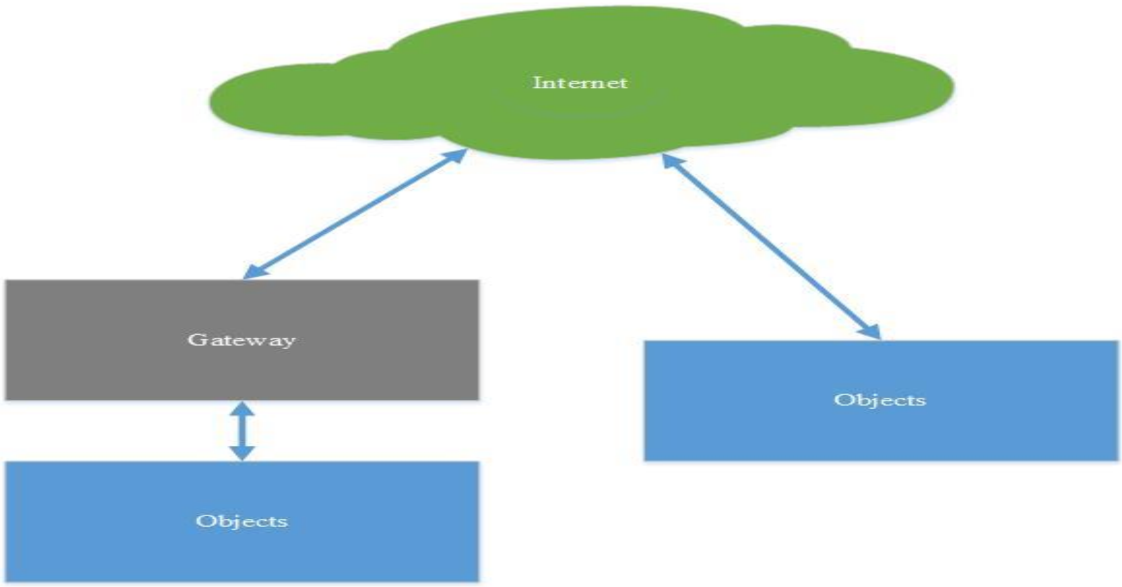

Fig 2: The simplistic view of the IoT. The objective is to connect everyday objects to the internet

On the other hand, the IoT is simply the internet that has undergone some morphism. It is, at its simplest, the connection of non-traditional network nodes to the internet. These nodes include everyday objects that are equipped with identifying or networking capabilities which would allow them to communicate, over the internet, with other objects (and applications). This has been necessitated by the increased need to measure and observe elements of the natural world.

As can be seen in figure 2, the IoT's main objective is to have everyday objects connect to the internet. Central to the realization of this vision is the maturity of M2M. Furthermore, the IoT relies on existing infrastructure and promises to utilize the knowledge acquired in building the present internet (Whitmore et al. 2015). This is because the IoT is essentially a point in time when the number of objects connected to the internet (current internet) reaches monumental numbers (Evans 2011).

Both M2M and IoT have been spurred on by the maturity of other fields of engineering such as the development of sensors and actuators, the efficiency in the manufacturing of microprocessors, etc. It is important to note that research in Radio Frequency Identification (RFID) gave birth to the IoT (Friedemann & Floerkemeir 2011). RFID has subsequently evolved into Near Field Communication (NFC), which is a short-range communication standard where devices are able to engage in radio communication with one another when brought into contact or close proximity. While RFID generally requires 'line of sight', NFC does not. The energy sector and its processes are the key business cases of the IoT (Boswarthick et al. 2012b).

M2M and IoT are proving popular because they offer efficiency and control. As the pressure on limited resources keeps surging due to the increase in the population (particularly in cities) and depletion of non-renewable resources, there is an unprecedented call for technologies that foster efficiency. According to the United Nation (UN) Habitant (2011), in the year 2007, more than 50% of the world's population was living in cities rather than rural areas. Hence cities must adapt to meet this surge in demand. This calls for efficiency in resource utilization and execution of tasks/ processes. It is no wonder machines/ robots are emerging as potential key players in industry and everyday life. According to Anton-Haro & Mischa (2015), machines excel more than humans in the execution of repetitive tasks and computational efficiency. Hence they are an appealing alternative to humans, particularly in automated and repetitive tasks, which M2M is at the centre of.

Furthermore, because of the vast amount of measuring and control that forms the basis of industrial processes, M2M and IoT present a very promising option towards increased industrial sustainability and reliability. Therefore, industry is inevitably having to adapt its processes to fit into the M2M and IoT visions. This is because M2M and IoT promise to form the basis of efficient industrial automated processes and life in general (Holler et al. 2014).

3. Applications of the M2M and IoT

3.1 Application 1: Smart Asset Management

One use case of M2M and IoT is in the management of assets (Holler et al. 2014) in an enterprise. It goes without saying that assets account for the largest percentage of any establishment's net worth. Hence it is imperative that a lot of resources (Human or otherwise) are allocated to ensure the proper utilization and management of these assets. Furthermore, proper asset management ensures sustainability and efficiency.

Two key components of asset management can be identified as; monitoring and maintenance. Monitoring involves the observation and checking of the quality of assets over a period of time to ensure continued good working order. This process implies keeping under systematic review the operational processes of these assets.

Monitoring usually requires a constant observation of the asset. Because of this requirement, it is usually a costly exercise to see through. However, with the development of M2M and the IoT, it is possible to meet this requirement while only responding to the genuine needs for intervention. This can be realized by setting thresholds and alerts that can be triggered when certain conditions are approached or reached.

Furthermore, M2M and IoT are well suited for the monitoring of hazardous goods within a factory. This kind of adoption of M2M and IoT would find use in factories that manufacture explosive or corrosive substances. Instead of constantly exposing factory workers to these substances, these can be monitored by RFIDs (or NFC) or other attached sensors. With data from these sensors, measurements can be taken, the substances can be assessed and necessary remedial steps can be taken. All this can be done at a 'safe' distance.

In addition to monitoring of these substances, another use case of M2M/IoT in dealing with hazardous goods is in the movement of these goods. RFID tags can be attached to the containers of these goods and using Near Field Communication (NFC) alarms can be triggered as compatibility of goods is threatened (see figure 3). Once alarms are triggered, the operator can take appropriate action to ensure no violation of compatibility concerns occur, hence avert disasters.

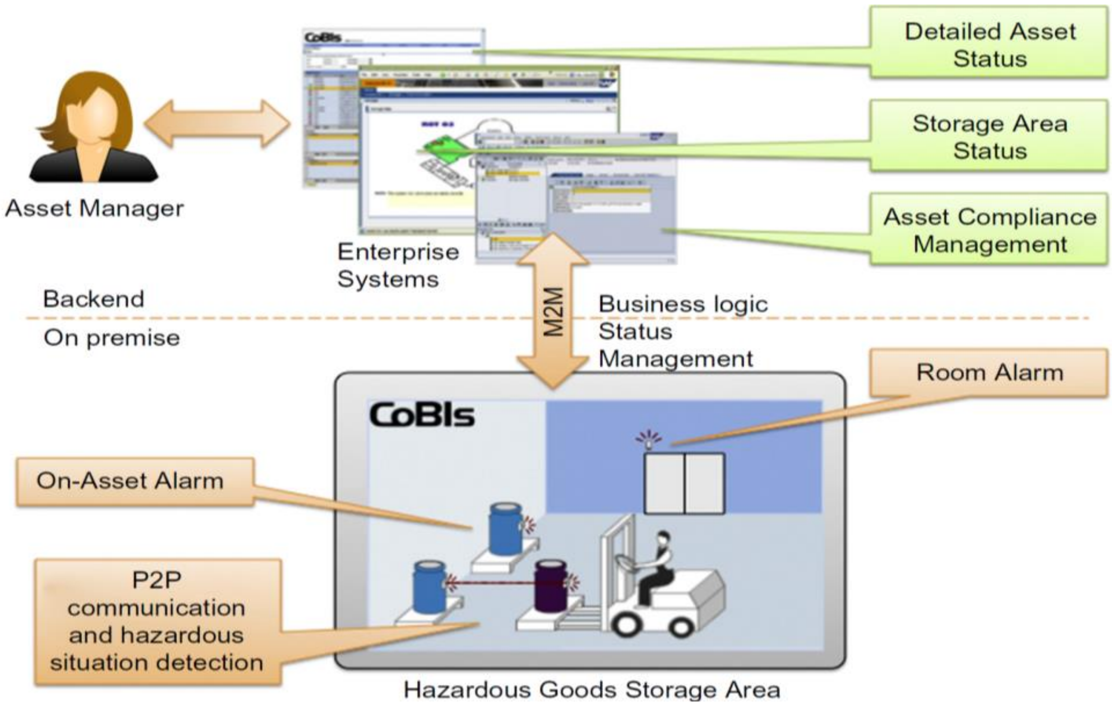

Fig 3: M2M/ IoT being used to monitor Hazardous goods (Holler et al. 2014)

Maintenance, on the other hand, entails taking remedial action to ensure that the effect of wear and tear are minimized as much as possible. Generally, maintenance goes hand in hand with monitoring and is often a result of outputs from monitoring exercises.

As industries adopt M2M and IoT solutions, assets will no longer be passively monitored. They will report events on demand. As the traffic is event triggered, there is a reduction in the flow of unnecessary traffic on the network. With this data from assets and the access of assets over the internet, it is possible to put in place remote and collaborative maintenance measures to ensure that downtime is minimized.

Furthermore, as the assets continue to poll data, it is possible to anticipate failures by analysis of this data. This, in essence, helps realize a proactive response to failures as there is near real-time monitoring and maintenance. Therefore, real-time/ immediate remedial action can be taken. Networks Appliance (NetApp) is an example of a company that has exploited this avenue to the great satisfaction of its customers (NetApp 2016).

3.2 Application 2: Waste Management

Waste management represents one of the major challenges facing cities across the world (Zanella et al. 2014). As the urban population continues to rise, so has the volume of solid waste. Hence the city managers are faced with an ever-growing challenge of how to collect and properly dispose of this waste.

Waste collection is a crucial service in every city. Solid waste if poorly managed, can cause serious pollution that can lead to undesirable results such as; the rise in epidemics, poor quality of life in cities, and reduced city appeal, among others (Balandin et al. 2015).

Research (Balandin et al. 2015; Kim et al. 2006; Nuortio et al. 2006) has shown that the challenge of high costs in dealing with solid waste management stems from two main issues: non-optimal vehicle routes and schedules and determining when to collect waste from bins. These have led to inflated costs and problems in the collection of waste and its delivery to designated dump sites/ landfills.

Fig 4: Smart bins can sense the levels of waste by being equipped with appropriate sensors (Enevo 2014)

Non-optimal vehicle routes are a common case where the waste truck takes unnecessary trips to the landfill or takes longer paths when shorter options are available. Proper planning can optimally minimize the number of trips to dump sites and avoid longer paths or unnecessary path traversals. Kim et al. (2006) have discussed ways to optimize vehicle routes.

On the other hand, determining the right time to collect the waste from bins is another key challenge that waste management companies face. Traditionally, the best estimate approach has been adopted by most companies. This sets a fixed time (once a week is a common trend for residential areas in Lusaka) for the collection of waste. While this approach seems to work well at first glance, close scrutiny shows that it is very rigid and non-optimal as shown by Kim et al. (2006).

Fig 5: M2M/ IoT can allow the bins to share data they collect to optimize waste collection (Enevo 2014)

With the advent of M2M and the IoT, this traditionally inefficient service can be improved through the introduction of sensing and analytics. One way this is already being done is through the use of smart bins. Smart bins (as shown in figures 4 and 5) are sensor fitted to enable them to measure, either by weight or volume, the level of the contents in them and intelligently relay this information to stakeholders to help them decide what the optimal time and route to collect the waste is. This eliminates/ minimizes wastage of resources due to collection of waste from partially filled bins. It also helps to decide on what the optimal path for a particular shift is (Nuortio et al. 2006).

Sensors located in the bins generate data about capacity, pollution, etc. M2M and IoT technologies connect the smart bins to a control center where optimization can be done. It is at the control center, usually in the cloud, where stakeholders (city managers, truck rental companies, drivers, etc.) have access to the analysed data from the bins, to aid with deciding the next course of action. The sensing is usually offered as a service to all the stakeholders.

With the data collected from the bins, a waste management company can have enough data to make decisions that lead to minimizing the number of vehicles and total traveling time on a particular route. This leads to route compactness as the amount of waste to be collected, on a particular route, is known beforehand hence measured against the truck capacity. It is then possible to predict the number of trips required (Kim et al. 2006).

Hence as the engineering fraternity pushes for industrial sustainability and efficiency, this is one avenue that can be explored and even stretched to meet other logistical challenges.

3.3 Application 3: Building Automation System (BAS)

Building Automation Systems (BAS) are computerized, intelligent systems that control and measure lighting, climate, security, and other mechanical and electrical systems in a building (Holler et al. 2014). With the adoption of M2M and IoT in BAS, it is possible to utilize the captured data by applying analytics on it to set up efficient ways to control buildings and their constituent systems.

The objective of BAS is to reduce energy and maintenance costs by adopting usage that minimizes misuse and abuse. This, in essence, increases control, comfort, reliability, and ease of use for the maintenance staff and tenants.

With a well-designed BAS, Heating, Ventilation, and Cooling (HVAC) can effectively be controlled to ensure considerate and eco-friendly use of energy. Furthermore, other aspects or systems of the building can be incorporated, such as the fire detection and intrusion systems to ensure that they work more intelligently and have more information to act on. This could reduce the number of false alarms and increase the 'hit' levels.

With the capabilities of M2M and IoT, it is possible to create subsystems (lighting, climate, security, etc.) that are as independent as possible, as the two paradigms encourage abstraction. What this entails is that a failure of one system does not always take down the other systems. This unpleasant occurrence is common with most BAS. One common example is the failure of the security system once a fire alarm (smoke detection system) goes off. This essentially compromises the security of the tenants in the building, hence creating a security loophole

Fig 6: A smart meter (BusinessGreen 2014)

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3.4 Application 4: Smart Metering

Smart metering (Holler et al. 2014) is one of the leading innovations that M2M and IoT have enabled. This is because it is a typical example of the model the two paradigms espouse. Smart utility meters (see figure 6) can be connected to the communication infrastructure and possibly the internet.

When utility meters have been connected to the communication infrastructure (figure 7) and possibly the internet, and are able to transmit usage and other contextual data, the reality of M2M and IoT can be achieved. Traditionally, utility companies like Zambia Electricity Supply Corporation (ZESCO), before the introduction of pre-paid meters, would have data collecting personnel go into the field to manually take meter readings and manually input them into utility calculation systems to figure out usage. This was both a costly and very unreliable approach as data was quite prone to errors.

While the pre-paid system has helped with the efficient distribution of energy, as a customer uses what is paid for, it still does not give much data to the utility company and indeed to the customer on the usage pattern of energy.

With smart metering, there is an increase in data captured. This is both in quantity and variety of the data. As the data capturing can be done continuously, it is possible to determine the utilization patterns over the course of a day. This information, if availed to the customer, would help in the understanding of how 'units' were consumed and possibly aid in identifying energy wastage. This would make bills predictable and guide the customer to adjust utilization.

On the other hand, this would enable the utility companies to remotely monitor, and possibly remotely manage both the infrastructure (meters, etc.) and distribution as more data is acquired. As a way of exploiting this information, the utility company can adopt varying tariffs to dissuade utilization during peak times and give incentives for off-peak utilization. This can help manage the load on the grid and reduce the need for the dreaded blanket load shedding.

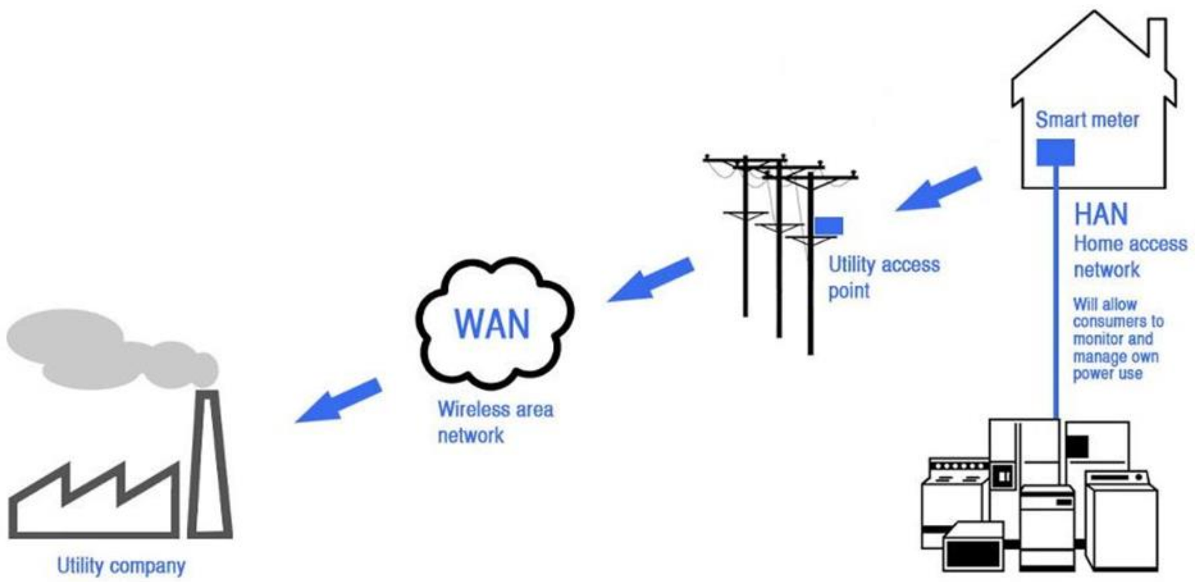

Fig 7: Smart metering topology

The overall benefit of smart metering is a reduction of electricity bills (a positive for the customer), better usage of the service, and general satisfaction for all parties involved.

3.5 Application 5: Smart Parking

The final example of the application of M2M and IoT, discussed in this paper, is in the management of vehicle parking spaces. With the rise in the number of vehicles in cities (e.g. Lusaka), a number of related challenges are faced. Firstly, there is an increased congestion on roads, leading to reduced hours spent on productive work as a lot of time is spent moving between locations. Secondly, due to the increased time spent on the roads, carbon emissions from vehicles go up, increasing the effect of global warming. This situation is made worse by the challenge of finding parking space when one gets to their destination.

While the government has tried to mitigate the challenge of congestion on roads, by the expansion and improvement of the road networks within major towns, the challenge that still persists is that of poor management of the limited parking slots. A sustainable and efficient way of handling this challenge needs to be identified as soon as possible. The limited parking slots are currently not properly managed and would be one area in city management that could benefit from the efficiency that comes with M2M and IoT (Zanella et al. 2014).

It is obvious that driving around looking for a parking space wastes gas, increases pollution, and frustrates motorists. M2M and the IoT have offered a lot of promise in resolving this challenge (Kumar & Siddarth 2010; Zhang 2014; Al-Kharusi & Al-Bahadly 2014; Lee et al. 2008). Using a Wireless Sensor Network (WSN) to accurately determine parking vacancies can enable cities to decrease the congestion on roads by efficiently utilizing the limited resources.

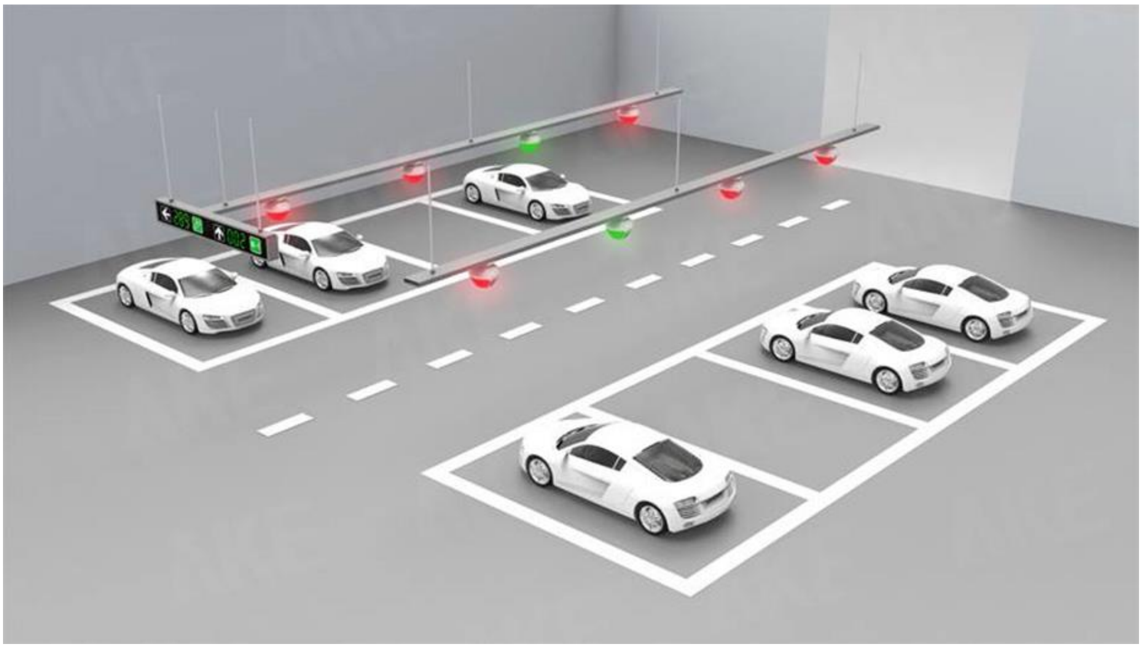

Fig 9: A smart carpark that is able to indicate available free slots (Shia 2016)

Research is rife in the adoption of M2M and IoT in this regard. While the standard M2M and IoT approaches of data transmission seem to fit all solutions, the key differences in the proposed approaches are in how the 'sensing' of vehicles/ or empty slots is done. Kumar and Siddarth (2010), and Al-Kharusi and Al-Bahadly (2014) propose the use of Closed-circuit television (CCTV) or cameras as the sensing nodes. While Lee et al. (2008) and Zhang (2014) use magnetic sensors (in addition to ultrasonic sensing in the case of Lee et al.). Inductive loops have also been used in the formative years, but have come with their own challenges.

Once the sensing has been done, usually by creating a network of sensors (figure 9), the captured data can be transmitted to meet varying needs. A typical smart parking system consists of the following primary subsystems; the sensing subsystem (WSN), the Communication subsystem, and the Parking management subsystems. Other additional subsystems such as the entrance display subsystem (figure 10), the client reservation subsystem, and the automated customer guidance subsystems may be incorporated to extend the solution to meet other related needs.

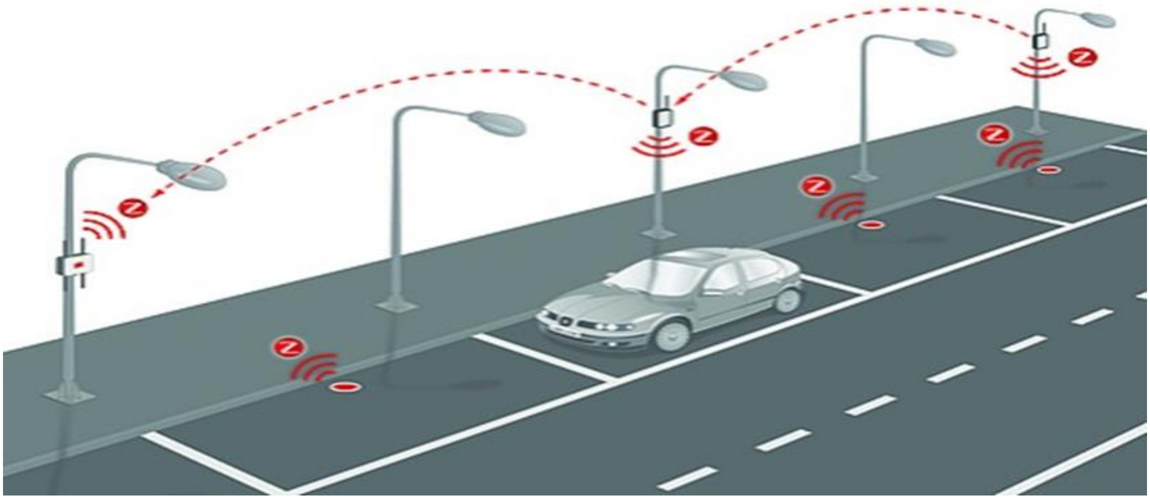

Fig 10: WSN can be used to sense available free slots. (Asin 2011)

As can be deduced, while the primary subsystems offer the basic requirements of the smart parking solution, the additional subsystems extend the benefits of the system. For example, with the automated customer guidance subsystem, the solution might be able to guide users to efficiently locate vacant parking slots hence reducing on the time and gas utilization. Without this subsystem, drivers may take long driving around in a car park in order to find the 'available' slot. With the client reservation subsystem, the customer is able to book a parking slot beforehand and be assured of finding one when he/she reaches the designated location. This removes the disappointment that comes with the 'chance' approach.

The core output of smart parking systems is a provision of automatic management of parking slots by accurate monitoring and making the information available to customers and facility administrators (Lee et al. 2008). This system resolves a number of challenges such as; traffic congestion (both on roads and in car parks), time wastage (increased working hours), wasted money, missed business opportunities/ time, poor public service, car emissions, poor visitors' experience, low parking space utilization, etc. (Al-Kharusi & Al-Bahadly 2014).

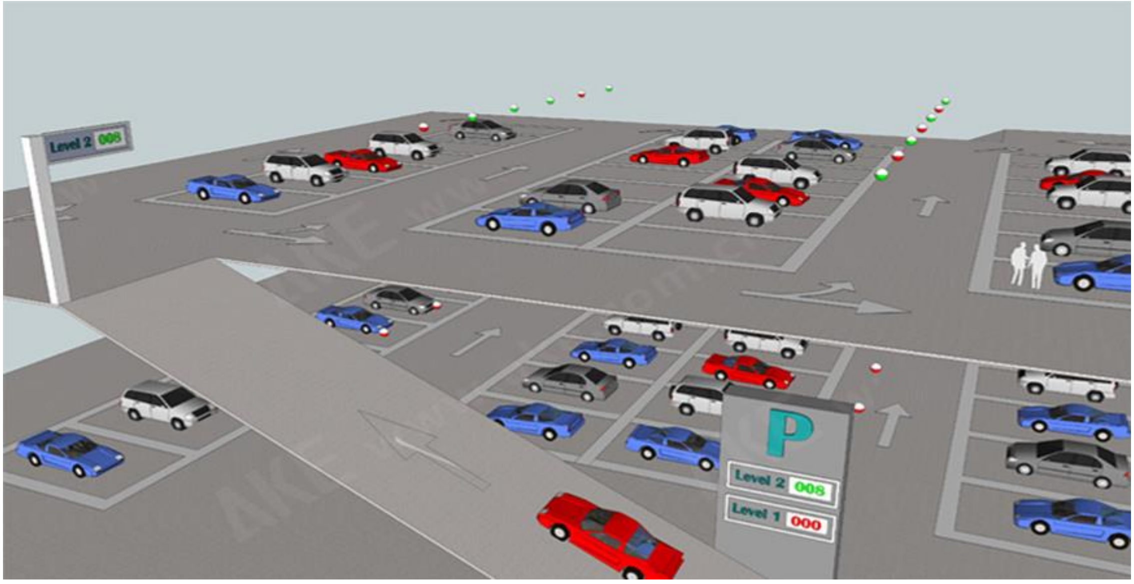

Fig 11: An entrance display subsystem can aid reduce wastage of time due to driving around the carpark looking for free slots.

4. Conclusion

With industrialization at the top of most developing countries' development agenda, ways of making industrial processes as efficient as possible, and ensuring a positive impact is had, on the surrounding communities are key to ensuring the survival of these industries. M2M and IoT are the two leading paradigms that are fostering efficiency through automation and making data available for better decision making in industrial processes.

In this paper, we have discussed what M2M and IoT are, and the potential impact they have on industrialization. Five examples of the application of these research paradigms have been presented to enable the reader to have an appreciation of practical ways that M2M and IoT are impacting the world. This is aimed at triggering the reader's imagination of possible scenarios and problems that can be solved by the two research paradigms. Central to the realizing of the visions of M2M and IoT is the connection of devices (sensor and actuators) to a communication network. Once that is realized, data can then be made available as a service, to foster efficiency and informed decision making.

While research continues to be done in an effort to improve and achieve standardization of M2M and IoT, sufficient work has been made to inspire developers and solution designs to develop applications that fit the M2M and IoT models. Hence M2M and IoT are pillars that industries can lean on to achieve sustainability and efficiency.

References

Al-Kharusi, H. & Al-Bahadly, I., 2014. Intelligent Parking Management System Based on Image Processing. World Journal of Engineering and Technology, 2(2), pp.55–67. Available at: http://www.scirp.org/journal/PaperDownload.aspx?DOI=10.4236/wjet.2014.22006\nhttp://www.scirp.org/journal/PaperInformation.aspx?PaperID=45644.

Anton-Haro, C. & Mischa, D., 2015. Machin-to-Machine Communications: Architecture, Performance, and Applications, WoodHead Publishing.

Asin, A., 2011. Wireless sensor platform eases quest for parking - Industrial Embedded Systems. Libelium. Available at: http://industrial.embedded-computing.com/articles/wireless-platform-eases-quest-parking/ [Accessed October 5, 2016].

Balandin, S., Andreev, S. & Koucheryavy, Y., 2015. Internet of things, smart spaces, and next generation networks and systems: 15th international conference, NEW2AN 2015 and 8th conference, ruSMART 2015 St. Petersburg, Russia, august 26-28, 2015 proceedings. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 9247(August 2015).

Boswarthick, D., Elloumi, O. & Hersent, O., 2012a. M2M Communication: A systems approach, John Wiley & Sons Ltd.

Boswarthick, D., Elloumi, O. & Hersent, O., 2012b. The Internet of things: Applications to the smart Grid and Building Automation, John Wiley & Sons Ltd.

BusinessGreen, 2014. Smart Metering Systems agrees £14m acquisition of Utility Partnership Limited. BusinessGreen. Available at: http://www.businessgreen.com/bg/news/2339680/smart-metering-systems-agrees-gbp14m-acquisition-of-utility-partnership-limited [Accessed October 6, 2016].

Enevo, 2014. Here comes an intelligent garbage bin that tells you when it has to be emptied. Available at: http://theinternetofallthings.com/iot-product-comes-intelligent-garbage-bin-tells-emptied-2014-01-02/ [Accessed October 5, 2016].

Evans, D., 2011. The Internet of Things - How the Next Evolution of the Internet is Changing Everything. CISCO white paper, (April), pp.1–11. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Internet+of+Things+-+How+the+Next+Evolution+of+the+Internet+is+Changing+Everything#0.

Friedemann, M. & Floerkemeir, C., 2011. From the Internet to the Internet of Things. From Active Data Management to Event-Based Systems and More, pp.242–259. Available at: http://www.ulb.tu-darmstadt.de/tocs/79304567.pdf.

Globescan, 2013. Mining industry faces a struggle to win public hearts and minds - @GlobeScan Blog. Available at: http://www.globescan.com/news-and-analysis/blog/entry/mining-industry-faces-a-struggle-to-win-public-hearts-and-minds.html [Accessed October 12, 2016].

Holler, J. et al., 2014. From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence, Available at: http://store.elsevier.com/product.jsp?isbn=9780124076846.

Kaplinsky, R., 1998. Globalisation, industrialisation and sustainable growth: the pursuit of the nth rent. IDS Discussion Paper, 365, pp.1–43. Available at: http://www.ids.ac.uk/files/Dp365.pdf.

Kim, B.-I.-I., Kim, S. & Sahoo, S., 2006. Waste collection vehicle routing problem with time windows. Computers & Operations Research, 33(12), pp.3624–3642. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0305054805001322\nhttp://www.scopus.com/inward/record.url?eid=2-s2.0-33645146288&partnerID=40&md5=972fba982145df133f5ba2501faada0c.

Kumar, P.V. & Siddarth, T.S., 2010. A Prototype Parking System using Wireless Sensor Networks. International Journal of Computer Communication and Information System, 2(1). Available at: http://www.ijcns.com/pdf/60.pdf.

Lee, S., Yoon, D. & Ghosh, A., 2008. Intelligent parking lot application using wireless sensor networks. 2008 International Symposium on Collaborative Technologies and Systems, pp.48–57. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4543911.

Lewis, C.M., 2007. "Modernisation and Industrialisation" Colin M. Lewis. London School of Economics and Political Science.

Marti, D.F. & Ssenkubuge, I., 2009. Industrialisation and industrial policy in Africa: is it policy priority? Policy, pp.1–59.

NetApp, 2016. AutoSupport – Remote Support Diagnostics – Support Automation | NetApp. Available at: http://www.netapp.com/us/services-support/autosupport.aspx [Accessed April 24, 2016].

Nuortio, T. et al., 2006. Improved route planning and scheduling of waste collection and transport. Expert Systems with Applications, 30(2), pp.223–232.

Pticek, M., Podobnik, V. & Jezic, G., 2016. Beyond the Internet of Things : The Social Networking of Machines. , 2016.

Shia, 2016. Smart Parking Systems for the Parking Companies. Available at: http://www.shia-today.com/smart-parking-systems-for-the-parking-companies.php [Accessed October 5, 2016].

United Nations -HABITAT, 2011. Global Report on Human Settlements 2011. Cities and Climate Change,

Whitmore, A., Agarwal, A. & Da Xu, L., 2015. The Internet of Things???A survey of topics and trends. Information Systems Frontiers, 17(2), pp.261–274.

Zanella, A. et al., 2014. Internet of Things for Smart Cities. IEEE Internet of things, 1(1), pp.22–32.

Zhang, Z., 2014. Cópia - A Street Parking System Using Wireless Sensor Networks. , 2013(2013), pp.5–11.

Non-Revenue Water reduction through adoption of Six Sigma; lessons from North Western Water & Sewerage Company.

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Abstract

Since 1994, Government of the Republic of Zambia has implemented reforms aimed at improving performance of the water sector .The sector reforms include among others; full cost recovery through user charges. The Water Supply and Sanitation Act No.28 of 1997 saw the establishment of the National Water Supply and Sanitation Council (NWASCO) whose function was to provide for, by local authorities, water supply and sanitation utilities like North Western Water and Sewerage Company. One major challenge faced by the company is the high rate of Non-Revenue Water (NRW). The company has not been consistence in NRW reduction. The adoption of Six-Sigma methodology as a data-driven methodology seeking to improve business processes in order to deliver high quality products has proved appropriate. The adopted Six Sigma in the experimental district of Solwezi illustrated that the NRW figures reached a record low of 18%. The research population included eight (8) districts in the province. Six-Sigma was only adopted in Solwezi as an experimental district while the other districts namely; Kasempa, Mufumbwe, Manyinga, Kabompo, Zambezi, Mwinilunga and Chavuma were control districts. To arrive at the conclusion, the research utilized the survey and Likert scale questionnaire in the data collection while the t-distribution and Statistical Process Control (SPC) were used in data analysis. The study illustrated that the adopted Six-Sigma methodology had an impact on NRW reduction. The research therefore, recommends the need for Institutional and regulatory changes in approaches towards NRW reduction as well as a further research in order to develop a generic and an all inclusive Six Sigma process that can be replicated by players in the water sector.

Key words: Non-Revenue Water, Six Sigma, process control, North Western Water and Sewerage Company.

1. Introduction

Strong underlying principles to any study are critical, the approach in this research focused on general and later specific aspects of Non-Revenue Water (NRW). Critical are the water sector reforms that include among other aspects; the reform process which inherently was political and required full commitment of policy makers to precisely balance financial and political objectives. The researcher totally agrees with the aspect of full cost recovery through cost reflective user charges. Chola (2015) wrote that sector reform number One (1) allowed certain decisions to be made by utility managers and separation of regulation and executive functions. However, a lot

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has to be done to realize the benefit of this autonomy.

1.1 Background

Since the mid 1990s, Government of the Republic of Zambia has implemented reforms aimed at improving performance of the water sector to increase and improve water supply coverage and quality of service throughout the country. However, the vision to increase coverage may not easily be achieved due to the loss of this essential product through NRW. This is a common practice in developing countries unlike developed ones. Shozo (2011) found that, "in developed countries, by virtue of appropriate reduction measures for NRW such as progress of replacement projects for water works facilities typified by pipelines in addition to proactive leakage control work and people's increasing awareness about water conservation; the proportion of NRW to total water production has gradually decreased year by year to less than 10% in advanced utilities". This should be desired by all our utilities through implementation of cost effective and sustainable strategies.

1.2 Objectives and Significance of the Study

a) Assess the effectiveness of NRW reduction strategies in the company.
b) Determine the impact of adopted Six Sigma techniques in NRW reduction.

1.2.1 Significance of study

The importance of reducing NRW to below sector benchmark is without doubt very critical for the viability of water utility companies. The benefits accrued are not only to several households, but also to society as whole. No business can continue to exist for long if it loses a considerable portion of its marketable product. Contrary, that is exactly what is happening with many water utilities in Zambia and world over. For North Western Water, high levels of NRW result in low levels of efficiency and loss of essential product. The immediate impact has been increased operational costs.As revenue from water sales decrease, investment in capital expenditure programs is significantly affected .In one-dimensional term, the utility is drawn into a vicious cycle that does not take in hand the core challenges.

1.2.2 Statement of the problem

The ever increasing customer base of the company i.e from 2000 customers in the year 2002 to 11,427 in 2016 (NWWSSCL, 2016) and ever growing service areas has caused the utility company to struggle to meet the persistently increasing water demand. This has highly been caused by high levels of water loss in the distribution networks .Consequently, customers end up paying for internal inefficiency through hiked prices, reduced supply hours and ultimately reduced water consumption. In addition, the company has struggled to be consistent in maintaining the sector benchmark of 25%.According to NWASCO (2014),the company only managed to reduce Non Revenue Water to 25% of water produced despite the desirable benchmark of 20%.

2. State of the Art

These Inconsistencies have negatively affected the viability as recovery costs are lowered, resulting in poor service delivery and hindered service extensions. Reducing these water losses is critical for efficient resource utilization, proficient utility management and enhanced consumer satisfaction. Therefore, based on these permutations, the company had to adopt approaches that could help reduce and guarantee consistency in NRW reduction.

2.1 The impact of inconsistencies in Non Revenue Water reduction

For the Utility Company, the ever-increasing population of North Western Province and expanding service areas results in failure to meet the ever increasing water demand. High levels of water loss in distribution networks attributed to pipe bust (figure 1) have a huge impact on service delivery.

Figure 1: Broken pipe due to lack of excavation clearance from the utility (Mufalo, 2016).

There is a relationship between operational expenses and investment capability. An extract from The International Water Association categorically outlines this relation (see figure 2).

The close relationship between NRW reduction and the corresponding loss of revenue that could have been used on reinvestment is the major reason why utilities should aim to drastically reduce NRW.

2.2 Global views on addressing inconsistencies

Roland (2010) reiterates that no business can survive for long if it loses a significant portion of its marketable product. However, that is exactly what is happening with many water utilities. High levels of NRW have resulted in low levels of efficiency. He further mentions that, “when a utility’s product (treated water) is lost, treatment and distribution costs increase while water sales decrease. To compensate for the lost product, substantial capital expenditure programs are often promoted to meet the ever-increasing demand”. In short, the utility enters into a vicious cycle that does not address the core problem.

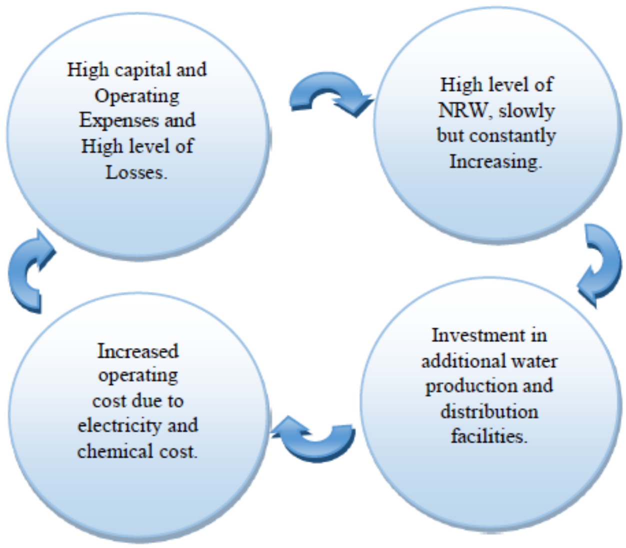


Figure 2: Vicious NRW Cycle (Roland, 2010)

2.2.1 Going beyond technical measures.

Beyond traditional approaches to NRW, Farley (2008) adds that, many utilities that have been successful in addressing NRW have gone beyond technical measures to address community behaviour that drives illegal connections and pilferage. This is done with the understanding that water loss is not just an engineering problem but also reflects a socio-cultural situation that requires changes in community behaviour and attitudes toward water usage.

2.2.2 Establishment of the strategy development team

The Managers’ Non-Revenue water hand book suggests the need for NRW reduction strategy team that should ensure that all components of NRW are covered and that the proposed strategies are feasible in terms of physical application and financial requirements. Such a team should consist of members from each operational department i.e. production, distribution and customer service. It may also include members from the finance, procurement and human capital departments. Choosing the right members promotes ownership by the utility’s various departments involved in the strategy’s implementation, and also ensure consensus with senior management.

2.2.3 Setting appropriate NRW reduction targets

Farley (2008) suggests that the strategy development team should set specific company-wide targets for NRW reduction, taking into account the utility’s other goals or policies that will either complement or conflict with NRW reduction. NWASCO on the other hand, has consistently set the general targets and published the ranking of top performers in NRW Reduction.

3. Conceptual Framework: NRW Reduction by Process Control

The reduction of NRW is a process just like any production system. Process control in the context of NRW will be inclined to process variable like reduction percentage. Factors like; pipe material used for leak repair, valves and pressure under which the appurtenances will be installed does significantly impact the quality (Roland, 2010). Anyone involved in NRW should target to achieve;

- Reduced variability
- Increased efficiency
- Safety

3.1 Reduced variability

Process control can reduce variability in NRW; hence achieve consistency in percentage reduction. In this way, the company can save resources. Table 1 shows how the company lost revenue due to NRW (UfW) according to the 2007/2008 sector report.

Table 1: Lost revenue due to UfW in 2007/2008(NWASCO, 2008)

NWWSC [Year]	Total Billing (in mi K)	UfW (%)	UfW (in mil K)
2008/2009	5,612	33.2	2,788

3.2 Increased efficiency

Some processes need to be maintained at a specific point to maximize efficiency. For example, a control point might be the pressure in the distribution network. Accurate control of pressure ensures process efficiency and avoids pipe bust. The company saves revenue by minimizing the resources required to reduce NRW.

3.3 Safety

A run-away process, such as an out-of-control water leakage may result if there is no maintenance or precise control of the process variables. The penalty of a run-away process can be disastrous in a utility. Therefore, accurate process control in NRW may also be required to ensure safety (Roland, 2010).

3.4 Elements of Six Sigma Process Improvement

This is an extract from (Points, 2016) of three key elements of Six Sigma Process Improvement:

- Customers
- Processes
- Employees

3.4.1 Customers:

Customers define quality. They expect performance, reliability, competitive prices, on-time delivery, clear and correct transaction processing and more. This means it is important to provide what the customers need to gain customer delight.

3.4.2 Processes:

There is need to define processes as well as defining their metrics and measures are the central aspect of Six Sigma. In a business, quality should be looked from the customer's perspective.

3.4.3 Employees

A company must involve all its employees in the Six Sigma program. It must provide opportunities and incentives for employees to focus their talents and ability to satisfy their customers. All team members should have a well-defined role with measurable objectives.

4. Methodology

The methodology focused on the application of Six Sigma at North Western Water & Sewerage Company, methods of sampling, data collection and analysis.

4.1 Application of six-sigma

Six-Sigma is a process improvement methodology originally developed by Motorola in 1986.The purpose of this methodology is to bring business improvement, quality performance and increase in profit by addressing business issues that may have existed for a long time (Hundozi, 2015). Other definitions relate to six-Sigma being a set of techniques and tools for process improvement. It seeks to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes (Geoff, 2001).

4.1.1 Adoption of DMAIC methodology

The process of reducing NRW requires mechanisms to monitor and report systematically. The process was implemented in Solwezi at the commencement of the year 2016.It involved the application of the DMAIC process.

The **DMAIC - D**efine (D), **M**easure (M), **A**nalyse (A), **I**mprove (I), **C**ontrol (C) methodology was chosen because the process of Non-Revenue Water Reduction already existed in the company.

4.1.2 Sample and population allocation

Figure 3 shows the allocation of sampling district to be Solwezi with the rest of the seven (7) districts representing the research population. It further shows the time horizon, techniques and procedures of data collected.

4.1.3 Definition (D)

In adopting the (D) in the DMAIC methodology, the company defined Non Revenue Water as the difference between the volume of water put into a water distribution system and the volume that is billed to customers. NRW comprises of three components as follows: Physical (or real) losses from all parts of the system and overflows at the utility's reservoirs. Commercial (or apparent) losses as caused by customer meter under registration, data handling errors, and theft of water in various forms. Unbilled authorized consumption as water used by the utility for operational purposes.

However, it is important to state that in some Asian countries, the term "NRW reduction measures" is unfamiliar. In Japan for instance a term "leakage control work" is used in place of NRW. The reason is that leakages account for the larger part of NRW in Japan. Losses due to water theft and metering inaccuracy are not common (Shozo, 2011).

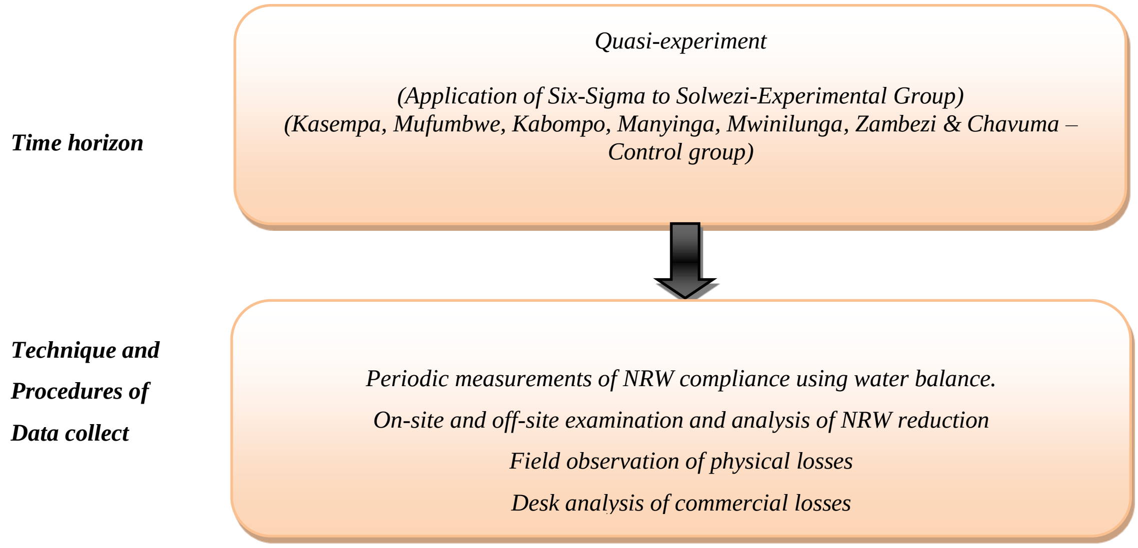


Figure 3: Illustrates relationship between time horizon, technique and procedures in experiment strategy.

4.1.4 Measurements (M) by Establishment of water balance

To facilitate uniformity in measurement, a water balance was established for each month from January to December. However, the main focus was on January, February and March as Leak detection and management happens to be a challenge during rainy season. Table 1 illustrates the components of a water balance as adopted.

4.1.5 Analysis (A)

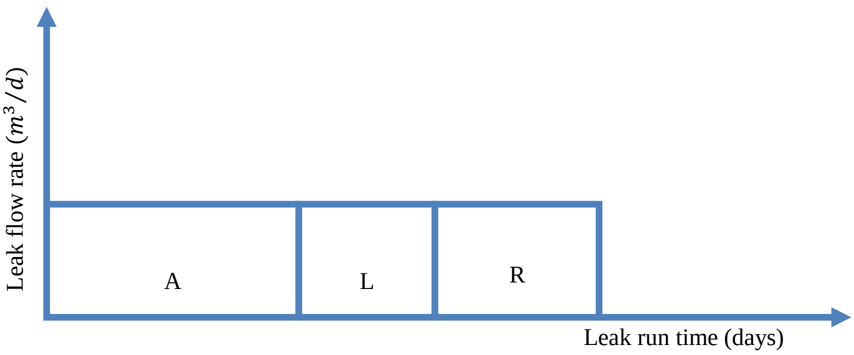
In analysing NRW reduction in Solwezi, Leak Run Time (LRT) was used as highlighted by (Farley, 2008)**.**The idea was to demonstrate that the volume of water lost from an individual pipe burst does not only depend on the flow rate of the event, but is also a function of run time and this is often overlooked. The leak run time consists of three components as in figure 4.

- **Awareness time**: time until the utility becomes aware that there is a leak
- **Location time**: time spent to precisely locate the leak so that a repair job order can be issued
- **Repair time**: time between issuing of repair job order and completion of the repair

Table 1: Established template of a water balance: Source (IWA, 2015)

<table>
<tr><td rowspan="9">System input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td>Revenue Water</td></tr>
<tr><td>Billed Un-metered Consumption</td><td rowspan="8">Non-Revenue Water(NRW)</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Un-billed metered Consumption</td></tr>
<tr><td>Unbilled Un-metered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses (commercial losses)</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses(Physical losses)</td><td>Leakage in Transmission and Distribution Mains</td></tr>
<tr><td>Storage Leaks and Overflows from Water Storage Tanks</td></tr>
<tr><td>Service Connections leaks up to the meter.</td></tr>
</table>

This was very useful to the Water Demand Management team in charge of leak management.



A - Awareness time/ leak run time (days)
L - Location time
R - Repair time

Figure 4: Leak run analysis adopted from The Manager's Non-Revenue Water Handbook.

4.1.6 Improve (I)

The company established NRW reduction strategy team composed of Black belt, Master Black belt and Green belt. These ensured that all components of NRW were covered and that the proposed strategies were feasible in terms of physical application and financial requirements. Lower members of the team comprised of members from operational department and customer service. It also embraced members from the procurement, finance and human capital departments. The chosen members promoted ownership and also ensured consensus with senior management.

4.1.7 Control (C)

Control was achieved when strategy development team set specific and appropriate NRW reduction targets. They also took into account the utility's other goals or policies that either complemented or conflicted with NRW reduction. This was compounded with NWASCO's general targets for NRW (table 2) and as published on March 2015.

Table 2: NRW benchmark (NWASCO, 2015)

Benchmark for UfW	**Good**	< 20%
	Acceptable	**20 – 25%**
	Unacceptable	**>20%**

In addition, other internal efforts included cleaning of buried meters and replacement of stack meters (figure 5 and 6). It is also important to note that the control process started way back in the year 2000 through a complete over haul of the system that saw a drastic reduction of in un-accounted for water (UfW) from 75% to 27%.This was purely due to the transition from Un-accounted for Water (UfW) to Non-Revenue Water (NRW).The difference between the two lies in the estimations and assumptions in UfW as opposed to accurate bulk water meter data in NRW computations.

Figure 5: Location of buried meters (Mufalo, 2016)

Figure 6: Stack meter (Mufalo, 2016)

5. Data Analysis

Data analysis by Likert scale was chosen for its flexibility and straightforwardness in drawing conclusions, reports, results and graphs from the responses.

5.1 Analysis of Likert scale data for control district

As earlier stated, some researchers argue that, where such data from a Likert scale are likely to have similar size gaps between data values, they can be analysed as if they were numerical interval data (Sauders, 2012) .Based on this assumption, parameters for the experimental district (Solwezi) were converted into interval data. The relative differences between two data values were measured and the data took values within the range and was treated as continuous data.

- **Inference:** Parametric analysis of ordinary averages of Likert scale data was justifiable by the central limit Theorem; analysis of variance techniques included the t-test.

- **Using the t-test:** a composition of a series of four Likert type items that represented similar questions was combined into a single composite score/variable. Therefore, the Likert scale data was analyzed as interval data.

Six Sigma targets variation in the business unit processes and focuses on the process improvement rather than final outcome. The Six Sigma prospective methodology as compared to other quality programs is focused on prevention of defects rather than fixing them and when applied in a business unit, it yields better results.

6. Findings

The experiment study and survey; aimed at testing the hypotheses that sought to establish whether the adoption of Six Sigma approach lead to any significant reduction in Non Revenue water.

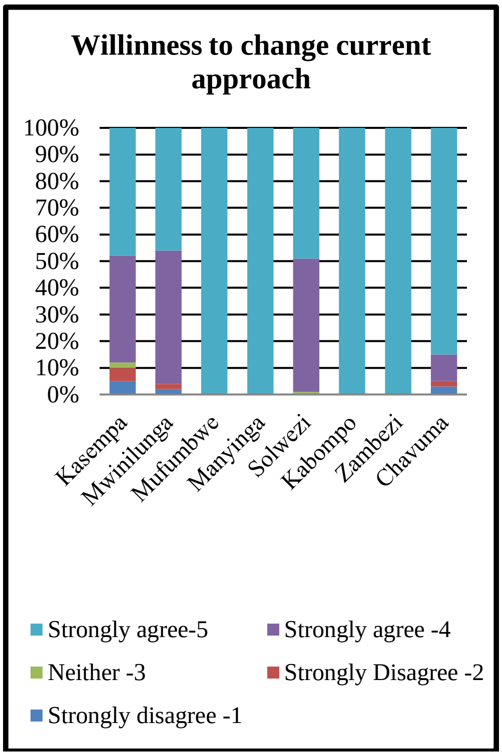
6.1 Survey findings

In the analysis, all data from districts that received control group questionnaires were treated as ranked data. Both the experimental district and control districts assessed the willingness to:

- Change current approach
- Adoption of Six-Sigma
- Involvement in NRW activities by management
- Involvement in NRW activities by General staff

Figure 8 to 11 below illustrates the survey findings from the Likert scale data.

Similar to willingness to change current approach (figure 7) and willingness to adopt Six Sigma (figure 8), both indicate above 95% in agreement. However, we see that despite agreeing to the change in approach, some districts like Mwinilunga and Manyinga in both cases having almost 50% of strongly agree respectively. This was attributed to the aspect of inclusiveness in the NRW process in these districts. Both districts were being supervised by non-technical staff resulting in lack of focus on Non-Revenue Water reduction. This was substantiated by major errors observed on the water balance submitted. It is in the researchers' findings that, elements of NRW reduction may require the team leader to be highly technical while receiving support from the entire team that should include non-technical staff.



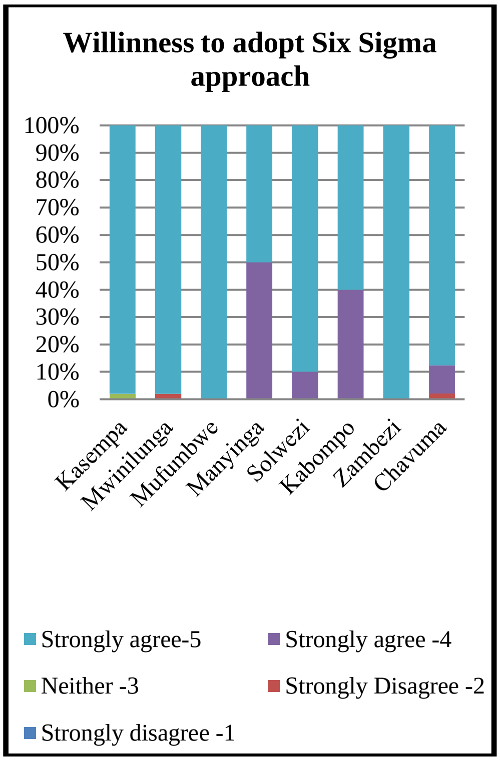


Figure: 7 Change of approach

Figure 8 Adoption of Six-Sigma

In general, both Management and general staff totally agreed on the involvement in the NRW reduction activities (figure 9 & 10). However, we see that most districts (figure 10) have the general staff not 100% in agreement on getting involved. The reasons advanced included the desire to shift responsibility to management. Several complaints on lack of support from Management were recorded. Looking at figure 9, we see a totally different response from management in all districts; 100% willingness was recorded. This was attributed to the sufficient knowledge on the consequences of high Non-Revenue Water. These include failure to meet the demand and reduced viability of the company. From the perspective of change in NRW approach, it is clear that the desire to adopt Six Sigma is evident. The third aspect of readiness assessment under change management focused on organizational assessment for change. All the districts have shown that they are skewed towards changing the approach to Six Sigma.

6.2 Experimental findings

The objective of presenting these findings graphically is to provide the basis for a substantive validation of the Six-Sigma process using statistical process control (SPC).This is aimed at pointing out the significance change in NRW figures after adoption of the Six-Sigma process. The eight (8) year company performance indicates the inconsistencies in the reduction of NRW (figure 11). The year 2014 saw the lowest NRW closest to the targeted figure, while 2011 completely departed from the normal average of below 30%.

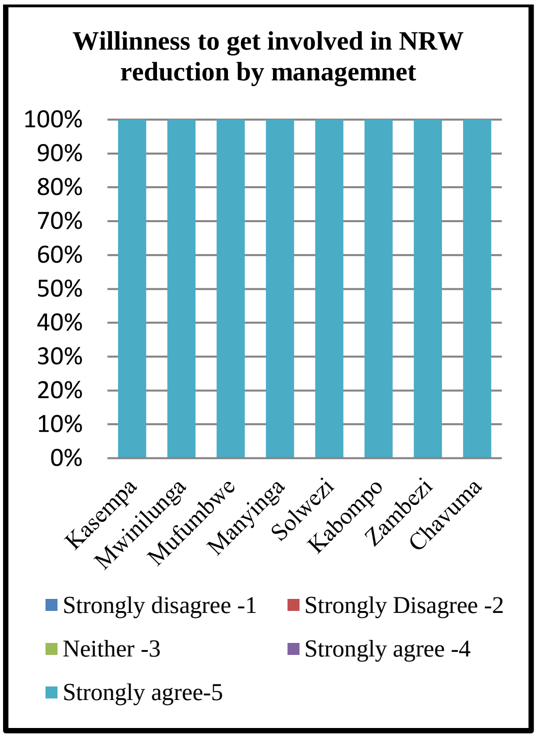


Figure: 9 Management involvement

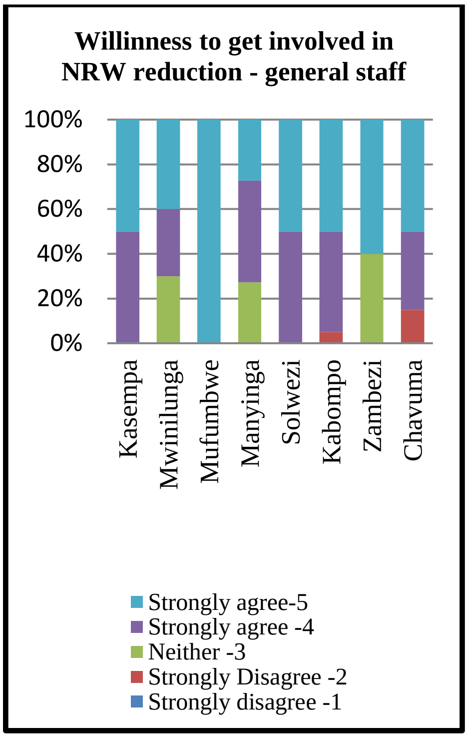
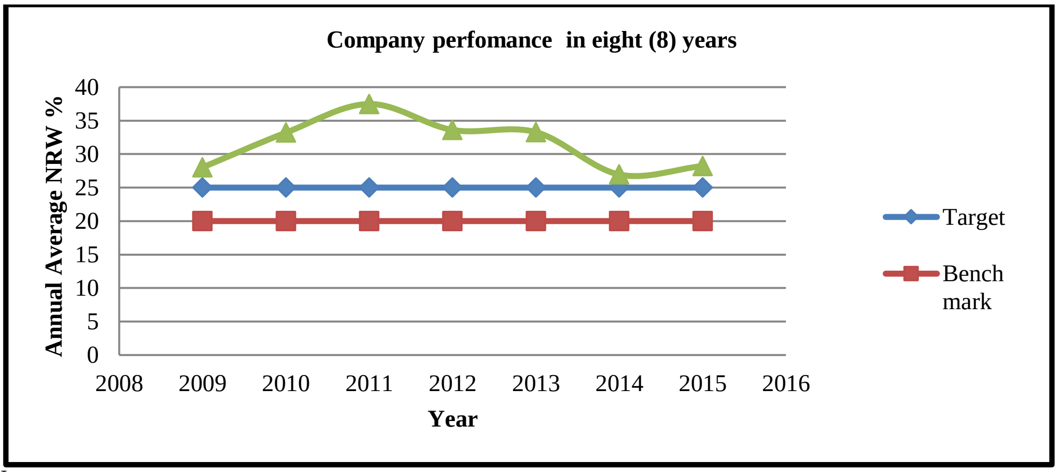


Figure 10 General staff involvement



Note:

1. *The utility company has a continuous water supply in all operational areas and the system fully pressurized to give representative data on NRW.*
2. *Annual figures are all computed from bulk meter readings and no estimates are applied*.

Figure 11: Company performance in eight years (NWWSC, 2016)

Figure 12 provides a good indication of the results of Six-Sigma implementation in Solwezi and shows significant difference in levels of NRW compared to other districts. Apart from Chavuma whose level is within the target of 25%, a further comparison of the two will still yield positive reduction in Solwezi if we consider the NRW/km/year. Longer Networks with low levels of NRW are more efficient on the basis of distance covered and volume supplied. Roland (2010) outlined “three important determinants of NRW”, namely; consumption, pressure and supply time. He maintains that any system with high consumption can easily indicate lower levels of NRW.A utility that has NRW level of 20% at an average pressure of 20 m is performing substantially better than a utility that also has NRW level of 20% but average pressure of only 10 m.

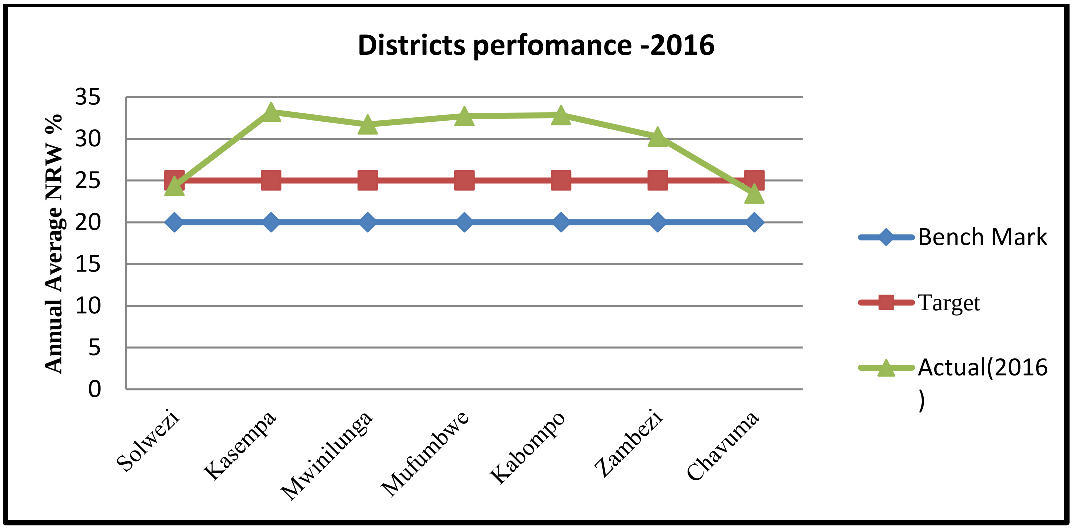


Figure 12: Districts performance in 2016 (MIS, 2016)

A comparison of the year 2015 and 2016 monthly average illustrates that, Solwezi recorded low levels of NRW in the critical months of January, February and March. These are known as critical months due to the conditions available during rainy season that make it difficult to detect and manage physical losses. We see that the year 2015 (figure 13) has nine (9) points out of target as compared to 2016 with only two points.

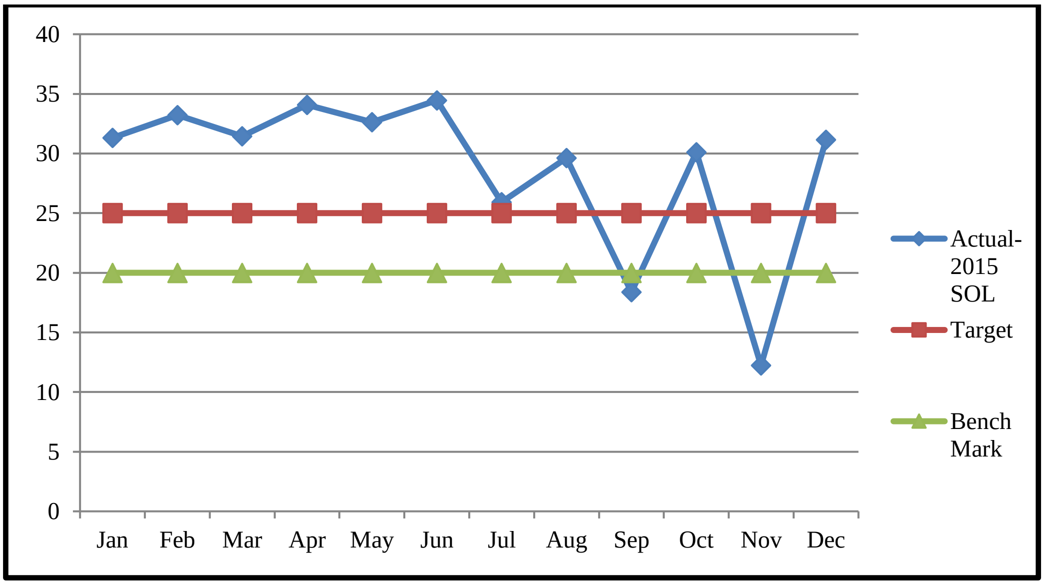


Figure 13: Solwezi District performance in 2015 –source NWWSC (MIS)

6.3 Process validation by Statistical Process Control (SPC)

In the experimental district, variations in results obtained before introducing the Six Sigma approach were attributed to the process or approach to NRW. The attributes included; operators (plumbers), leak detection equipment, lack of NRW guidelines and the existing operational environment .

6.3.1 Control chart

Control charts were developed using the NWASCO NRW targets with the relationship in measurements of the processhown in figure 14.

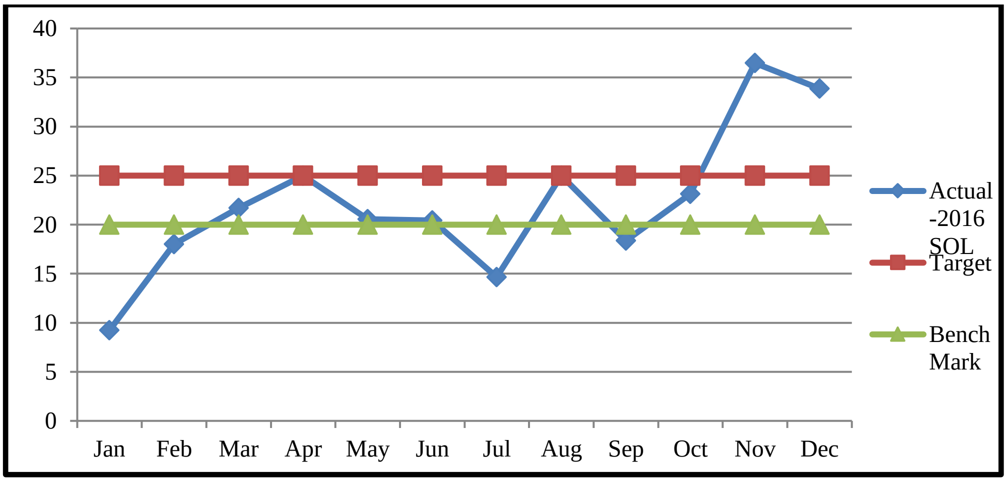


Figure 14: Solwezi districts performance in 2016 (MIS, 2016)

Table 3 Relationship in Measurements

C_{pk}	*Sigma level*	*Area under Probability density function*	*Process Yield*	*Process fallout(in terms of DPMO/PPM*
1.00	3	0.9973002039	99.7%	2700

Note: Process capability and Process capability index analysis was performed using the SQCpack software (Anon., 2016) . The result of this analysis confirm that the Six Sigma quality process was within desired minimum process capability for one sided specification.

7. Conclusions and Recommendations

The objectives of the study were:

a) To assess the effectiveness of NRW reduction strategies at North Western Water & Sewerage as compared with standard practice.

b) Determine the effect of Six Sigma technique in Non-Revenue Water reduction.

7.1 Conclusions

7.1.1 Assess the effectiveness of NRW reduction strategies for the company compared with standard practice.

The study sought to determine the effectiveness of current approaches in Non Revenue Water reduction for the eight (8) operational districts. This was assessed through the Likert scale questionnaire which sought to outline the challenges in the current Non Revenue Water approaches. The assessment was uniform throughout the eight districts and the response was indeed skewed towards the acknowledgement that the current NRW approaches were not inclusive. They lacked proper strategies to help the districts reduce the NRW. In some instance, lack of involvement emerged as the major reason. A statistical analysis by t-distribution indicated a significant difference in the responses which again illustrated that the current NRW approaches do not fully support consistent reduction in NRW. In any case, the findings in the Likert scale questionnaire illustrated that charging the approach was desirable.

7.1.2 Determine the effect of Six Sigma techniques in NRW reduction.

The study has shown that the adoption of Six Sigma had an impact on NRW reduction and has further proved that the impact was sustainable. The Experimental district (Solwezi) recorded a massive reduction in NRW up to a monthly average of 18% during the research period of 2016. It has also been illustrated that during the critical period of January to May, the NRW figures reached a record low as compared to previous years (figure 14).The statistical analysis by t-distribution has also indicated significance difference in the sample and population mean, rendering Six Sigma as an appropriate approach to reducing NRW. When the experimental district's NRW process was checked against process control permutations, results illustrated that the process was within the limits during the whole period of implementation with the process capability and capability index within desired values (table 3)

7.2 Recommendations

The company should scale up implementation of Six Sigma; the following have to be considered;

- Education and communication of Six Sigma should be made a key priority during implementing.
- Modification of job descriptions to better reflect the Six Sigma focus and requirements.
- Implementation should be owned by process owner and process manager models.
- Six-Sigma should be integrated with strategic plans, business, operating, and human resource plans.
- The focus should be less on "belts" and more on operational excellence.
- The company should align compensation and recognition (e.g., monetary and otherwise) with the Six Sigma objectives.
- Documentation on Six Sigma should be made simple and easy to understand.
- All employees should be given the tools they need to demonstrate ideally through quantitative and qualitative measures.

The lessons to be drawn from further studies on Six-Sigma would help devise best conditions needed to develop a Six Sigma process and its sustainability in a water utility company. The focus should be on;

- A research on other options to upgrade Non-Revenue Water policy in water utility companies or the water sector as a whole.
- An exploratory study on the risk of a possible conflict between Six-Sigma and other quality control procedures indigenous to a particular water utility company.
- An assessment of a mandatory Six Sigma process in all utility companies.

References

Anon., 2016 . *SQC Software.* [Online] Available at: www.pqsystem.co/quality-solution/statistical-process-control/SQCpack/audit-trail-and [Accessed 3rd June 2016].

Chola, 2015. *Water Supply and sanitation in Zambia:Reform and regulation,* LUSAKA: NWASCO.

Farley, M., 2008. *Manager's Non-Revenue Water Handbook.* New York: USAID.

Geoff, T., 2001. *Six Sigma: SPC and TQM in manufacturing and services.* s.l.:Gover Publishing.

Hundozi, E. L. a. B., 2015. *Quantitive Methods in Process improvement.* s.l.:PECB.

International Water Association, 2015. *Water Balance.* [Art] (IWA).

NWASCO, 2014. *Urban and Peri-Urban water supply and Sanitation report,* Lusaka: National Water and Sanitation Council.

NWWSSCL, MIS., 2016. *Management Information System -North Western Water & Sewerage,* Solwezi: NWWSSCL.

Points, T., 2016. *Six-Sigma Elements* . [Online] Available at: www.tutorialspoint.com/six_sigma_key_elements.htm [Accessed 24th May 2016].

Roland, R. ., 2010. *The issues and challenges of reducing Non-Revenue Water.* Mandaluyong City,Philppines: Asian Development Bank.

Sauders, M., 2012. *Research Methods for Business Students.* Sixth ed. United Kingdom: Thornhill .

Shozo, Y., 2011. *Non-Revenue Water Management-Considering Developing Countries.* 1st ed. Tokyo: suido Sangyo Shibun.

Optimization of Copper Ore Heap Leaching Efficiencies at Mopani Copper Mines, Mufulira West Heap Leach Plant.

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Abstract.

This work was aimed at determining the leaching efficiencies at the normal operating parameters of Mufulira WestHeap Leach Plant and to optimize these parameters in order to recover more copper from the ore than what is currently recovered. The addition of ferric ion to oxidize the sulphide mineral components of the ore was among the very important aspects of this work. The Mufulira West ore contains generally less than 1% acid soluble copper. However, the amount of acid insoluble copper is taking an upward trend. The Mufulira west heap leach efficiencies and recoveries as of October 2015 wereaveraging 82% and 60% respectively. Acid heap leaching involves metal extraction from low grade ores by use of a leachant in this case, H_2SO_4. Raffinate (barren solution from solvent extraction process) mixed with H_2SO_4 is sprayed on the heaped ore to produce a pregnant leach solution. Though cheap, the process may be, affected by various parameters which include pH, particle size, residence time and ferric ion concentration among many others. In order to investigate these parameters and determine the optimum conditions, laboratory bottle roll tests were carried out on a seven day basis upon which the leaching efficiencies under the normal operating parameters of pH1.3 and particle size -13mm was established to be 87%. At this optimum particle size and an optimum ferric addition of 22gpl, the leaching efficiency was improved to 92%.

Keywords: Mopani Copper Mines, Mufulira, raffinate, Solvent extraction, heap leaching, efficiency

Introduction.

Mopani Copper Mines plc, (MCM) is a Zambian registered Copper Mine owned by Carlisa Investments, a joint venture company of Zambia Copper Mines- Investment Holding

(ZCCM-IH), Glencore and First Quantum Minerals, whose administrative headquarters are located in Kitwe. The company has mine sites at Nkana, Kitwe, which consist of an underground mine and cobalt plant while the Mufulira mine site consists of an underground mine, a concentrator, smelter and the refinery. Figure 1 is a map showing the locations of Mufulira and Kitwe town in which MCM mine sites are found.

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Figure 1: Map showing locations of Mufulira and Kitwe town, accessed from www.maps-streetview.com/zam-map.

The Mopani Copper Mines Mufulira west heap leach plant has been operating since 2007and treats copper ore of Mufulira west portal via the hydrometallurgical route and has stacked an estimated 3,221,474 tons of ore. The principal sulphide copper minerals are chalcopyrite (~60%), bornite (~40%) and traces of chalcocite. Oxide minerals which are confined to near surface occurrences and supergene enrichment zones comprise of malachite, azurite and chrysocolla.

The agitation leach plant and the in-situ leach operations supply Pregnant Leach Solution (PLS) to the three Solvent Extraction Plants (SXP) before it is taken to the electrowinning plant for the production of copper cathodes.

Literature review.

According to an investigations of Teixeira (2007) the in-situ leaching, showed that ferric ions are a strong oxidant that is capable of oxidizing the sulphide minerals in ores.

Sulphide minerals are difficult to leach at ambient temperature and atmospheric pressure due to the formation of a layer of sulphur (precipitates) on the minerals during leaching. This sulphur layer coats the mineral during the first few minutes of leaching hence passivating it, retarding diffusion of the leachant to the unreacted mineral surface hence slowing leaching (Hourn et al, 1999). Figure 2 below shows a model of the oxidation of chalcopyrite, by Fe^{3+} with the formation of a low porous layer of sulphur.

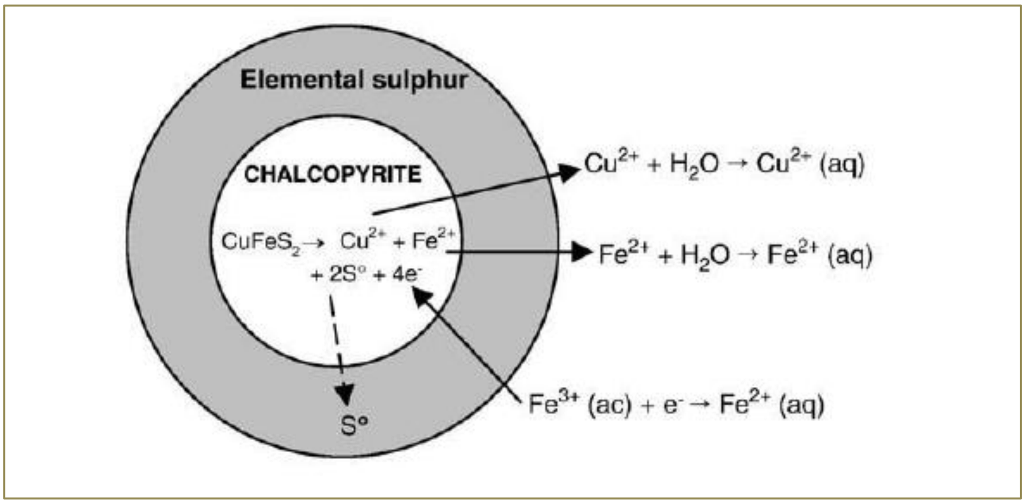

Figure 2: A model of chalcopyrite oxidation, a sulphide mineral, by Ferric ions, Munoz (1979)

In general, according to Hourn et al (1999), the reaction for sulphide minerals inthe presence of ferric sulphate solution is given by

$MS_{(s)} + Fe_2(SO_4)_{3\ (aq)} \rightarrow MSO_{4(aq)} + 2FeSO_{4\ (aq)} + S^o_{(s)}$ …………………………..[1]

For specific copper mineral such as chalcocite, it is as follows:

$Cu_2S_{(s)} + Fe_2(SO_4)_{3(aq)} \rightarrow 2CuSO_{4\ (aq)} + 2FeSO_{4(aq)} + S^o_{(s)}$ ………………………[2]

The other reactions which occur during leaching when ferric sulphate is used in the leachant are:

$FeS_2 + 7Fe_2(SO_4)_3 + 8H_2O \rightarrow 15\ FeSO_4 + 8H_2SO_4$ ………………………… [3]

$2FeSO_4 + 0.5\ O_2 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + H_2O$ ……………………………… [4]

$S^o_{(S)} + 3Fe_2(SO_4)_3 \rightarrow FeSO_4 + 4H_2SO_4$ ………………………………. [5]

Reaction equations 3 and 4 can act as a source of ferric ions which is the oxidant in this case. Several attempts have been made to leach sulphide minerals and several researchers have been successful and processes have been patented worldwide and plants have been established to leach sulphide minerals using the several processes which have been developed.

The chemistry involved in the dissolution of copper oxide minerals is relatively simple and can be presented by the following reactions, Gupta, (2003)

Malachite:

$Cu_2(OH)_2CO_3 + 2H_2SO_4 \rightarrow 2CuSO_4 + CO_2 + 3H_2O$ …………………………..[6]

Chrysocolla :

$5CuSiO_3.7H_2O + 2H_2SO_4 \rightarrow 5CuSO_4 + 5SiO_2 + 9H_2$…………………………..[7]

Azurite:

$Cu_3(OH)_2\ (CO_3) + 3H_2SO_4 \rightarrow 3CuSO_4 + 4H_2O$ …………………………………[8]

Ballester *et al* (2008), investigated the effect of the ferric ions on chalcopyrite dissolution and concluded that the presence of Fe^{3+}favours dissolution of the mineral at a suitable ferric ion concentration although high ferric ion concentration reduces the leaching kinetics of the mineral. This was explained by passivation at low redox potentials. These researchers also concluded that diffusion of the ferric ions to the mineral core to oxidize the sulphide mineral component of the ore was the rate controlling step.

Hiroyoshi and Miki (2001) also studied the effect of ferrous ions on chalcopyrite oxidation and concluded that ferric ions have a favourable effect on copper extraction and the kinetics were controlled by the ratio of Fe^{2+}/Fe^{3+}.

Thomas and Ingraham, (1969) leached synthetic covellite using rotating disks in acidified ferric sulfate solutions in a wide range of temperature from 25 to 80°C and established a dual leaching mechanism. Furthermore, found out that the leaching rates were almost directly proportional to the ferric concentration at diluted solutions (concentrations below 0.005M), but almost independent of ferric concentration at high concentrations.

Leaching.

Leaching can be defined as the selective dissolution of the value mineral(s) of an ore or concentrate due to the action of a leachant, a reagent which contains the active anion or cation which causes a specified phase to go into solution, Burkin (2001).

A variety of leaching agents may be used, sulphuric acid being the most common used because of it's low cost and availability. Lixiviants are chemical solutions used in leach mining to enhance dissolution of metals in ores, Zanbak (2001).At the Mufulira West heap leach plant, the raffinate which is sprayed on the stacked ore is mixed with sulphuric acid.

The various methods of leaching include:

- In-situ leaching
- Heap leaching
- Percolation leaching
- Pressure leaching
- Agitation leaching
- Bacterial aided leaching

Heap leaching techniques enable the processing of different kinds of ores which could not otherwise be exploited under viable economic conditions. Modern day heap leaching has a variety of low energy consumption, Zanbak (2012).

Heap leaching involves the following steps, Basov, (2015)

- Mining the ore
- Crushing the ore (if necessary)
- Agglomerating the ore (if necessary)
- Placing the ore on an impermeable pad
- Irrigating the ore with the appropriate lixiviant to dissolve the valuable metals
- Collecting the leachate in a pond or tank(pregnant or value bearing solution)
- Recycling the barren solution (with additional lixiviant) back to the heap.

Figure 3 shows a simplified diagram of the general heap leach scheme.

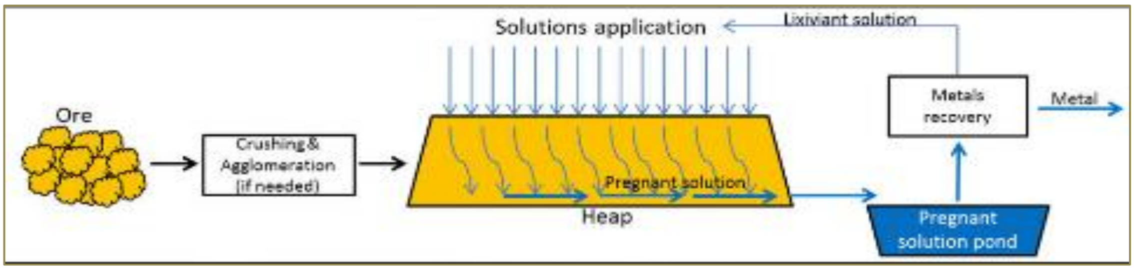

Figure 3: A simplified diagram of the heap leach scheme, Basov (2015), www.mininginfo.com/heap-leach-mining

Thermodynamics of leaching.

Pourbaix diagrams, also known as E_h-pH diagrams, show the stable phases of an aqueous electrochemical system. These diagrams are particularly useful for leaching because it shows the reactions that are favourable under different conditions. Thermodynamic considerations are important in leaching in that they provide basic guidance in choosing the combination of reagents and their concentrations so as to obtain favourable free energy changes associated with any proposed reaction. However, these diagrams do not provide kinetic information. i.e. the reaction may be thermodymically favourable but if the kinetics is too slow, then the reaction will not take place, Angeles (2011).Figure 4 and 5 show the Pourbaix diagrams of copper and chalcocite respectively.

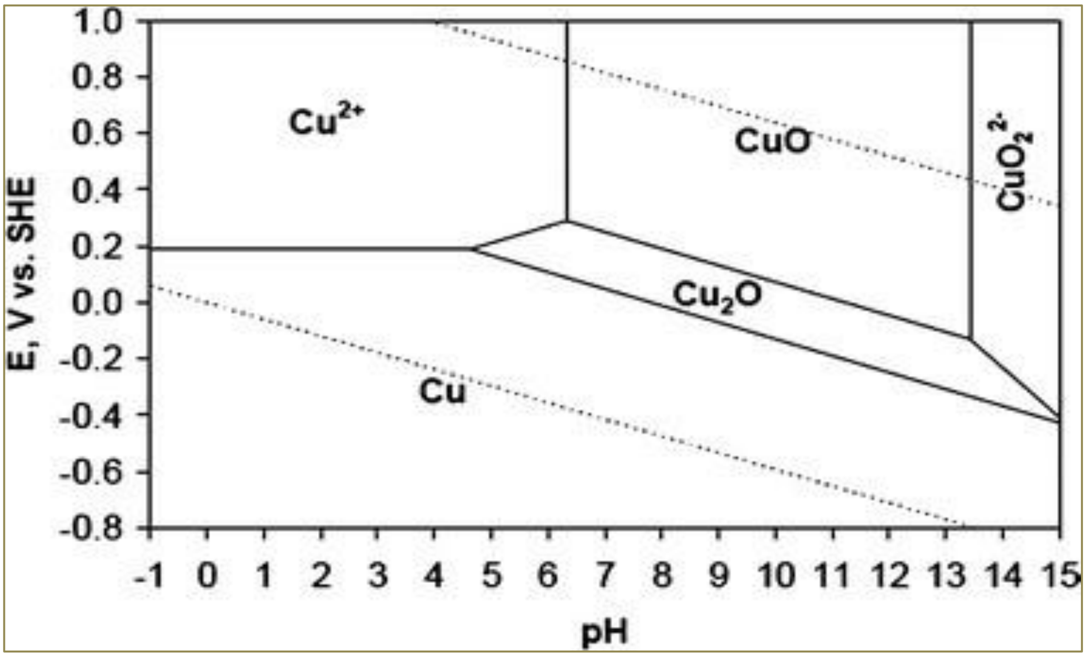

Figure 4: Pourbaix diagram for copper, K.Caiden (2001), accessed from www.researchgate.net/figure/27864-Pourbaixdiagram

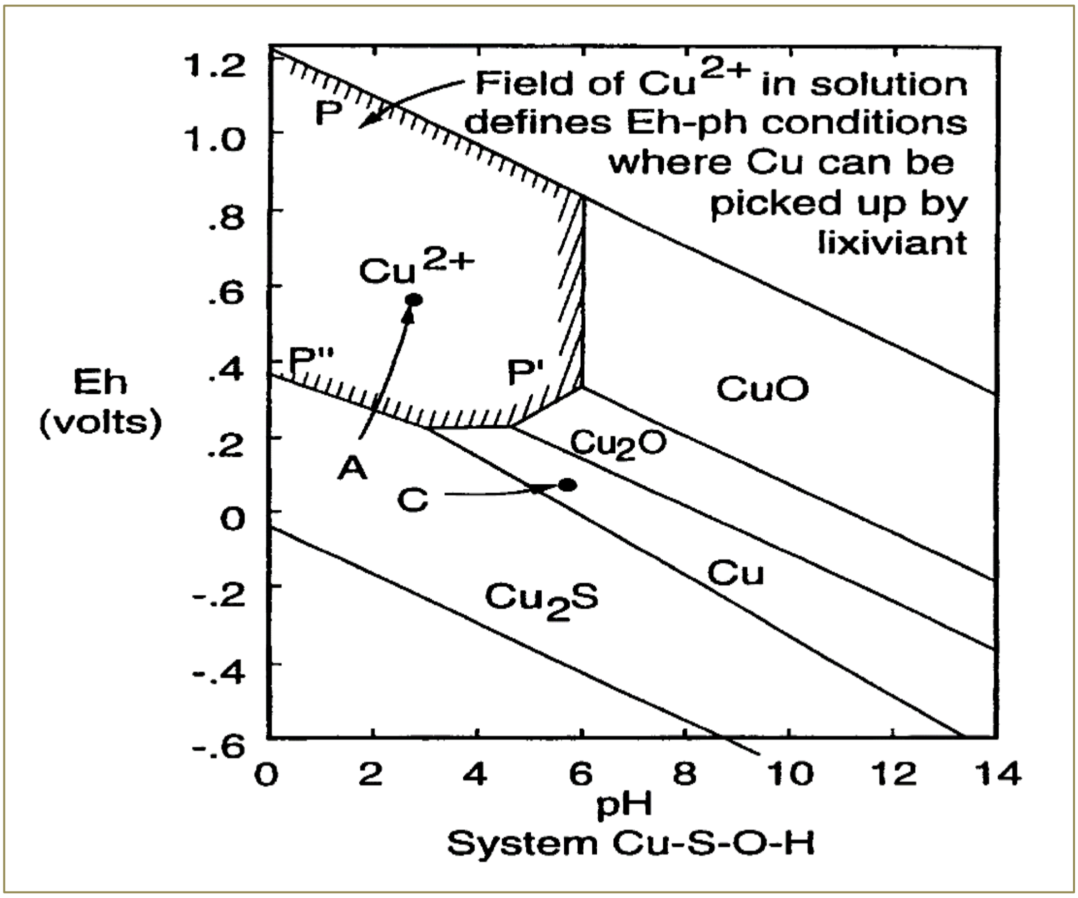

Figure 5: Pourbaix diagram of Chalcocite, W.Chesworth (2001), accessed from www.researchgate.net/figure/36513-pourbaix diagram

It is often the case during leaching that participating species will exchange either H^+ cations or OH^- anions and/or electrons. When the exchange involves H^+ or OH^- then there is an involvement of pH change. The involvement of electrons is measurable by redox potential which is designated as E_h, this enables us to study the effects of pH and E_h on leaching systems, Gupta (2003)

Kinetics of heterogeneous reactions.

In heterogeneous liquid-solid reactions there are a number of ways in which reactions occur at the particle surface. The particle may react with the liquid reactant giving soluble products where the particle shrinks until it disappears as the reaction progresses. The solid may also react to produce an insoluble product whereby the reacting core shrinks while the particle does not change in size. The last scenario occurs when the solid reacts and a gelatinous layer forms around the surface of the particle while the unreacted core shrinks, Muzenda (2015) as shown in figure 6.

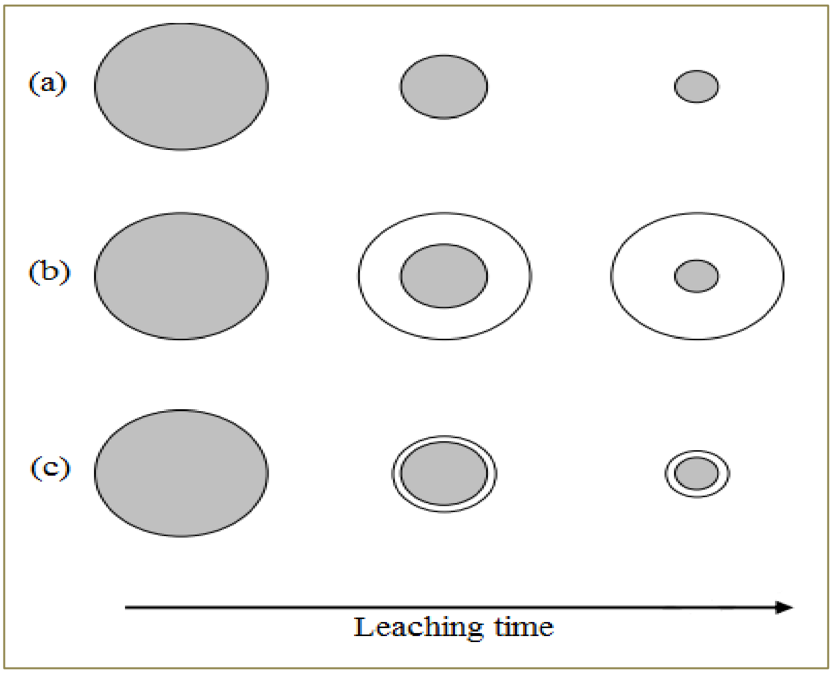

Figure 6: Shrinking core models, Muzenda (2015)

The leaching process may be as follows, as outlined by Gupta, (2003)

- Diffusion of the reactant through the diffusion layer
- Adsorption of the reactant on the solid
- Chemical reaction between the reactant and the solid
- Desorption of the product from the solid
- Diffusion of the leaching product through the diffusion layer

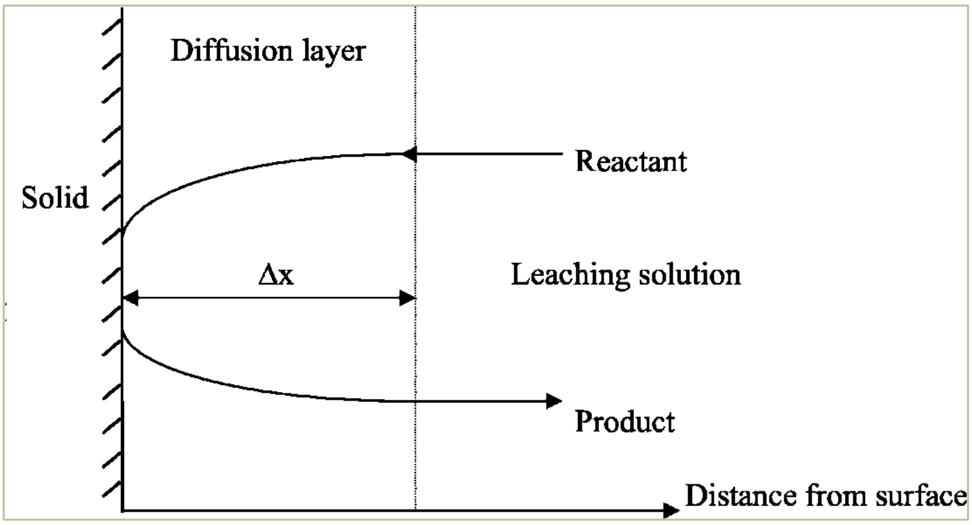

Figure 7: Basic sketch of the leaching process, Biomine-European Union project, (2002), acessed from biomine.skellefyea.se/leaching.htm

Where Δx is the diffusion layer.

Fick's law of diffusion.

The rate of diffusion is governed by Fick's law of diffusion because diffusion is the rate controlling step during heap leaching as per figure 7.

Fick's law of diffusion is given by:

$J= -D\frac{dC}{dx}$ …………………………………………………………………………. [9]

Where:

J is known as the flux, i.e. the amount of substance that diffuses through a unit surface per unit time.

D is diffusion constant (unit of surface/unit of time)

$\frac{dC}{dx}$ is the concentration gradient (the change in particles per volume, over a certain distance.

The leaching rate is thus dependent on the area of the leaching body, the diffusion coefficient and the concentration gradient. In addition, the concentration gradient is dependent on the thickness of the diffusion layer Δx.

Methodology.

A raffinate samples were collected from the SX1 E3 pond in a 5L container from which a subsample was analysed for pH, Cu and Fe.

Three runs of each test were carried out at this stage. 250ml of raffinate was added to 250g of the ore in the sample bottles to achieve 50% solids throughout the test. The bottles were then placed on a sieve shaker for seven days of continuous leaching.

The bottles were suspended daily (09:00 am) to allow pregnant leach solution (PLS) sampling during the course of the leach test. The volume of the sample solution withdrawn was measured and analyzed for pH, Cu and Fe content.

After seven days of continuous leaching, the leach residue sample was filtered, washed, dried, pulverized and analyzed for %TCu and %AsCu. The results of the determination stage bottle roll leach test were tabulated upon which the average leaching efficiency and recovery were determined.

The test procedure was carried out as outlined in the determination stage while varying parameters:

- Residence time at 7, 14,21 and 30 days
- Particle size at -13mm, -3mm, -2mm and -1.65mm
- Leach pH was varied at 1.2, 1.3, 1.5, 1.8
- Ferric ion addition was investigated at 24 gpl, 22gpl, 17gpl,9gpl,1.4gpl
- pH at the optimum ferric addition, 1.2,1.3,1.5,1.8

Results and discussions.

The effects of residence time, particle size, pH and ferric ion addition on the leaching efficiencies and recovery are discussed.

The leaching efficiency and recovery were calculated using equations 11 and 12 below:

Leaching efficiency was calculated as follows:

$$\frac{(\%AsCu\ in\ feed - \%AsCu\ in\ residue)}{\%AsCu\ in\ feed} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [11]$$

Where:

%AsCu is the acid soluble copper in the feed or residue

Recovery was calculated as follows:

$$\frac{(\%TCu\ feed - \%TCu\ residue)}{\%TCu\ feed} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [12]$$

Where:

%TCu denotes the total copper in the feed or residue

Figure 7 below presents the daily average grams per litre of copper extracted obtained from the bottle roll tests under the normal leaching conditions used at the Mufulira West heap leach plant. The leaching efficiency was determined to be 87% (based on acid soluble copper) and recovery (based on total copper) 72%.

The current leaching efficiency at the Mufulira West heap leach plant is 82% (based on acid soluble copper) and the recovery is 60% (based on total copper). The results of the leaching efficiency and recovery obtained from the bottle roll tests are higher than the current operating values. This is expected because standard bottle roll tests are carried out at a laboratory scale to determine the leachability or the possible metal extraction levels from the ore.

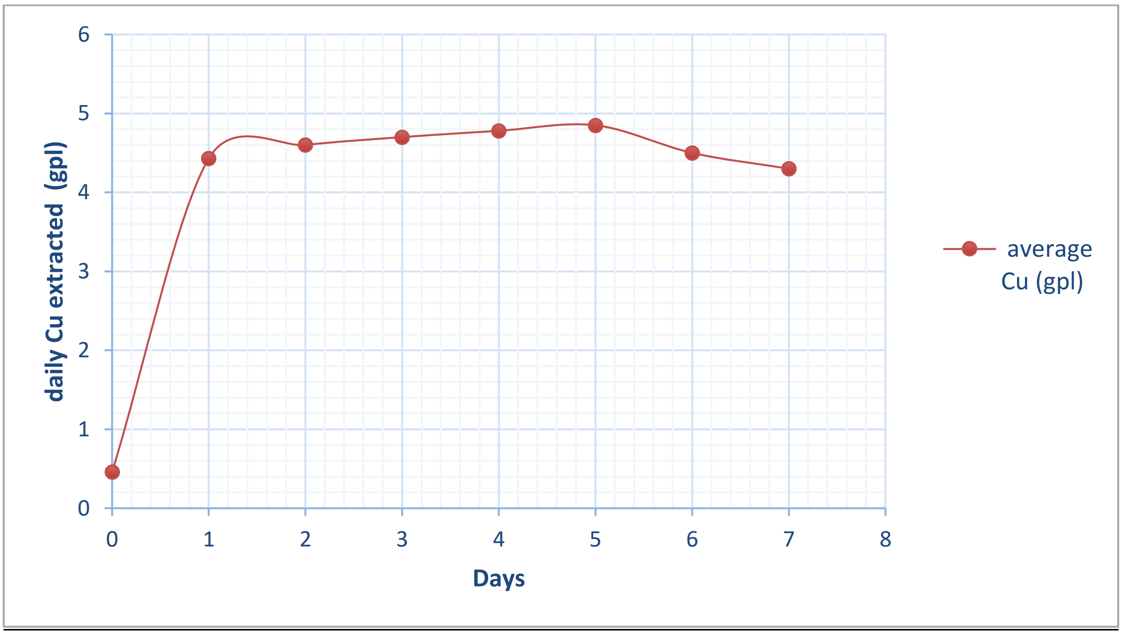

Figure 8: Shows the daily gpl Cu against time (days)- determination stage

Optimization stage

Effect of residence time.

Figure 8 shows the effect of residence time on leaching of the ore at -13mm and pH 1.3 by showing the daily grams per litre (gpl) copper extracted. The grams per litre of copper extracted reach a constant value after 22 days of leaching. The highest leaching efficiency of 92% and recovery of 78% were obtained after 30 days.

The results of the leaching efficiency and recovery agrees with the literature which shows that the highest leaching efficiency was after a longer period of 30 days. It is expected that more of the mineral is dissolved if the residence time is increased thus increasing the leaching efficiency and overall recovery. However, increasing the residence time of leaching comes with cost implications such as increasing the leach liquor (raffinate) requirement among many others.

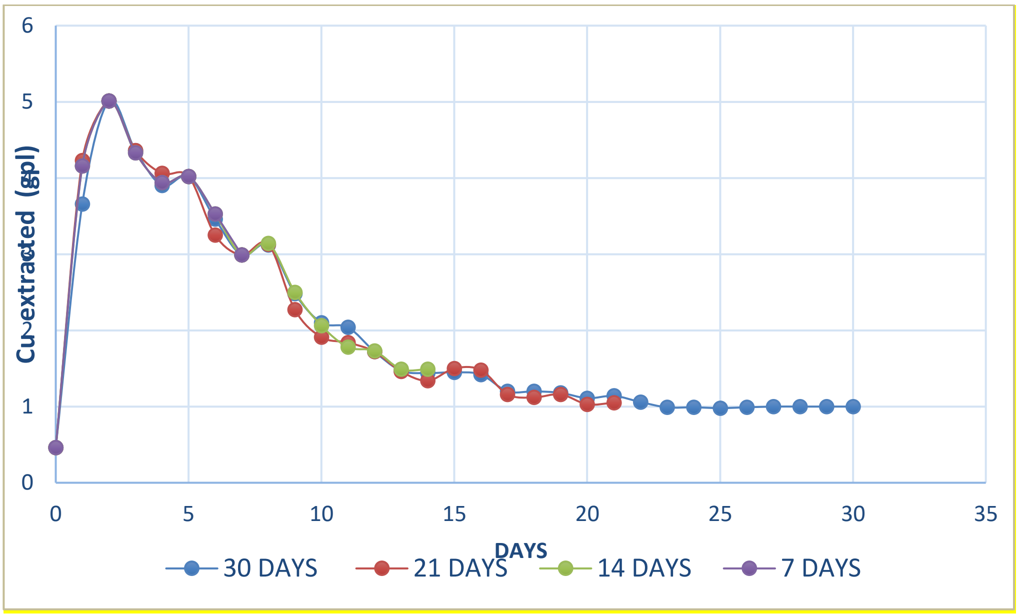

Figure 9: graph of daily gpl Cu against time (days)- Effect of residence time at pH 1.3 and particle size -13mm.

Effect of particle size.

The effect of particle size on leaching is shown in figure 9. The -13mm particle size showed good leaching kinetics with the maximum copper extraction being attained on the second day compared to the other particle sizes. The highest leaching efficiency of 88% and recovery of 72% respectively were attained. More copper was extracted from the coarser particle size because diffusion (the rate controlling step), was not hindered by the fine ore compacting into a dense mass thus making the penetration of raffinate difficult.

The -13mm particle size showed better leaching kinetics than the finer sizes because the raffinate was able to percolate through the ore, in other words, there was sufficient contact between the mineral ore particle and the raffinate. This is in agreement with *Miller et al (2003)*, who concluded that particle size is related to the permeability of the heap.

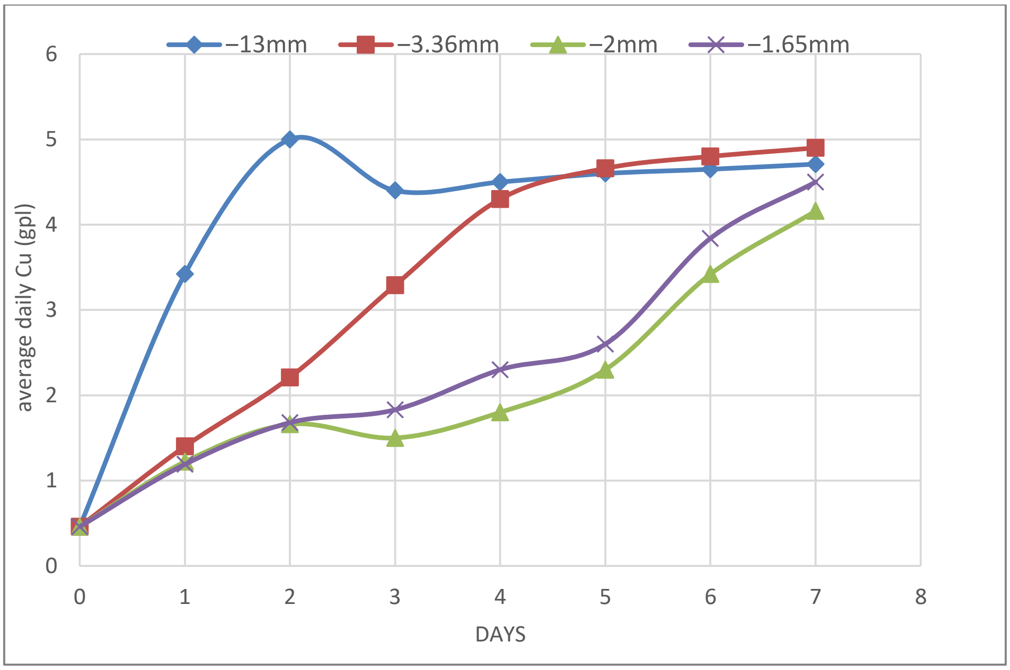

Figure 10: The Effect of particle size on leaching.

Effect of pH.

Figure 10 shows the effect of pH on leaching; higher concentrations of copper were obtained at lower pH with the highest leaching efficiency of 88% and recovery on total copper of 72%.

Lowering the pH below 1.3 did not improve the leaching efficiency or recovery. *Mweene and Kawala, (2014)* investigated the most effective raffinate pH for leaching low grade copper ores; they obtained higher overall recovery of about 42.23% at a pH of 0.6.

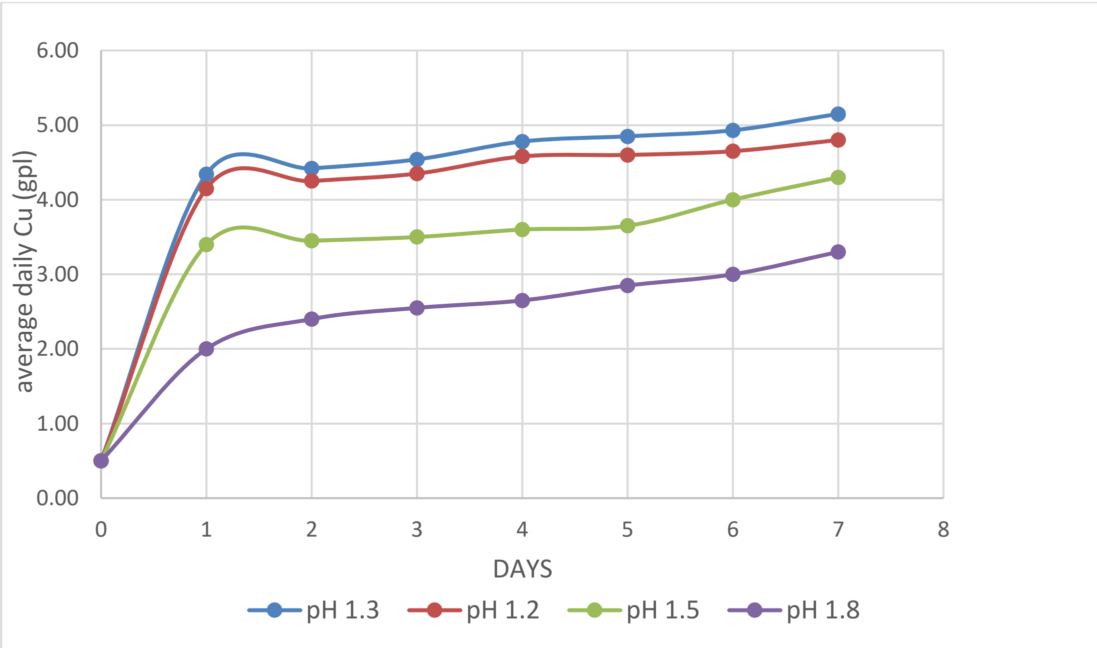

Figure 11: Shows the effect of pH on an average daily gpl Cu against leach days.

Effect of ferric ion concentration.

Figure 11 shows the effect of Fe^{3+} ion concentrations at pH 1.3 and -13mm particle size. It is important to note that leaching efficiency is calculated on the basis of the oxide mineral that is leached and recovery is calculated on the basis of the sulphide mineral that is leached, hence at this stage, the results can reveal whether or not the sulphide mineral component was oxidized to some extent.

The highest leaching efficiency and recovery of 92% and 85% respectively was attained at 22gpl Fe^{3+} ion concentration. Increasing the Fe^{3+} ion concentration to 24gpl did not increase the leaching efficiency and recovery due to the sulphur formed resulting in passivating the mineral surface thereby inhibiting diffusion of the ferric ions to the unreacted part of the mineral (*Beckstead et al, 1976).*

The leaching kinetics however improved upon comparing the leaching efficiency attained in 30 days during the residence time stage was 92% and the leaching efficiency attained in 7 days with 22gpl Fe^{3+} ion concentration was also 92%.

It can be observed from the results that dissolution of acid insoluble copper improves when ferric ions are introduced in the leach system. The results indicate that the sulphide minerals were oxidized and subsequently leached when the final leach residue was analyzed. This is because the recovery increased when Fe^{3+} was introduced for example the recovery on total copper at pH 1.3, -13mm particle size with no ferric ion addition was 69%, whereas at 22gpl Fe^{3+} ion concentration, the recovery increased to 81%.

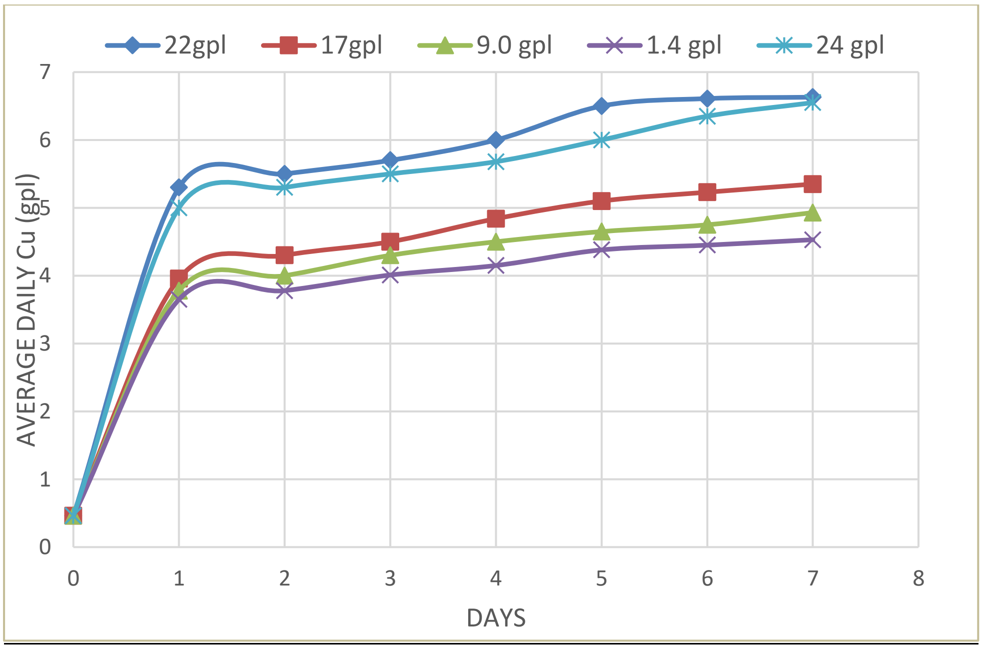

Figure 12: Shows the effect of ferric ion concentration on leaching.

Figure 12 below shows the leaching efficiencies and recoveries obtained at the various ferric ion concentrations. The green and red arrows indicate the maximum leaching efficiencies and recoveries obtained at 22gpl followed by a decrease in the leaching efficiency at an increased ferric ion concentration.

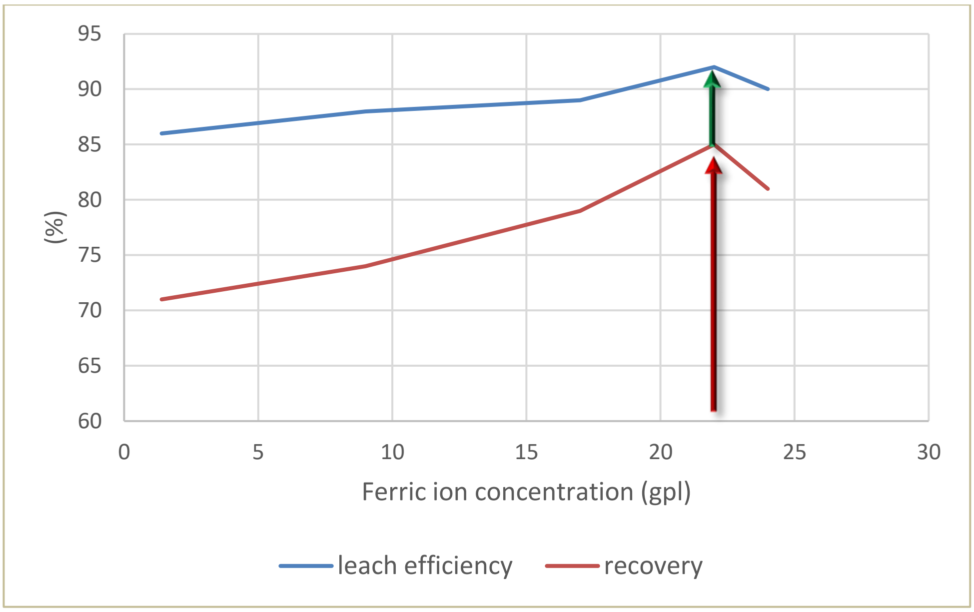

Figure 13:Leaching efficiencies and recoveries at the various ferric ion concentrations

Effect of pH at the optimum ferric iron concentration

Figure 13 shows the effect of pH at 22gpl which was found to be the optimum ferric ion concentration. At a leach pH of 1.3, the highest leaching efficiency and recovery of 92% and 85% respectively were attained.

Antonijevic et al, 2000, found that the dissolution of copper sulphide minerals, particularly chalcopyrite with ferric sulphate diminishes with decreasing pH due tothe acid preventing hydrolysis and precipitation of ferric salts and the chalcopyrite surface lacks iron which provokes passivation.

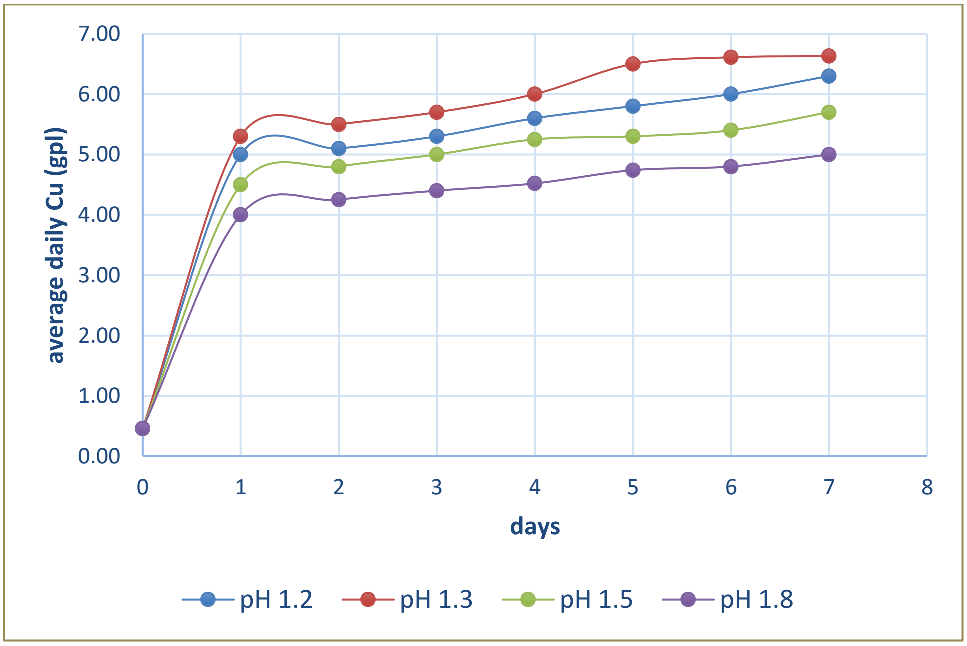

Figure 12: Shows the effect of pH at 22gpl ferric ion concentration

Optimum parameters

Figure 14 shows a comparison of the optimum parameters (pH 1.3, particle size -13mm) with and without 22gpl of ferric ion, which was found to be the optimum ferric ion concentration.

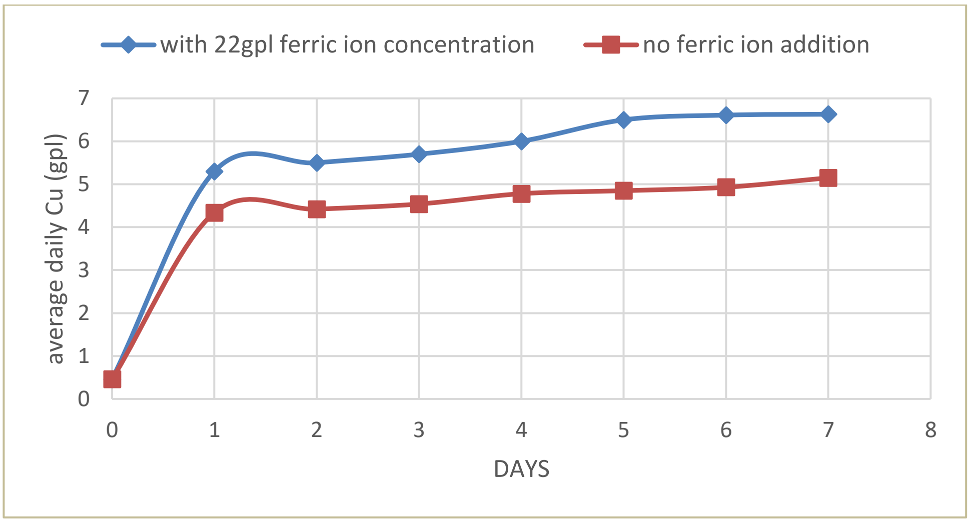

Figure 14: Shows a comparison of the optimum parameters with and without 22gpl ferric ion concentration.

Conclusions.

From the experimental results, the leaching efficiency under the normal operating conditions of the Mufulira west heap leach plant of particle size -13mm and pH 1.3, was determined to be 87%. The optimum leaching conditions were determined as -13mm particle size and a pH of 1.3.

From the results it was found that the optimum ferric ion addition of 22gpl increased the leaching efficiency to 92% from 88% under the optimum conditions. The recovery also increased significantly from 72% to 85% upon the addition of 22gpl Fe^{3+}. It can be concluded that the leaching conditions upon addition of ferric sulphate were oxidizing. The results achieved during the ferric leaching of the Mufulira west ore have shown that leaching of the copper sulphide mineral component of the ore by oxidizing is technically feasible. This is evident from the significant increase of the recovery on total copper.

The total iron levels in the PLS were less than 0.2 gpl in all cases of the ferric ion concentrations that were investigated. This is suitable for use in conventional solvent extraction circuits as the current EW at Mopani copper mines is operating at an average of 2.69gpl Fe in the advance electrolyte.

Recommendations.

From the above findings, it is recommended that:

1) Ferric ion concentration of 22 gpl should be added to the ore for efficient leaching to obtain leaching efficiencies and recoveries of about 92% and 85% respectively attained after 30 days of continuous leaching at the normal operating conditions. With the addition of 22gpl of ferric ion concentration, a leaching efficiency of 92% was obtained in 7 days of leaching. Ferric leaching can significantly reduce the leaching time.

2) A particle size of -13mm and pH of 1.3 be maintained. Excessive fines should be avoided otherwise fines would compact into a dense mass and pose difficulties of raffinate penetration.

References.

Burkin, A, R, (1966). *The Chemistry of hydrometallurgy.* New York: Science publishers,INC.

Antonijević, M. B. (2000). *Investigation of the leaching of chalcopyrite ore in acidic solutions.* Hydrometallurgy 73, Elsevier.

Ballester, A. (2008, February). *Leaching of Chalcopyrite with ferric ion-Part I.* Retrieved from Researchgate publications: www.researchgate.net/publication-229310266

Basov.V. (2015). Heap leaching solutions. *Mining Technology*.

Beckstead, L. (1976). *Ammonia, oxidation leaching of chalcopyrite—reaction kinetics.* Metallurgical and Materials Transactions.

Biswas, W. D. (1980). *Extractive Metallurgy of Copper.* Pergamon Press.

Fathi, H. (1970). *Principles of Extractive Metallurgy* . New York: Science Publishers .

Free, M. L. (2013). *Hydrometallurgy: fundamentals and applications* . Utah: WILEY.

Gupta, C. K. (2003). *Chemical Metallurgy.* Mumbai: Wiley-vch.

Hiroyoshi, N. M. (2001). *Enhancement of chalcopyrite leaching by ferrous ions in acidicferric sulfate solutions.* Hydrometallurgy 60, Elsevier.

Hourn, M. M. (1999). Atmospheric mineral leaching process. *Engineering and mining journal* , 45-56.

Mweene, J. K. (2013). *Optimal pH for heap leaching of low grade copper-cobalt-iron ore.* Kitwe: BSc thesis, Copperbelt University.

Vukovic, M. V(2000). *Investigation into the feric leaching of covellite sludge at high ferric ion concentratons.* Retrieved from Science Direct : www.sciencedirect.com/m.V/3156843

Muzenda .E, O. (2015). Predictive models of leaching processes. *7th international conference on latest trends in engineering and technology*, (pp. 136-137). Pretoria.

Mweene, J. K. (2011). *Optimal pH for Heap leaching low grade copper-cobalt ore.* Kitwe: Copperbelt University.

P.B Munoz, J. M. (1979). *Reaction mechanism for the acid ferric sulphate leaching of chalcopyrite.* Msc. Thesis, University of Central Venezuela.

Schaming, J. (2011). *an investigaton of leaching chalcopyrite ore* . Ontario: University of Queens .

Thomas & Ingraham, T. (1969). *Kinetics of dissolution of synthetic dignite and chalcocite in aqueous acidic ferric sulphate solutions.* Can.Metall.

Zanbak. C. (2001). Heap leaching technique in mining. *sustainable development in the minerals industry.* Milos Island: Society for Mining, Metallurgy and Exploration.

Orebody Modelling and Resource Estimation for Konkola East at Number 3#, Chililabombwe, Zambia

Gwen Nachande[1] and Cryton Phiri[2]

ABSTRACT

Konkola Copper Mine is one of the most northerly of the Zambian Copperbelt Mines which comprises of two orebodies: the North and South Orebodies separated by a barren gap. The Konkola East Orebody is located within the perimeter of the North Orebody at No.3 shaft.

Konkola East, at Number 3#, where the study area lies is a recent project that has been undertaken mainly for the sole purpose of Grade control and mine scheduling. Quality Assurance and Quality Control (QAQC) are systematic actions and operational techniques considered at KCM. QAQC is a very important aspect for resource estimation as lacking proper quality control data results in having to exclude entire drilling campaigns from the estimation database thus affecting resource tonnage, grade and classification.

It is therefore the main objective of this project to generate a resource model for Konkola East, carry out statistical analysis and thereafter estimate the resource. The generation of a resource model for the Konkola East area provides a sustained competitive advantage value, easy access of geological information as well as adding to the expansion of resources in terms of Grade, tonnage, volume etc. to the entire Konkola Copper Mines.

Keywords

Resource, Tonnage, Grade, Database, Quality Assurance

1. INTRODUCTION

1.1 Location and Access

The Konkola Mine is located in Chililabombwe town approximately 26km north of chingola in the Copperbelt province of Zambia (Figure 1). It is accessible through the Great North Road, via Ndola, Kitwe and Chingola.

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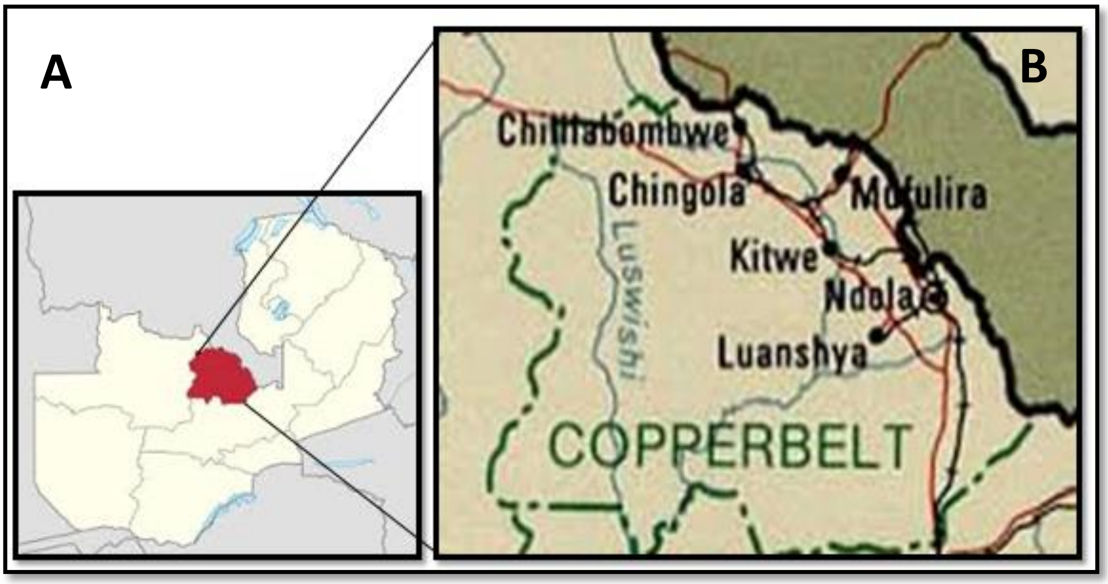


Figure 1:-Map of the Copperbelt province of Zambia (A) showing the location of Chililabombwe (B) where Konkola Copper Mines is situated. (Source: Google maps)

1.2 Problem Statement

Konkola East at Number 3# is a recent project that has been carried out and as drilling is still taking place, all information obtained would have to be stored in a centralized database. This geological database will be used to conduct feasibility studies, generation of a resource model and finally perform resource estimations.

1.3 Literature Review

Konkola Mine as a whole has had block models generated, but non for this particular area of interest that lies on the Eastern Limb of the main Konkola mine Orebody. Much of the previous works on resource models generated have been done by:-

- **SRK** which generated a 3-dimensional model of the Konkola Mine based on a 1.0% TCu cut-off grade.

- A 3-D model was prepared by the MinRED department, Anglo American plc in Johannesburg for the Konkola Deep Mining Project (KDMP) area in November 2000. This model serves as a long range planning model to be used for planning and scheduling of the Konkola Deep Mining Project (KDMP) 4 shaft project.

- Another geological model was developed by Gemcom Africa (Pty) limited with the aim of coming up with a geological model that would lay a foundation for future mine planning as well as geological modelling for Konkola Copper Mines.

1.4 Objectives

- To create a geological database for Konkola East.
- Carry out Geostatistical analysis on the study area.
- Run Resource estimations for the Konkola East Orebody.

The above outlined objectives were achieved by the use of a mine software known as Surpac, version 6.6.2, which was used to import drilled borehole data for the creation of a geological database and also to perform resource estimations for the Konkola East area.

1.5 Present Work

The present work carried out at Konkola involved desk study which gave information on the Konkola Mine, consultations from supervisors to come up with meaningful information on the project was also done. As a greater part of the project involved literature reviews and visual analysis, compilation of borehole data for the entire Konkola East was done for the purpose of creating a geological database from the drilled borehole data in order to come up with a probable orebody model.

Validation of borehole data for Quality Assurance and Quality Control measures concerned with accuracy, contamination and precision through the use of standards, blanks and duplicates was carried out and thereafter, a mine software known as SURPAC, version 6.6.2 was used to import the drilled borehole data in preparation for the creation of a geological database. The geological database module in Surpac is used when conducting feasibility studies and also performing estimations from drilled borehole data.

A resource model for Konkola East was then generated and its volume, tonnage and grade calculated which eventually led to resource estimation of the study area.

The benefits of creating a block model for the Konkola East orebody includes an enhanced grade control system which can be used to manage the allocation of materials to be extracted from blasting. This scope will include grade evaluation and quantities to extract per block, report generation, quick recall of blasting already done for reconciliation purposes and also a fully integrated system for grade estimation parameters and product classification.

2. METHODOLOGY

The methodology used in this research project was divided into two; - the Qualitative and Quantitative approach. The data collection process included literature reviews and visual analysis as summarised in the flow chart in Figure 2.

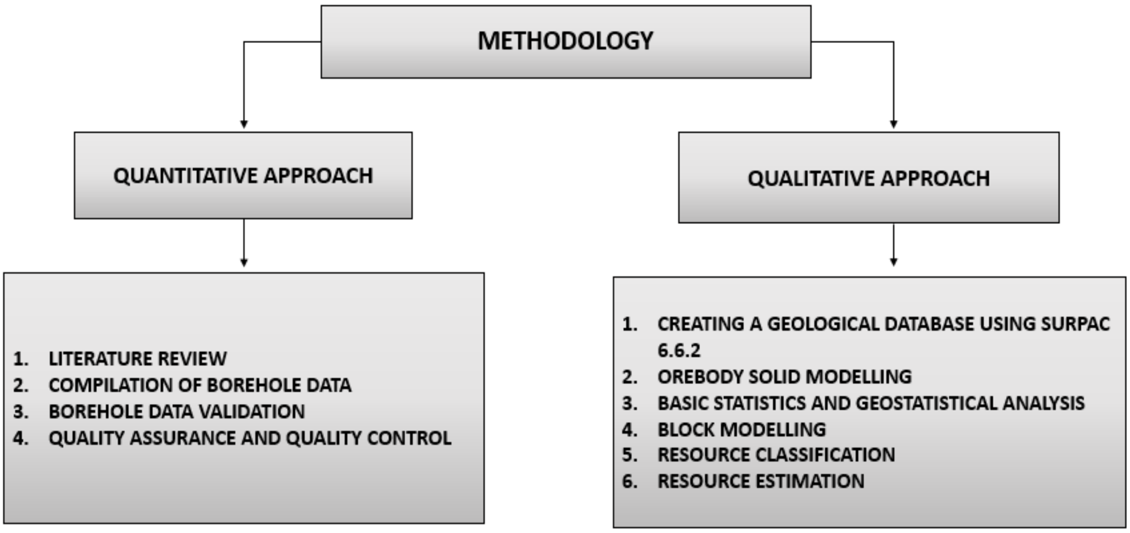


Figure 2:- Methodology techniques used in the data collection and interpretation process.

2.1 Data Collection Process

A total of about 110 drilled borehole data was compiled from the study area. Each of the logged boreholes was entered and stored as in the formats below;

- **COLLAR TABLE**:-which describes the location of the drill hole collar, the maximum depth of the hole, and that a linear hole trace was calculated when retrieving the hole.

Table 1:- Format of the Collar Table

BH_ID	Y	X	Z	DEPTH	HOLE_PATH
BPN396	0.5	63	21		
BPN397	4.4	66	32		

- **SURVEY TABLE**: This stores the drill hole survey information that was used to calculate the depth, dip and azimuth.

Table 2:- Format of the Survey Table

BH_ID	DEPTH	DIP	AZIMUTH
BPN396	0.5	63	21
BPN397	4.4	66	32

- **ASSAY TABLE**: the assay table stores lab analysed results of the total copper (TCu %) present from the drilled boreholes.

Table 3:- Format of the Assay Table

BH_ID	SAMPLE_ID	FROM	TO	TCU%	ASCU%	TCO%	ASSAY_CODE
BPN376	RR1234	33.65	34.6	0.06	0.03	0.01	0
BPN376	RR3456	34.6	35	0.1	0.03	0.01	0

- **GEOLOGY TABLE**: The information stored in the geology table identifies the borehole drilled, the sample ID allocated to it and the formations present according to their length intervals.

Table 4:- Format of the Geology Table

BH_ID	FROM	TO	FORMATION
BPN293	10.74	14.94	FWC
BPN293	14.94	21.64	OSU

2.2 Quality Assurance and Quality Control (QAQC)

Quality Assurance is defined as the systematic actions necessary to provide adequate confidence in the data collection and estimation process. Quality Control is simply the operational techniques and activities that are used to satisfy quality requirements. The main QAQC measures carried out on the logged boreholes were associated with accuracy, contamination and precision as outlined below;

i).ACCURACY: - Which is the closeness of agreement between a measured quantity value and a true quantity value of a measurand. This was assessed through the use of Standard Reference Materials (SRMs).

The results in figure 3 show that after analysis of the samples in which SRMs were inserted, majority of the samples fell within the acceptable range of Standard Deviations (-2 to +2) and these were considered as "passed" samples that were now ready for importation into the geological database. One sample with ID DK856 circled in red did not fall within the standard acceptable limits and was thus considered a "failed" sample.

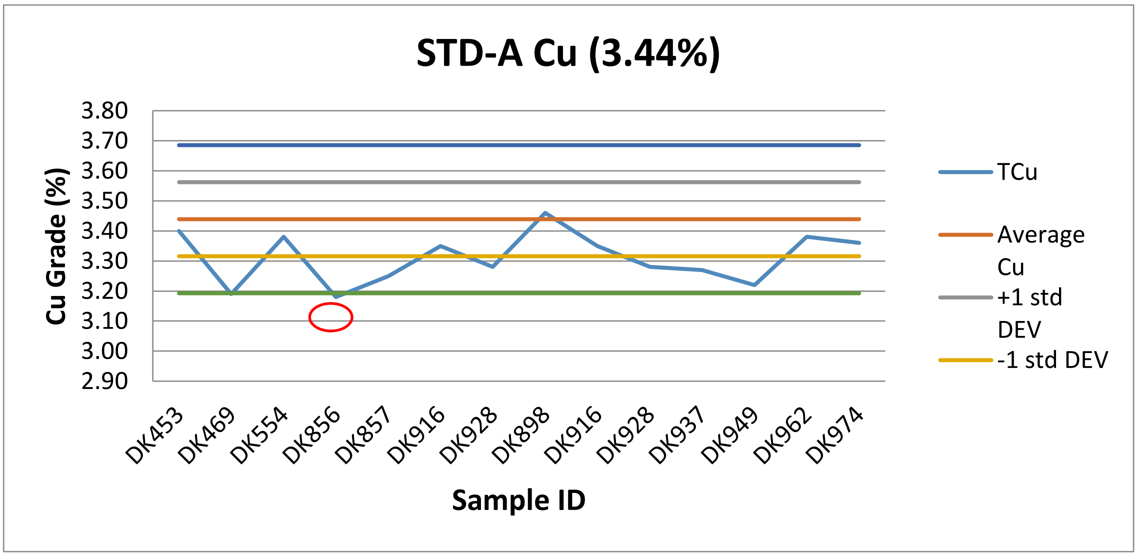


Figure 3:- Graph illustrating Accuracy monitoring results for the 14 samples used.

ii).CONTAMINATION:- this is the transfer of material from one sample or environment to another sample which affects the reading of the original material. This may take place during sample preparation and/ or assaying or merely through sample manipulation. Contamination was assessed through Blanks which are barren samples on which the presence of elements undergoing analysis has been confirmed to be below the corresponding detection limit as shown in figure 4.

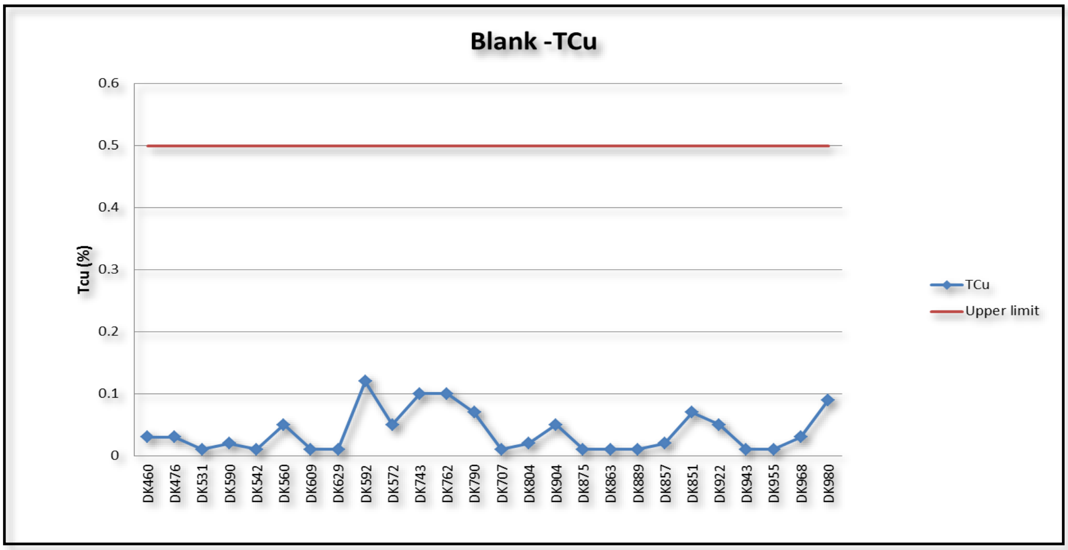


Figure 4:- Graph illustrating the results of blank samples after lab analysis.

From the results in figure 4, all of the Blank samples analyzed are well below the detection limit of 0.5% TCu, thus validating the QAQC test for the rest of the samples to be free from contamination. **iii).PRECISION:-** is defined as the closeness in agreement between indications or measured quantity values obtained by duplicate measurements on the same or similar objects under specified conditions. It is assessed through a series of repeated measurements on the same sample material or through successively different original-duplicate sample pairs.

The graphs in figure 5 shows results after a *re-assay* was carried out on six randomly selected drilled borehole samples. The Original Sample ID was ensured to match the Duplicate ID of the same sample after re-assay tests were carried out on the Original.

As seen from the graph (Figure 5A), all six samples taken for re-assay show results that are well within the deviation limits (-10 to +10) and have a positive linear correlation with each other, thus, these were considered as “passed” values and the drilled boreholes they represented were now ready for database creation.

On the other hand, Figure 5B shows sample results that did not fall within the set limits of the deviation range (-10 to +10). The degrees of correlation between each pair of the randomly picked samples suggest a low precision level as all of the values obtained fell outside the acceptable set.

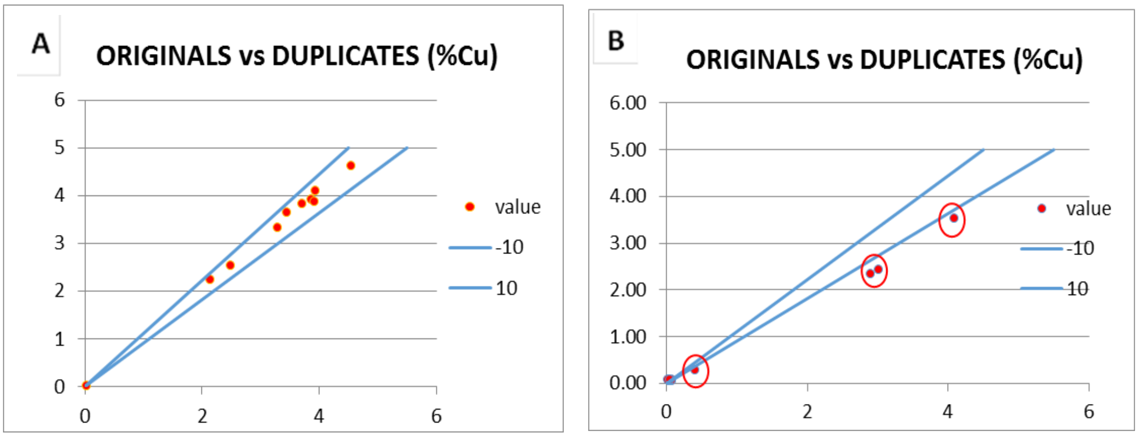


Figure 5:- Graphs showing passed precision results in (A) and another showing failed precision results in (B)

A mine software known as **SURPAC** version **6.6.2** was then used to import the valid drilled borehole data in preparation for the creation of a geological database. A Geological database is a collection of geological information that is organized, can easily be accessed, managed and updated. It is from this information that a probable orebody solid model was generated as shown in Figure 6.

2.3 Estimation

Kriging is a method of estimation used to interpolate spatial data. Ordinary kriging was selected for this study because of the statistical characteristics involved in the estimation of a resource.

2.4 Basic Statistics

For the model to validate well, the histogram of the blocks needs to follow the same general shape as that of the histogram of the composited input data. To control the impact of outliers on the block grade estimates, basic statistics and variography play a very important role.

A normal distribution curve (Figure 7) based on input drill hole data from the study area shows that the area has an average grade of 3.25% Tcu as represented by the highest peak. The graph is normally distributed which to mean that the mean is equivalent to the median as is the mode thus resulting in a symmetry about the center.

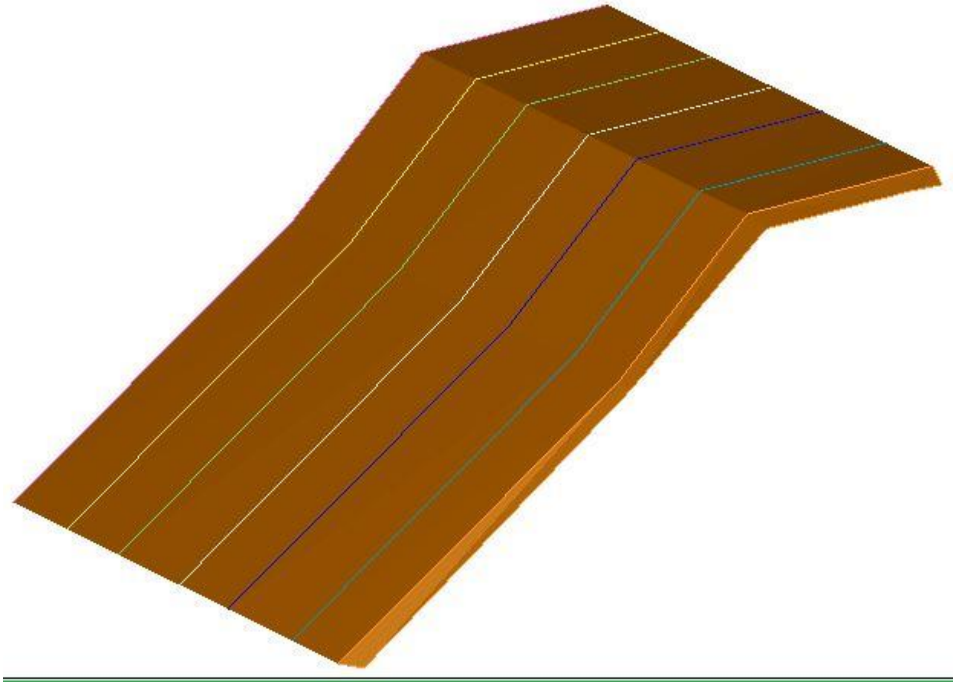
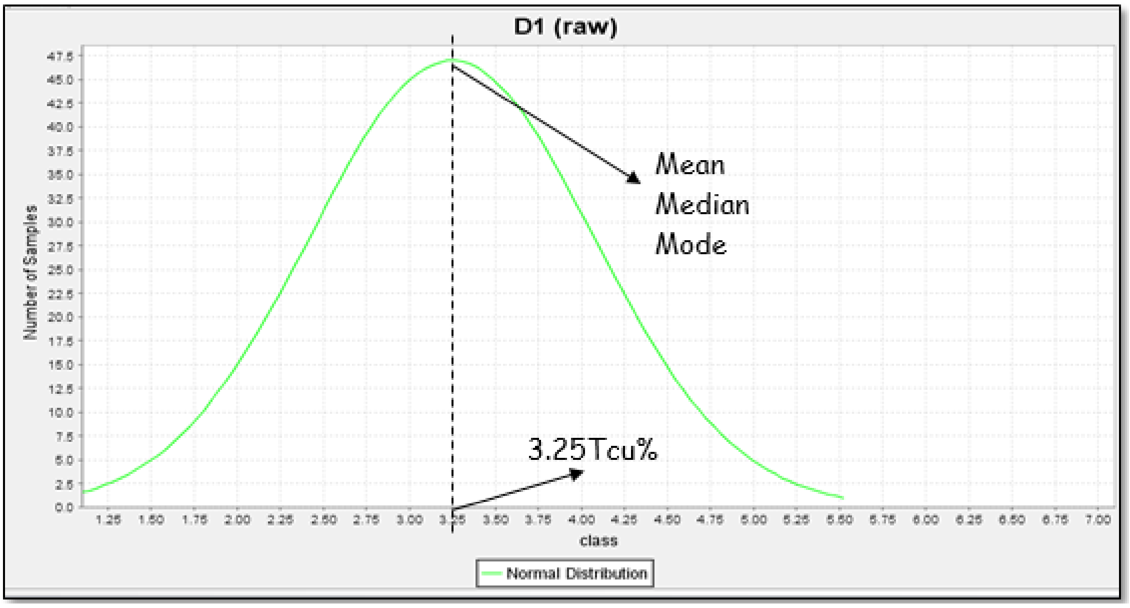


Figure 6:- Orebody solid model of Konkola East.

Figure 7:- Graph showing a normally distributed curve of the grades obtained from the study area.



2.5 Variogram Map

Variograms are used to calculate and analyse the geological variation in an orebody according to the drill hole data collected. Using the variogram map (Figure 8), the direction of maximum continuity can be obtained based on the azimuth that appears to have the lowest total variance. As observed from the variogram map, the highest continuity of grade variation at Konkola east occurs along the strike i.e. 110°NW with grades being in the medium-low variation range. This suggests that there is a high relationship in the continuity of the grades found in the orebody.

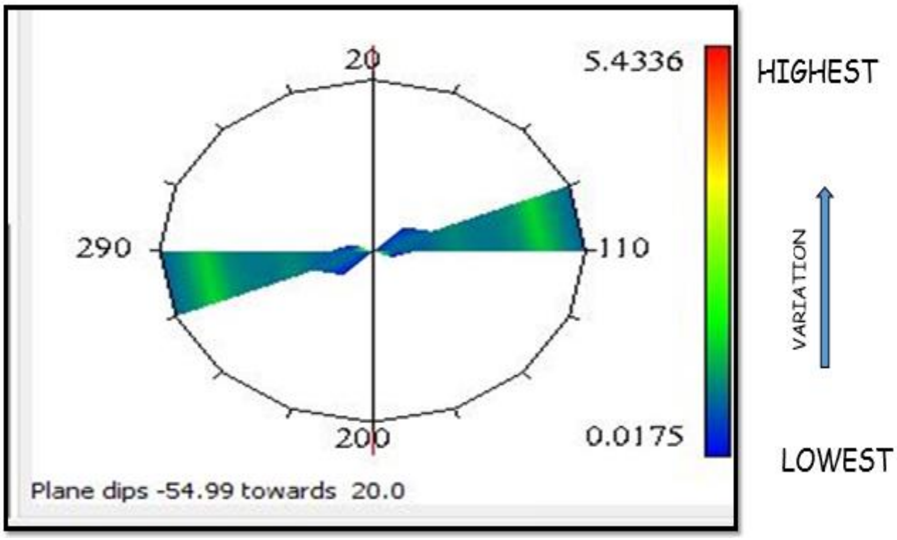


Figure 8:- Variogram map of the study area showing the continuity trend of the grades.

2.6 Resource Estimation

The block model consists of blocks of dimensions 5x2x5m and it is from these dimensions that the volume of the konkola east block model is calculated.

- The tonnage as calculated by Surpac is given by the formula:

  Tonnage=Volume x Specific Gravity (s.g)

  Where s.g for Konkola East at 3# is placed at 2.58.

- Tcu Metal content is taken as a partial percentage of the Tcu grade given by the formula:

  Tcu Metal= (Tonnage x Tcu)/100

- The market price depends on the copper price at a particular time and it is given by:

  Market Price=Tcu Metal x Cu price.

2.7 Classification of the Konkola East Resource Model

A Mineral Resource can be sub-divided in order of decreasing geological confidence, into Measured (Pass 1), Indicated (Pass 2) and Inferred (Pass 3) categories as shown in figure 9. These passes represent the classifications of the orebody.

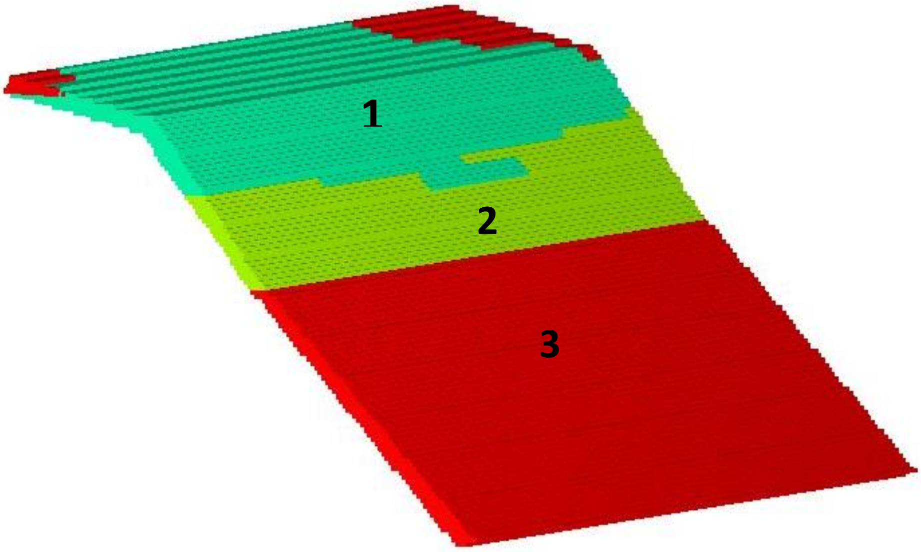


Figure 9:- Classification of the Konkola East Orebody model into pass 1, pass 2 and pass 3 in order of decreasing geological confidence.

A 'Measured Mineral Resource' is that whose tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of geological confidence. (Pass 1)

An 'Indicated Mineral Resource' is that whose tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of geological confidence. (Pass 2)

An 'Inferred Mineral Resource' is that whose volume and/or tonnage, grade and mineral content can be estimated with a low level of geological confidence. (Pass 3)

3. CONCLUSION

A good resource is said to have all three categories present i.e. the inferred, indicated and the measured ore resource. The Resource of the Konkola East Orebody was estimated as in Table 5.

- Therefore, the Konkola east resource model has a Grand total volume of 2,262,631m^3.
- A total tonnage of 5,835,008.63 tonnes and an average Tcu% grade of 3.36%.

Total Cu-metal content of the orebody is 196,056.29 tonnes and with the current copper prices valued at 4,718.99 USD/t, thus, the resource model at Konkola East is worth a market price of 440,872,595.8 USD.

Table 5:- Summary of estimates for the Konkola East Resource model.

Classification	Volume (m^3)	Tonnes	Tcu (%)	Tcu_metal (tonnes)	market price
Measured	827,356.25	2,134,579.13	3.22	68,733.45	324,352,463.2
Indicated	320,081.25	825,809.63	2.99	24,691.71	116,519,932.6
Inferred	1,114,193.75	2,874,619.88	3.58	102,911.39	485,637,820.3
Grand Total	2,261,631.25	5,835,008.63	3.36	196,056.29	925,187,671.9
				USD	440,872,595.8

With due respect to the set objectives, a valid geological database for Konkola East was created putting into account the necessary measures and standards. A Resource Model was then generated using the valid drilled borehole data and finally the resource of the konkola east orebody estimated.

4. REFERENCES

Brock, B.B., (1961). The structural setting of the Copperbelt. In: Mendelsohn, F. (Ed.), *The Geology of the Northern Rhodesian Copperbelt.* Macdonald, London, pp. 81–89.

JORC, (1999). Australasian Code for Reporting of Mineral Resources and Ore Reserves (The JORC Code), The Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia (revised and republished in this volume, see Appendix 1, p683–698).

Armstrong, R.A., Robb, L.J., Master, S., Kruger, F.J., Mumba, P.A.C.C., (1999). 'New U–Pb age constraints on the Katangan sequence, central African Copperbelt'. Journal of African Earth Sciences, v. 28, p. 6–7.

Baker, C K and Dodd, S F, (1994). 'Broker's Rules of Thumb for Mineral Valuation: A Focus on Gold Equities, in Proceedings Valmin 94,' p. 139–154.

Binda, P.L., (1997). *Cenozoic analogies for the Katangan copper deposits of Zambia*. In: Charlet, J.-M. (Ed.), Colloque International, p. 199–215.

Bowen R and Gunatilaka (1977). *Copper and its economics*. Applied science publishers, London, p. 52-57.

Brock, B.B., (1961). *The structural setting of the Copperbelt*. In: Mendelsohn, F. (Ed.*), The Geology of the Northern Rhodesian Copperbelt. Macdonald*, London, pp. 81–89.

Cahen L(1978). ‘ Geological background to the Copper bearing strata of Southern Shaba (Zaire)’.

Cahen, L., Snelling, N.J., Delhal, J. and Vail, J.R. (1984)- *The geochronology and Evolution of Africa*., Clarendon Press, Oxford, 512p

Canadian Institute of Mining and Metallurgical Processes, (2003). Estimation of Mineral Resources and Mineral Reserves Best Practice Guidelines.p8

Philip, G M and Watson, D F, (1988). How Ore Reserves Can Be Estimated Through Computational Methods, in Resource and Reserves Symposium, p. 49–58.

Stephenson, P R and Miskelly, N, (1997). *International Standards for Reporting of Mineral Resources and Reserves* - Status, Outlook and Important Issues, in Proceedings World Gold 97, p. 265-273.

Prevalence and effects of Total Dissolved Solids on water quality in selected parts of Lusaka

Michael Kapembwa[1]

Abstract

The total dissolved solids (TDS) in domestic water of selected parts of Lusaka were investigated. The objective was to determine the aesthetic quality of the water for human consumption and the technical effects of TDS on domestic equipment. The TDS of the water samples were calculated using the electrical conductivity readings at 25^{o}C. The electrical conductivity was measured in-situ using a calibrated GLP+ ESC Crison conductivity meter. It was found that the electrical conductivities of water samples from Chamba Valley, Nyumba Yanga, and Kabulonga were 200, 700 and 920 μS/cm respectively and these corresponded to the respective TDS levels of 140, 490 and 644 mg/L. All the water samples were found to be potable since the TDS levels were below 1000 mg/L. However, the palatability of the water samples varied. Water with TDS levels of less than 300 mg/L is considered palatably excellent; between 300 mg/L and 600 mg/L, good; and between 600 mg/L and 900 mg/L, fair. Therefore, the water samples from Chamba Valley were found to be as excellent compared to the ones from Nyumba Yanga and Kabulonga which were good and fair respectively. Furthermore, the TDS levels of the water samples from Nyumba Yanga and Kabulonga were high enough (above 200 mg/L) to have both the aesthetic effects of color change and a technical effect of scale formation on equipment when heated. The turbidity of the water changed from clear to milky whitish with suspended particles which was an indication of the precipitation of some inorganic salt constituents like carbonates. The scaling of the salts on heat exchanger surfaces of various appliances has both a performance and economic impact due to increased thermal conductivity. The pH of all the water samples were between 7.1 -7.4; the pH of most drinking-water lies within the range 6.5–8.5.

Keywords: Water, Total Dissolved Solids, Conductivity, Scale, Precipitation

1. Introduction

Lusaka is the capital city of Zambia, the country with one of the fastest growing economies in Africa with an average GDP growth rate of 6.3% per annum between the years 2003 and 2013 (Aridas and Pasquali, 2013). The city has a population of over 2.3 million people (Zambia Data Portal, 2013). In 2001, the local utility company had 52 boreholes (Nkhuwa, 2001) and in 2009, 57.52% of water supplied to the city by the utility company was from groundwater sources (Makayi, 2010). Residents in new residential areas where the utility company is yet to provide services also use groundwater as a source of drinking-water via the sinking of boreholes. The major groundwater aquifer of the city and the surrounding areas is dolomite (calcium magnesium

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carbonates) (Lambert, cited in Mdala, 1976) which is considered to be hydrologically equivalent to limestones (calcium carbonate) (Jones, cited in Mdala, 1976). As a result, the quality of water has substantial amounts of dissolved minerals salts. This is evidenced by the formation of precipitates when the water is heated which eventually forms a scale on the walls of water vessels and surfaces of heat exchangers as shown in Fig. ***1***. The aim of this paper is to investigate the quality of the water in terms of total dissolved solids (TDS) in selected parts of Lusaka. The objective is to determine the aesthetic quality of the water for human consumption and the technical effects on domestic equipment. The focus of the paper is on secondary water contaminants, therefore, parameters such as the microbial and radiological aspect are not considered.

Fig. 1: (a) precipitate in boiling water; (b) precipitate scale on the heating element; (c) scraped precipitate from a heat exchanger surface

2. Literature Review

2.1 Secondary contaminants

Secondary water contaminants are substances present in water that are not health threatening but can cause a wide variety of problems. These problems can be grouped into three categories; aesthetic, cosmetic and technical effects. The aesthetic effects are basically undesirable tastes or odors whereas cosmetics are the undesirable effects on the body. The technical effects are those that cause damage to water equipment or reduce the effectiveness of treatment for other contaminants (US Environmental Protection Agency, 2016).

2.2 Total dissolved solids (TDS)

Total dissolved solids (TDS) are an example of secondary water contaminants. By definition, TDS are water soluble minerals dissolved in water that can pass through a 2-micron filter (Raisbeck et al., 2007). Small amounts of organic solids (micro molecules) can be part of the measurable TDS. However, species like sugar and alcohol and large organic solids (macromolecules) are not included in TDS because they do not conduct current (Holmes-Farley, 2004). The principal constituents of TDS are usually calcium, sodium, chloride, magnesium, potassium cations, sulfate and hydrogen carbonate and nitrate anions (World Health Organization, 1996). Therefore, TDS is used as an indicator for chemical contaminants (PASCO Scientific, 2010) but pose no health hazard (US Environmental Protection Agency, 2016) or at least there is no reliable data available on the health effects associated with its ingestion (World Health Organization, 1996). The high levels of TDS in drinking water, however, may be objectionable to consumers (World Health Organization, 2011). According to Nkhuwa *et al* (2008), even though the TDS have no known health effects, it raises concerns if the high TDS levels are due to nitrates which are known to have health effects.

2.3 Effects of TDS on water quality

According to the World Health Organization (1996), the presence of the TDS in water may affect its taste. The palatability of drinking- water may be rated as excellent, good, fair or poor depending on the levels of TDS in water. Table 1 shows the various ratings in relation to TDS.

Table 1: Palatability of drinking-water in relation to total dissolved solids

Palatability	TDS Levels (mg/L)
Excellent	< 300
Good	300-600
Fair	600-900
Poor	900-1200
Unacceptable	> 1200

However, water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste (World Health Organization, 1996).

The TDS levels between 200 mg/L and 500 mg/L lead to increasing scaling problems in various equipment such as hot water pipes and heat exchanger surfaces of boilers, geysers, kettles, and steam iron thereby reducing heating efficiencies. When the TDS levels exceed 500 mg/L, it usually results in severe scaling (Water Research Australia, 2017).

2.4 TDS levels of groundwater sources of Lusaka

TDS levels of groundwater sources across many sites and settlements in Lusaka vary due to the nature of the aquifer and activities surrounding the water sources. A study in John Laing, a high-density settlement in Lusaka showed that some water from various borehole sites had high conductivity measurements and thus high TDS levels. The conductivity measurements ranged from 676 and 1962 μS/cm (TDS of 473 and 1373 mg/L) with an average of 1,140 μS/cm (TDS of 798 mg/L) (UNEP DEWA, 2003). A study by Nkhuwa *et al* (2008) found that the TDS of the water samples in other places (mainly high density) such as Chawama area was about 710 mg/L whereas Kalingalinga, Kanyama, Matero, Chipata and George averaged about 405 mg/L .The acceptable limit of potable water for human consumption is 1000 mg/L (World Health Organization, 1996). TDS levels in water from most of these sites are within the acceptable limits. Therefore, the most likely effect of TDS if any are aesthetic and technical.

2.5 How to estimate and reduce TDS in water

Since TDS constituents conduct current when dissolved in water (form ions), the measurements of the conductivity of the water can be used to determine the amount of TDS by using a conversion factor (CF) shown in Figure 2. The approximate concentrations of TDS in water provide information on the quality of water depending on the designated use (PASCO Scientific, 2010).

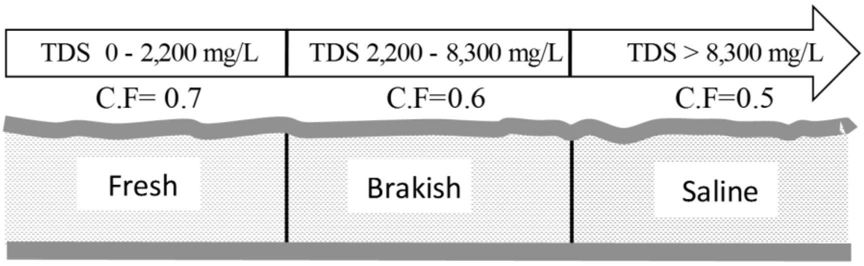

Fig. 2: Different type of water with approximated total dissolved solids (TDS) in mg/L and conversion factors (C.F); Adapted from (PASCO Scientific, 2010)

In order to reduce TDS levels in water, various treatment technologies can be employed depending on the type of the water and its intended use. For water meant for drinking and domestic use, home treatment technologies such as reverse osmosis (RO) can be used at point-of-use (POU) (Artiola, Farrell-Poe and Uhlman, 2009). However, economic costs may prove to be a challenge to some households.

3. Methodology

3.1 Experimental Setup and Procedure

The water samples were collected from groundwater sources in three different places in Lusaka i.e. Nyumba Yanga area, Kabulonga area, and Chamba Valley by random sampling. The selection of the three areas was based on the observation of precipitate formation and scale formation when water was heated. This was more evident in the first two areas whereas, with the last one (Chamba Valley) it was comparatively low. Therefore, the results would offer good comparisons of levels of TDS from observation of precipitate and scale formation. Two samples of 750mls of water were collected from these areas and placed in clean and transparent plastic water bottles covered with bottle tops to avoid contamination. The samples were then taken to the laboratory for testing. The experimental setup is shown in Figure 3.

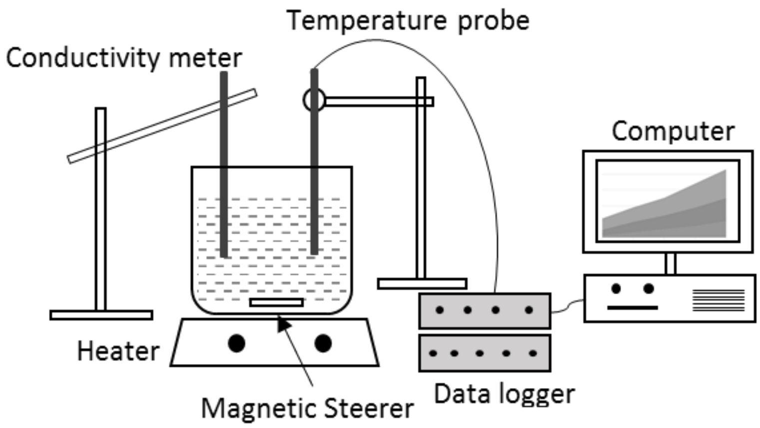

Fig. ***3: Experimental Setup***

The pH of the water samples was noted before the water was cooled to about 20°C and poured into the glass beakers. The beakers were then placed on a heater with a magnetic stirrer and were covered with a paper film to reduce water evaporation. The water samples were continuously stirred to ensure that the temperature of the water was uniform and the conductivity meter readings were representative. The temperature which was increased from 20°C to 100°C was measured using PT 100 temperature probes connected to a data logger and the readings were recorded on a computer. The accuracy of the temperature probe was 0.01°C.The conductivity readings were measured using a calibrated GLP+ ESC Crison conductivity meter.

3.2 Determination of Total Dissolved Solids (TDS)

Electrical conductivity readings were taken at different temperatures ranging from 24°C to 100°C but the readings at 25°C were the one used to determine the TDS using the equation below (Hubert and Wolkersdorfer, 2015).

TDS (mg/L) = Conductivity $(\mu m/cm)$ $\times$ conversion factor (equation 1)

The conversion factor in equation 1 can vary between 0.40 and 0.96 depending on the type of water. Where the dissolved solids are not known, a value of 0.65 is used as an approximation (PASCO Scientific, 2010). For freshwater, the conversion factor of 0.7 is used as shown in Figure 2.

4. Results and Discussion

Figure 4 presents a graph of electrical conductivity against temperature for water samples collected from the three different areas and Table 2 presents the pH, the electrical conductivity at 25°C as well as the calculated TDS.

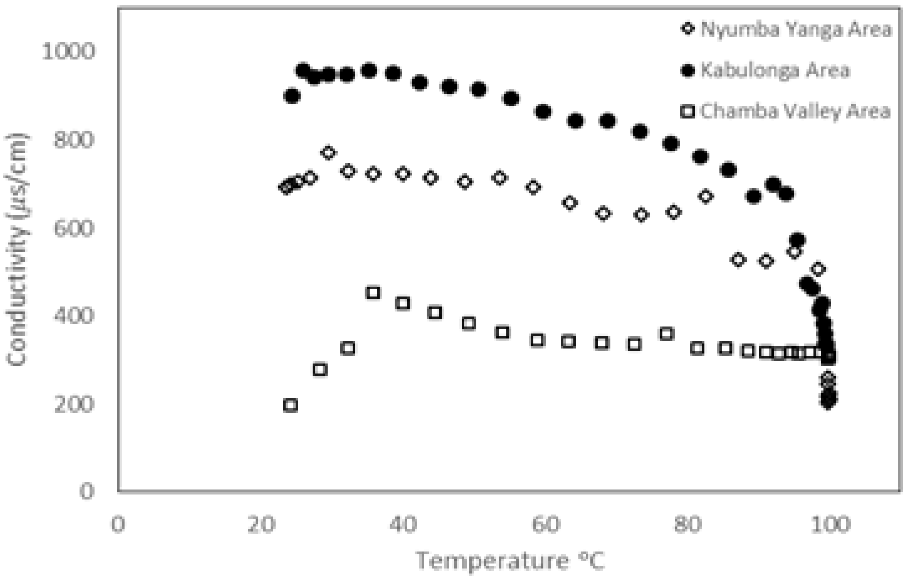

Fig. 4: Change in conductivity with temperature

Table 2: Calculated (estimated) total dissolved solids in three water samples

Water Sample	pH	Electrical Conductivity at 25°C (μS/cm)	Conversion Factor	Total Dissolved Solids (mg/L)
Chamba Valley	7.4	200	0.7	140
Nyumba Yanga	7.2	700	0.7	490
Kabulonga	7.1	920	0.7	644

The pH of all the water samples was between 7.1 and 7.4. According to the World Health Organization (2007), the pH of most drinking-water lies within the range 6.5–8.5. Therefore, this was within the normal range for drinking-water. The conductivity of the water samples from Chamba Valley, Nyumba Yanga, and Kabulonga ranged from 196, 693, 900 μS/cm at 24.2 °C to 307, 203, 334 μS/cm at 100 °C. In all the three samples, initially, the conductivity increased with increase in temperature but later begun to reduce. This is because conductivity is affected by several factors related to the concentration, degree of dissociations, valences, and the mobility of ions in solution. Therefore, temperature affects the conductivity. Each increase of 1 °C causes an increase of 2% in the conductivity (PASCO Scientific, 2010). This is the reason why the conductivity readings of the water samples initially increased with an increase in temperature. However, as the temperature of the water samples increased, the water became supersaturated and caused some dissolved salt ions to precipitate to a size of more than 2-microns thereby reducing the concentration of the dissolved ions. This resulted in the reduction of conductivity values as seen in Figure 4.

From the graph in Figure 4, it can also be deduced that precipitation of dissolved mineral salts in water samples from Chamba Valley started at 27.5 °C whereas, for Nyumba Yanga and Kabulonga, precipitation started at 29.5 °C and 36 °C respectively. The downward trend of the conductivity readings indicates that precipitation continued as the temperature of the water samples was increased. The formation of the precipitates from dissolved inorganic salts such as carbonates had an effect on the turbidity of the water by changing the color of the water from clear to milky whitish. Since, domestically, people are encouraged to boil drinking water in order to kill germs (Artiola, Farrell-Poe and Uhlman, 2009), it means that they have to deal with such turbidity issues. Over a prolonged period of time, the precipitates have a technical effect on the domestic appliances and equipment and this may lead to economical costs. This is because the precipitates build up and scale on the heat exchanger surfaces resulting in reduced heating efficiencies thereby consuming more power to effectively function. Attempts to mechanically remove the scale from the heat exchanger surfaces is not only inefficient and cumbersome but may shorten the lifespan of the appliances. For the scales to be removed without tampering or destroying the heat exchanger surfaces, the anti-scale chemicals have to be used which are an added costs.

The calculated TDS levels of Chamba Valley, Nyumba Yanga, and Kabulonga were 140, 490 and 644 mg/L. These results fall well within the stipulated range of TDS of up to 1000 mg/L for potable water (World Health Organization, 2011). Therefore all the water samples were fit for human consumption. However, according to Table 1, the water samples from Chamba Valley were found to be palatably excellent whereas the ones from Nyumba Yanga and Kabulonga were good and fair respectively.

Although there are only three areas investigated in this study, the review of TDS levels of groundwater sources in John Laing, 798 mg/L, Chawama, 710 mg/L and an average of 405 mg/L for places like Kalingalinga, Kanyama, Matero, Chipata and George is an indication that water from these sources in relation to TDS is potable but may differ in terms of palatability and degrees of scaling on heating equipment. . In cases where the TDS in water cause unbearable aesthetic, cosmetic or technical effects, home-based water treatment technologies such as reverse osmosis (RO) may be employed at the point-of-use to overcome such challenges. The downside of it is that such an installation may be expensive for some households.

5. Conclusion

The total dissolved solids levels were used to determine the water quality in selected parts of Lusaka. The electrical conductivity of the respective water samples was used to calculate the TDS levels. It was found that the electrical conductivity of water samples from Chamba Valley, Nyumba Yanga, and Kabulonga were 200, 700 and 920 μS/cm respectively and corresponded to TDS levels of 140, 490 and 644 mg/L. All the water samples were found to be potable since the TDS levels were below 1000 mg/L. However, in terms of palatability, the water samples from Chamba Valley were excellent compared to the ones from Nyumba Yanga which were good and those from Kabulonga fair. The precipitates that formed in the water samples when heated had an aesthetic effect. This was evidenced with a change in turbidity where the color changed from clear to a milky whitish with suspected precipitates of inorganic salts. The prolonged formation of the precipitates results in the TDS having a technical effect by forming scales on heat exchanger surfaces of equipment which has both a performance and economic effect due to increased thermal conductivity. The pH of all the water samples was between 7.1 and 7.4 which was within the range (6.5–8.5) of most drinking-water.

In cases where the TDS cause unbearable effects, home treatment systems such as reverse osmosis devices may be employed.

6. Acknowledgements

The author would like to thank the Crystallization and Precipitation Research Unit at the University of Cape Town, South Africa for the use of the laboratories and the team at Kmet Consultants.

References

Aridas, T. and Pasquali, V (2013), Countries with the Highest GDP Average Growth, 2003-2013, (available online https://www.gfmag.com/global-data/economic-data/countries-highest-gdp-growth [accessed: 20/8/2016])

Artiola, J.F., Farrell-Poe, K. L. and Uhlman K. (2009) Water Facts : Home Water Treatment Options. Report AZ1498, The University of Arizona, Tucson.

Holmes-Farley (2004), What is TDS?, (available online www.reefkeeping.com/issues/2004-04/rhf/feature/ [accessed: 10/10/2016])

Hubert E and Wolkersdorfer C (2015) "Establishing a conversion factor between electrical conductivity and total dissolved solids in South African mine waters." *Creative Commons Attribution Licence*, Vol. 41(4), pp. 490–500.

Makayi B (2010) "Water Accounting Framework-A Case Study of Lusaka Water and Sewerage Company." The University of Zambia, Lusaka, pp. 1-48.

Mdala, C L (1976) Geographical Exploration for Groundwater in Limestone Aquifers of Zambia, University of Zambia, Lusaka, pp. 1-92.

Nkhuwa, D C W (2001) "Relevance of groundwater quality assessment in the Lusaka aquifer," in People and Systems for Water, Sanitation, and Health. *Proc. 27th WEDC Conference*, pp. 472–474, Lusaka.

Nkhuwa, D C W, Kafula T and Ahmed A H (2008) "A Preliminary Inventory of Hazardous Medical Waste Disposal Systems and their influence on Groundwater Quality in Lusaka." *Medical Journal of Zambia*, Vol. 35(4), pp. 129–138.

PASCO Scientific. (2010) Water Quality Field Guide. Report PS-2829A, PASCO scientific, Roseville

Raisbeck M F, Riker S L, Tate C, Jackson R, Smith M. A, Reddy K J and Zygmunt, J R. (2007) "Water Quality for Wyoming Livestock & Wildlife: A Review of literature pertaining to health effects of inorganic contaminants." Laramie, pp. 49–50.

UNEP-DEWA (2003), Habitat Project Document. Lusaka, (available online http://www.atelim.com/john-laing-mass-media-and-misisi-areas.html?part=10 [accessed on 3/1/2017])

US Environmental Protection Agency (2016), Secondary Drinking Water Standards: Guidance for Nuisance Chemicals, (available online https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals [accessed on 15/9/2016])

Water Research Australia (2017), Certificate of Analysis: Drinking Water Quality, (available online https://www.waterra.com.au/_r170/media/system/attrib/file/148/Water_Quality.pdf [accessed 10/01/2017])

World Health Organization (1996) Total Dissolved Solids in Drinking-Water Guidelines for Drinking-Water Quality. Report WHO/SD/WSH/03.04/16, World Health Organization, Geneva

World Health Organization. (2007) pH in Drinking-water: Revised Background document for development of World Health Organization Guidelines for Drinking-Water Quality. Report WHO/HSE/WSH/10.01/14, World Health Organization, Geneva.

World Health Organization. (2011) Guidelines for Drinking-water Quality Fourth Edition. Report ISBN 978 924 1548151, World Health Organization, Geneva

Zambia Data Portal (2013), Population and Housing Census of Zambia, Zambia Data Portal. (available online http://zambia.opendataforafrica.org/ZMPHC2015/population-and-housing-census-of-zambia-2011-2035 [accessed: 4/10/2016])

Process Optimisation of Tailings Leach Plant - Konkola Copper Mines Plc, Zambia

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Abstract

The Acid Soluble Copper (ASCu) recovery across Tailings Leach Plant (TLP) was over a long time averaged below 71% against the business plan target of 76%. This gap translates into a loss of more than 300 tons per month of primary cathode copper. The decrease in the ASCu recovery was mainly due to gradual diminishing of ASCu grades in input material from Nchanga Underground (NUG) and Nchanga Open Pit (NOP) coupled with the ingress of water to the post leach circuit. The latter was caused by underperformance of Horizontal Belt Filter (HBF) plant which was later decommissioned. Prior to that, HBF plant could treat pre leach material at 60% w/w solids and produce filter cake consisting of 80% w/w solids which was then re-pulped with raffinate and pumped to the leach pachucas for leaching. The outage of this plant resulted in sending material with higher water content to post leach circuit which led to excessive raffinate bleeding from the circuit, reduction in Wash efficiency from 95% to 89% and high consumption of reagents (lime and acid). A more efficient mode of operation was clearly required to counter these operational constraints. A Total Quality Management (TQM) team was constituted in February, 2011 to specifically look at ways of improving ASCu recovery at lowest possible cost of production. The aim of this paper is to review the process investigation and implementations of various conditions and operating parameters which were carried out to improve the ASCu recovery. The implementation of the TQM's recommendations resulted in improved overall ASCu recovery from about 71 to 79 - 83%.

Keywords: Tailings Leach Plant, Acid Soluble Copper, Recovery, Horizontal Belt Filters, Total Quality Management

1. Introduction

The Leach Plant at Konkola Copper Mines (KCM) Plc, is a subsidiary of Vedanta Group of Companies, has since commissioning in 1974 continued to raise its throughput for it to remain viable economically. This is mainly due to gradual dwindling of ASCu grades in input material from NUG and NOP from over 0.70% to as low as 0.40% as well as increased cost of production. The plant was designed to treat about 25,000 tpd of dry material with process ASCu recovery of 80% (Holmes *et al.*, 1976). The operation started with leaching of low-grade tailings using strong sulphuric acid followed by solution recovery and cementation of copper. TLP Stage II was

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commissioned with the introduction of a Solvent Extraction plant and an Electrowinning facility. Production was 200 tons primary copper per day, and the throughput was 25,000 tonnes per day of dry solids. The modification of TLP circuit in 1985 under TLP Stage III expansion saw an installation of auto dilution system, the EIMCO E-Duc technology, at thickener center to improve ASCu recovery as well as plant flexibility (Grosse *et al.,* 2004). To ensure the integrity of the CCD hydraulics given the limited static head available between the thickener launder and the downstream mixing vessel, SysCAD simulation software was used. This was necessary to provide sufficient driving head for the EIMCO E-Ducs to effect the desired dilution and to ensure that the thickener launders would not overflow. The dynamic simulation also allowed checks to be made on pumping calculations made by KCM and pumps suppliers (Weir-Envirotec and Warman). This development enabled the introduction of Counter Current Decantation (CCD) washing system and resulted in treating an addition of approximately 20,000 tpd of dry material from large reserves of 135 million tonnes of reclaim tailings stockpiled since the early 1930s. This raised primary copper production from 200 to 250 tpd (Taylor, 2002; Kordosky, 2002).

One of the critical but silent features of TLP Stage III expansion was the installation of one of the world's largest HBF plant (Chisakuta *et al.,* 2003). The HBF plant had 26 filters each of 80.5 m^2 effective filtration area and consisted of the pre-leach and post-leach sections. The pre-leach handled non-acid feed and was necessary to reduce fresh water input to circulating process liquor thereby reducing the amount of raffinate bleed. The filtrate was recycled as process water while the filter cake at 20% w/w water was re-pulped with process liquor and pumped to the leach pachucas (vessels for leaching). The post-leach filters worked on the same principle of operation as the pre-leach except that it handled acidic material from acid thickener (terminal thickener underflow). The filter cake was washed with raffinate in the wash zone of the filters to displace residue solution copper in the cake so as to minimize ASCu losses. With the HBF in operation, the wash efficiency was expected to be about 95% with the overall ASCu recovery at 80%. However, the HBF plant was decommissioned under TLP Stage IV expansion project. The aim of TLP Stage IV expansion project was to increase throughput from 45,000 to 60,000 tpd at minimal cost of production. Prior to that, a lot of capital work was put into the rehabilitation of the HBF plant with a view of improving its operation. However, the performance of the filters was below expectations (with plant availability as low as 15%) as losses of ASCu continued due to low wash efficiency.

The exclusion of HBF plant resulted in increase in loss of ASCu in solution through excessive bleeding of raffinate from the circuit which led to high lime and acid consumption. Furthermore, process control across CCDs proved to be a challenge owing to water ingress into the post leach circuit. This contributed to decrease in overall ASCu recovery to as low as 71%. A more efficient mode of operation was clearly required. A TQM team was formed to specifically look at ways of improving ASCu recovery at lowest possible cost. This paper reviews the process investigation and implementations of various conditions and operating parameters which were carried out to improve the ASCu recovery.

2. Process Description

The various units that make up TLP consist of many individual pieces of equipment and operating conditions which have great effect on the overall ASCu recovery.

The plant design capacity is currently at 60,000 tpd of dry tailings, though about 48,000 tpd of material is being treated on average with minor process control challenges. The main sources of material are NUG and NOP via concentrator and reclamation dams. The tailings from the reclamation dams consisting of about 0.30% ASCu grade are now being reclaimed to supplement on the tailings from concentrator with ASCu grade of about 0.50%. By adjusting the tonnage of reclaimed material, variations in tonnage from current tails can be compensated resulting in a very steady feed to the plant.

On the main plant, the 14,884 m^3 reclaimed pre-leach thickener (RPLT) and the current pre-leach thickener (CPLT) with settler areas of 0.18m^2/tonne/day are fed with slurry (about 40% w/w solids), through the feed launder. De-watering of the slurry is achieved by flocculation as well as steel rakes attached to the drive mechanism which assists in settling of solid particles. The concentrated slurry is drawn as underflow, containing about 60% w/w solids, through the basal and suction lines and then pumped for leaching while the overflow, which is water, is sent into water circuit for reclamation and plant usage.

Leaching is achieved in air agitated leach pachucas. There are three banks of leach pachucas each containing a set of four equi-volume pachucas. Optimal leaching time per bank for normal flow rates, assuming all leach pachucas are in circuit, is approximately 2 hour with solids content of about 44%. Acid addition is effected by pH changes in the slurry sensed by a probe which transmits signals to an actuator to either open or close the automatic acid valve. The pH is normally operated in the range of 1.5 - 2.2.

The washing circuit is composed of CCD1, 2, 3, 4 and 5 with CCD2 as primary thickener while 3, 4 and 5 are wash thickeners. The CCDs are of same size, design and operate on the same principle as the pre-leach thickeners. The overflow from CCD2 which is richer in soluble components is pumped to CCD1 for clarification before gravitating to pregnant liquor storage tanks. The solution gets richer in soluble metal value as it moves from CCD5→ CCD4→CCD3. CCD3 overflow gravitates to the SX clarifier as Low Pregnant Liquor Solution (LPLS) for clarification before being pumped to the pregnant storage tank. The solids progressively lose their valuable copper metal as they move from CCD2→CCD3→CCD4→CCD5. CCD5 is the final unit in the washing circuit. The raffinate solution from SX is added in the mixing vessel at CCD5 to help in the washing of the solution copper. The U/F from CCD5 is pumped to Muntimpa pachucas for neutralization and final disposal.

The Solvent Extraction (SX) plant runs a split circuit with pregnant liquor flow as high as 1400 m^3/hr per stream. The plant consists of four streams. Currently, only three streams are operational and one is on standby. Each stream comprises three Extraction (E) and two Stripping stages (S). The streams operate in serio-parallel mode with E1 – E2's in series on HPLS and raffinate generated is sent to CCDs and Leach Pachucas. E3s operate in parallel to E1 – E2's and are on LPLS with the raffinate produced being pumped to CCDs. The PLS is brought into contact in the extraction units with organic solution at pH 1.5 – 3.0. In the stripping section, the reaction is reversed by carefully controlling the operating conditions. The organic solution containing copper is contacted with spent electrolyte containing free acid at 160 – 180 gpl and 32 – 35 gpl copper tenor. By using a lower volume flow of spent electrolyte than that of the PLS, the concentration of copper is increased in the spent electrolyte up to 40 - 60 gpl. The electrolyte is pumped to tank house, as advance electrolyte with free acid in the range of 135 – 150 gpl.

The Tank House (T/H) comprises three units with a total number of cells of 320. Each of 8.98 m^3 cell is loaded with 62 copper starters weighing about 6 kg, as starting cathodes. In the cells current as high as 36 KA is passed through the electrolyte. Unit I receives advance electrolyte and the overflow from individual cells is collected and pumped to unit II. The same sequence is repeated such that the spent electrolyte from unit III is collected and sent to SX. The copper metal deposited is allowed to accumulate for a few days and is then harvested. Figure 1 shows a simplified flow sheet of the TLP circuit.

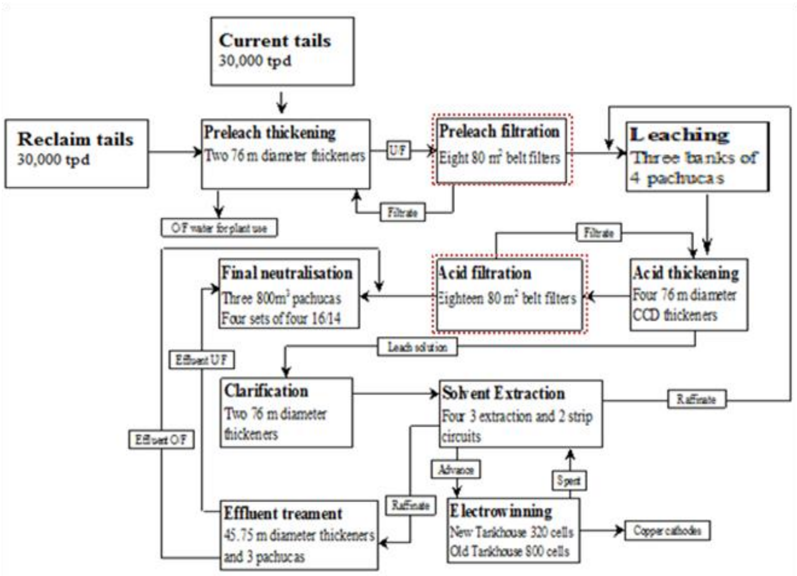


Fig. 1: Flow sheet of the Tailings Leach Plant circuit (TLP Technical Report, 2011).

3. Analysis of Operating Conditions and Parameters

In this section, the effect of changes in various conditions and operating parameters on the ASCu recovery are analyzed.

3.1 Effect of Leach Pachuca pH Control and Residence Time on Recovery

The pH control in leach pachucas is one critical process parameter which has direct impact on ASCu recovery as shown in figure 2. The pH of 1.8 was found to result into high leach efficiency of 88% at a rate of 700 tpd acid consumption. At this optimum pH, the free acid was about 3.0 gpl and had no significant effects on the extraction equilibrium kinetics at SX plant. For smooth control of pH in leach pachucas, the pH control was automated.

The effect of residence time in leach pachucas on ASCu recovery is direct proportional (Collao *et al.*, 2003). Poor availability of pachucas was the main challenge which reduced the residence time. This was mainly as a result of sanding out caused by low air pressure for agitation as well as the leaching process taking place at high feed densities (above 1350 gpl). The plant on average was operating at 50 – 75% leach pachuca availability and this contributed to about 2.2% loss in leach efficiency.

The optimisation and proper control of leach pH coupled with maximising leaching time led to improved leach efficiency from 84 - 85% to about 87 - 88% thereby increasing ASCu recovery by 2.2%.

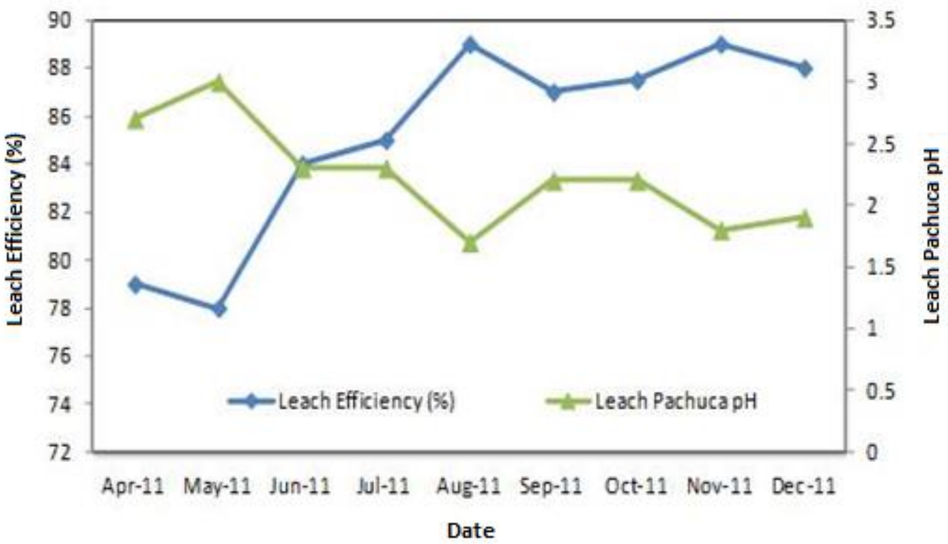


Fig. 2: Relationship between Leach Efficiency and pH

3.1.1 Acid Dilution Project

In order to improve leach efficiency at reduced acid consumption, Acid Dilution System (a USD 0.6 million Pilot Plant project) was designed and installed using raffinate solution at the primary leach pachucas in C-Bank. Pre-dilution of acid in the leaching process involved minimising the local acid concentration near the addition point which proved to reduce acid consumption by up to 50% as well as lowering the Gangue Acid Consumption (Grosse *et al.*, 2004). The Pilot Plant comprised of stainless steel mixing tank, venturi spurger mixer, feed pump, and acid control valves, pH probe and associated instrument control devices. The first phase was unfortunately rocked with problems such as pipe and pump failures/trip outs, leaking flanges, malfunctioning of control valves. The aforementioned led to the inconsistent running of the plant. Modifications were done to the initial pilot plant and the second phase commenced in June 2011. A number of trial attempts were conducted aimed at optimising acid consumption without compromising leach efficiency. Results obtained indicated acid consumption reduction of up to 20%. Prior to that, TLP was consuming about 24 kg-acid/tonne-material treated which was above budget figure of 18 kg-acid/ton-material. It was then recommended to implement Acid Dilution System in A and B Banks to further reduce acid consumption.

3.2 Effect of CCDs Operations on Recovery

The analysis showed that ASCu loss in solution across CCDs through washing was greater than that in solids through leaching in leach pachucas. Figure 3 below shows that an increase in wash ratio (amount of solution fed to the CCD circuit per unit mass of solids in the leached residue) from 1.0 to 2.0 made a significant impact on wash efficiency. The wash efficiency of above 91% was achieved by operating the wash ratio at about 2.1. This translated into a reduction from 0.75 to 0.40 gpl of ASCu solution loss through washing.

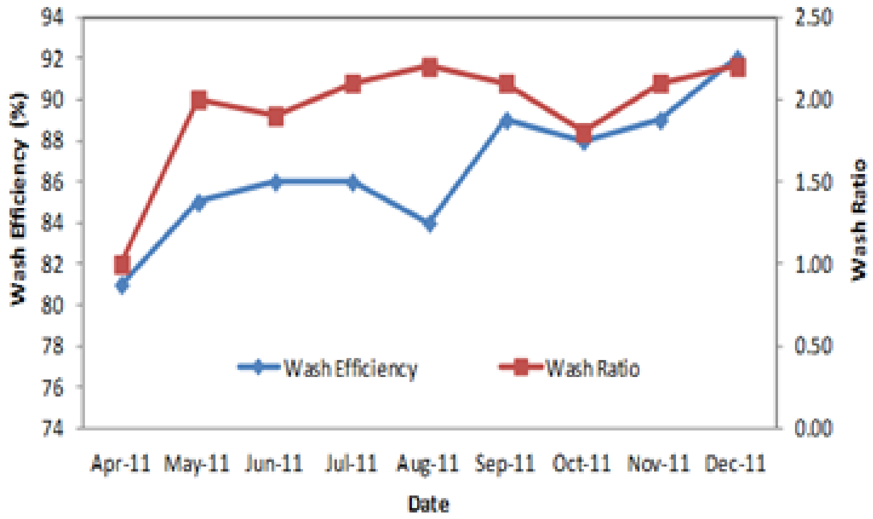


Fig. 3: Relationship between Wash Efficiency and Wash Ratio

Figure 4 shows the relationship between CCDs U/F densities and ASCu recovery. The trends indicated that as the density of the underflow was operated at optimal range of 1580 - 1600 gpl, the losses reduced substantially from over 15 tpd to less than 10 tpd. This resulted in an increase in the ASCu recovery by 1.25%.

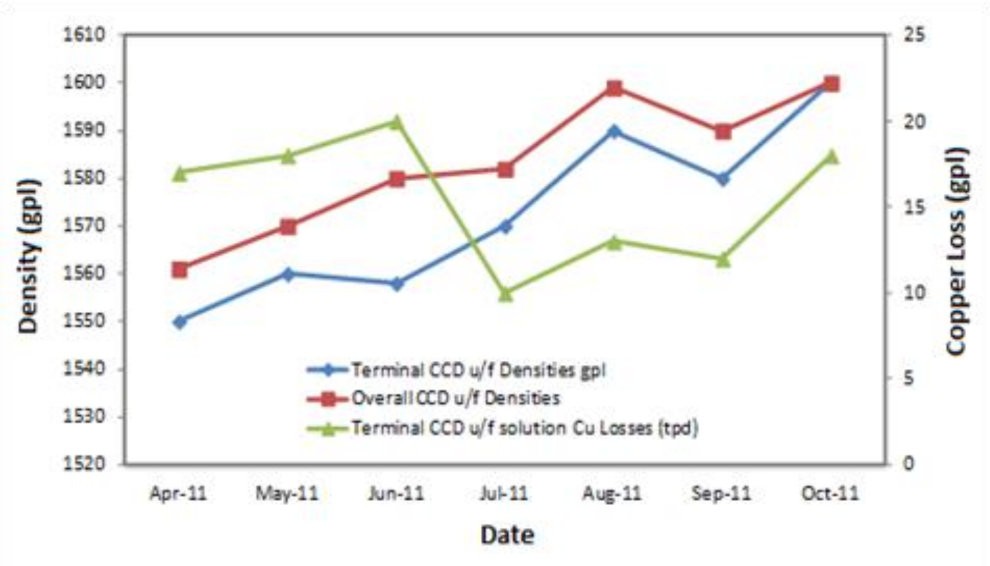


Fig. 4: Relationship between CCDs densities and Solution copper loss

It is evident that both wash ratio and underflow densities have a significant influence on the ASCu recovery. Optimisation of both the wash ratio and underflow densities led to an increase in wash efficiencies from 86% to about 91% and consequently ASCu recovery by 2.5%.

3.2.1 Installation of Jaguar Flocculant Make-Up System

To reduce flocculant consumption for pre-leach and post-leach operations thereby improving CCDs operations, a Jaguar flocculant make-up system was installed. Preparation of flocculants is a critical activity which has an impact on dosage quantity as well as thickener performance (Mwenechanya *et al.*, 1987). The Old Reagent plant was in a bad state and running without reasonable instrumentation control equipment. The machines were using compressed air to blow the powder to the hydration tanks and the amount of reagent utilized was quantified using the timer assuming steady flow of the powder, with target being 180 kg per batch mixed at concentration of 1.02 gpl. However, there was inconsistence in the flocculant concentration due to human errors as well as losses as a result of the powder being blown off by the wind before it could reach the hydration tanks. There was need for retrofitting the Reagent plant with a more efficient System.

The Project to retrofit the Reagent plant was done in two phases. Phase I involved retrofitting the wetting and mixing system while taking advantage of the existing spaces of hopper and feeding system. The wetting and mixing system were purchased with the complete package of instruments for auto control. The new system involved: bulk bag weight in loss system, receiving hopper, screw feeder, screw feeder motor, water pump, water pump motor, water tank, tank level indicators and auto valves for process control. Phase II involved both Mechanical and Civil Works which were required to increase the capacity of the hydration tanks, Installation of mechanical agitators as opposed to air agitation; online measured dilution as opposed to non-measured dilution in dilution boxes at thickeners.

The installation of a Jaguar flocculant make-up system resulted in improved accounting of flocculant and reduction in consumption by 20% with a payback period of less than 10 months.

3.3 Effect of SX Operations on Recovery

Organic management in the SX plant is critical to maximize copper transfer from Leaching-Washing to Electrowinning circuit (Escobar *et al.*, 2003; Ritcey and Ashbrook, 1989). In 2010, the plant recorded a loss of organic solution of about 150 m^3 per month on average despite steady addition of about 35 m^3 per month so as to maintain the strength at 14%. The Organic/Aqueous (O/A) ratio in the same year averaged 0.8 against a target of 1.1 resulting in extraction efficiency of 89%. The O/A ratio has a direct relationship with extraction efficiency as shown in figure 5. The month of July, 2011 recorded the lowest O/A ratio of 0.6 with the corresponding extraction efficiency of 86%. At 0.9 – 1.2 O/A ratios, the extraction efficiency of about 98% was achieved. Loss of organic was manifested in crud levels being as high as 200 m^3 per stream against the allowable limit of 100 m^3 per stream. This was due to high Total Suspended Solid (TSS) in the PLS from CCDs which was averaging 150 - 200 ppm. Prior to that, the crud levels were as high as 500 m^3 per stream and TLP was operating one of the most expensive SX plant in the world because of high consumption of extractant and diluent (15 kg/t-Cu and 65 kg/t-Cu respectively) and was over 100% of world best practice average values. At low O/A ratio, the mixer is starved of extractant in relation to PLS Cu, and increasing the organic concentration by addition of extractant has an inverse relationship with extract O/A ratio. At low O/A ratio, the increased delta copper in the organic as a result of addition of fixed volume of extractant is greater than at high O/A ratio. At high O/A ratio, there is an abundance of extractant relative to the Cu from the PLS and so increasing organic concentration has insignificant effect (A Cognis Overview, 2009). It was preferable to adjust organic flow instead of organic concentration as it incurs significant cost in comparison to the other option. Furthermore, running a circuit with high organic concentration has the potential to lead to excessive chemical transfer of iron.

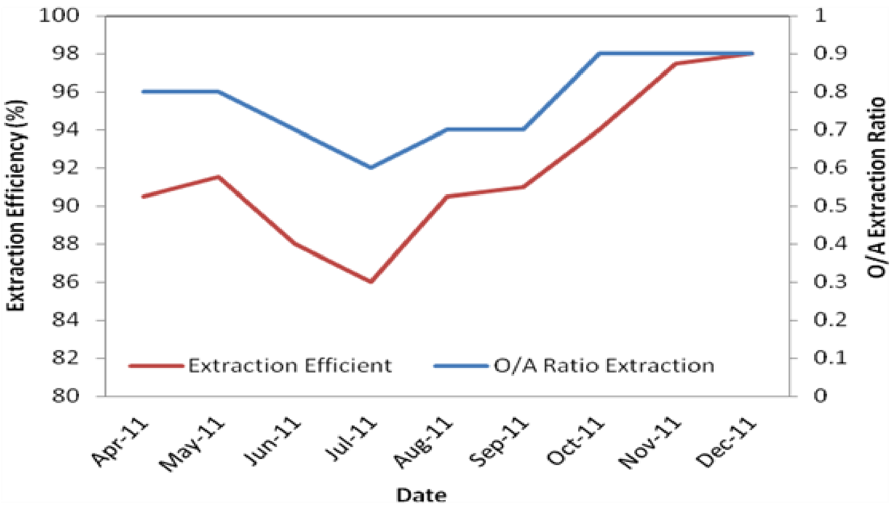
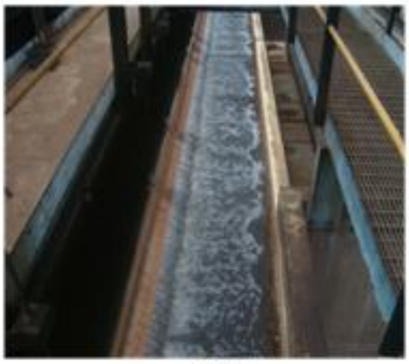


Fig. 5: ***Relationship between SX extraction efficiency with O/A ratio***

Other operating conditions which were altered include; replacing of 0.46 m (18 inch) discharge pipes of SX weirs with a 0.61 m (24 inch) pipes to avoid flooding of weirs as shown in figure 6, the loss of organic through seepage was minimised by replacing the worn out lining of the SX drains and sumps, an auto system was installed to recycle aqueous from the stripped organic tank to the striping mixers. These changes led to an increase in extraction efficiency to 98% at the same time reduced consumption of extractant and diluents to around 4.0 kg/t-Cu and 40 kg/t-Cu respectively.



Before

After

Fig. 6: Solvent extraction weir

3.3.1 Organic Management in SX

To improve organic management in SX, two solvent extraction pilot plants were set up to evaluate the performance and compatibility of the Chemorex CP160 copper extractant and Arcoga M5774 which was in use. The work was aimed at improving critical SX parameters at low cost of production as CP160 was more cost effective compared to M5774 extractant. The following are the parameters analysed; extraction and stripping efficiency, copper loading capacity, copper uptake, iron rejection or transfer, phase disengagement, reaction kinetics, organic entrainment in raffinate-advance streams and comparisons of build-up of floating, interfacial and bottom crud.

The testing was conducted in two phases on a continuous mode. In Phase I the pilot plant was run with Arcoga M5774 on stream A and Chemorex CP160 on stream B while Phase II of test work involved running blended reagents 50% M5774 and 50% CP160. All tests works were conducted at organic concentration of 13% o/v extractant in shellsol (BP Mining Solvent) to simulate current plant conditions.

The organic to aqueous ratios on extraction were maintained within the recommended limits of between 0.9-1.1. The advance electrolyte flow rate was at 2.7 liters per minute for both streams, Stripped organic flow rates averaged 5.5 and 5.1 liters per minute for M5774 and CP160 respectively and raffinate flow rate averaged 7.3 and 7.5 liters per minute for M5774 and CP160 respectively.

The results in phase I showed that Chemorex CP160 performed better with average extraction efficiency of 94.8% against 93.8% for M5574. In Phase II there was no significant difference in performance of a blend of M5774 plus CP160 and unblended CP160 with extraction efficiencies averaging 96%. Copper transfer averaged 3.04 gpl for Arcoga M5774 and 3.08 gpl for test extractant CP160. Both extractants revealed copper uptake capacity of 0.24 gpl per extractant volume concentration. On the stripping efficiencies there was no significant difference between the two reagents even when blended. Both reagents in Phase I and II of test work gave an average stripping efficiency of 55%. Organic entrainment averaged between 8 and 10 ppm in raffinate and advance from both the control stream (Stream A on M5774) and test stream (stream B on unblended and blended CP160). Both blended and unblended extractants indicated identical Iron transfer of 0.06 gpl. Iron like other metallic elements in raffinate and advance solutions from the two test streams were assayed by Nchanga Analytical Department. For crud generation, a comparison of the relative build up of solids, interfacial and bottom crud between the two reagents indicated no major difference.

Phase II of the test work involved blending of 50% M5774 and CP160. The results revealed that the two extractants are compatible but indicted no synergism effects sometimes expected from mixed extractants in terms of extraction efficiency, stripping efficiency, iron rejection, copper loading capacity, and reaction kinetics. The average phase disengagement time were 69.3 and 67 seconds on the extraction side for M5774 and CP160 respectively while for stripping it was 55.6 for M5774 and 62.6 seconds CP160. No tests of cross checking the oxime formation (authenticating) were conducted due to lack of testing facilities.

Following successful pilot testing of Chemorex CP160, the extractant was introduced at Nchanga's TLP. This resulted in stability of plant operations at reduced cost of production.

3.4 Effect of Spillage and Excessive Raffinate Bleed on Recovery

Spillage at TLP usually comes from draining of pachucas due to sanding out, line chockages, CCDs and raffinate vessels overflow (as a result of process control challenges). Initially, Spillage was being pumped to effluent treatment plant (ETP) for neutralization prior to disposal. The loss of copper through spillage was considered to be insignificant and was unaccounted for. It was discovered that about 30 - 50 tonne/month of ASCu was being lost. The copper loss through spillage and excessive raffinate bleeding were attributed to challenges on volume balance as a result of decommissioned HBF plant. Modifications were made on the circuit to allow spillage material to be recycled to the CCDs. Figure 7 shows the graph of ASCu loss through spillage during the period under investigation. The month of December after intervention showed a significant reduction in ASCu loss (below 10 ton per month compared to previous months). The analysis showed a gain in ASCu recovery of 2.1% through proper management of spillage and raffinate bleed control.

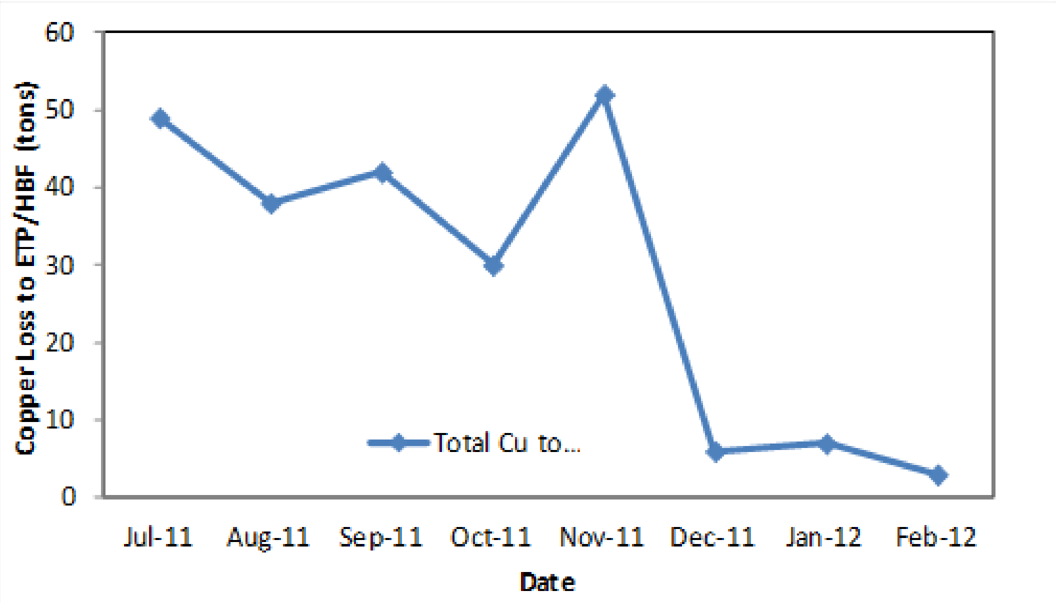


Fig. 7: Shows ASCu loss through spillage

3.5 Effect of Tank House Activities on Recovery

The process of electrowinning is energy intensive and is critical in improving ASCu recovery in a leach plant (Davenport *et al.*, 2011). The current efficiency at electowinning was over a long time averaging 88% against a set target of 92%. This impacted negatively on the overall TLP ASCu recovery. A number of activities were carried out in tank house aimed at analysing and evaluating of key parameters associated with current efficiency. These activities involved analysing the current fed to the electrowinning system from integrator readings, analysing the weights of the copper cathodes pulled from various tank house cells, selecting specific tank house cells (test cells), checking weights from test cells for every pull, taking weights and dimensions of copper starter sheets used in the tanks, check anode condition and dimensions. Other activities included improving on wet flapping, electrode contact washing, frequent disludging of cells and checking hanger bars and bus bars conditions. Data was collected and current efficiency determined from different cells. This led to improvement of current efficiency from below 85% to 93% thereby increasing ASCu recovery.

3.6 Overall Trend of ASCu Recovery

Starting from early 1990s, diminishing in ASCu grade and volume control challenges due to operational problems at HBF are major constraints that resulted in decline in the leaching and washing efficiencies. Leaching dropped from 87 – 90% to below 84% and washing from 88 – 92% to below 88%. The decline in leaching and washing efficiencies resulted in drop in recovery from 78 – 80% achieved during TLP stage II to lower figures below 71%. Figure 9 shows the trends of ASCu recovery under the period of investigation.

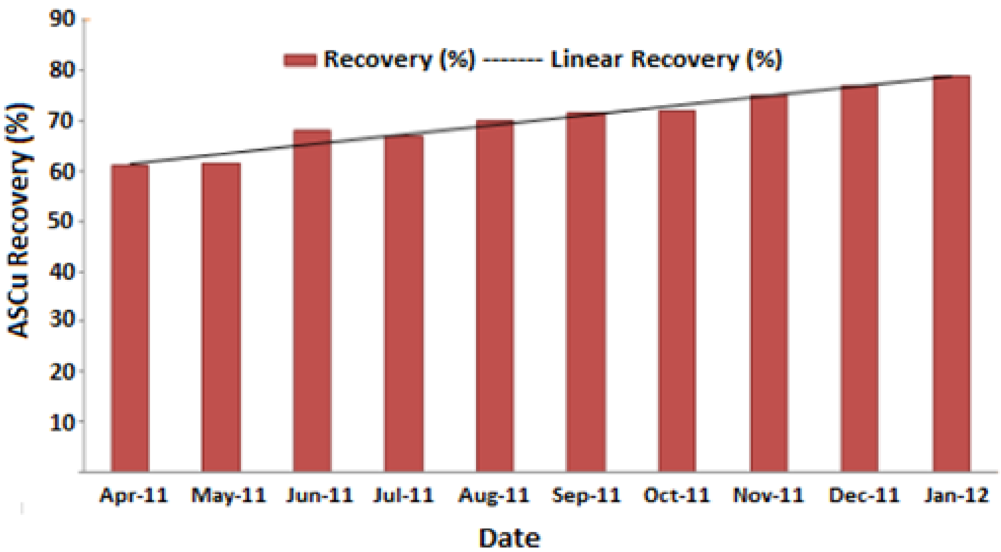


Fig. 9: Shows the Trend of ASCu Recovery during period under investigatio

4. Future Trends

To counter the effect of dwindling ASCu grades in the input which has largely contributed to low recoveries and consequently low production, treatment of Chingola Refractory Ores (CRO) should commence (TLP Technical Report, 2011). CRO is one of the company's largest ore reserves in excess of 150 million tons; it was mined from NOP and stockpiled in dedicated dumps. CRO consists of vermiculite type layered silicate in which much of the copper is included as copper atoms within the silicate lattice thus making it poorly respond to flotation. Extensive laboratory tests carried out over the years have shown that one viable route of CRO treatment is elevated temperature agitation leaching at above 60^{o}C followed by concentration and purification at SX and electrowinning.

To improve ASCu recovery further, preliminary investigation shows that the recovery could be increased to approximately 85% by installing two more conventional thickeners for washing coupled with mechanical agitation in leach Pachucas. This is expected to increase wash efficiency to about 95% and leach efficiency to 89% (through improved leach Pachuca availability to above 90%).

5. Conclusion

TLP has gone through various phases of upgrade in order to be viable economically owing to operational constraints of critical sections and dwindling in ASCu grade by over 60% in the input from upstream. This coupled with the decommissioning of HBF plant contributed to decrease in ASCu recovery. The analysis showed that optimizing both the wash ratio to 2.0 and underflow densities across CCDs to 1650 gpl led to increase in ASCu recovery by 3.0%. The improvement in organic management resulted in increased extraction efficiency and consequently increased the ASCu recovery by 2.5%. Improved spillage management and raffinate bleed control resulted in ASCu recovery gain of 2.1%. The optimal leach pH and residence time contributed to increase in ASCu recovery by 2.2%.

Preliminary investigation shows that the ASCu recovery could further be increased to approximately 85% by installing two more conventional thickeners for washing coupled with mechanical agitation in leach Pachucas. This is expected to increase wash efficiency to about 95% and leach efficiency to 89% (through improved leach Pachuca availability to above 90%).

References

A Cognis Overview (2009) Cognis Operation of Copper Solvent Extraction Plants

Chisakuta G C Banda M and Chabinga M (2003) "Process Development at Tailings Leach Plant," The South African Institute of Mining and Metallurgy. *The third Southern African Conference on Base Metals*, pp. 379-390

Davenport W G King M Schlesinger M and Sole K C (2011) *Extractive Metallurgy of Copper*, 5th edition, Elsevier.

Escobar, V., Treasure, P.A., and Dixon, R.E., (2003). "High Current Density EMEW® Copper Electrowinning," Hydrometallurgy. *Electrometallurgy and Environmental Hydrometallurgy*, Vol. II, pp. 1369–1380.

Grosse, J. Danysz, A and Banda, M. M. (2004) Design and Implementation of the Re-introduced KCM CCD Circuit, Chingola.

Holmes J A Deuchar A D Stewart L N and Parker J D (1976) "Design, Construction and Commissioning of the Nchanga Tailings Leach Plant." *Extractive Metallurgy of Copper*, Vol. II pp. 907-925.

Kordosky G (2002) "Copper recovery using leach/solvent extraction/electrowinning technology: forty years of innovation," *Proceedings of the International Solvent Extraction Conference*, Johannesburg, pp. 853–862.

Mwenechanya S K Mawer J A and Chowdhury S (1987) "Copper 97," *Proceedings of the International Hydrometallurgy and Electrometallurgy*. Vol. III, CIMM.

Ritcey G M and Ashbrook A W (1998) Handbook of Separation Techniques for Chemical Engineers, 2nd Edition, McGraw-Hill Inc., New York, pp. 2-105–2-130.

Taylor J (2002) "Re-commissioning of the CCD Circuit," *The 2002 Zambia Mining and Metallurgy Conference*, Kamenza Hall, Konkola.

TLP Technical Report (2011) Improvement of ASCu Recovery at Tailings Leach Plant, Konkola Copper Mines, Chingola.

Promotion of Renewable Energy Technologies in Rural Electrification Programme

Patrick Mubanga[1]

Abstract

Renewable energy sources remain one of the major technologies that nations are promoting in order to replace fossil energy sources which are not environmentally friendly. Some of the renewable energy technologies include mini hydro and solar power sources. These sources once verified could provide a sustainable solution for electrifying rural communities, especially in developing countries. Realizing the benefits of renewable energy sources, the Rural Electrification Authority (REA) has initiated the promotion of renewable energy technologies, mainly to electrify rural communities. Although these technologies are suitable for providing electricity in isolated and remote rural areas, their implementation programs have not been successful as expected (Anders, et al., 2000).

The purpose of this paper is to outline the renewable energy projects that the Authority is currently undertaking to promote the utilization of renewable energies technologies in implementing rural electrification projects. The paper further provides challenges experienced through the promotion of renewable energies and strategies that have been put in place to address the challenges.

Considering the vastness of the country and the nature of settlement of the rural population which is mainly not concentrated, the most effective method of electrifying the rural population is the use of renewable energy technologies which can easily target the population.

Keywords: renewable energy sources, fossil energy sources, sustainable, mini hydro power, solar power.

1.0 Introduction

The Rural Electrification Authority (REA) is a statutory body created through an Act of Parliament, the Rural Electrification Act No. 20 of 2003. The Authority's mandate is to provide electricity infrastructure in rural areas of Zambia using appropriate technologies in order to contribute to improved productivity and quality of life to the rural population. To that effect, the Authority has been implementing projects such as extension of the national grid, construction of substations, solar and mini grid hydro power development studies since 2006 (REA, 2014).

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The motivation of the paper is to share the challenges and strategies that the Authority has put in place. It hoped that the strategies that have been put in place will provide a platform for new players to join in the development of the technologies. Deployment of the technologies will therefore contribute to improved service delivery of energy services in the rural areas thereby enlightening the social and economic standards of the rural community.

1.1 Energy Policy

Zambia has a liberalised energy sector that supports private sector participation. The Energy Regulation Board (ERB) is Zambia's regulatory body that regulates the energy tariffs and also ensures that safety standards of energy projects are met and at the same time consumers are protected. Therefore, all energy projects go through the ERB for approval and licencing. The tariff for energy projects are fully regulated by ERB. However, tariff is set individually for each project depending on the cost of the generation assets (ERB, 2017).

However, it must be pointed out that inadequate policies, limited application of appropriate technologies, limited financing and weak institution framework are some of the problems that have affected rural electrification in most developing countries (Hanyika, 2005).

2.0 Projects being implemented by the Authority to promote renewable energy

In the quest to promote renewable energy technologies and increase access to electricity in rural areas, the following are the renewable energy projects that are being spear headed by the Authority:

2.1 Lunga and Chunga Solar Mini Grid

In line with the Authority's Strategic Plan for 2014 to 2018, REA identified the implementation of solar mini grids as one way of increasing the access to electricity in rural areas. The Authority identified two sites for the implementation of solar mini grids namely, Lunga in Lunga District of Luapula Province and Chunga Wildlife Camp in Mumbwa District of Central Province with capacities of 300kWp and 200kWp respectively (REA, 2014).

Due to financial constraints, the construction of the two projects has been phased and is scheduled to be implemented over a period of 3 years. The first phase involves construction of buildings to house the solar systems while the second phase comprises construction of low voltage network for distribution of power to various load centres. The third phase will involve installation of solar panels, inventors and charge controllers. Installation of billing systems will also be done. In terms of status, phase one commenced last year and is scheduled to be completed by the end of March 2017 (REA, 2014). .

2.2 Project Details

The project detail of the two sites is provided as follows:

2.2.1 Chunga Solar Mini Grid

The Chunga solar mini grid project is located in Mumbwa District of Central Province. The project involves the construction of a 200kWp solar mini-grid system to supply electricity to Chunga community and surrounding areas including the Department of National Parks and Wildlife Services, formerly Zambia Wildlife Authority (ZAWA)-Chunga offices and Boarding School, Chunga Rural Health Centre, Community Shops, various religious church structures and 75 Households (REA, 2016).

2.2.2 Lunga Solar Mini Grid

The Lunga Solar Mini Grid project is located in Lunga District of Luapula Province. The initial project component involves the construction of a 300kWp solar mini-grid system to supply electricity to the district and surrounding areas with beneficiaries namely Lunga Basic School, Lunga Rural Health Centre, Lunga District offices, Chief Kasoma Lunga's Palace, Market and Shops, Churches, and 880 Households (REA, 2016).

2.3 Wind Resource Assessment Study

The Lunga Wind Assessment Feasibility study was being undertaken jointly with the Technology Development and Advisory Unit (TDAU) of the University of Zambia (UNZA). The assignment involves assessing the wind potential for power generation in Lunga district of Luapula province. Installation of the mast by TDAU started in mid-February 2017 and is scheduled to be completed by mid-March 2017. Consequently, wind speed measurements will be undertaken over a period of one year once the mast is installed (REA, 2016).

2.4 640kW Kasanjiku Mini Hydropower Station

The Government of Zambia through the Rural Electrification Authority (REA) is in the process of developing the 640kW Kasanjiku Mini Hydropower Station project on the Kasanjiku Falls locally known as the “Matukuta” Falls. The project site is located on the Kasanjiku River about 15 km north-west of Ntambu village and 18 km upstream of the confluence of the Kasanjiku River with the Kabompo River in Mwinilunga District in North-Western Province, approximately 130 km south-east of Mwinilunga town. The project is also approximately 235 km north-west of Solwezi town.The project involves electricity supply to Ntambu community and surrounding areas located in Mwinilunga District, approximately 850 kilometres from Lusaka (REA, 2015).

The Kasanjiku Mini Hydro Power Project site had been earmarked for implementation by the Rural Electrification Authority (REA) as highlighted in the REA Strategic Plan covering the period 2014 to 2018. The project was awarded to the Engineering, Procurement and Construction (EPC) Contractor and the Owner’s Engineer. The construction of the power station is expected to start this year and will be implemented over a period of 3 years (REA, 2015).

The project had been phased due to budgetary constraints. Under the 2016 plan, only the access road to the power station was to be constructed and the contractor had since completed constructing the two base layers of the 10km gravel access road making the site accessible. The contractor had also started excavation and blasting works for the weir, canal, forebay and power house in addition to the road works (REA, 2015). Below is a picture of the project site

Fig. 1.Kasanjiku project site (REA, 2015)

2.6. Zengamina hydropower station

Zengamina hydropower power station operated by Zengamina Power Company (ZPC) is located in Ikelenge District of Northwestern Province was officially commissioned on 14th July 2007. The plant has an installed capacity of .75MW and supplies power to the District namely Kalene Hospital , the local clinics, the Kalene Farm orphanage, schools and residential houses including Government offices.

During the construction phase of the project, the Authority provided funds and recently the Authority also provided funds towards the construction a power lines to enable ZPC reach new customers. In 2013 , the Authority handed over a feasibility study and engineering design report to ZPC to enable them undertake second phase of the power station at an installed capacity of .7MW. Refer to figure 2 for the aerial view of the plant.

Fig.2:.Zengamina hydro power station (REA, 2017)

2.6 60kW Mpanta solar plant

The project is designed to generate 60kW of electrical power from an array of Photovoltaic modules to supply the Mpanta community within the catchment area of radius of 1.5km. Samfya District is located 820km North of Lusaka while Mpanta is located 40km East of Samfya. The plant currently has a consumption of 50kW which is in excess of 80% of its maximum attainable power capacity. The project was implemented for a period of two (2) years at an estimated cost of K13 million. Currently the plant supplies power to 480 households, school, a clinic and 10 shops at a local market (REA, 2013). Refer to figure 3 showing the solar plant.

3.0 Challenges

The following are the challenges experienced during the implementation of the renewable energy technologies:

1. High upfront costs, especially conducting feasibility studies and project development. Over the years, the Authority has undertaken a number of feasibility studies especially in hydro power development at an estimated of K10million. The huge investment cost associated with undertaking feasibility studies is a barrier to attracting private sector investment.

2. Most equipment is imported, with no or limited local options for manufacturing.Most of the equipment that is used in renewable technology is imported from outside the country

which increases the cost of buying the equipment thereby increasing the cost of implementing renewable technologies.

Fig. 3: Mpanta solar plant (REA, 2014)

3. Research, development and production of renewable energy infrastructure occur outside the country. The knowledge associated with research and development of the technologies is not localised which makes it difficult to sustainably manage the operations and mainatence of the renewable energy schemes. Furthermore, this does not also allow for innovation to suit the local environment.

4. Inadequate policy framework and policy measures which do not provide effective uptake of private sector investments in sector. The policy framework and measures do not attract the private sector to invest in the sector due to inconsistent policies. This to a certain extent increases the cost of doing business in the sector. For example there is no clear policy for getting Power Purchase Agreement (PPA)

5. Relatively low tariff levels contributing to low uptake of private sector investments. The aim of the private investor to make money by investing in a business that will maximise profits. The low tariffs that are characterised in the energy sector are therefore a hindrance to the would be investors.

6. Lack of awareness on the use and development of renewable technologies. Currently there are very few institutions that are involved in conducting awareness on the use of the renewable energy technologies. The low awareness has led to the low uptake of the utilization of the technologies.

4.0 Strategies to address the challenges

The following are the strategies that the Authority has undertaken to address some of the challenges associated with the promotion of renewable energy technologies:

1. Initial Investment costs especially for undertaking feasibility studies and construction

   are high hence hindering the involvement of the private sector. Through REA, Government with support from Cooperating Partners is spear heading the undertaking of feasibility studies to bring down the cost of implement the renewable energy technologies. Once studies have been undertaken, the Authority will advertise to allow for the private sector participation. Through this process, the investment cost of undertaking feasibility studies is covered which helps the private sector to participate.

2. Considering that most equipment is imported, the Authority with support from other

   Government agencies are working on the revision of certain relevant legislation that will help bring down the cost of importing renewable energy equipment in the country. Once approved, Government will zero rate the importation of certain equipment. Currently most solar energy equipment is zero rated in terms of import tax.

3. Over the years, the Authority has released the need for research and development in the

   deployment of renewable energy technologies. Currently the Authority has partnered with various institutions involved in research and development to help localise the technologies and also build capacity. Some of the notable institutions include TDAU - UNZA, USAID, and JICA. Furthermore, some learning institutions have gone a step further by introducing courses in renewable energy that will go a long way in building capacity.

4. As earlier indicated as a pioneer in the development of the renewable energy

   technologies, the Authority is working with institutions like Energy Regulation Board to help streamline the policy framework. Therefore, Government through Energy Regulation Board has developed a Renewable Energy Feed-in-Tariff (REFiT) strategy and regulatory support mechanisms. It is envisaged that the strategy will expand the deployment of renewable energy through creation of a platform for effective processing of licenses and technology-based standardized Power Purchase Agreements (PPAs).

5. The relatively low tariff levels in the sector have significantly contributed to low

   investment. The Authority has learnt over the years, that in order to attract investment, there is need to provide a subsidy to help bring down the capital cost of investing. Over the year, the Authority has been proving capital subsidy to various developers which has helped bring down the cost of implement projects. The subsidy will therefore help reduce the investment cost and also allow the investor to break even in terms of the operation costs.

6. One of the challenges that the Authority has realised over the years of implementing

   The renewable energy technologies is the lack of awareness. The Authority has partnered with various media institutions in spear heading the awareness messages. A number of promotional messages have been running on the local TV including the annual competition for the journalists. The current load shedding has provided an opportunity for the development of off-grid renewable energy technologies for both Government and the private sector. The Authority has positioned itself to develop the technologies and also conducting sensitisation programs

5.0 Conclusion

The strategies that have been put in place in the promotion of renewable energy technology will go a long way in ushering the Authority to be a premium provider of the technologies in line with the strategy focus of the institution. The institution will therefore continue forging new boundaries with support from Government and Cooperating Partners in ensuring that the technologies are promoted in rural electrification program. In rural areas, installation of renewable technologies such as solar home systems has positively contributed towards the economic, social and environmental development of the communities. For example, it has been observed that performance of pupils in schools installed with solar home systems improve as pupils are able to study at night. On the other hand, income generating activities such as shops start to operate longer hours hence increasing the rural communities' income levels (Anders, etl., 2000). However, in order to effectively promote the utilization of the technologies, there is need to effectively address the challenges faced in the deployment of the technologies.

References:

Journals:

Hanyika, C, H. (2005) "Rural Electrification Policy and Institutions in a Reforming Power Sector." Retrieved from http://www.un.org/esa/sustdev/sdissues/energy/op/parliamentarian_forum/haanyika_policy_institutions_re.pdf

Reports:

Anders, E., Anders, A., Mattias, N., Oscar, S. K., & Clotilda, M. (2000) Rural people pay for solar: experiences from the Zambia PV-ESCO project. Report on solar projects

REA (2013) Mpanta Solar Mini Grid. Internal report

REA (2013) Rural Electrification Authority Strategic Plan. Internal report

REA (2014) Annual report. Internal report

REA (2015) Kasanjiku Mini hydro Power Station. Internal Report.

REA (2016) Lunga Wind Assessment. Internal Report.

Prospects in the industrialisation of mineral related SME's in South Africa

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Abstract

A flourishing small business sector usually increases competitiveness in an economy and is an efficient vehicle for the creation of jobs. Even though the South African government is committed to the promotion of the beneficiation of local minerals; the country still has the potential to further raise the level of beneficiated product and small and medium enterprises (SMEs) within the mining and minerals sector can be used as a driver for this.

Small scale mining and processing operations may have a semi-industrial or fully industrial character. Here the degree of mechanisation, internal organisation and compliance with international industrial standards is advanced. These operations are most frequently financed and managed by partners from industrialised countries. These types of operations often produce niche products, on small and high-grade mineral deposits, which demand complicated exploitation or concentration techniques. These are usually found in countries with a positive investment climate. This kind of operation generates few problems and they act as positive examples for the rest of the small scale mining community. Small scale mining and minerals processing already takes place on a sizeable scale in South Africa. Opportunities for SMEs within this sector are found mainly in gold, diamonds, coal and industrial minerals.

This paper looks at the prospects for the industrialisation of the existing SMEs within the minerals sector of South Africa so that they can realise the potential to take over and mine economically where large scale mining operations are unable to operate profitably and has resulted in the closure of many of them. In this way small scale mining and minerals processing can make a more meaningful contribution to the total production both in South Africa and globally.

Keywords: minerals, mining, industrialisation, South Africa, beneficiation.

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1. Introduction

Mining and minerals is the cornerstone of the South African economy. South Africa is the world's leading producer of precious metals (gold and the platinum group metals) and the important ferrous metals chromium and vanadium, and ranks among the top producers of aluminium, diamonds, iron ore, manganese, coal, titanium, and zirconium. Evaluation of South Africa's mineral wealth is estimated at US$2.5 trillion (Citi Bank, 2011), making the country the wealthiest mining jurisdiction. In mining, beneficiation is a variety of processes whereby extracted ore from mining is separated into mineral and gangue, the former suitable for further processing or direct use. The term is used interchangeably with "value-addition". Based on this definition, the term has come to be used within a context of economic development and corporate social responsibility to describe the proportion of the value derived from asset exploitation which stays 'in country' and benefits local communities (Citi Bank, 2011).

Small scale mining offers a means of survival and in some cases of enrichment for many in South Africa especially in rural areas where job opportunities are scarce. Some small scale mining operations may have a semi-industrial or fully industrial character. Here the degree of mechanisation, internal organisation and compliance with international industrial standards is advanced. These operations are most frequently financed and managed by partners from industrialised countries. These types of operation often produce niche products, on small and high-grade mineral deposits, which demand complicated exploitation or concentration techniques. These are usually found in countries with a positive investment climate. This kind of operation generates few problems. Moreover, they act as positive examples for the rest of the small scale mining community.

A flourishing small business sector usually increases competitiveness in an economy and is an efficient vehicle for the creation of jobs. The fall in the real price of minerals has led to the closure of numerous large scale operations. Well managed small scale mining and minerals processing operations have the potential to take over and mine economically where large scale mining operations are unable to operate profitably. In this way small scale mining and minerals processing operators that can lead to the establishment of a Small or Medium Enterprise (SME), can make a meaningful contribution to the total global production. Small scale mining and minerals processing already takes place on a sizeable scale in South Africa.

In South Africa the definition of small scale mining is based on the broader definition of small businesses as set out in the (Government Gazette, 2003). Table 1 summarises these classifications.

Table 1: Classification of mining and quarrying operations in South Africa based on the National Small Business Development Act (Government Gazette, 2003)

Size of class	Total full time equivalent of paid employees	Total turnover	Total gross asset value (fixed property excluded)
Micro	< 5	< R 200 000	< R 100 000
Very small	< 20	< R 4 million	< R 2 million
Small	< 50	< R 10 million	< R 6 million
Junior	< 200	< R 39 million	< R 23 million

Small Scale mining and processing activities are wide spread across the country and they occur in all nine provinces in South Africa. These activities are predominantly conducted in the rural parts of the country but mineral availability is a key determining factor (Mahlatsi, Phaahle, Ndaba, & Landu, 2011). Table 2 shows the different mineral categories exploited by this sector.

Table 2: Mineral commodities exploited by Small Scale Processing Operations in South Africa (Mahlatsi, Phaahle, Ndaba, & Landu, 2011)

Category	Commodity type	Location
Precious minerals	Gold	Gauteng, North West, Mpumalanga
	Diamonds	Northern Cape, North West, Free State
Semi-precious minerals	Tiger's eye, rose quartz, amethyst, feldspar, jasper	Northern Cape
Energy Related minerals	Coal	Mpumalanga, Kwa-Zulu Natal
Other Industrial minerals	Granite, sandstone, slate, aggregate, clay, gypsum etc.	All nine provinces

NB.: Uranium bearing minerals are not exploited by the small scale mining and processing sector

Industrialisation is understood as part of a process where people adopt easier and cheaper ways to make things, using better technology, it becomes possible to produce more goods in a shorter amount of time. A single person can produce more things.

This paper highlights the prospects of selected operations for the industrialisation of the existing SMEs within the minerals sector of South Africa so that they can realise the potential to take over and mine economically where large scale mining operations are unable to operate profitably and has resulted in the closure of many of them. In this way small scale mining and minerals processing can make a more meaningful contribution to the total production both in South Africa and globally.

2. The prospects for the industrialisation of the existing SMEs within the minerals sector of South Africa

SMEs in South Africa currently face a number of challenges which hinder their ability to industrialise. These challenges include shortage of electricity (load shedding), high interest rates, red tape in administration, water shortages (drought), lack of available funding and low levels of education (skills deficit) (Thulo, 2015).

Strategies, plans and frameworks can however be put together by both government and the business sector to help minimise these challenges that will assist the SMEs to grow and hence industrialise (Ramukumba, 2014). The Department of Trade and Industry who is responsible for the development of the countries National Industrial Policy Framework in their action plan of 2016 stated that the Black Industrialists Programme provides support to majority black-owned manufacturing companies. This support includes access to finance, access to markets, skills development and standards/quality/productivity improvement. The scheme seeks to assist in the process of industrialisation and the development of these SMEs into serious players in both the domestic and global market over the next 10 years (Department of Trade and Industry, 2016).

2.1 Selected prospects for industrialisation of SMEs in the minerals sector

2.1.1 Coal mining and processing

South Africa's indigenous energy resource base is dominated by coal. Internationally, coal is the most widely used primary fuel, accounting for about 36% of the total fuel consumption of the world's electricity production. About 77% of South Africa's primary energy needs are provided by coal (Department of Energy, Republic of SA, 2015). This is unlikely to change significantly in the next two decades owing to the relative lack of suitable alternatives to coal as an energy source. Many of the deposits can be exploited at extremely favourable costs and as a result, a large coal mining industry has developed. In addition to the extensive use of coal in the domestic economy, about 28% of South Africa's production is exported, mainly through the Richards Bay Coal Terminal, making South Africa the fourth-largest coal exporting country in the world. South Africa's coal is obtained from collieries that range from among the largest in the world to small scale producers. About 51% of South African coal mining is done underground and about 49% is produced by open-cast methods (Mahumapelo, 2015).

Mining activities on opencast and underground mines also offer a variety of contracting services some of which are already being undertaken. Most of these activities require a fairly high degree of skills, experience, capital and an experienced and dedicated workforce. The mining industry is regulated by a range of legislation. It is essential for all entrants to the mining industry to be familiar with and comply with this legislation to secure prospecting and mining rights, to retain prospecting and mining rights, and to avoid the potential consequences of non-compliance (Coaltech; Mahumapelo, 2015).

The research done by (Mahumapelo, 2015) and interviews conducted with small scale coal mining and processing companies showed that it is a major challenge to gain entry into the sector because of the lack of skilled staff and the lack of finance to apply for the prospecting/mining permits and for procurement of the necessary equipment. To become a supplier of coal to Eskom is also a huge challenge for up and coming suppliers due to the stringent requirements. A comparison was also done on coal samples which are used as the feed to these small scale coal mining and processing operations versus Eskom's coal specification and the feed did not meet the requirements. The cost of upgrading this feed using existing technology and processes would not be economically viable for small scale operators.

The opportunity however that does exist for small scale operators that have access to these types of coal feed material to industrialise is with respect to briquetting of the coal and the sale of these briquettes for the purposes of steam generation in boilers, heating, drying processes and for the replacement of conventional liquid fuel and wood. Berkowitz (1979) indicated that suitably prepared pulverised coal can be compacted into strong, homogeneous briquettes and with various refinements this technique has been used since the mid-1800s to upgrade a variety of low-rank coals and coal fines that would otherwise have little commercial value. The briquetting process is however linked to the nature of the coal feed and a clear distinction is made between briquetting with and without binders. The prospect that arises for small scale coal operators to industrialise is to invest in existing technology and follow the process of briquetting with the use of binder as illustrated in Figure 1.

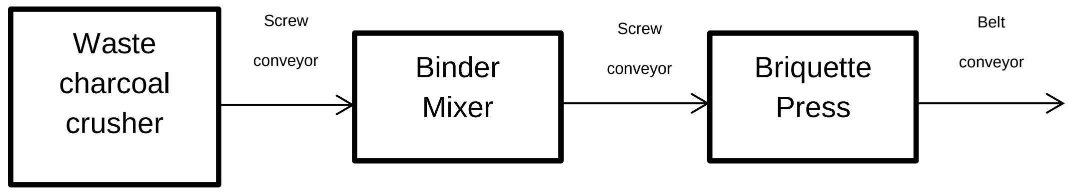

Figure 1: Typical Coal Briquetting (with Binder) Process (Agico Group, 2012)

2.1.2 Dimension stone quarrying and processing

Industrial minerals such as granite, sandstone and slate can be classified under dimension stone. According to Ashmole and Motloung (2008a) the dimension stone industry is relatively large in value when compared to non-fuel minerals and the consumption of natural stone is growing a rate significantly faster that most mineral products. Ashmole and Motloung (2008b) also state that the dimension stone industry has grown at an average rate of over 7% per annum since 1986.

Table 3 shows the world production of dimension stone for the period 2003-2010 and it is then subdivided into gross and raw production. It can be seen that the processed production, which shows the final product of the quarrying industry, is a surprisingly low percentage of the total volume extracted. It is around 30% of the gross quarrying. The total production of stone waste, accounting for both the quarrying waste and the processing waste, is still the largest output of this sector, reaching about 70% of total volume extracted (Furcas & Balletto, 2013).

Table 3: World production of dimension stones, thousand cubic meters from 2003-2010 (Furcas & Balletto, 2013)

Year	Gross quarrying	Quarrying waste	Raw production	Processing waste	Processed production	Processed production as a % of gross quarrying	Total production of stone waste	Total waste production as a % of gross quarrying
2003	57,000	29,222	27,778	11,400	16,400	29	40,622	71
2004	61,650	31,557	30,093	12,300	17,800	29	43,857	71
2005	64,750	33,176	31,574	12,950	18,650	29	46,126	71
2006	70,450	36,098	34,352	14,100	20,250	29	50,198	71
2007	78,500	40,167	38,333	15,750	22,550	29	55,917	71
2008	79,600	40,711	38,889	15,950	22,950	29	56,661	71
2009	79,150	40,446	38,704	15,900	22,800	29	56,346	71
2010	84,450	43,161	41,289	12,350	28,950	34	55,511	66

The processing operations of dimension stone include much more variation than extraction. The procedure is depicted in Figure 2.

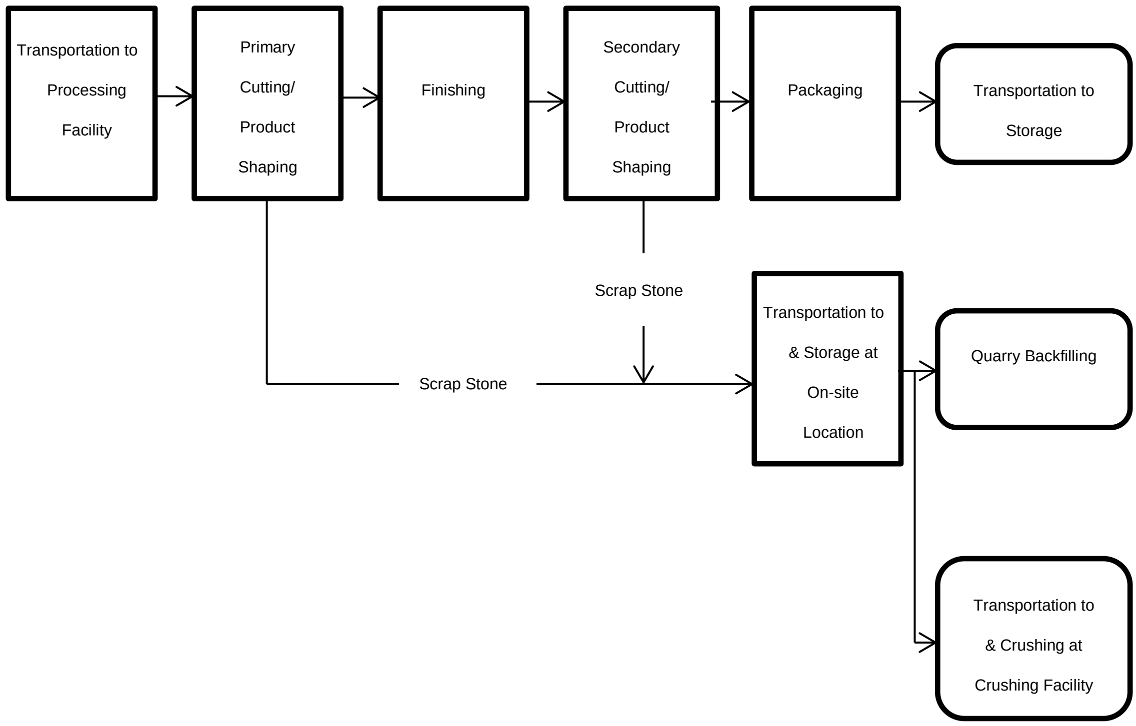

Figure 2: Process flow diagram for dimension stone operations (University of Tennessee, Center for Clean Products, 2008)

An extensive literature search was done on the dimension stone industry in South Africa but the last reliable data published for the sector was in 2005 by the then Department of Minerals and Energy of the Republic of South Africa.

Table 4: South Africa's Granite Production, Local Consumption and Exports (Department of Minerals and Energy, 2005)

Year	Production (mass, kt)	Local consumption (mass, kt)	Exports (mass, kt)
1995	718,1	91,5	626,6
1996	708,7	84,8	623,9
1997	764,0	88,0	676,0
1998	743,9	74,3	669,6
1999	636,5	66,5	570,0
2000	951,2	99,5	844,8
2001	846,7	85,6	761,1
2002	705,8	75,2	630,6
2003	463,2	78,5	384,7
2004	527,1	145,4	381,7

Table 4 indicates the total production from 1995 to 2004 with more than 87% of the mass of dimension stone mined being exported and as little as 13% kept for local beneficiation. During this time South Africa's main countries of export were Switzerland (42%), Italy (29%), China (15%) and Belgium (13%). The outlook at this point in time had indicated that even though the dimension stone industry was growing internationally (also confirmed in Table 3) the exchange rates made South African pricing uncompetitive. Exclusive dimension stone materials however were still able find a market but these were at reduced volumes (Department of Minerals and Energy, 2005).

In the past quarrying of dimension stone was carried out by traditional methods developed over many centuries. This is however becoming exceedingly challenging from a technical perspective requiring inputs from geology, mining engineering, blasting technology, non-explosive rock breaking, rock mechanics, mine design and reserve evaluation. One therefore has to be very well versed in a variety of cutting and splitting techniques as well as an understanding of both geology and the physical properties of the material (Ashmole & Motloung, 2008a).

Although the environmental impacts of dimension stone are generally not significant and can be managed effectively, most stone operators are relatively small scale and they tend to be less well equipped to respond to the increasing environmental demands because of the lack of resources and training (Ashmole & Motloung, 2008b). Since the dimension stone industry is largely dependent on production volumes (and the reduction of waste) this is a huge prospect for the industrialisation for small scale operators. In order to industrialise and improve productivity to meet the demands of the market the following is suggested by (Domaracka & Muchova, 2013):

- Inclusion of a Quality Management Process – Performing inspections that begin at the moment of excavation and also regular inspections throughout the production process.
- Innovation – Use of obsolete processing technology and physically demanding machinery that cause damage to the dimension stone should be replaced by modern technology.
- Production Management – reduction in costs on poor quality, optimising costs, optimal use of resources (human, material and technology).

Jalil, et al. (2014) were tasked with solving the problem of a Pakistan dimension stone operation that in spite of having sufficient quantity of machinery and skilled labour were unable to produce sufficient volume of product to meet the demands of the market. Their proposed solution for improving productivity was:

- A change in the processing plan with additional focus on the proper utilisation of workers and machinery.
- Optimal reduction in the quantity of machinery utilised and the distribution of workers into three shifts of seven hours. This optimised not only machine utilisation but also the number of hours worked by staff.
- Production improvement plan – workers were also motivated through the accomplishment of their fiscal and social needs.

A good example of industrialisation was also noted in the report by Department of Minerals and Energy (2005) of how a local granite processing plant moved from Brits to Marikana in the North West Province of South Africa to consolidate operations. There was a joint venture that was entered into between Marlin Corporation and a Chinese Company, Xiamen Wanli Stone Co. Ltd who had a number of existing quarries and eight processing plants in South Africa. Small blocks of granite (regarded as waste) which are normally difficult to sell were used to manufacture tombstones, garden furniture, basins and kitchen sinks. The operation employed 50 people which according to Table 1 is considered as small scale. Modern Chinese equipment was used at the plant and quality control inspections were carried out right through the process (Department of Minerals and Energy, 2005).

3. Conclusion

Small scale mining and processing activities are wide spread across the country and they occur in all nine provinces in South Africa. The challenges faced by the sector which is seen as an obstacle to industrialisation include shortage of electricity, high interest rates, red tape in administration, water shortages, lack of available funding and low levels of education.

The Department of Trade and Industry through the National Industrial Policy Framework and their action plan of 2016 are providing support to manufacturing companies in the form of access to finance, access to markets, skills development and standards/quality/productivity improvement. The scheme has been specifically set-up to assist in terms of industrialisation and the development of these emerging SMEs into serious players in both the domestic and global market over the next 10 years. Taking all of this into consideration, the two major prospects identified for SMEs in the minerals sector to industrialise are in coal processing and the quarrying of dimension stone.

The opportunity that does exist for small scale coal operators that have access to low calorific value coal feed material to industrialise is with respect to briquetting of the coal and the sale of these briquettes for the purposes of steam generation in boilers, heating, drying processes and for the replacement of conventional liquid fuel and wood. Existing technology and processes already exist overseas that can be utilised within South Africa for the purposes of briquetting coal with the use of a binder.

Since the dimension stone industry is largely dependent on production volumes (and the reduction of waste) this is a huge prospect for the industrialisation for small scale operators. This can be done by the improvement of the management of the existing operations, increasing skills levels of staff and also removing the use of obsolete processing technology and also physically demanding machinery that cause damage to the dimension stone and replacing it with modern technology.

SMEs within the minerals sector of South Africa can therefore have the potential to take over and mine/process economically where large scale mining operations are unable to operate profitably. In this way SME’s in the small scale mining and minerals processing sector can make a more meaningful contribution to the total production both in South Africa and globally.

References

Agico Group. (2012). *Charcoal Briquetting Plant*. Retrieved from http://www.briquette-machine.com/Wood-Briquetting-Presses.html: http://www.briquette-machine.com

Ashmole, I., & Motloung, M. (2008a). Dimension Stone: The Latest Tends in Exploration and Production Technology. *Surface Mining 2008* (p. 35 to 70). South Africa: The South African Institute of Mining and Metallurgy.

Ashmole, I., & Motloung, M. (2008b). Reclamation and Environmental Management in Dimension Stone Mining. *Surface Mining 2008* (p. 155 to 179). South Africa: South African Institute of Mining and Metallurgy.

Berkowitz, N. (1979). *An Introduction to Coal Processing.* New York: Academic Press.

Citi Bank. (2011). *Citi 2010 Annual Report.* USA: Citigroup Incorporated.

Coaltech. (2015). *Coaltech.* Retrieved 05 7, 2015, from Guidelines on a small scale coal mining in South Africa: http://www.coaltech.co.za/chamber%20databases%5Ccoaltech%5CCom_DocMan.nsf/0/FB9CD43CC875CE0E422574030023772F/$File/Task%203.3%20-%20Small%20Scale%20Mining%20Guidelines.pdf.

Department of Energy, Republic of SA. (2015). *Coal Resources*. Retrieved from Department of Energy, Republic of SA: http://www.energy.gov.za/files/coal_frame.html

Department of Minerals and Energy. (2005). *South Africa's Mineral Industry 2004/2005.* Pretoria: Department of Minerals and Energy.

Department of Trade and Industry. (2016). *Industrial Policy Action Plan 2016/17 - 2018/19.* Pretoria: Department of Trade and Industry.

Domaracka, L., & Muchova, M. (2013). Dimension Stone Production Quality and Its Financing. *The 1st Research Conference in Technical Disciplines*, 35-40.

Furcas, C., & Balletto, G. (2013). Converting waste from the dimension stone industry into sustainable environmental resources. Current trends, market opportunities and future outlooks. *Proceedings of The 28th International Conference on Solid Waste Technology and Management -ICSW*, (pp. 104-115). Philadelphia.

Government Gazette. (2003, November 26). No. 26 of 2003: National Small Business Amendment Act, 2003. Republic of South Africa.

Mahlatsi, S., Phaahle, T., Ndaba, M., & Landu, L. (2011). *Methods for developing the ASSM sector within South Africa.* South Africa: Mintek.

Mahumapelo, P. (2015). *Development of a basic guide for small micro medium enterprises aspiring to enter the local coal industry.* South Africa: Mintek.

Ramukumba, T. (2014). Overcoming SMEs Challenges Through Critical Success Factors: A case of SMEs in the Western Cape Province, South Africa. *Economic and Business Review, Vol 16, No 1*, 19-38.

Thulo, L. (2015). *The biggest challenges faced by SMEs in 2015*. South Africa: SME South Africa.

University of Tennessee, Center for Clean Products. (2008). *Granite Dimensional Stone Quarrying and Processing: A Life Cycle Inventory*. USA: Natural Stone Council.

Quality Management Practices, Focusing on the Manufacturing Industry Based in Lusaka, Zambia

Mathew Saili[1]

Abstract

The major purpose of the study was to assess the application of quality management systems in enterprises and if as a consequence it does affect productivity. The daunting question is why are there only 20 quality management certified companies as opposed to over 1006 registered manufacturing companies in Lusaka (MCL)? The research targeted companies in Lusaka province focusing on the manufacturing companies. The study adopted the survey research design/strategy. This is because of the flexibility offered by the survey research strategy. The survey method is well accepted as it is a fact-finding study that involves adequate and accurate interpretation of findings.

A Random Sampling Method was used as it involve probability sampling procedure in which simple random subsamples that are more or less equal on some characteristic are drawn from the population

About 20(twenty) enterprises or companies were targeted for the administration of the questionnaires in Lusaka province. Structured questionnaires were administered personally to the sampled firms. Follow up face-to-face interviews were held with the respondents to get clarifications and additional qualitative data.

The research revealed that the two most overriding barriers to implementation Quality Management Systems are lack of resources and lack of top management support. These results are valuable to the existing topics in the body of knowledge that relates to Quality Systems. This confirms why only less than 2% of manufacturing companies are registered for ISO certification as per ZABS register. There is an urgent need in future research therefore to analyse the barriers to quality management implementation in manufacturing companies in Lusaka and Zambia at large so that QMS may be successfully implemented.

To attain a competitive edge manufacturing, customer satisfaction, cost effective manufacturing costs, and improved productivity companies must unreservedly embrace quality management practises.

Keywords: Quality Management System, Manufacturing Companies, Productivity, Barriers, Customer Satisfaction

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Abbreviations and Acronyms

DV	- Dependent Variable
GLOCAL	- Global and Local
GMP	- Good manufacturing practice
ISO	- International Organization for Standardisation
IV	- Independent Variable
IVV	- Intervening Variable
QMS	- Quality Management System
SME	- Small and Medium scale Enterprises

1. Introduction

1.1 Status of Quality Management System Certification in Lusaka

The major purpose of the study was to assess the application of quality management systems in enterprises and if as a consequence it does affect productivity. The daunting question is why are there only 20 quality management system (QMS) certified companies as opposed to over 1006 registered manufacturing companies in Lusaka (MCL)?(see APPENDIX-1) . The research targeted companies in Lusaka province focusing on the manufacturing companies. The study adopted the survey research design/strategy. This is because of the flexibility offered by the survey research strategy. According to Cooper and Schindler (2003), the survey method is well accepted as it is a fact-finding study that involves adequate and accurate interpretation of findings.

1.2 Concept of Quality and Quality Management

Quality Management refers to the planned and systematic actions deemed as necessary to provide adequate confidence that a product or service satisfy given requirements for quality (Boraham & Ziarati, 2002).

In various industry, government and companies they are now realizing that there is need for them to implement quality assurance as a means to gain competitive advantage over their competitors. The opening up of trade barriers by regional and international integration has prompted governments and companies to improve their products in terms of quality of their products and services, in order to remain competitive in this GLOCAL environment (Biljana Angelova, Jusuf Zekiri, 2011)

Customer requirements and preferences have also been dynamic and in most cases consumers are becoming more and more demanding on value for tax payers money and quality on goods, products and services they procure.

Worldwide more than 1 609 294 companies are registered with quality standard organizations (ISO Executive Summary, 2015). It is therefore important that more and more government departments and companies must start to implement Quality Management and management systems to be competitive and eventuality gain improved customer satisfaction.

No matter how we perceive customer satisfaction, however, there can be no doubt that it is the key to profitability over the long term (Oliver, 1997: 10)

1.3 Problem Statement

Statistics from ZABS indicate that there are only 20 ISO certified manufacturing companies in Lusaka as opposed to over 1006 registered manufacturing companies. Appropriate application of Quality Management practices plays an important role for any company whether small or big to remain competitive in the industry. In spite of the important role played by manufacturing companies in Zambia, in particular Lusaka, the number of quality certified companies is very low as evidenced from numbers of companies certified.

The gap being addressed is that there is no known information or readily available data on barriers for manufacturing companies failure to certify there quality management systems to ISO or ZABS, and why there are so few QMS certified manufacturing companies. This information is necessary for companies to understand the importance and prepare themselves for QMS certification.

From the researcher's interaction with some of the Small and Medium Enterprise business owners/managers, there were some indication that many manufacturing companies are not Quality certified and do not have formal Quality Management practices or do not apply appropriate Quality Management practices. There is also an aspect that the Quality Management practices are often not documented. Further, it is also believed that the majority of these manufacturing companies are started and managed by people with low entrepreneurial skills, inadequate education or technical and management background.

It is generally noted that manufacturing companies in Lusaka lack qualified personnel, inability to have the systems audited by independent personnel/firm, insufficient capital, lack of proper standard operating practices (SOP) or not having Quality Management records at all, inability to separate business and family/personal finances, lack of business strategy, and some companies do not understand the use of and importance of Quality Management.

The following contact information may be provided as a footnote for all authors of the paper: current employment affiliation; postal, telephone number and electronic mailing address.

1.4 Research Objectives

The main research objective for this study is to assess the manufacturing company's quality management practices and certification by manufacturing companies in Lusaka. In broadening the main objective, the following are the sub objectives:

1. To assess presence of QMS certification of manufacturing companies in Lusaka.

2. Are there the barriers to QMS certification?

1.5 Research Questions

1. Is there presence of QMS certification of manufacturing companies in Lusaka?
2. Are there the overriding barriers to QMS certification?

1.6 Significance of the Study

The study is useful to the Ministry of commerce Trade and Industry, ministry of labour, manufacturing companies, managers and investors.

It would enable the manufacturing companies and other stakeholders to understand the benefits accruing from appropriate application of Quality Management practices in terms of increased productivity and revenue as a result of improved production and quality of goods and services. It would also assist local manufacturing companies to be competitive on the Glocal market.

This study will enable manufacturing companies (SMS's and MNC's) to know the overriding barriers to Quality Management System certification. It would also enable manufacturing companies identify their strengths and weaknesses in the Glocal market environment.

The study would enable company owners and entrepreneurs to appropriate Quality Management practices required of manufacturing organizations. It would also give some indication to managers and entrepreneurs on the areas where they are strong and where they are weak so as to make improvements.

The findings of this study would enable manufacturing organizations know and understand the importance of appropriate Quality Management practices for accountability in the manufacturing industry as well as prudent management of resources.

1.7 Delimitation (Scope) of the Study

The study were limited to the manufacturing companies in Lusaka province which has the highest concentration of manufacturing companies in Zambia. Due to limitation of time not many companies were visited.

1.8 Researcher's Conceptual Framework

The research on using Quality Management to enhance productivity is explained in the theoretical framework shown in figure 1. In this study, it is assumed that implementation of quality assurance can impact on improving productivity, hence reducing on reworks, material wastage, and optimising production. As shown in figure 2 the independent variable is determinants of Quality Management, while the dependent variable is improved Productivity. While customer preference is believed to have a significant effect on the original IV-DV relationship. Additionally it can also be noted that standards and good operating practices (IVV-Intervening Variable) can have significant effect on the DV (dependent variable), see figure 2.

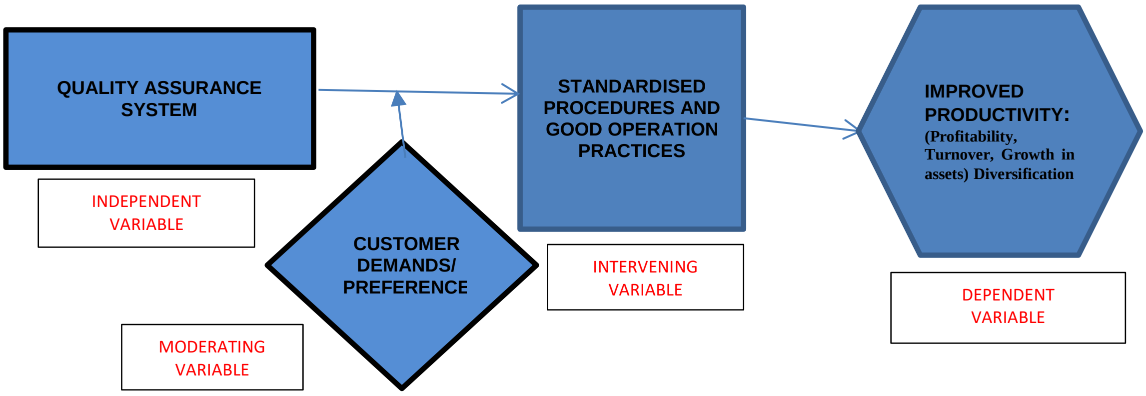

Figure 1: Theoretical framework *(Source: Authors own conceptual model, 2015)*

The moderating variable included the customer's perception, needs and likes. While the intervening variable may include standardized procedures and good operation practices. The dependent variable being improved productivity which determine the quality of service and product performance. Hence the need to strengthen the independent variable that is effective Quality Management as it responds to the growing and dynamic needs of the Glocal community.

1.9 Five pillars of support for Improve Productivity

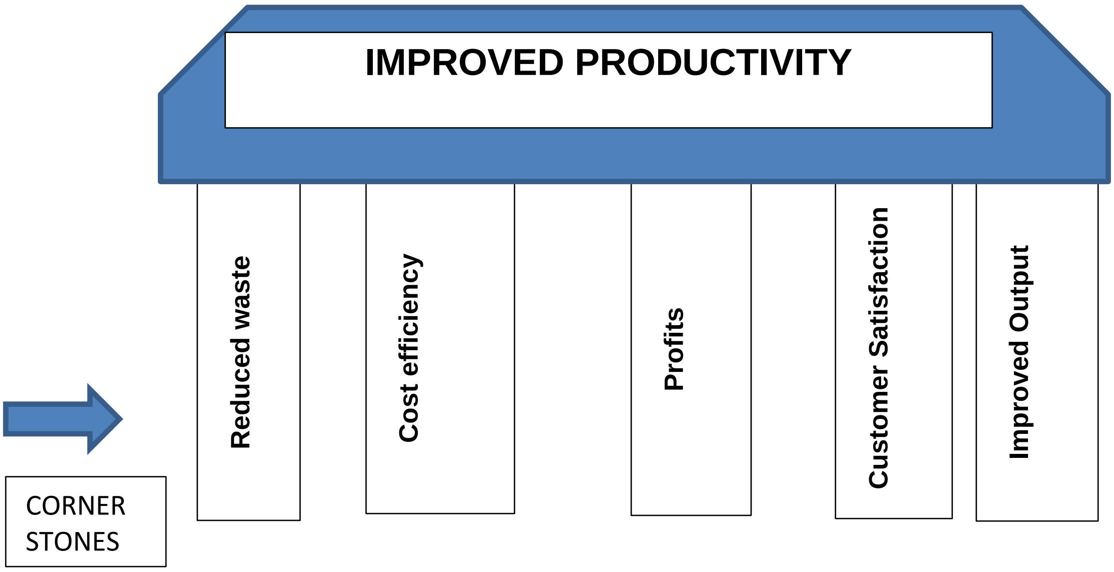

Figure 2: Five pillars of support for Improve Productivity

2. Literature Review

2.1 Introduction

In today's competitive environment the mere success and survival of any enterprise whether it is a small scale unit or large scale enterprise depends upon the achievement and maintenance of a satisfactory level of quality, productivity, and at the same time at reasonable price with the optimum use of the all the factors of production , not just one of them. An enterprise is productively efficient when it is producing its product or service at the lowest unit cost that it can.

This paper describes how quality directly or indirectly affects the productivity and then cost of the product. In developing countries like in India there are so many difficulties to gain the high quality and high productivity due of many reasons.

Contributors in the Improvement of Concept of QUALITY

Images by: http://www.rajeshtimane.com

2.2 Theories and Definitions on Productivity

According to Bernolak (1997) productivity means "how much and how good we produce from the resources used," whereas The European Association of National Productivity Centers (EANPC, 2005) defines productivity as "how efficiently and effectively products and services are being produced." Efficiency in this context refers to "doing things right" or utilizing resources to accomplish desired results (Grünberg, 2004). Effectiveness, on the other hand, is often described as "doing the right thing"; it refers to the extent to which customer requirements are met (Neely et al., 1995). Thus, effectiveness highlights the importance of reaching a desired objective, whereas efficiency focuses on the process or means involved.

In general, productivity is often defined as a relationship between output produced by a system and quantities of input factors utilized by the system to produce that output. Here, the output can be any outcome of the process, whether a product or service, while input factors consist of any human and physical resources used in a process. It follows that, in order to increase productivity, the system must either produce more or better goods from the same resources, or the same goods from fewer resources. Stated differently, productivity improvement refers to an increase in the ratio of produced goods or services in relation to resources used.

Every nation wants to increase productivity and quality of product at lower price. For this they should reduce wastage of resources and must find other substitutes that were environment-friendly. Proper education and training of labor should be given for better quality. Government should arrange to import advanced technology and machinery on easy terms for industries. Lastly, industries should understand their responsibilities if they want to improve profits and productivity and to stay competitive in the global market (Suman Kumari, Anuradha, &S.K Sharma, 2013)

2.3 Principles of Quality Management

The 8 principles of quality management can be outlined as follows:

1. **Customer-Focused Organisation** – in order to continue customer relationships, organisations should fully understand current and future customer needs, meet customer requirements and strive to exceed customer expectations at all times.

2. **Leadership** – leadership plays a crucial role in organisation's, ensuring unity of purpose and direction of the company that allows leaders to create and foster an effective internal environment. This in terms allows employees to become fully involved in achieving the company's objectives.

3. **Involvement of People** – as the most valuable resource within any organisation, involvement of employees at all levels is the essence of the company. Full employee involvement ensures that each person's abilities can be used for the entire organisation's benefit.

4. **Process Approach** – another critical component of any quality management strategy, the anticipated result is achieved more competently when related resources and tasks are managed as a process within the company.

5. **Continual Improvement** – striving for continual improvement should be a primary objective of any organisation, to consistently perform tasks and duties at the highest level of efficiency at all times.

6. **Factual Approach to Decision** Making – to ensure that all decisions are made fairly and effectively, decisions need to be based on the analysis of data and information rather than an emotional level or unproven hypothesis.

7. **Mutually Beneficial Supplier Relationships** – a company and its suppliers are mutually dependent, which means that a favorable relationship augments the capacity of both supplier and company in order to create value and foster quality management within the workplace improvement strategy.

2.4 The Role of Leadership in Quality Management

Leaders provide a unity of purpose, while also establishing the direction of the organisation. As such, the responsibility of leaders consists of creating and maintaining the internal environment. In this environment, employees are able to become completely involved in achieving the organisation's goals and aims. In this way, good leadership is essential in order to improve quality across the organisation, as the leading force that sets objectives and assists employees to implement these objectives.

The role of leadership in Quality Management is comprised of the following factors:

Be proactive and lead through example rather than dictating – true leaders lead in a way that is active in implementing and following through on actions, rather than simply dictating actions without leading by example.

Develop challenging objectives and targets – through goal setting, leaders are able to foster constant growth and development across the organisation, by continually improving the standards of goals within each department.

Implement clear initiatives and strategies to bring these goals into fruition – once goals have been set, leaders implement these goals accordingly to involve all levels in quality management campaigns across the organisation and strive for certification (Sharma, 2005).

2.5 Servqual

SERVQUAL or RATER is a service quality framework. SERVQUAL was developed in the mid-1980s by Zeithaml, Parasuraman & Berry. SERVQUAL means to measure the scale of Quality in the service sectors.

By the early 1990s, the authors had refined the model to the useful acronym RATER:

- Reliability
- Assurance
- Tangibles
- Empathy, and
- Responsiveness

2.6 Kaizen Quality Improvement Philosophy's and Programs

KAIZEN is a Japanese word for "improvement", or "change for the better" refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, and business management. It has been applied in healthcare, psychotherapy, life-coaching, government, banking, and other industries. When used in the business sense and applied to the workplace, kaizen refers to activities that continually improve all functions, and involves all employees from the CEO to the assembly line workers. It also applies to processes, such as purchasing and logistics that cross organizational boundaries into the supply chain. By improving standardized activities and processes, kaizen aims to eliminate waste (see lean manufacturing). Kaizen was first implemented in several Japanese businesses after the Second World War, influenced in part by American business and quality management teachers who visited the country. It has since spread throughout the world and is now being implemented in many other venues besides just business and productivity.

The five main elements of kaizen

- Management teamwork
- Increased labour responsibilities
- Increased management morale
- Quality circles
- Management suggestions for labour improvement

2.7 Six Sigma

Six Sigma is a set of tools and strategies for process improvement originally developed by Motorola in 1985.Six Sigma became well known after Jack Welch made it a central focus of his business strategy at General Electric in 1995, and today it is used in different sectors of industry.

- Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability in manufacturing and business processes. It uses a set of quality management methods, including statistical methods, and creates a special infrastructure of people within the organization ("Champions", "Black Belts", "Green Belts", "Orange Belts", etc.) who are experts in these very complex methods. Each Six Sigma project carried out within an organization follows a defined sequence of steps and has quantified financial targets (cost reduction and/or profit increase)

2.8 Lean Manufacturing

Lean manufacturing, lean enterprise, or lean production, often simply, "Lean," is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for.

2.9 DMAIC

DMAIC is an abbreviation of the five improvement steps: Define, Measure, Analyse, Improve and Control. All of the DMAIC process steps are required and always proceed in this order:

- Define the problem, the voice of the customer, and the project goals, specifically.
- Measure key aspects of the current process and collect relevant data.
- Analyze the data
- Improve or optimize the current process
- Control the future state process to ensure that any deviations from target are corrected.

2.4 Quality Management System Model

Figure.3 gives the Quality Management Process Model which shows how customer satisfaction can be enhanced by continual improvement of Quality Management processes.

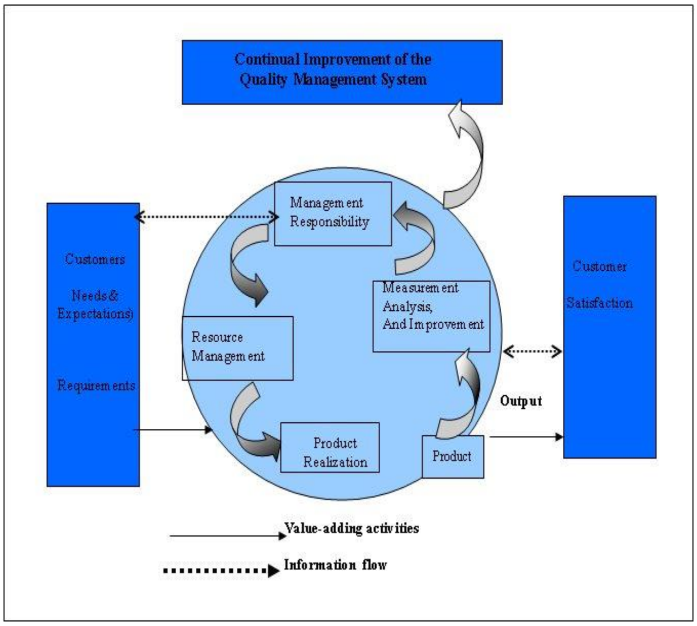

Figure.3. Quality Management processes. (Source: Generic quality management model)

3. Research Methodology

The research used interviews based on a structured questionnaire (Donald R. Copper *et al*, 2011), to answer the questions surrounding QMS certification and related issues.

Using the questionnaires, we be able to determine qualitatively from the responses weather organisations were QMS certified.

3.1 Target Population

The sample for analysis were manufacturing companies in Lusaka province (MCL).

3.2 Sampling Size and Sampling Procedures

Due to limit of time 20 companies were interviewed (Mark Sunders, et al. p.283, 2012) in Lusaka.

3.3 Findings

The information gathered were tabulated in Table-1 indicating Lack of resources and lack of certification.

Table 1: Results from manufacturing companies in Lusaka

COMPANY	Lack of Resources(Human and Financial)	Lack of Quality Management System Certification
1	X	X
2	X	X
3		
4	X	X
5	X	X
6		X
7	X	X
8		X
9		X
10		X
11		
12	X	X
13	X	
14		X
15		X
16		X
17	X	X
18		
19		X
20	X	X
TOTALS	**10**	**16**
PERCENT OF BARRIER	**50%**	**80%**

3.4 Advantage of QMS Implementation

There is no doubt that proper quality assurance management improves business, often having a positive effect on customer satisfaction (Stefan, 2003), investment, market share, sales growth, sales margins, competitive advantage, and avoidance of litigation. Quality assurance can make any company competitive." Implementing quality assurance often gives the following advantages:

1. Increases customer satisfaction and retention
2. Reduces waste and increases productivity.
3. Reduces material and resources wastage
4. Creates a more efficient, effective operation
5. Enhances marketing
6. Improves employee motivation, awareness, and morale
7. Promotes international trade
8. Increases profit
9. Common tool for standardization.

3.5 Discussion on Barriers to Quality Management System Certification

The research has shown that the dominant barriers can be reclassified into two namely lack of resources and lack of top management support for QMS certification. Lack of Resources embraces both financial and human resources. It is important for corporate top management create an enabling environment to stimulate and endorse QMS by getting everybody involved at all levels (Hernández, *et al*, 2013; Saraph, *et al*, 1989). Leadership is synonymous to successful implementation of the QMS. Top management of organizations must be able to motivate, maintain enthusiasm throughout the organization and to identify effective ways to overcome barriers they face in order to successfully implement the quality management system. The data in table -1 is valuable to the existing body of knowledge that related to Quality Systems. There is practical evidence from Zambian contemporary countries such as Singapore adoption of QMS has resulted in improved GDP and Human development Index (HDI), Abdullah, *et al*, 2009.

3.6 Conclusion

The comparison of imperial data (in Table-1) confirms that there are very few QMS certified manufacturing companies in Lusaka. This indicated a need to improve top management and cooperate participation to improve QMS in Lusaka, Zambia. The results will help managers that are interested in implementing Quality Systems to mitigate barriers in the process towards certification of their Quality System. It is further recommended that a larger sample study be undertaken to incorporate a larger population of manufacturing industries in Zambia as a whole.

4. Reference

Abdullah, M., Uli, J., & Tari, J. (2009). The relationship of performance with soft factors and quality improvement. Total Quality Management, 20, 735–748.

Bernolak, 1997, Effective measurement and successful elements of company productivity: The basis of competitiveness and world prosperity, International Journal of Production Economics, 52(1-2), 203-13.

Biljana Angelova, Jusuf Zekiri, October 2011, International Journal of Academic Research in Business and Social Sciences, Vol. 1, No. 3.

Donald R. Copper and Pamela S. Schindler (2011), Business Research Methods, 11th edition, McGraw-Hill/Irwin Series, Singapore.

Grünberg T. 2004, Performance Improvement-Towards a method for finding and prioritising potential performance improvement areas in manufacturing operations, International Journal of Productivity and Performance Management, Vol. 53, No. 1.

Hernández, V., González, B. P., & Aquiahuatl, E. (2013). Human approach in the quality management system of manufacturing SMEs in Mexico Theoretical review and proposal of a conceptual model. Contaduría Y Administración, 58(2), 113–133. http://doi.org/10.1016/S0186-1042 (13)71212-9.

Mark Sunders, Philip Lewis, Adrian Thornhill (2012) Research Methods for Business Students, 6th Edition, Pearson Education Limited, England.

Neely, A. D. Mike Gregory and Ken Platts (1995) Performance measurement system design A literature review and research agenda, International Journal of Operations & Production Management, Vol. 25 No. 12, 2005 pp. 1228.

Oliver, Richard L. (1997), Satisfaction: A Behavioral Perspective on the Consumer, New York: Irwin/McGraw-Hill.

Saraph, J. V, Benson, P. G., & Schroeder, R. G. (1989). An Instrument for Measuring the Critical Factors of Quality Management. Decision Sciences, 20(4), 810–829. http://doi.org/10.1111/j.1540-5915.1989.tb01421.x

Sharma, D.S. (2005), "The association between ISO 9000 certification and financial performance", The international Journal of Quality Management 40: 151–172.

Stefan Tangent, 2003. Work Study, Volume 52. Number 7. pp. 347-354, MCB UP Limited. ISSN 0043-8022

Suman Kumari, Anuradha, & S.K Sharma, December 2013, International Journal of Application or Innovation in Engineering & Management, Volume 2, Issue 12.

APPENDIX-1: ISO CERTIFIED COMPANIES ZAMBIA (2015)

ZAMBIA BUREAU OF STANDARDS
MANAGEMENT SYSTEMS CERTIFICATION

LIST OF ORGANISATION WHICH ARE CERTIFIED IN ISO STANDARDS

S/No	ORGANISATION	STANDARD (S)
1	Total Zambia Ltd	ISO 9001:2008
2	Simply Red Industrial and Agro Ltd	ISO 9001:2008
3	Project Management and Training Consultancy (PMTC) Ltd	ISO 9001:2008
4	Barloworld Equipment	ISO 9001:2008
5	Davies & Shirtlif	ISO 9001:2008
6	Gourock Ropes and Canvas (Z) Ltd	ISO 9001:2008
7	Zambia Metal Fabricators	ISO 9001:2008, 14001 and OHSAS
8	Zambian Breweries	ISO 9001:2008,
9	Konkola Copper Mine	ISO 9001:2008, 14001 and OHSAS 18001
10	Elsewedy Electric (Z) Ltd	ISO 9001:2008
11	Lafarge Cement (Z) Ltd	ISO 9001:2008
12	Seed co (Z) Ltd	ISO 9001:2008
13	Airtel (Z) Ltd	ISO 9001:2008
14	Mopani Copper Mines	ISO 9001:2008, 14001 and OHSAS 18001
15	Parmalat (Z) Ltd	ISO 22000
16	Universal Mining and Chemicals (Z) Ltd	ISO 9001:2008
17	Kafue Gorge Regional Training	ISO 9001:2008
18	Puma Energy	ISO 9001:2008
19	Chloride Zambia	ISO 9001:2008
20	Lublend	ISO 9001:2008
21	Polythene Products	ISO 9001:2008
22	Sandvik	ISO 9001:2008
23	Morganite	ISO 9001:2008
24	National Airports	ISO 9001:2008
25	Scaw Ltd	ISO 9001:2008
26	Ndola Lime	ISO 9001:2008, 14001 and 18000
27	Global Industries Limited	ISO 22000:2005
28	Zambezi Portland Cement	ISO 9001:2008
29	Zambia Meteorological Department - AeMS	ISO 9001:2008

Recharge estimation in the Barotse basin using base flow analysis coupled with a water balance

Joel Kabika[1], Imasiku A. Nyambe[2] and Edwin G. Nyirenda[3]

Abstract

Sustainable groundwater management requires knowledge of recharge. Estimates of groundwater recharge can be obtained by stream flow analysis, especially baseflow analysis. Analysis of the stream flow hydrograph, specifically separating baseflow from quick flow is one of the ways of estimating groundwater recharge. In this paper the two baseflow recession curve methods namely the Rorabaugh method coupled with a regional water balance were used to estimate the recharge in the Barotse basin.

Long term daily stream flow data from six sub-basins and gridded meteorological data were used to analyse the groundwater recharge in the area. The estimated annual recharge in the basin was found to equal 50 mm that is 6% of the annual precipitation with uncertainty of ±2%. The results compare well with the earlier study done by JICA, which estimated annual recharge as 40 mm/year.

Keywords: Baseflow, Quick flow, Water Balance, Groundwater Recharge, Hydrograph,

1. Introduction

Baseflow as defined by Hall (1968) is the portion of river flow that comes from groundwater or other delayed sources. The analysis of the baseflow component of a stream hydrograph has a long history of development since the early theoretical and empirical work of Boussinesq (1904), Maillet (1905) and Horton (1933). Several useful reviews have been written including Hall (1968), Nathan and McMahon (1990), Tallaksen (1995) Chapman (1999) and Smakhtin (2001). A number of methods that have been developed, which can be grouped into three basic approaches: baseflow separation, frequency analysis and recession analysis. Numerous analytical methods have been developed to separate base flow from total stream flow (McCuen, 1989). Although most procedures are based on physical reasoning, elements of all separation techniques are subjective. A common practice of estimating baseflow is to apply different methods and compare the results to obtain the best possible estimate. In this study recharge in Barotse basin is estimated using baseflow recession Meyboom (Meyboom 1961), Rorabaugh (Rorabaugh 1964) and the water balance method.

2. Site description

The Barotse sub-basin of the Zambezi river is located between Latitude 13- 18° South and Longitude 22-26° East and covers an area of about 118 994 km^2 (ZAMWIS, 2007). The general altitude ranges from 880 m in the extreme South on the Zambezi to around 1200m in the extreme

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North East. About 90% of the area of the basin is in the Western part of Zambia with small percentage in Angola and Namibia. The Barotse sub-basin is part of the great Central African Plateau (CAP) characterised by degraded Plateau areas traversed by a network of rivers, streams and dambos of varying density and are largely confined to the area east of the Zambezi River (MEWD/JICA, 1995). The aggraded Plateau is composed of semi consolidated or unconsolidated deep sands (Kalahari sands). It is characterised by extensive, level to very gently undulating plains with generally widely spaced drainage lines and areas where complexes of dunes and pans (some containing small lakes) predominate. The relief is level to gently undulating where drainage density is low and more pronounced where drainage density is high. Rainfall is markedly seasonal, falling between October and April although; the start and the ending of the rains are extremely variable. Mean annual rainfall declines south-eastwards from 1,100 mm in northwest Kalabo District to less than 600 mm in south-western Sesheke District.

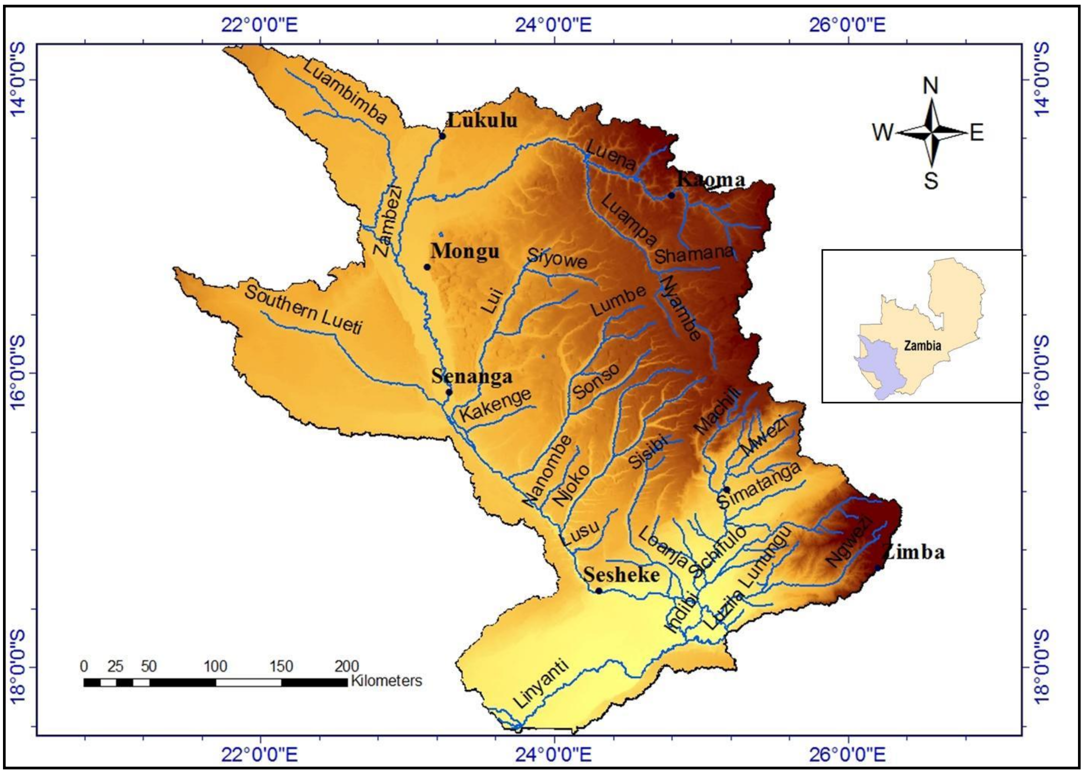

Figure: 1 Map of Barotse Basin

Temperatures are high from the second half of August until the rains start in October and again shortly after the rains. Cool temperatures prevail from May to the first half of August, with night-time temperatures approaching freezing in July in the southwest of the basin. The average temperatures in July are between 14-16^{o} C and in November are between 22-24^{o} C (ZACPLAN, 1998). The annual pan evaporation is estimated at 2300 mm and is high from August to November and low from December to July. Actual annual evapotranspiration is 654 mm against an average rainfall of 763 in 87 days mm rainfall and 87 rainy days. The average annual wind speed is 1.5 m/s and relative humidity is estimated at an average of 62.5% with 3104 annual sunshine hours and 8.5 mean hours per day. (MEWD/JICA, 1995) The major soils in the basin are Acrisols, Aerosols Gleysols, Fluvuvial Leporols, Planosols, and Pozols.

3. Materials and Methods

3.1 Baseflow Analysis

Baseflow is the groundwater contribution to stream flow. It is an important component of the hydrologic cycle that helps in understanding the surface water-groundwater interaction. There are various methods used to estimate recharge from the base flow analysis. A common practice of estimating recharge from baseflow is to apply different methods and use the average. The inherent differences among the methods need to be considered while comparing the results (Risser et al., 2005). In this paper, recharge from baseflow has been estimated from daily stream flow data using two automated baseflow separation and water balance methods: A Visual Basic spreadsheet macro written to automate the estimation of groundwater recharge from stream or spring hydrographs using the adapted Meyboom method (Posavec et. al. 2009) and the RORA computer program developed by the United States Geological Survey (Rutledge and German, 1998) which uses recession-curve-displacement method commonly referred to as the Rorabaugh method (Rorabaugh, 1964).

3.2 Seasonal Recession Method(Meyboom Method)

The Meyboom method uses stream hydrograph data over two or more consecutive years (Meyboom, 1961). The baseflow is assumed to be entirely groundwater discharged from the unconfined aquifer. An annual recession is interpreted as the long-term decline during the dry season following the phase of rising stream flow during the wet season. The total potential groundwater discharge (V_{tp}) to the stream during this complete recession phase is derived as:

$$V_{tp} = \frac{Q_o t_1}{2.3026} \qquad [3.1]$$

Where V_{tp} (L^3)is the total potential groundwater discharge, Q_o (L^3T^{-1})is the baseflow at the start of the recession, and t is recession index (days), the time that takes the baseflow to drop from Q_o to 0.1 Q_o. The underlying assumptions of this method are that the Catchment area has no dams or other method of stream flow regulation and that snowmelt contribution to runoff is negligible for regions with snow fall. The amount of potential baseflow, V_t remaining at some time, *t*, after the initiation of a baseflow may be estimated by:

$$V_t = \frac{V_{tp}}{10^{\left(t/t_1\right)}} \qquad [3.2]$$

The difference between the remaining potential groundwater discharge at the end of a given baseflow recession and the total potential groundwater discharge at the beginning of the next recession represent the recharge that has taken place between these two recessions. The Meyboom method is an idealized analysis assuming that all groundwater discharge is by means of baseflow to streams. In reality however, there are consumptive uses of groundwater in the basin i.e. evapotranspiration and abstraction for irrigation or other uses and these uses need to be accounted for during the analysis.

The Meyboom method was implemented using a Visual Basic spreadsheet macro written to automate the estimation of groundwater recharge from stream or spring hydrographs (Posavec et. al. 2009) .

3.3 Recession-Curve-Displacement Method (Rorabaugh Method)

The recession-curve-displacement method (Rorabough method) (Rorabaugh 1964) is intended for analysis of flow systems that are driven by area diffuse-recharge where the stream is considered the sink (discharge boundary) of the groundwater flow system. With this method groundwater recharge is considered to be approximately concurrent with the peaks in the stream flow (Rutledge and Daniel, 1994). The method has the strongest theoretical basis of any of the hydrograph-separation techniques; it is based on the closed-form solution of the one dimensional groundwater flow equation (Halford and Mayer, 2000). The method is only applicable to stream systems and catchments where regulation and diversion of flows are negligible, and where the entire watershed or drainage area is upstream from the gauging station where the discharge data have been collected.

Rorabaugh (1964) expressed groundwater discharge to a stream as a complex function of time after a recharge event and found that the function can be approximated after "critical time" by an equation that expresses the logarithm of groundwater discharge as a linear function of time. The critical time can be calculated using equation [3.3].

$$T = C_1(Log\,Q^2) + C_2(LogQ) + C_3 \qquad [3.3]$$

Where T = time (T),

Q = discharge (L^3/T),

C1, C2, C3 = coefficients.

And critical time is given by equation (3.4) which is the time that the total potential discharge equal to approximately one half of the total volume of the water that has recharged the system (Rutledge and Daniel 1994).

$$T_c = 0.2144K \qquad [3.4]$$

Where

T_c = critical time (T),

K = the recession index (T).

Rutledge and Daniel (1994) showed that the total potential groundwater discharge at critical time after the peak in the stream flow is equal to approximately one half of the total volume of the water that recharged the system. Using their findings combined with the principle of superposition, the total recharge can be estimated for a recharge event from equation 3.4.

$$R = \frac{2(Q_2 - Q_1)K}{2.3026} \qquad [3.5]$$

Where

R = total volume of recharge (L^3),

Q_1 = groundwater discharge at critical time as extrapolated from the stream flow recession preceding the peak (L^3/T),

Q_2 = groundwater discharge at critical time as extrapolated from the stream flow recession following the peak (L^3/T),

K = the recession index (T).

This method estimates total recharge for each stream flow peak. The disadvantage is the time required to calculate recharge for each peak. Potential groundwater recharge is shown to equal approximately one-half of the total volume that recharged the system at a “critical time” after the peak (Rorabaugh, 1964).The RORA computer program developed by the United States Geological Survey (Rutledge and German, 1998) which uses recession-curve-displacement method commonly referred to as the Rorabaugh method (Rorabaugh) was used in the second analysis of recharge for the Barotse Basin.

3.4 Water balance Method

The water balance of the Barotse Sub-basin was developed using the following general formula(Chen et al. 2006),

$$P = ET + q_s + q_b + q_N + \Delta S \qquad [3.6]$$

Where P is the precipitation (LT^{-1});ET is the evapotranspiration (LT^{-1});q_s the surface runoff (L^3T^{-1}); q_b the groundwater contribution to runoff (L^3T^{-1}); which is the definition of baseflow; q_N is the net flux (L^3T^{-1}); of any water entering or leaving the region other than precipitation e.g., water diversions, groundwater flux across the basin boundaries, and irrigation); and ΔS the Change in stored water (L^3T^{-1}); within the area. (Chen et al., 2006)

The evapotranspiration including evaporation from open surfaces given in equation 3.6 is by far the largest loss amounting to 70% of precipitation (Brutsaert, 1982). The general assumption that ΔS is negligible on a long-term basis was taken for the analysis in Barotse basin. Assuming further that that q_N in Eq. 3.5is neglected as well, at least on a regional scale then Eq 3.6 reduces to

$$P - ET = q_s + q_b \qquad [3.7]$$

Equation 3.7 means that the difference between precipitation and ET emerges as surface runoff and baseflow. If the change in the stored water volume is negligible, as was assumed, then on a long-term basis, baseflow must represent a lower bound to groundwater recharge within(Chen et al., 2006) Base-flow index (BFI), which is the ratio of baseflow and total stream runoff ($Q = Q_b + Q_s$) over time

$$BFI = \frac{Q_b}{Q_b + Q_s} \qquad [3.8]$$

Inserting Eq 3.7 into Eq 3.6 yields

$$BFI * (P - ET) = BFI * q \approx q_b \approx R \qquad [3.9]$$

Where R is the recharge (LT^{-1});

4 Results and Discussion

4.1 Base flow analysis

Baseflow analysis was carried out on six sub-basins in Barotse basin using the automated computer programme of Rora developed by the USGS. The six sub-basins were selected on the basis that they had had at least a minimum of 2 year continuously daily stream flow records. The other remaining sub- basins were not analysed as they had only water level records which could not be converted into flows because of none availability of rating curves. A minimum of two years was chosen as the method needed at least two consecutive years to estimate the recharge that has taken place. The sub-basins analysed included Lui, Luena, Namitome, Kataba, Sefula, and Luampa Figure 4.1

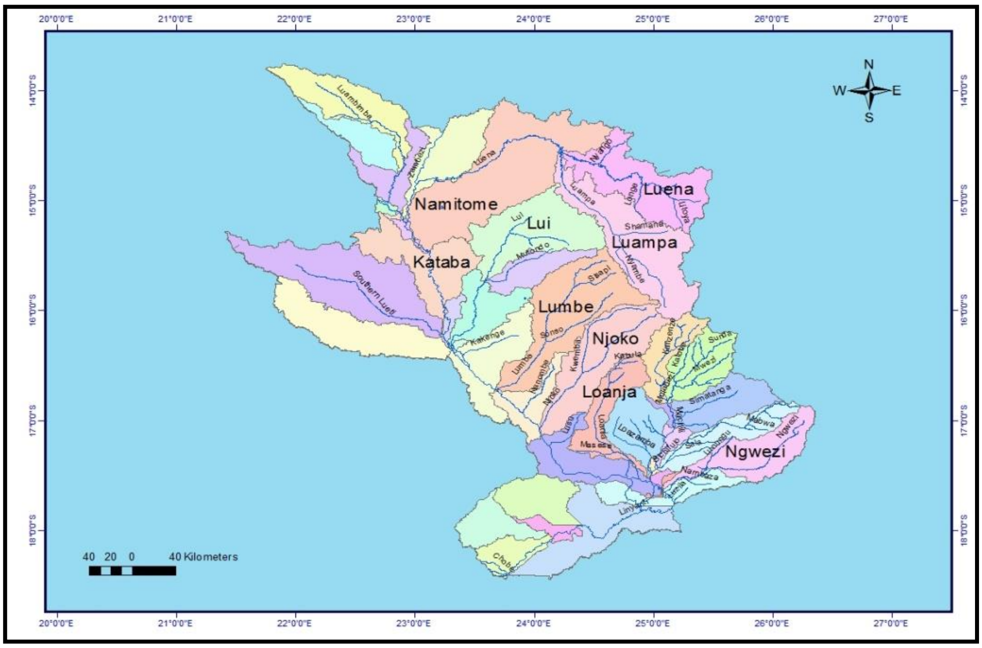

Figure 4.1 Sub-Basins of Barotse

4.2 Meyboom method

Daily stream flow data from Department of Water Resources Development Affairs (DWRD) for the six sub-basins were used to estimate the recharge. Using an automated spreadsheet developed from the Meyboom method (Posavec et. al. 2009) the average recharge was found to be 41.834 mm (Table 4.1) and the average percent of the precipitation was 5%.

4.3 Rorabaugh Method

Using the Rorabaugh methods the estimated recharge of the six sub-basins are shown in Table 4.2. The average annual recharge of the six basins analysed was found to be 50 mm/year which is about 6% of the average annual rainfall received in the basin. The major source of error was in the size of the drainage area of some of the sub-basin. Rora requires that the drainage area should be not more than 1,295 Km^2 for better results but for Luena sub-basin it was 13, 918 Km^2. The results are in the same range as the one from the section 4.2.1 under the Meyboom method except for Luena sub-catchment which had a very low recharge value of 1.57 mm per annum. This could be attributed to the large drainage area that was used in the calculation.

Table 4.1 Results from Meyboom method.

Sub-Basin	Catchment Area(Km^2)	Period	Recharge (mm/year)	% of Annul Precipitation
Lui	1853.51	1962-1975	36.40	4.33
Luena	13918.38	1972-1991	50.71	6.04
Kataba	477.29	1972-1986	60.12	7.16
Namitome	718.26	1964-1981	49.32	5.87
Luampa	7016.00	1962-1982	23.5712	2.8

Table 4.2 Results of six basins using the Rorabaugh method

Sub-Basin	Catchment Area(Km^2)	Period	Recession Index (Days/log Q)	Recharge (mm/year)	Percent precipitation (%)
Lui	1853.51	1962-1975	180	70.05	8.34
Luena	13918.38	1972-1991	180	1.57	0.19
Kataba	477.29	1972-1986	180	61.80	7.36
Sefula	139.96	1980-1991	180	98.81	11.76
Namitome	718.26	1964-1981	180	48.34	5.75
Luampa	7016.00	1963-1966	180	23.27	2.81
Average				50.14	5.97

4.4 Comparison of the Results from the two Methods

Comparison of the results from the two methods showed R^2 = 0.4848 from the correlation analysis. Only two sub-basins namely Kataba and Namitome showed similar results. The other four had average difference of between 7-33 mm/year. Sefula showed a difference of 290 mm/year. This could be attributed to errors in the gauge readings and in the rating curve. Secondarily the error could be from the excessive size of the drainage area i.e. Luena. The average annual recharge from the two methods is about 5-8% of the annual precipitation.

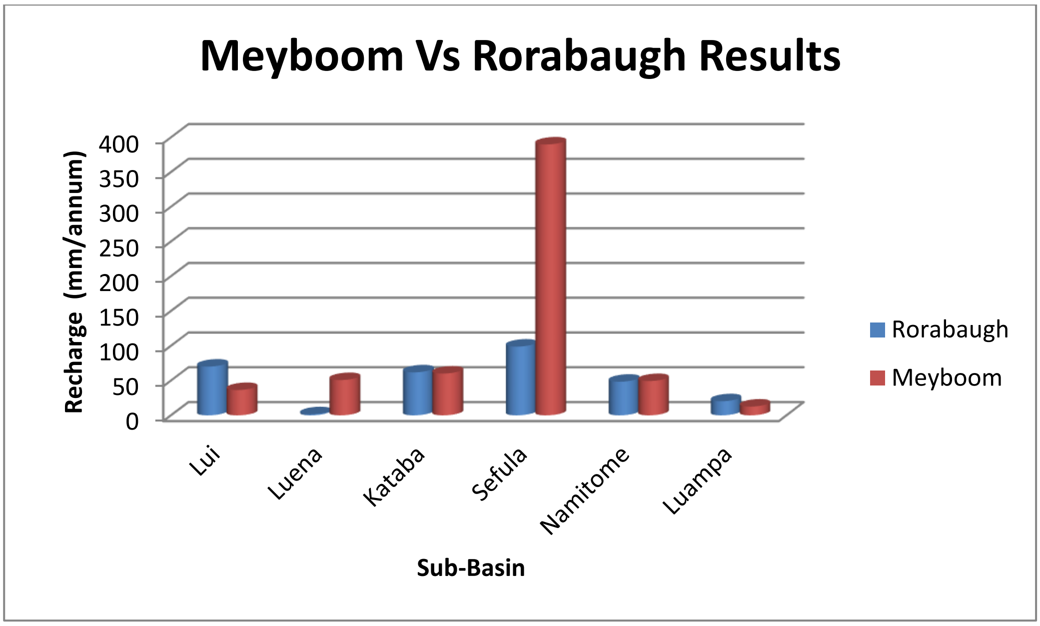

***Figure: 4.3: Comparison of the correlation between the Meyboom and Rorabaugh Method*.**

4.5 Comparison of the annual recharge with Land cover Geology and Slope

An investigation was performed to look for the relationship between the estimated annual recharge (Table 4.3) and physical characteristics of the basin. A comparison of Land cover geology and slope was used because of their effect on recharge:

4.5.1 Average Slope versus annual recharge

Most of the basin is generally flat with average slope of 0.347 (Figure 4.3). From the six sub-basins analysed four had the same average slope of 0.288; Luena and Sefula that had slopes of 0.426 and 0.205, respectively. There was a slight correlation of recharge and slope of the basin (Figure 4.4) with steep slope showing a lower value in recharge that is Luena whereas the basin with the lower value of the slope for example Sefula had the highest recharge rate (Table.4.3) and (Figure 4.3). This was so because the lower slope allows more water to infiltrate compared to the high slope basins.

Table 4.3 Comparison of the annual recharge with Land cover Geology and Slope

Sub-Basin	Basin Area(Km^2)	Period	Meyboom Recharge (mm/year)	Rora Recharge (mm/year)	Average Slope (%)	Land-cover	Lithology	Baseflow Index
Lui	1853.51	1962-1975	36.4	70.05	0.288	Savana	Sand	0.932
Luena	13918.38	1972-1991	50.71	1.57	0.426	Agriculture	Sand	0.957
Kataba	477.29	1972-1986	60.12	61.8	0.288	Grassland	Sand and Alluvium	0.992
Sefula	139.96	1980-1991	389.8	98.81	0.205	Grassland	Alluvium	0.995
Namitome	718.26	1964-1981	49.32	48.34	0.288	Cropped area	Sand	0.99
Luampa	7016	1962-1982	23.57	23.27	0.288	Agriculure	Sand	0.834

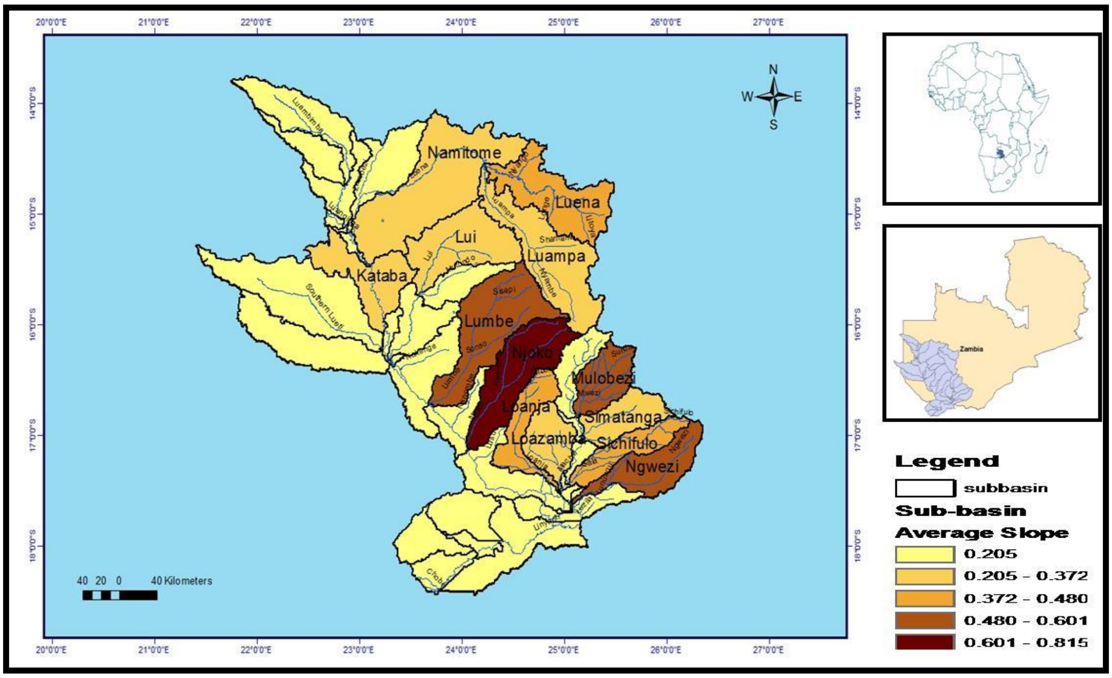

Figure 4.3. Average sub-basin percent Slope

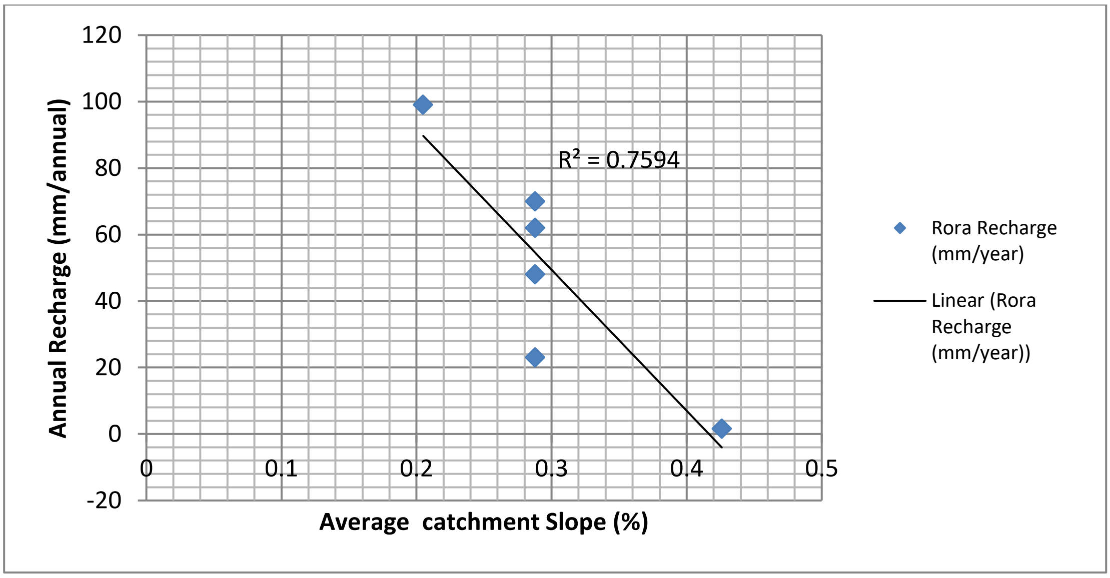

Figure 4.4: The graph showing the correlation of recharge and the catchment slope in the six sub-basins in the Barotse Basin in Western Zambia

4.5.2 Land cover and the annual recharge

Annual recharge it was correlated to land cover. Annual recharge was less in irrigated areas of Luena and Luampa which recorded 1.57 and 23.27 mm respectively (Table 4.3 above). The grassland areas of Sefula had highest annual recharge probably due to low evapotranspiration (Figure 4.5).

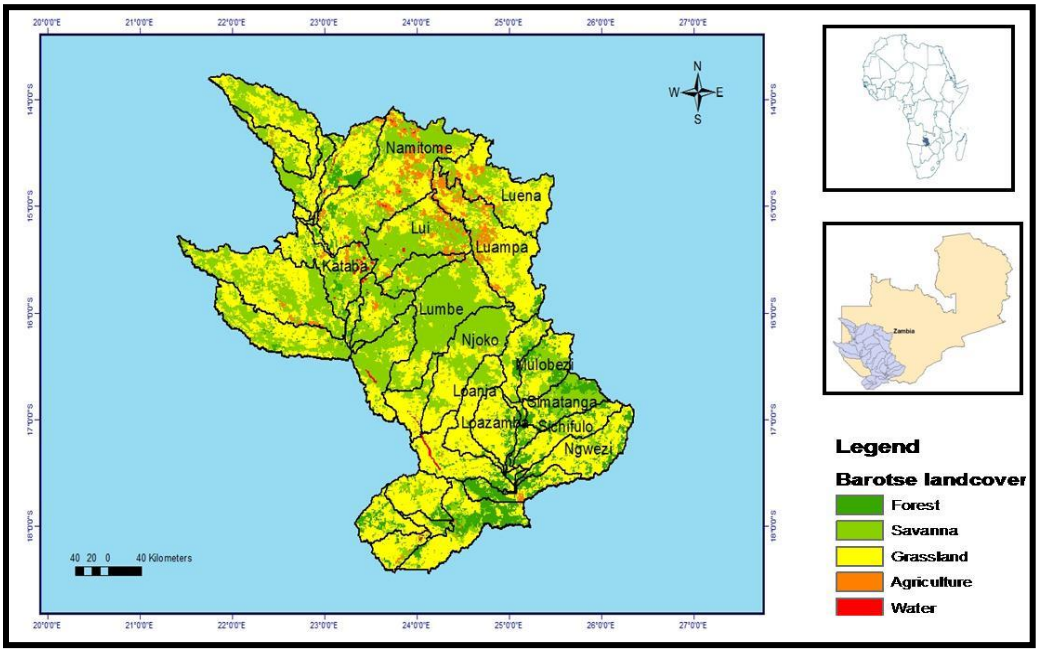

Figure 4.5: Map showing the Land use and Land Cover in the six sub-basins of the Barotse Basin in Western Zambia

4.5.3 Geology versus recharge

It was difficult to compare the annual recharge with the surface geology in the Barotse Basin as the area is homogenous with only smaller percentage of varying surface geology Figure 4.6

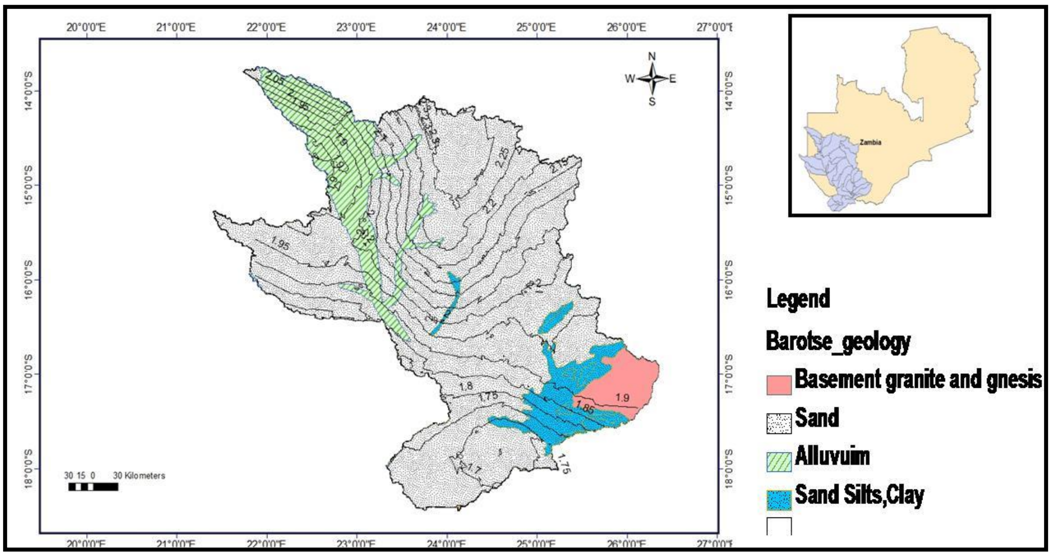

Figure 4.6 : A surface geological map indicating a varied geology from the Basement granite/gneiss to alluvium in the six sub-basins in the Barotse Basin in Western Zambia.

4.6 Water Balance

A water balance model was set up using precipitation data from data TRMM stations 3B42and Evapotranspiration (Figures 4.7 and 4.8, respectively). Using the PART program from the USGS the average Base Flow Index (BFI) for the basin was calculated for the six sub basins (Namitome, Sefula, Kataba, Lui, Luena, and Luampa) in Table 4.3.GIS was used to generate surfaces from the point measurements.

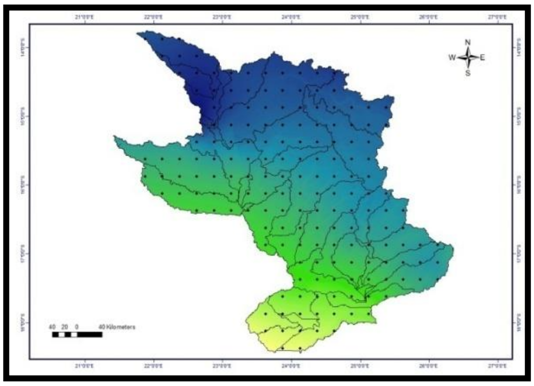

Figure 4.7 Distribution of the climatic Station for Precipitation used in the analysis

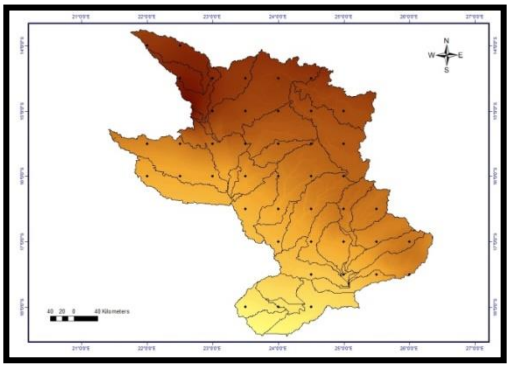

Figure 4.8 Distribution of the climatic Station for Evapotranspiration used in the analysis

From the long-term mean annual values of the point measurements of Precipitation (P)(1998-2008)and Evapotranspiration (ET) (2000-2005), surfaces were generated using the ordinary kriging method (Figures 4.9 and 4.10). From the results it was observed that the rainfall varies spatially from north-east to south-west with the north receiving average annual daily rainfall of 2.3 mm/day and the south 1.6 mm/day. The Evapotranspiration map was subtracted from the Precipitation map to generate the runoff map (Figure 4.11).

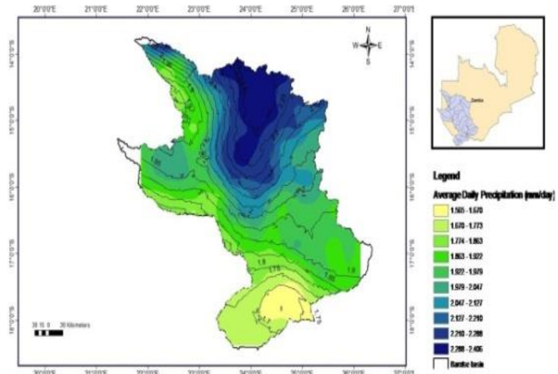

Figure 4.9 Average daily Precipitation

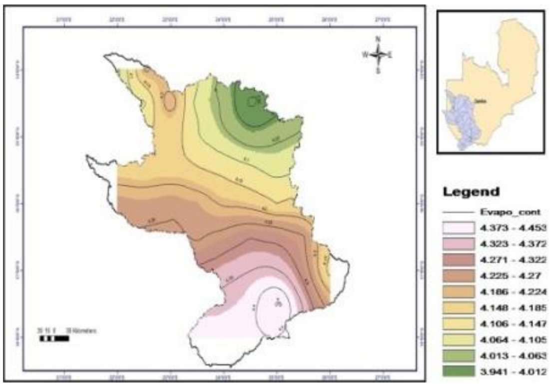

Figure4.10 Average daily Evapotranspiration

The spatial distribution recharge map (Figure 4.12) was obtained by multiplying the runoff map (Figure 4.11) with the Base flow index maps (Figure?). From Figure 4.12 it can be seen that the main recharge areas are in the northern and the central parts of the basin due to mainly the higher rainfall in these regions. The recharge is mainly in January, February and occasionally in December with an average daily recharge of 1.84 mm/day, 1.46 mm/day and 0.48 mm/day respectively, in these months (Table 4.3). The negative values of recharge indicate that no recharge took place in that particular month and that groundwater was lost to evapotranspiration. Taking January and February as the recharge months, the annual recharge from the water balance can be estimated as:

Annual Recharge = average daily recharge x number of days

Av R= (1.84*31)+(1.45*28)

=95.35mm/year

% of Annual Precipitation =(95.35/763)*100

= 12.5%

Therefore the estimated recharge from the water balance is 95.35 mm/year. This value is slightly high because of the some of the assumption taken in the calculations.

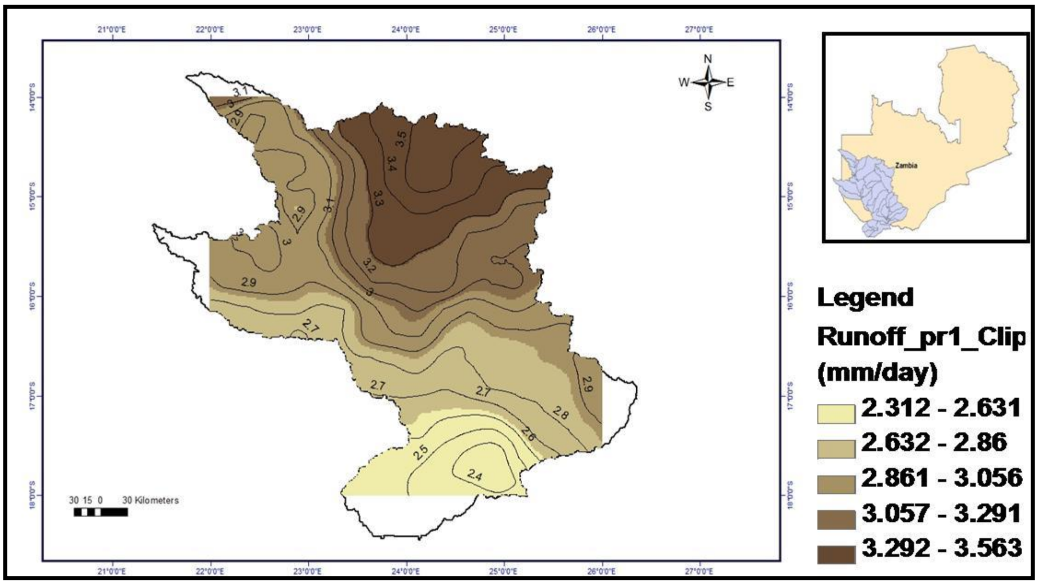

Figure 4.11 Average daily Runoff in Barotse

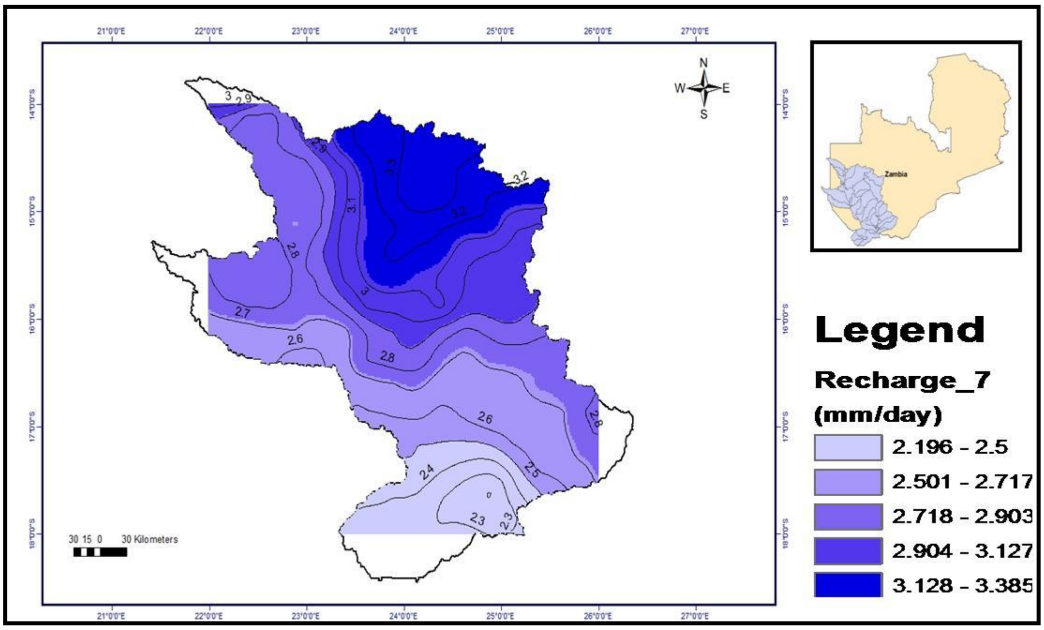

Figure 4.12 Average daily Recharge in Barotse

4.7 Discussion on baseflow analysis results

The baseflow analysis indicates that the average recharge in the Kalahari Sand aquifers of in Barotse basin is 50 mm, which is 5.6% of the average annual precipitation. The estimated safe yield was found to be 1405x106 m^3 of water available for use per annum.

This result agrees well with the study by (JICA/MEWD, 1995), which found the average annual recharge to be 40 mm. The slight difference observed in the results may be attributed to the fact that the Meyboom and Rorabaugh methods are idealized in that they assume that all groundwater in a catchment is by means of baseflow to the stream. In reality however, there are consumptive uses of groundwater in a catchment for example evapotranspiration and irrigation which needs to be accounted for in the analysis (Meyboom, 1961).

From the comparison of the geology versus recharge, there was very little difference due to the fact that the area has a uniform geology cover which is a thick blanket of sand soil ranging from 20 m in the south to 70 m in the northern part of the study area (Chongo, 2010). However, Foster, et al., (1982) argued that the thickness of the Kalahari Sand cover in Botswana limits the infiltration of recharge into the groundwater. Specifically, the statement is that no diffusive recharge is likely to occur in areas where the thickness of the Kalahari Sand cover exceeds 4 m with a mean annual rainfall of 450 mm. In the present study area the sand cover far exceeds 4 m, while the amount of annual rainfall is approximately 1.5 times higher. A possible reason for the recharge is the higher rainfall (763 mm/annum) in Barotse Basin. The results from this current study confirms the Houston, (1990) hypothesis that the amount of recharge depends on the rainfall, soil and vegetation. Houston, (1990) concluded that the timing of recharge corresponds to the heaviest rainfalls when the rate of incoming precipitation (400 mm/a) temporarily exceed the intense evapotranspiration flux.

From the comparison of land cover and the annual recharge it was observed that there is correlation between the land cover and recharge. Annual recharge was less in agriculture areas of Luena (1.57 mm) compared to the grassland in Luampa which recorded 23.27mm respectively. The results of the comparison of recharge and land cover are in line with what Houston, (1990) found that the recharge depends on rainfall, soil and vegetation cover.

Regardless of the limitation the baseflow analysis confirmed that there is recharge taking place in the Kalahari Sand aquifers of Barotse basin and that it is driven by rainfall intensity, soil and vegetation cover**.**

5 Conclusion

In conclusion the baseflow analysis showed that the annual average recharge in Kalahari Sand aquifers of Barotse basin is 50 mm giving about 6.1% of the average annual rainfall received in the area (763 mm/year) whereas the results from the water balance show that the recharge is 95.35 mm/year. The difference in the results can be attributed to the assumption taken in the development of the water balance. The recharge occurs mainly in January, February and occasionally in December showing that it is driven by intensity of the rainfall. It is also influenced by the pattern of rainfall with the northern and some parts of the central region being the main recharge areas.

6 Acknowledgement

The work was carried out as part of the groundwater resources assessment in the Kalahari sand aquifers in western part of Zambia under the IWRM-CENTER at the University Zambia with funding from the Danish Government (DANIDA) which is part of the bigger water sector support

Project in the Ministry of Energy and Water Development and the Ministry of Local Government and Housing.

7 Reference

Arnold, J.G., and Allen, P.M. (1999): Automated methods for estimating baseflow and ground water recharge from streamflow records. J. Am. Water Resource. Assoc. 47(2), 411–424

Bevans, H.E., 1986. Estimating stream-aquifer interactions in coal areas in eastern Kansas by using streamflow records. In: Seymour (Ed.). Selected Papers in the Hydrologic Sciences,

Brutsaert, W.H., Lopez, J.P., 1998. Basin-scale geohydrologic drought flow features of riparian aquifers in the southern Great Plains. Water Resour. Res. 34 (2), 233–240.

Chapman, T., 1997. A comparison of algorithms for streamflow recession and baseflow separation. In: McDonald, A.D., McAleer, M. (Eds.), Proceedings, International Congress on Modelling and Simulation MODSIM 97. Hobart, Tasmania, Australia, pp. 294–299.

Chen WP, Lee CH (2003) Estimation of groundwater recharge using water balance coupled with base-flow-record estimation and stable-base-flow analysis. Environ Geol (2006) 51: 73–82 DOI 10.1007/s00254-006-0305-2

Chongo, M. (2010). The Spatial distribution of Saline Groundwater in the Kalahari Sand Aquifer-A Case Study in the Sesheke Area using Geophysical Methods. Masters thesis. University of Zambia, 97 pp

Daniel, J.F., 1976, Estimating groundwater evapotranspiration from streamflow records: Water Resources Research, v. 12, no. 3, p. 360-364.

Denconsult (1998), Sector Studies under ZACPLAN. Final Report. Introductory volume

Foster, S.S.D., Bath, A.H., Farr, J.L., Lewis, W. J. (1982). The likelihood of active groundwater recharge in the Botswana Kalahari. Journal of Hydrology, 55, 113–136.

Halford, K. J., & Mayer, G. C. (2000). Problems associated with estimating ground water discharge and recharge from stream-discharge records. Ground Water, 38(3), 331–342.

Hall FR, 1968. Base flow recession - a review. Water Resources Research 4(5): 973-983.

Horton, R. E. (1940). An approach towards physical interpretation of infiltration capacity. In Proceedings of the Soil Science Society of America 5 (pp. 399–417). Wiley InterScience. Retrieved from www.interscience.wiley.com

Houston, J. (1990). Rainfall-runoff-recharge relationships in the basement rocks of Zimbabew. In: Lerner, D. N., Issar, A., Simmers, I. (Ed.), Groundwater recharge; a guide to understanding and estimating natural recharge. International Contributions to Hydrogeology 8, Chapt (pp. 271–283). Hannover, Germany.

Japan International Cooperation Agency & Ministry of Energy and Water Development,

Republic of Zambia. (1995). “The study on the national water resources master plan in the republic of Zambia”: Final Report.

Knisel, W.G., Jr., 1963, Baseflow recession analysis for comparison of drainage basins and geology: Journal of Geophysical Research, v. 68, no. 12, p. 3649-3653.

Kristijan Posavec, J. P., Andrea Bačani 2009. A Visual Basic spreadsheet macro for estimating groundwater recharge. *scientific papers,* 21**,** 5.

Maillet, E., 1905. Essai d'hydraulique souterraine et fluviale: Librairie scientifique. Hermann, Paris.

Mau, D.P., Winter, T.C., 1997. Estimating groundwater recharge from streamflow hydrographs for a small mountain watershed in temperature humid climate, New Hampshire, USA. Groundwater 35 (2), 291–304.

Meyboom, P. 1961. Estimating ground-water recharge from stream hydrographs. *Journal of Geophysical Research,* 66**,** 1203-&.1214.

Moore, R.D., 1997. Storage-outflow modelling of streamflow recessions, with application to a shallow-soil forested catchment. J. Hydrol. 198, 260–270.

Nathan, R.J., and McMahon, T.A., 1990, Evaluation of automated techniques for base flow and recession analysis: Water Resources Research, v. 26, no. 7, p. 1,465-1,473.

Nichols, W., 1994. Groundwater discharge by phreatophyte shrubs in the Great Basin as related to depth to groundwater. Water Resource. Resourse. 30, 3265–3274.

Padilla A, Pulido-Bosh A, Mangin A, 1994. Relative importance of baseflow and quickflow from hydrographs of karst spring. Ground Water 32, 267-277.

Posavec, J., Pearson, K., Kristijan, P., & Andrea bačani, P. (2009). A visual basic spreadsheet macro for estimating groundwater recharge. Applied Hydrogeology, 21, 19–23.

Risser, D., Gburek, W., & Folmar, G. (2005). Comparison of methods for estimating ground-water recharge and base flow at a small watershed underlain by fractured bedrock in the eastern United States 31 pp.

Rorabaugh MI, 1964. Estimating changes in bank storage and groundwater contribution to streamflow. Int. Ass. Scientific Hydrology. Publ 63, 432-441

Rutledge, A.T., and Daniel, C.C., 1994, Testing an automated method to estimate ground-water recharge from streamflow records: Ground Water, v. 32, no. 2, p. 180-189.

Rutledge AT, 1998. Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records-Update. US Geological Survey, Water Resources Investigations Report 98-4148

Rutledge, A.T., 2000, Considerations for use of the rora program to estimate ground-water recharge from streamflow records: U.S. Geological Survey Open-File Report 00-156, 44 p.

Rutledge, A.T., 2003, Use of RORA for complex ground-water flow conditions: U.S. Geological Survey Water-Resources Investigations Report 03-4304, 5 p.

Smakhtin VY, 2001. Low flow hydrology: a review. Journal of Hydrology 240:147-186.

Snyder, F.F., 1939, A conception of runoff-phenomena: Transactions of American Geophysical Union 20: p. 725-738.

Sujono J, Shikasho S, Hiramatsu K, 2004. A comparison of techniques for hydrographic recession analysis. Hydrological Processes 18, 403-413

Tallaksen, L.M., 1995. A review of baseflow recession analysis. J. Hydrol., 349–370.

Toebes, C., and Strang, D.D., 1964, On recession curves: 1, Recession equations: Journal of Hydrology (New Zealand), v. 3, no. 2, p. 2-14.

Werner, P.W., Sundquist, K.J., 1951. On the groundwater recession curve for large watersheds. IAHS General Assembly, Brussels, IAHS Publ. 33, pp. 202–212.

Wittenberg, H., 1994. Determination of groundwater recharge by baseflow separation—regional analysis in North–East China. IAHS Publ. No. 221, pp. 69–75.

Wittenberg, H., 1994. Nonlinear analysis of flow recession curves. IAHS Publ. 221, pp. 61–67.

Wittenberg, H., 1999. Baseflow recession and recharge as nonlinear storage processes. Hydrol. Process, Special Issue Process Interactions in the Environment.

Recycling Newspapers using deinking flotation Technology

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Abstract.

All the newspaper printing companies in Zambia import blank white paper for printing newspapers from South Africa which is a major drain on the foreign currency of the country. As a way of saving this much need resources, there is urgent need to find ways of producing this paper locally so as to supply the newspaper companies in Zambia (Chisanga, 2000).

Paper is recyclable and flotation deinking technology is a very well-known way to do this, which involves detachment of ink particles from the fibre followed by the dispersion of the detached ink particles which are then flocculated to form large particle aggregates which become more hydrophobic and hence can be removed by flotation (Larsson, 1987).

This work which was done at the Geological Survey Department of the Ministry of Mines and Mineral Development of Zambia, was on laboratory scale, whose main objective was to recycle locally used newspapers to produce clean white papers, with the view of trying to apply the result to pilot and possibly full industrial commercial plants.

To achieve this, the effects of time and consistency for pulping and flotation, amounts of surfactants as well as chemical reagents (Jick, lemon, Methylated spirit, Acetone) and the pH were investigated.

The Newspapers were successfully recycled by producing clean white deinked papers. A simple process flow sheet was suggested which could be considered for the process design. Finally, it was recommended that this project could be used as a baseline on which, a possible plant could be constructed for paper production in this county.

Keywords: Deinking Flotation Technology, Reagents, pH, Ministry of Mines and Minerals Development.

1. Introduction.

According to the Australian Newspaper Plan libraries (2016) a newspaper is defined as, "a serial publication which contains news on current events of special or general interest. The individual parts are listed chronologically or numerically and appear, usually at daily, once a week, fortnightly or monthly. "The Newspaper may be read online or on hard copy. The United Nations report (2015) contends that most newspapers becomes useless and are discarded immediately after being read and as such they pose environmental problems, when not properly disposed off, contrary to the millennium development goals (MDGs). Paper is recyclable and paper recycling has both economical as well as environmental benefits to society (Slater, 2009). Miller (1988)

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defined recycling as the collection and reprocessing of a resource. Chiras (1997) further argued that recycling involves the returning of materials to manufacturers where they can be reprocessed to new products. Currently, paper recycling is being done by Zambezi paper recycling company, but, the paper produced is of very low quality (Chisanga, 2000). Therefore, blank paper rims are bought from South Africa to be used by all the newspaper printing companies, which affects price of newspapers in Zambia, due to changes in currency of the Zambian Kwacha. The major newspaper printing companies in this country includes; Zambia Daily newspaper, the Times of Zambia newspaper, the Post newspaper, etc.

This work, was conducted at the Geological Survey Department of the Ministry of Mines and Mineral Development of Zambia, on a lab scale with the view of expanding it to a pilot project and possibly, eventually to a full industrial scale.

2. Literature Review.

Froth, film and oil flotation processes the well known ones of froth flotation is the most widely used. Flotation process is a physico-chemical process used in the separation of hydrophilic particles from those whose surface are hydrophobic, involving three contact between solid-liquid, solid- gas and liquid -gas phases (Wills, 2006). This is applied in mineral processing, drinking and waste water treatment, petrochemical industries, food and oil processing industries, removal of radioactive nuclides from soils, plastic recycling industries, paper recycling industries to mention a few (Matis, 2009).

The History of Flotation dates as far back as 1869 when William Haynes patented a process for separating sulphide and gangue particles whereas application in paper recycling was first used by the early 1930s with the first deinking patent being filed by Hines 1933, and it was not until twenty years later that the first commercial scale production was started in the USA 1952 and 1959 in Greece (Schwinger, 1991). In Zambia paper recycling started in 1981 by Zambezi Paper Mills Company (Chisanga, 2000). Froth flotation is said to be direct when the valuable particles are collected from the froth while leaving the undesired particles in the tails, the opposite of this is called reverse flotation, (Orlando, 2016).

For flotation to be effective, reagents such as regulators may be added to the pulp to activate or depress collector adsorption on the surfaces of selected particles (Crozier, 1992). Regulator known as depressants when adsorbed on the surface of a particle prevents, the adsorption of collector on that surface and thus such particles may have their surfaces hydrophilic (water loving) whereas regulators known as activators when adsorbed on the surfaces of particles promotes collectors adsorption on such surfaces rendering them hydrophobic (water repellent) (Crozier, 1992). Collectors may either be physically or chemically adsorbed on the particle surfaces and when air bubbles are generated, the hydrophobic particles stick on to their surfaces and are then carried along the froth phase. Frothers are introduced to the pulp to promote the formation of a stable froth and formation of stable air bubbles (Wills, 2006).

The mechanisms for the bubble-particle attachment are very complex and consist of three steps: collision, attachment and detachment (Wills, 2006).The activity of a mineral surface in relation to flotation reagents in water depends on the forces which operate on that surface. The forces tending to separate a particle and a bubble are shown in figure 1.

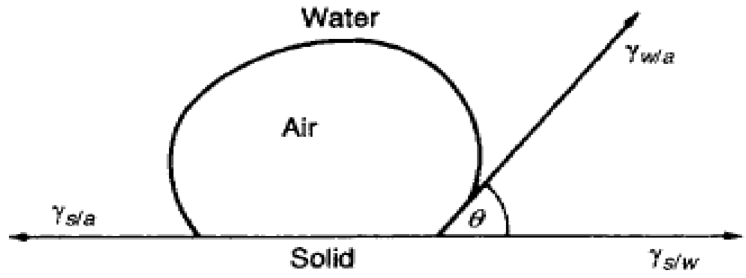

Figure 1: The three phase contact angle on hydrophobicity

The tensile forces lead to the development of an angle between the mineral surface and the bubble surface at equilibrium as shown in equation 1.

$\gamma s/a = \gamma\ s/w + \gamma w/a\cos\theta$.. [1]

Where

γs/a is the surface energies between solid and air

γs/w is the surface energies solid and water

γw/a is the surface energies water and air,

$\theta$is the contact angle between the mineral surface and the bubble.

The force required to break the air bubble – solid particle interface is called the work of adhesion *Ws/a.* This is equivalent to the work required to separate solid-air interface and produce separate air water and solid-water interfaces.

$w\ s/a = \Upsilon w/a(1 - \cos\theta)$.. **[2]**

From equation 2, it can be observed that hydrophobic particles form a large contact angle θ and thus are carried to the froth phase whereas the hydrophilic particles when they collide with the air bubbles they form a smaller contact angle and hence are cannot be carried to up along with the air bubbles, thus remaining in the tail and not floated. The adsorption of particles to bubbles is essential to separating the selected particles from the pulp (Wills, 2006).

Paper recycling in general

Paper recycling involves collection of used or waste paper for reprocessing purposes for reused (Stevenson, 2010). Paper to be recycled usually have a lot of contaminants (staples, nuts, screws, foil, cans, plastics, films, bags, dirt, cloth, yard waste, leather, Inks & toners, Stickiest, Coatings, Fillers, Papermaking additives etc.) of various size distribution (Larsson, 1987). The figure 2, shows the techniques best applicable for efficient removal of contaminant depending on the particle size range, specific gravity, stiffness, surface properties etc. (Cool, 1987). For example flotation process may be effective in removing particles whose size ranges from 2 µm to about 100µm, based on their surface properties. Ink particles are effectively removed by washing or/and flotation process.

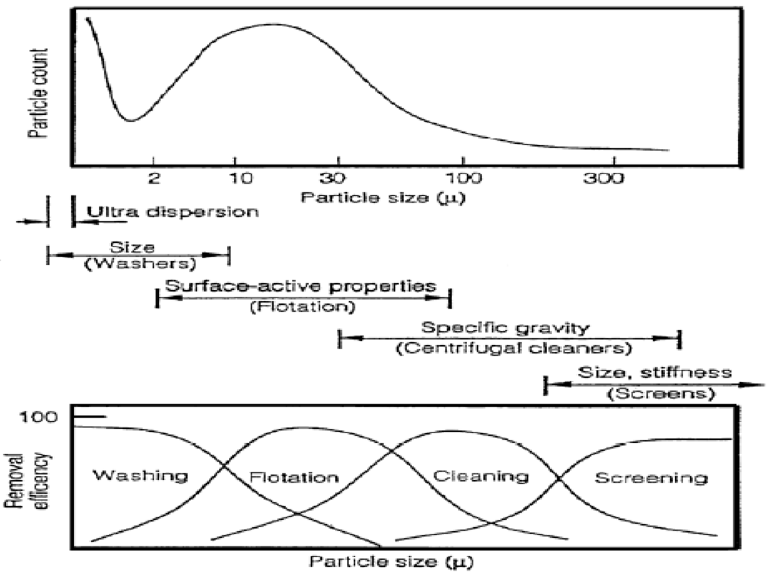

Figure 2: The techniques best applicable for good removal efficiency of contaminant depending on the particle size range

The major processes involved in paper recycling includes among others; Pulping, Cleaning, Screening, Deinking (Washing and Flotation), Kneading, Bleaching, Water Treatment, and Solid Waste Handling (Aisbl, 2015).

Pulping: For paper recycling, a Pulper device's main objective is to convert waste paper into pulp of well separated fibres (secondary fibres) and other waste paper components whereas for virgin paper from wood, it is used to separate fibres (primary fibres) from other wood components. Proper pulping is a requirement if unit operations downstream (cleaning, screening, flotation) are to be efficient and effective (Glembotskii, 1960).

Cleaning is based on particle separation in a centrifugal flow field (specific gravity) (Venditti, 2008). Cleaning may be used to remove heavy weight contaminants (metals, sand, and some varnish particles) or light weight contaminants (hot melt adhesives and various plastic particles.

Types of cleaners include;

- High Density Cleaner: These remove very **large, heavy** contaminants such as rocks, staples, glass. This is done after pulping (early in the process) to protect downstream equipment from damage.
- Forward Cleaners; these removes **fine, heavy** contaminants particles such as sand and inks, they are also called cyclones, hydro cyclones, or cleaners.
- Through Flow Cleaner: These removes **fine, light** contaminants such as glues, adhesives, plastics, foam. They are also called light-weight cleaners or reverse cleaners.

Screening separates contaminants based mainly on size, but also on shape and deformability in paper. Screens may be fine or coarse (Glembocki *et al*, 1961). Coarse screens removes contaminates which are larger in size than the paper fibre particles by keeping them on a screen while allowing fibre go through the openings (coarse screening holes range from 6mm to 1.6 mm of the screen) whereas fine screens removes fine contaminants which are smaller than paper fibre particles by retaining on a screen the paper fibre particles while allowing fine contaminants which are smaller than paper fibre particle to go through the openings (fine screening slots range from 200 to 100 micrometres of the screen).

De-inking involves the detachment of ink particles from fibres, followed by flocculation of ink particles and finally the removal of flocculated ink particles from the pulp and it can be accomplished by either washing or flotation (or both), effectively depending on the ink particle size (Larsson, 1987).

De-inking Flotation involves removing hydrophobic ink particles (ink particles and toners) by floating them to the surface with air bubbles leaving the ink free fibre particles in the cell. In other words the process of flotation de-inking is a physic-chemical process used to separate flocculated ink particles from the de-inked fibres; it utilizes the difference in surface properties of flocculated ink particles and the de-inked fibres by application of appropriate chemical variables and process variables. The process is reverse flotation in that the desired products are collected in the tailings / sink stream while the undesired particle are collected through the froth phase. It's important to note that when floating the ink particles some fibres end up finding themselves in the froth and so they are lost.

Washing (De-inking) consists of removing all small particles (such as ink and mineral fillers) with water through a screen. Large particles including fibres are retained on the screen.

Bleaching involves the removal of coloured residual lignin from chemical pulp to increase its brightness, cleanliness and other desirable properties, while preserving the strength and carbohydrate yield of the unbleached fibre, with due regard for potential effects on the environment (Ragauskas, 2013). In paper recycling to increase paper strength primary (from wood) bleached pulp is mixed with secondary (from paper recycling) bleached pulp.

Water Treatment and Solid Waste Handling include treatment of waste water so that it can be recycled back in to the system, precipitation of chemicals so that they can be reused back in to the system, treatment of remaining waste for easy and environmentally safe waste disposal. It also involves safe deposition of solid waste and/or recycling the solid waste to generate compounds that may be recycled back into the system (Usherson, 1992). The figure 3 shows ~~below~~ a typical deinking flow sheet for the recycling paper (Ma, 2000).

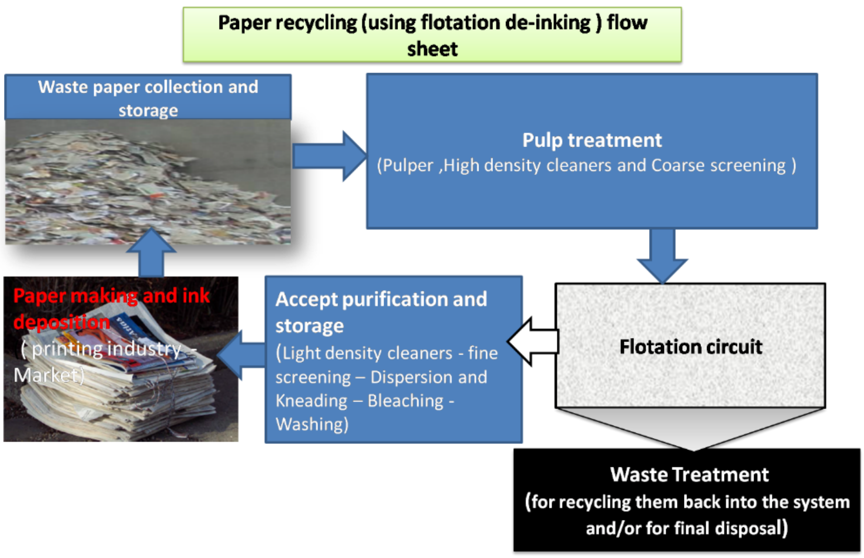

Figure 3: Shows a Typical Flow sheet for the recycling of waste paper.

Flotation Deinking.

Processing of materials by floatation involves the understanding of the interaction between the three components of flotation processing. These include the chemical characteristics of the material, the chemistry and the process variables by which the system is controlled (Fuerstenau, 1988).

The Chemical Characteristics of the Materials.

Deinkability behaviour of a material depends mainly on four factors; Ink type, Printing technique and printing conditions, aging of the print and Paper surface. These four factors can be grouped into two main categories namely Ink properties and Paper surface (Crozier, 1992).

- Ink particles

The Concise Oxford English Dictionary defined ink as “a coloured fluid used for writing, drawing, or printing.” In general an ink particle is composed of colorants, binders, driers, carrier substances and ink additives or modifiers. The ink may be water based or oil based. The composition of inks used for offset printing (most common for e.g. newsprint) and rotogravure printing (common for e.g. magazines) may vary. For example, offset inks have a higher viscosity, while rotogravure inks are less viscous. Most inks are hydrophobic, which is a good prerequisite for the deinking chemistry to work. Some inks are very difficult to remove, and so paper or board printed with such inks has to be recycled separately from others (Aisbl, 2015). The hydrophobic properties of ink particles is due to the presence of surfactants in the soaps of metals and Wetting agents sub components of ink, the following table 1shows the main and sub-components of ink and their functions (Lare, 2005).

Different types of inks have different particle size and applications, the size of the ink particles is important in determining the separation process which is best applicable in removing the ink particles.

Glembocki (1961) contends that paper made materials usually contains above 90% cellulose fibres which are the principal structural constituent and the cellulose component (which consist of the β-anhydro glucose units with dominant hydroxyl groups) are responsible for the chemical properties of paper. Glembocki(1961) furthes agues that the source of this fibre includes; mostly wood but also non-wood raw materials such as bagasse, cereal straw, bamboo, reeds, esparto grass, jute, flax, and sisal. Investigations by Schwinger and Dobias (1991) have shown that the chemical and physical characteristics of cellulose are reduced upon rewetting because of changes in the basic structure during swelling caused by alkaline environment and this reduces the fibre bonding potential, due to elimination of H-bonding sites for liquids. Thus unlike metals, paper cannot be recycled indefinitely, so it required in paper recycling that virgin (from wood) paper pulp should be mixed with recycled paper pulp to increase fibre strength on final paper product (Larsson, 1987).

Chemical used in de-inking.

Gullichsen (2000) contends that, Sodium hydroxide is used to adjust the pH towards the alkaline region and thus it; Promotes fibres welling and so help the mechanical release of the stiffer ink from the fibre surface. Also saponifies the fatty acids, hydrolyses the ink resins and also causes an ionization of the carboxylic groups of the cellulose fibres. This result in release of the ink due to ionization of fibres the ink´s surface groups, saponification fatty acids and hence generation of electrostatic repulsive forces, mechanical stress at the ink/fibre interface after swelling.

Husovska and Veronika(2013) ugued that, Hydrogen Peroxide forms a per hydroxyl anion (HOO^-) in water which attacks the groups causing yellowing (that occurs with the addition of sodium hydroxide) in the lignin called chromophores. The hydrogen peroxide can also break the chemical cross-linkage that is formed between alkyl binders of the ink when stored and dried. Husovska and Veronika (2013) further contends that Sodium silicate stabilize the hydrogen peroxide by inactivating the metal ions in the process causing breakdown of hydrogen peroxide and by maintaining a stable pH an optimization of the effect of the hydrogen peroxide is acquired, to a small effect improves dispersion of ink, due to attachment to colloidal particles, Sodium silicate or water glass is frequently used in conjunction with sodium hydroxide, especially in the de-inking of ground wood papers. It not only serves as an alkali to swell fibre and as a dispersant of ink particles, but also buffers the pulp to a pH range which is favourable to the action of hydrogen peroxide.

Surfactants may be Anionic, Cationic and Non-ionic. Venditti (2008) and Yulin (2004) ugued that surfactants perform three functions: as a dispersant to separate the ink particles from the fibre surface and prevent the re-deposition of separated ink particles on fibres; as a collector to agglomerate small particles to large ones and change the particle surface from hydrophilic to hydrophobic; as a frother to generate a foam layer at the top of the flotation cell for ink removal, shorter chain fatty acids enhance the foaming ability but ink removal is reduced.

Sodium Hydrosulphite is mainly used as a reductive bleaching agent to bleach recycled pulp and to decolorize the coloured fibres (Gullichsen, 2000).

These compounds are commonly added in the Pulper to form complexes with multivalent metal ions to prevent peroxide decomposition. DTPA and EDTA are the most common chelates used in the paper recycling industry. However, compounds like DTPA and EDTA have been banned in some countries, for example, Sweden and Norway (Chiras, 1997).

Dispersants: Sodium tri-polyphosphate and tetra sodium pyrophosphate are sometimes added to the Pulper to provide multiple functions such as ink dispersion and metal chelating. Use of laundering anti-re-deposition agents such as carboxy-methylcellulose and sodium poly-acrylate can also help disperse the ink particles, prevent re-deposition of ink on the fibre, and increase de-inked pulp brightness.

Solvents: Organic solvents were once widely used to dissolve waxes and varnishes, but environmental concern has curtailed the use of these chemicals. Solvents used in wastepaper deinking include C-12 to C-14 hydrocarbons and glycol ethers (Matis, 2009).

Water hardness ($CaCl_2$): In newsprint flotation, fatty acids or soaps are used as ink collectors, and a moderate amount of calcium ions 100 to 300 ppm is required to make the ink floatable. No additional hardness or calcium ions are added when non-ionic surfactants are used (Sevenssons, 2011).

Mechanism of ink removal.

The flotation de-inking process involves a lot of complex steps; as a result of it's of complexity there are five different mechanism models proposed (Sevenssons, 2011). These include; the Schweitzer mechanism, the Bechstein mechanism, the Ortner mechanism, the Hornfeck mechanism and the Larsson-mechanism, with The Larsson mechanism being most widely accepted.

In the Schweitzer mechanism, soap is considered to adsorb on the ink surface thus lowering the surface energy on the ink particle, after detaching; ink particles are collected by air bubbles to the froth phase. The Schweitzer mechanism does not take into consideration the surfactant adsorption on bubbles or the effect to of Ca^{2+} on soap.

The Bechstein mechanism focuses on the collector (being precipitated soap) of suspended ink particles and the blowing in of air bubbles resulting in the flotation these hydrophobic ink particles.

The Ortner mechanism is similar to Bechstein mechanism, however the Ortner mechanism is divided into three steps and they include;

- Soap adsorption to ink particles
- the generation of a system constituted by ink particles and air bubbles and
- Calcium ions acting as bridge between ink and bubbles.

The Hornfeck mechanism; takes into account the negative electrical charge of the ink surface on the soap adsorption. But Soap is not adsorbed by its hydrophobic part instead they precipitated on the ink particle resulting in the ink particles to be hydrophobic and being floated by air bubbles.

In the Larsson-mechanism (1987) the main parameters of the process are regarded to be the Zeta potential, the concentration of Ca^{2+} ions, the precipitation of soaps and the agglomeration of ink particles. The Larsson-mechanisms based on five phenomena taking place in the process, these include an alkali ionizes the fatty acids $R - COO^{-}$ at the ink surface providing stabilization for the suspended ink particles.

1. The adsorption of surface-active agents at the surface of the ink particle is driving the dispersive interaction between the ink and surfactant.
2. Addition of Ca^{2+} ions increases the negative zeta potential of the dispersed particles and causes formation of calcium soap particles on the surface, making the particles even thus more hydrophobic.
3. The repulsive forces and the increase in surface energy cause ink particles to agglomerate.
4. The hydrophobic particles are easily floated by air burbles, due to their increased size.

Mechanisms of fibre loss.

The solid material in the froth that is removed in the rejects stream is commonly referred to as ***"stoke loss".*** It consists of ink, fillers, fibres and fines (Turvey, 1993). In paper recycling, the reported amount of pulp loss varies. For instance, Zabala and McCool (1988) reported stoke losses of 8% on a full-scale deinking system, of which 3%wasfibre. Linck et al. (1987) reported the total losses in two deinking plants to be 9.7 and4.8%, with the pulp losses (fibres and fines) king between 4.5% and =0.25%, respectively. In various laboratory studies, fibre losses of 2 to 65% have been reported (Galland et al. 1977; Petri 1994; Schwinger and Dobias 1991; Liphard et al. 1993).

Selective Flotation.

The fibre particles whose ink is not fully dethatched from its surface or the fibre particles were ink re-deposition has occurred on its surfaces has its surface rendered hydrophobic by the surfactants and consequently these particles may end up finding themselves in the reject stream (Wills, 2006).

Physical Entrapment.

Some de-inked fibres may find themselves in the reject stream because they get trapped between the bubbles as the air bubbles to the froth phase. Once taken to the froth phase ink re-deposition occurs on its surfaces and its surface is rendered hydrophobic by the surfactants and consequently these particles end up finding themselves in the reject stream as well (Ma, 2000).

Entrainments Mechanism.

Another mechanism by which fibre loss occurs is by entrainment. In this mechanism, the pulp fibres and pulp fines are hydraulically transported into the froth along with the floated water**.** The phenomenon of entrainment is well-documented in the literature on mineral flotation, as it explains the unwanted recovery of hydrophilic gangue in flotation cells (Schuberg, 1982). Surfactant spray technique can be applied to almost all paper grades to improve the total performance of flotation deinking, Significant cost savings, reduce surfactant usage and carryover reduce water treatment costs (Venditti, 2009).

Flotation circuits.

Flotation is done in Roughing, Cleaning and the Scavenging stages to improve its efficiency where each stage consists of a series of flotation cells. Each stage has a specific purpose. (Kawatra, 2015).

- **Roughing** flotation recover as much of the valuable material as possible, with less emphasis on the quality of the Accept product, but removal of undesirable materials as much possible. (Glembocki, 1961).
- **Cleaning** subjects the Accept product of roughing especially flocculated ink to further removal to produce as much deinked paper pulp as possible. The Reject from the cleaning step may be returned to the rougher step.
- **Scavenging** The rougher flotation Rejects is often taken to the scavenger flotation step whose main purpose is to recover any of the fibres that were not recovered during the initial roughing stage (Wills 2006). This might be achieved by changing the flotation conditions to make them more favourable for less fibre loss. The Accept from the scavengers step is returned to the pulping stage or even the rougher feed for refloating. The reject from the scavenger cells may be

3. Methodology.

The experimental procedure was conducted as follows:

i. Zambia Daily and Times of Zambia newspapers were cut into the sizes of 10 by 20 mm by hands.
ii. The cut papers together with tap water and other chemicals were placed in the Denver flotation cell in order to make the pulp, whilst keeping the air valve fully closed. When the pulp was fully formed, the air valve was then completely opened to allow for flotation process to take place.

Venditti (2008), contends that consistency may be expressed as shown in equation 3 below.

$$\boldsymbol{consistency} = \frac{\boldsymbol{mass\ of\ paper} \times \mathbf{100}\ \%}{\boldsymbol{mass\ of\ paper + mass\ of\ fluid}} \text{.......................................} [3]$$

iii. The resulting float/concentrate (ink) of the flotation process was taken to a washing screen (100µm) to remove ink from it by water spray. The sink/tail (deinked paper fibres) was also taken to the washing screen (100µm) to remove ink.
iv. The paper from the froth phase and that from the tailings product were drained separately and then allowed to dry in open air. The fibre loss was further determined using formula 4.

$$\boldsymbol{FIBRELOSS} = \frac{\boldsymbol{MASS\ OF\ FIBRE\ IN\ FROTH\ PHASE} \times \mathbf{100}\%}{\boldsymbol{MASSOF\ FIBRE\ IN\ SINK + MASS\ OF\ FIBRES\ IN\ THE\ FROTH\ PHASE}} \text{..................} [4]$$

- All the collected waste water from the froth phase washing screen and the from the sink (tailings stream) washing screen where put together, the total volume was measured and from this a representative sample solution of 10ml was obtained. Blank samples solutions were prepared by getting the paper from Zambia daily mail on which no ink has been printed on, then the subjecting this paper to the same conditions that the waste newspaper was subjected to, then likewise 10 ml of the 100µm screen underflow solution (from float and sink washing screens) was obtained as well, the standard solutions were to be prepared by obtaining the actual ink from Zambia daily mail then preparing several samples of different concentrations(these are called standards solutions) whose ink volume content is known. Then the sample solutions, the blank solution and the standard solutions were to be taken to the UV electro-photometer, which would give the volume of ink contained in the 10ml sample solution, To measure the volume of ink removed from the newspaper, the volume of ink in the measured 10ml sample solution was to be extrapolated to the initial volume from which the 10 ml sample solution was obtained (Ewing, 1986). However there was no money to have the samples tested so ink removal was not analysed.

- After the above parameters were observed, certain values were taken in to order to come up with the complete process for producing clean white paper pulp, the flotation cells conditions suiting the rougher cells, cleaner cells and the scavenger cells were applied to the final process and the pictures were taken of the resulting dried paper pulp.

4. Results and Discussions.

Process flow chat sugestion

The suggested flow chart for the whole process is shown in figure 4. Waste paper to be recycles should first be sorted into a category, for instance newspaper category The pulping sub system's main purpose should be maximising ink detachment from fibres. The rougher cells should be promoting the removal of the dethatched ink as much as possible from the paper fibres. But the cleaner cells are to promote the removal of ink with reasonable fibre loss. Finally the scavenger cell are to promote the prevention of fibre loss as much as possible.

From figure 4, it can be seen that the Rejects (float) from the cleaner cells as well as the Accept (sink) from the scavenger cells may need to be recycled back to the system, whereas the Accepts (sink) of the cleaner cells should be the final product which should proceed to paper making. Furthermore the reject of the scavenger cells should be washed on the 100 µm screen to remove ink (ink is less than 30 µm for newspapers) and recover fibres to be recycled back in to the scavenger cell.

The waste water collected from the exits may need to be recycled back in to the system upon necessary treatment, if possible some chemicals may be precipitated from the waste water so that they can be reused back in to the system if not then the remaining waste may be treated for easy and environmentally safe waste disposal.

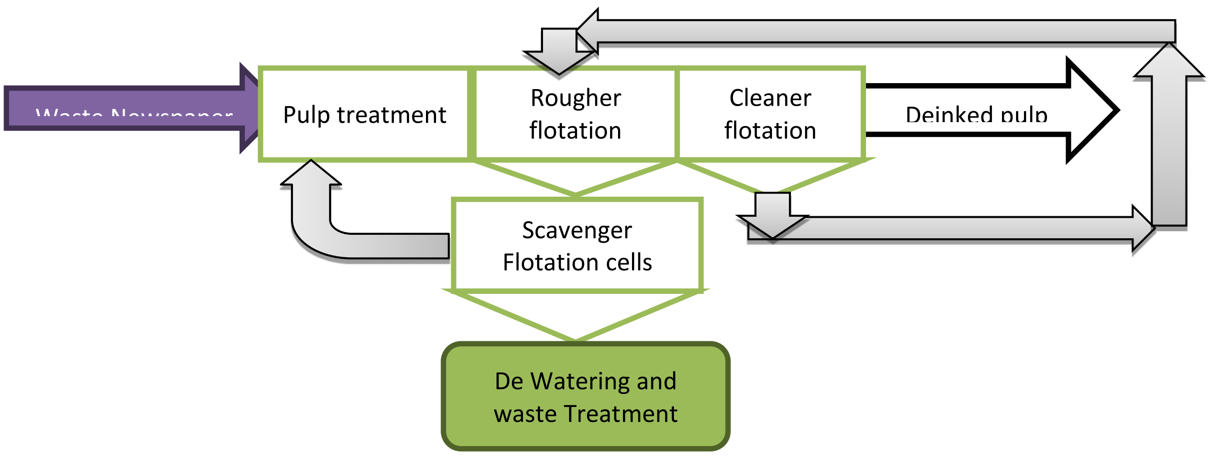

Figure 4: The Suggested process flow sheet for paper recycling.

Data Collection.

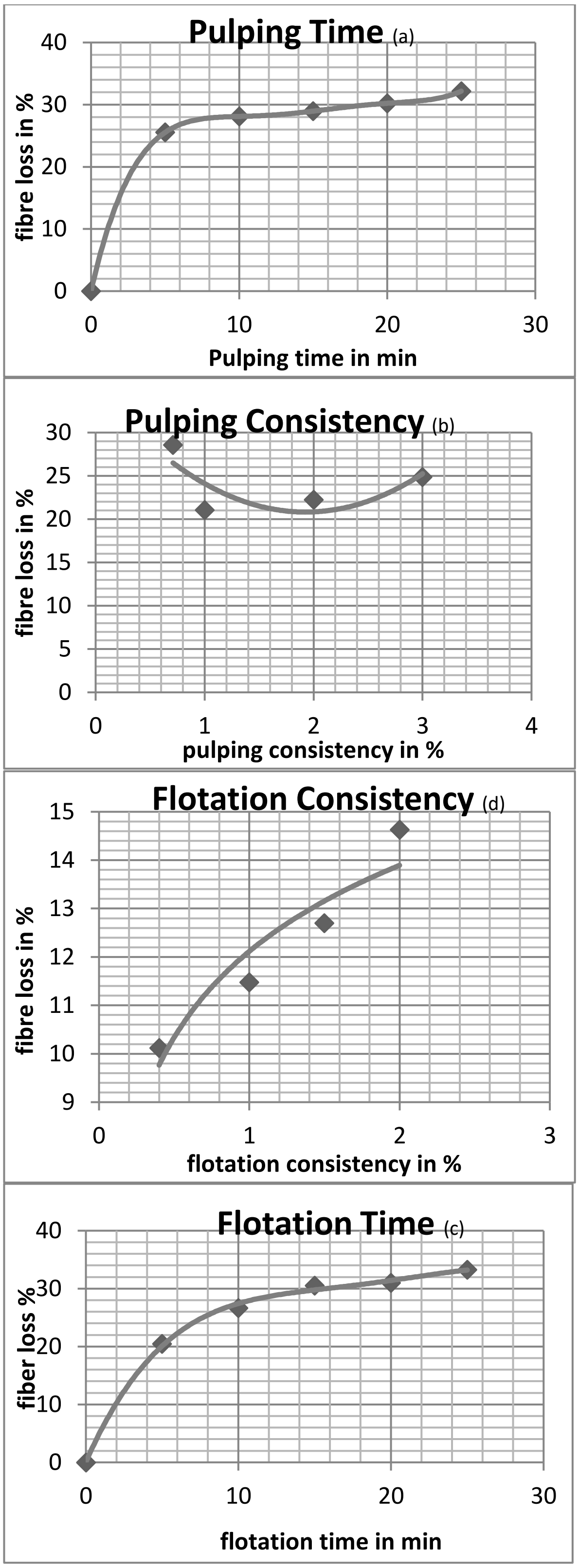

Figure 5: The effects of time and consistence on deinking, (a) pulping time, (b) pulping consistence, (c) flotation time and (d) flotation consistence.

From figure 5 (a) it can be seen that the increase in pulping time resulted in the increase in the fibre loss which could have been due to paper being more and more made in to pulp and hence increase the fibre loss due to entrainment and entrapment of fibre particles during the subsequent flotation. Increase in ink removal could have been due to the promotion of the ink detachment effect due to force from pulping. Figure 5(b) shows that increase in pulp consistency had a parabolic effect on fibre loss. Ink removal was increasing as well, because consistency helped to increase friction during pulping thereby promoting ink detachment effect. Therefore for the actual process pulping time of 15 minutes and pulping consistency of 2% were selected.

From figure 4(a), the effect of pulping time on fibre loss was less especially between the intervals 5 to 25 minutes. In the interval from 0 to 5 minutes the paper was not fully separated in to individual fibres as compared to the time beyond five hence the steep slope. On the other hand from figure 4 (c), increase in flotation time resulted in increase in fibre loss due to the increase in probability of fibre loss due to entrainment or entrapment flotation mechanisms with respect to time. The resulting increase in ink removal with flotation time may have increased air bubble and ink particle collision probability there by promoting true flotation mechanism.

From figure 4(d) Increase in the flotation consistence could result in the increase fibre loss possibly because of entrainment and entrapment mechanisms being at full play. Increase in flotation consistence resulted in the increase in ink removal due to increase in the probability of ink detachment from the fibres which could have been due to the friction as a result of dense pulp, thereby increasing detergency efficiency. Therefore for the actual process flotation time of 15 minutes and flotation consistency of 0.7% were selected.

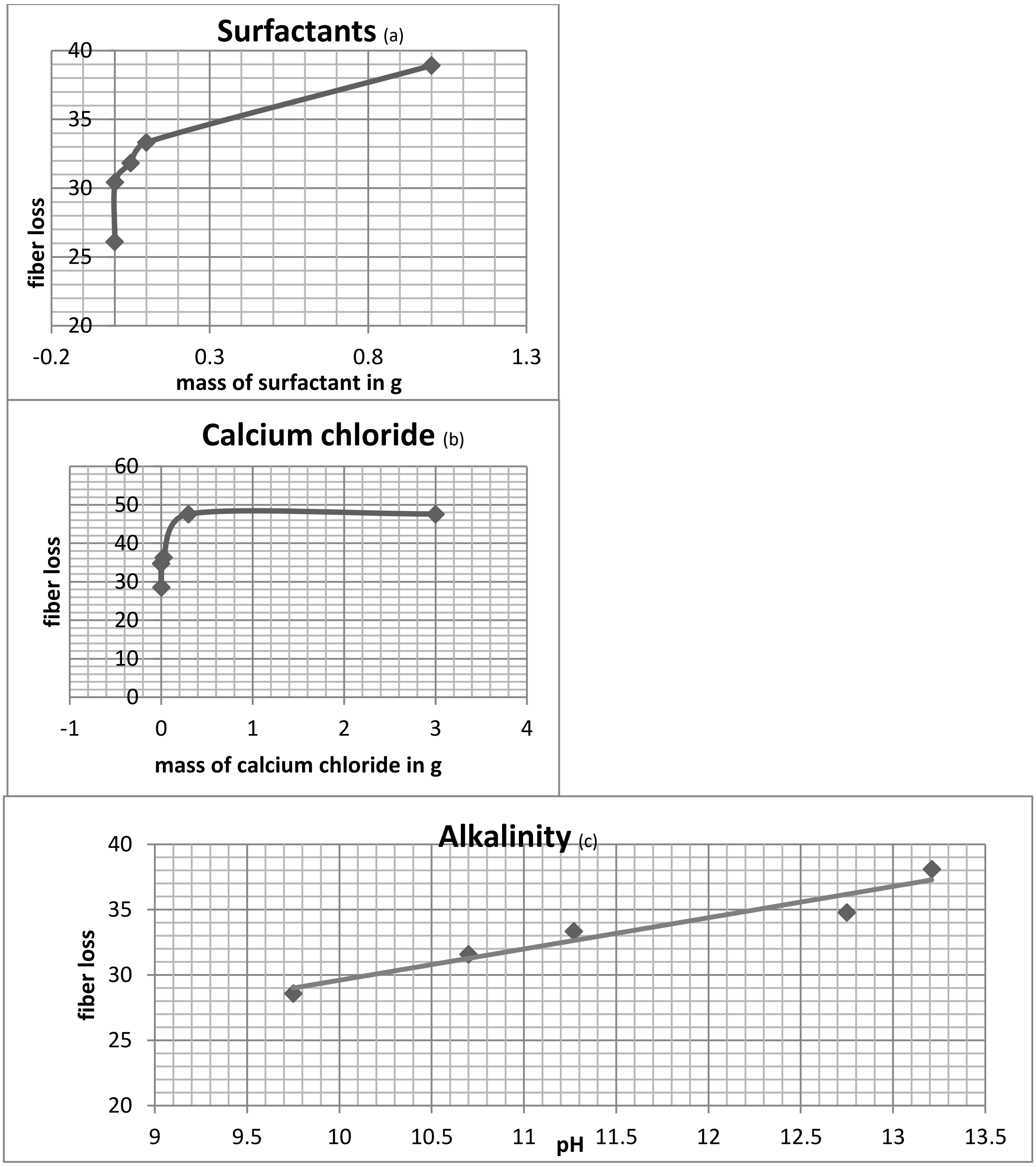

Figure 6: The Larsson mechanism. The effects of (a) anionic surfactants, (b) calcium ions and (c) alkalinity on deinking

It was observed from figure 6(c) that alkalinity increase cause fibre swelling and thus paper was being dispersed in to individual fibres resulting in good ink detachments effect which in turn results in the dispersion of the paper fibres into separated fibres thereby increasing the fibre loss due to entrainment and entrapment of fibre particles. This is a good requirement for the Pulper and rougher cells.

Increase in surfactant as shown in figure 6 (a) could have had caused increase in ink removal up to a critical micelle concentration (CMC) there after its increase was having little or no effect on fibre loss the same trend was observed for ink removal. The water used in the experiment was not distilled and so it had some calcium ions prior to the addition of calcium chloride. Increase in calcium ions as shown in figure ~~5~~ 6(b) could have promoted flocculation of ink particles up to a certain point. Thereafter excess calcium ions added to the system was observed to have little or no in fibre losses could have been due to the decrease in the contacts angle between the air bubble and the fibre particles.

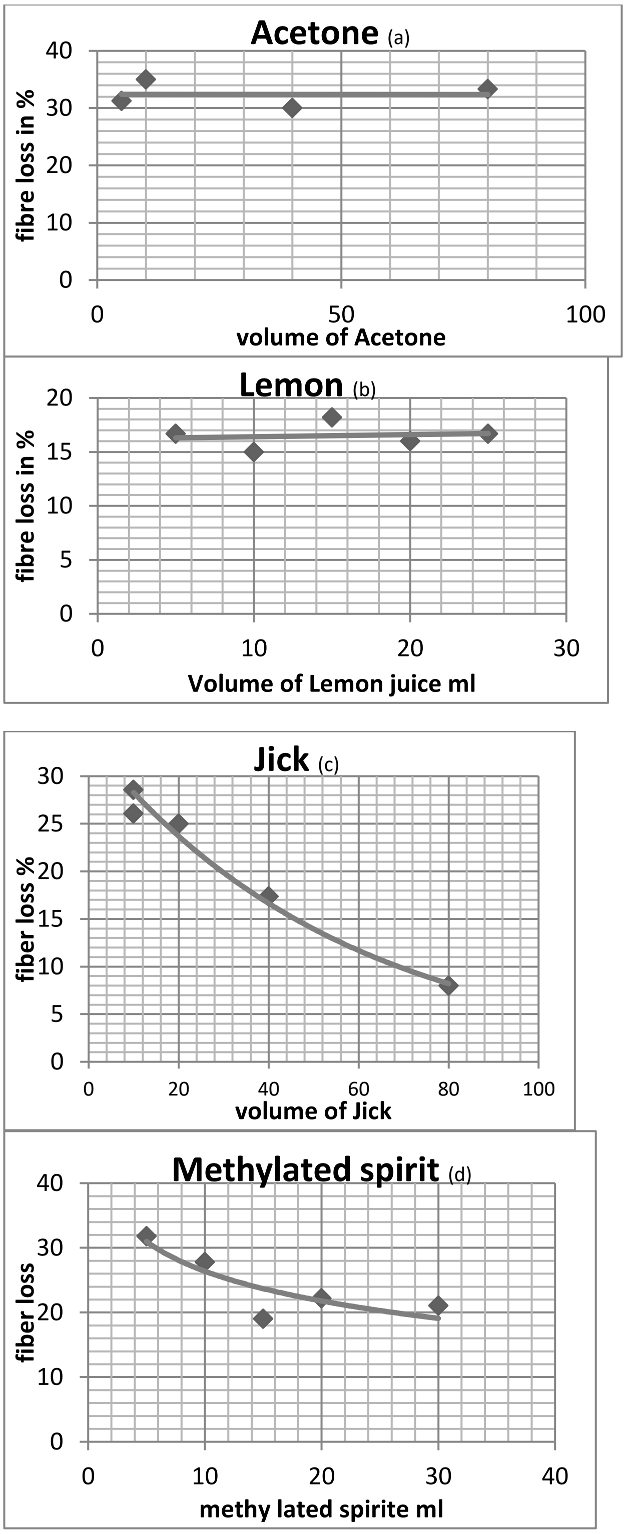

Figure 7: The effect of the concentrations of (a) Acetone, (b) Lemon, (c) Jick and (d) Methylated spirit on de-inking flotation.

From figure 7(d), increases in Methylated spirit quantities had a good fibre loss reducing effect but not as effective as Jick. The froth formed due to its effect was very stable and could rise to higher heights as compared to that of Jick. Therefore the Ink removal due Methylated spirit was more as compared to that of Jick.

Increase in addition of Jick had an excellent effect on the fibre loss reduction as shown in figure 7(c). This could have been probably because it was reducing the contact angle between the air bubbles and the fibre particles but it was leaving a yellowing colour on to the fibres which are partly because Jick is alkaline in pH. The reduction in fibre loss was good requirement scavenger cells.

According to figure 7(a), Acetone had a constant fibre loss of about 32.5 ± 2.5%, this is because its increase was increasing the pH of the process towards the acidic region and for the pH to be brought back to the alkaline pH of 9, sodium hydroxide was being added hence the result. However, acetone was leaving undesired reddish colour on the fibre, coupled with the fact that the 32% fibre loss happened to be too high and as such it was not incorporated in the main process design.

As for lemon as shown in figure 7(b), the fibre loss was constant to about 16 ± 2g. The reason for the constant value of fibre loss was the same as that of acetone, though on the contrary, lemon was observed to have an effect of changing the yellow colour to white colour. In addition to this brightening effect on the fibres, it had half fibre loss in comparison to the Acetone. The results obtained were applied in the suggested process flow sheet (figure 8); in practice it was a batch process. Upon implementation of these results the following were the observations; low fibre loss (5.64 %) was observed in the reject of the scavenger cell due to Jick. This can further be reduced by fine screening the scavenger reject and then recycling the resulting overflow fibres back to the scavenger cells. Ink detachment in the Pulper was high with increasing pulping time and consistency as well as high alkalinity (pH=13.21), but resulted in the colour of pulp turning brown. The conditions for each sub system of the suggested flow sheet were applied according to table 6 of the appendices and the resulting fibres were dried and photo were obtained, the length and width of the photos were between 1.5 cm to 2 cm these photos are shown in figure 8.

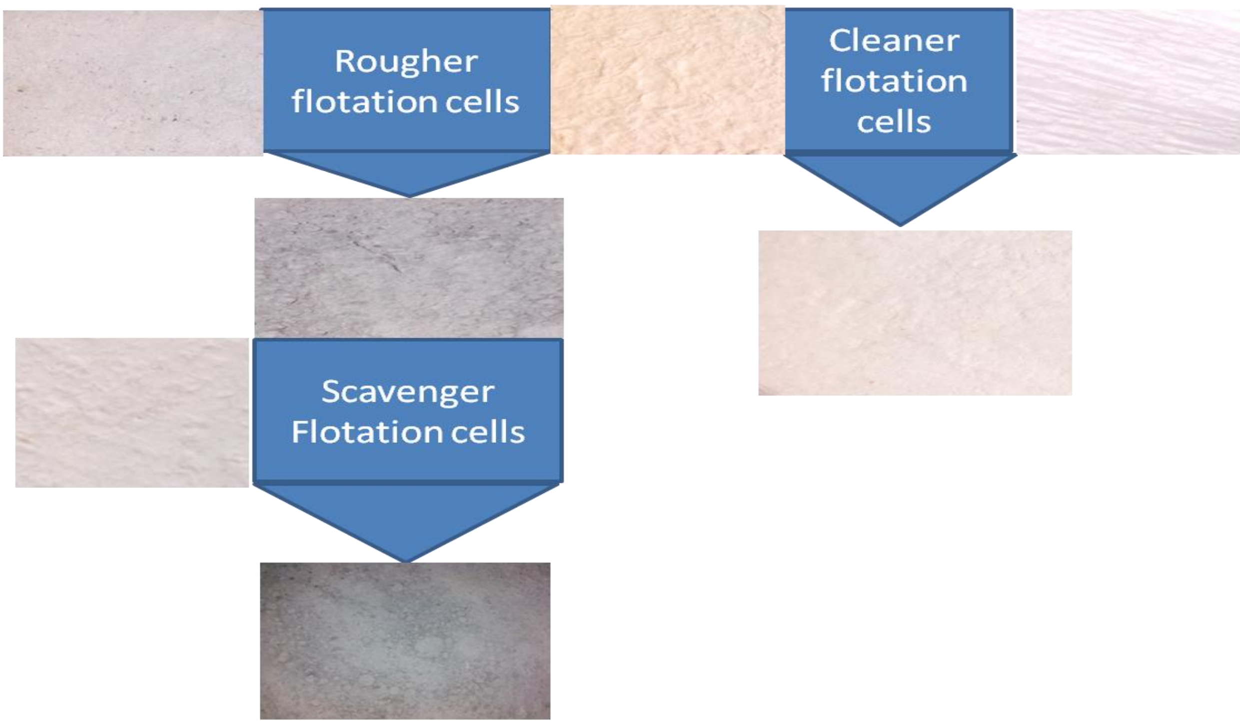

Figure 8: The suggested flow sheet and the analyses of ink removal.

5. Conclusions.

Despite facing challenges in the execution of this work, it was concluded that the newspapers were successfully recycled by producing clean white deinked paper pulp using flotation de-inking technology, from which new paper products can be produced. It was further concluded that the secondary fibres should be mixed with primary fibres in order to increase resulting paper strength. Simplified flow process sheet was suggested as shown in figures 7 and 8. The table 1, below sums up the results of the suggested flow sheet. The first column represents the various sub systems, the conditions to be applied in them and the main objective of each of these subsystems are indicated in the second and third column respectively.

Table 1: The summary of the conditions used in the suggested flow sheet.

Unit	Conditions	Purpose
Pulper	High temperature High pulping consistency High alkalinity High pulping time	Pulp treatment (maximising ink detachment)
Rougher cells	Methylated spirit High flotation time High flotation consistency High alkalinity	To increase ink removal as much ink as possible.
Scavenger cells	Use of Jick Low flotation time High alkalinity Use of flotation column	preventing fibre loss as much as possible
Cleaner cells	Use of lemon juice High flotation time Low flotation consistency Low alkalinity, Reasonable surfactant and calcium ions.	Promoting ink removal as much as possible with reasonable fibre loss.

Bibliography.

Aisbl. (2015). *Paper Making Proceses.* Brussels: Confederation of European Paper Industries.

Bulatovic, S. M. (2007). *Handbook of Floatation Reagents: Chemistry, Theory and Practice: Volume 1* .

Carré, L. M. (2004). *Deinking difficulties related to ink formulation,*. Grenoble: Centre Technique du Papier.

Chiras. (1997). *Environmental Quality*. Washington DC, USA.: Executive Office of the President, US.

Chisanga, C. (2000). *resaerch gate*. Retrieved june 14, 2016, from www.researchgate.net: https://www.researchgate.net/publication/283795980

Crozier. R. D, (1992). *Flotation Theory, Reagents and Ore Testing.* New York: Pergamon Press.

Ewing, G. w. (1986). *Instrumental Methodes of Chemical Analysis.* Singapore: Mcgraw-hill International.

Friends of Earth. (2008, September). *Recycling.* Retrieved june 23, 2016, from www.foe.co.uk.

Glembotski, V.A and Classen, V.I. (1972). *Theory of Flotation, 2nd edn.* Moscow: Nedra.

Gullichsen. (2000). *Chemical Pulping- papermaking science and technology*. Helsinki: Fibreline operration in.

https://www.nla.gov.au. (2016, june 12). Retrieved from Australian newspaper library: https://www.nla.gov.au

Husovska, V. (2013). *Investigation of Recycled Paper Deinking.* Western Michigan: Western Michigan University.

Hanumantha Rao1, *. a. (2011). Challenges in Sulphide Mineral Processing. *The Open Mineral Processing Journal*, 4, 7-13.

Kawatra, S. (2015). *Flotation Fundamentals.* MTU Chemistry.

Larsson, A. (1987). *Surface Chemistry in Flotation Deinking.*

Ma, C. J. (2000). Enzymatic Deinking Technologie. *De-Inking of waste paper*, 8.

Matis, K. A. (2009). *Innovations in Flotation Technology.* NATO ASI Series.

Miller.J. (1988). *Environmental Science.* California: Wadsworth Publishing Company.

Mining Chemicals HANDBOOK. (2004). CYTEC.

ministry of mines and mineral development. (2016, june 1). Retrieved from www.mines.gvt.zw: www.zambia- mining .om

NZ Institute of Chemistry. (2002). Printing Ink Technology and Manufacture. *Chemical Processes in New Zealand*.

Orlando .j and Rojas, O. (2016, june 20). *http://www4.ncsu.edu/~ojrojas*.

Princples of Flotation. (2006). Retrieved March 2013, from GlobalSpec: http://www.globalspec.com

Ragauskas, A. J. (2013). *Basics of Bleaching Chemical Pulps.* Georgia: Georgia Institute of Technology.

Retner. (2008, april 25). *Inkjet prints are not deinkable*. Retrieved june 16, 2016, from http://blog.tonercartridgedepot.com/2008/04/25/.

Schwinger, K. A. (1991). *The Influence of Calcium Ions on the Loss of Fibre.* 1st. Res. Forum on Recycling.

Sevenssons. (2011). *The influence of surfactant chemistry on flotation.* G ö t e b o r g: Chalmers.

United Nations. (2015). *The Millennium Development Goals Report.* New york: United Nations.

Usherson, J. (1992). Recycled paper and sludge. *Recycled Paper News,*.

Using Statistical Experimental Design Techniques to Determine the. (n.d.). 26.

Venditti, R. A. (2008). *Reducing Fiber Loss In Laboratory and Mill-scale Flotation Deinking using Surfactant Spray Technology.* Wood and Paper Science -- NCSU.

Weiss, N. (1985). *SME Mineral Processing Handbook.* New York: SME/AIME.

Wills, B. A(1988). *Mineral Processing Technology. 6th ed.* Oxford:Butterworth-Heinemann.

Wills, B. A and Napier-Munn, T. (2006). *An introduction to the practical aspects of ore treatment and mineral recovery* (7th ed.). Oxford: Butterworth-Heinemann.

Yulin Zhao, D. (2004). *Roles of Surfactants in Flotation Deinking.* N. W., Atlanta,: Georgia Institute of Technology.

Small and Medium Enterprises (SMEs) and Industrialisation in Zambia: Challenges and Opportunities.

Happy Musumali[1]

Abstract

The aim of the study was to investigate the performance of Small and Medium Enterprises sub-sector in the Zambian economy in driving the country's industrialisation transformation and development. The objectives of the study were to; (i) outline the factors that hinder the performance of the sub-sector, (ii) outline opportunities that exist in the sub-sector, (iii) outline remedial measures to make the sub-sector vibrant. Data for the study were collected between July 2015 and June 2016. Primary data were collected using structured questionnaires and secondary data were obtained from published literature and reports.

Results obtained showed that there were a number of factors that hinder Small and Medium Enterprises. These factors range from access to finance to lack of access to modern technology. Regarding the potential opportunities for Small and Medium Enterprises in Zambia to rebound and play the crucial role of engine of growth. The study revealed that the sub-sector has not utilized the enabling business environment that the government had provided. The results further showed that remedial actions needed to be undertaken to improve the performance of the sub-sector such introduction of entrepreneurial studies at all levels of our educational system. This study has established that the sub-sector played and continue to play significant role in the growth, development and industrialization of many economies. In Zambia, Small and Medium Enterprises have performed below expectation in fostering industrialisation.

Keywords: SMEs, Industrialisation, Economic development, Wealth Creation, Central government

1. Introduction

Micro, Small and Medium scale enterprises was a major tool used by developed nations to attain socio- economic development. In recent times, small scale industrial sector has become the backbone of modern day economies in creation of employment in the informal sector, increasing the tax base for the country and improving incomes for the low earners (MCTI, 2007). Historical facts show that prior to the late 19th century, cottage industries for instance mostly small and medium scale businesses controlled the economy of Europe. The Industrial Revolution changed the *status quo* and introduced mass production (Thomas, 2001). The twin oil shocks during the 1970s however, undermined the mass production model, which triggered the unexpected

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reappraisal of the role and importance of small and medium sized enterprises in the global economy (Wendrell, 2003).

There is a consensus that if all stakeholders are to show serious commitment to the development of the SMEs sub-sector, it follows that the economy must necessarily witness meaningful transformation and prosperity. A dynamic SME sub-sector is vital and imperative for the overall economic development of the country. Aside from providing opportunities for employment generation, SMEs help to provide effective means of curtailing rural-urban migration and resource utilization. By largely producing intermediate products for use in large–scale companies, SMEs contribute to the strengthening of industrial inter-linkages and integration. A vibrant, efficient and effective SME sub-sector generates many resultant benefits for stakeholders, employees, customers, employers as well as the entire economy's benefits. Employees require new skills and knowledge to improve their performance on the job and to compete with their counterparts in other parts of the world. Customers on their part tend to enjoy personalized service and attention because of the keen competition, focus and innovation, which characterise the operations of SMEs. Employers or rather SME entrepreneurs on the other hand are either motivated or compelled by competition to learn and broaden their knowledge and skills in order to meet up with the challenges of maintaining good relationship with their financiers (banks and other financial institutions), auditors, regulators and even their competitors. They achieve this by belonging to and participating actively in the activities of appropriate chambers of commerce, trade groups, various for and exhibitions where ideas, new concepts and knowledge are shared and discussed. The bottom line of all these is that the relevant SME would remain efficient and profitable and hence contribute to the growth and development of the entire economy.

1.1 Background

In Zambia, the practice of Small and Medium enterprise (SME) sector has had no policy since independence in 1964 until the early 1980s. Chisala (2008) reviewed that the country had no special legal framework aimed at promoting small and medium scale enterprises because the economy was enjoying the high global prices of copper in the world hence ignoring micro, small and medium enterprises sector. Copper prices eventually collapsed in the mid 1970s at the time when oil prices soared to U$D 53.54/barrel. With decreasing profitability in the copper industry the Zambian government sought alternative ways of sustaining its economy by promoting the Small and Medium Enterprises sub-sector (Chisala, 2008).

It was in the 1980s that the government realised the vital role of the Micro, Small and Medium Enterprises sector in contributing to the social economic development of the country and it recognised that they were operating under extreme financial difficulties leading to the enactment of the Small Industries Development (SID) Act of 1981 to make the sector more orderly and effective (MOF, 2002; FSD Zambia, 2009) aimed at enhancing the contribution of the sector to the national economy by addressing the inherent sector challenges. In the same year another Small and Medium Enterprises came dubbed Small Enterprise Development Organisation (SIDO), which was aimed at helping to improve on SID Act of 1981 (Kingombe, 2004; MCTI, 2007). In 1996, the Government of the Republic of Zambia repealed the small Industry Development (SID) Act of 1981 and established the Small Enterprises Development Board (SEDB) to provide for the development of Small and Medium Enterprises Development Act No. 29 of 1996.

Since the United Nation Independence Party (UNIP) government's era subsequent administrations have formulated policies to foster creation of financial institutions designed to provide lending services to Small and Medium Enterprises. In the late 1990s, the government started implementing the Structural Adjustment Program (SAP), which was aimed at enabling the Government to access international funding from the international community that included the International Monetary Fund (IMF) and the World Bank Group. It was anticipated that SAP would bring about high economic growth (SAP Monitor, 2000) that would trickle down to the citizens and uplift their living standards, instead the program brought about extreme poverty among majority of Zambians. The program entailed privatization of state owned companies, devaluation of the currency (kwacha), curtailment of credit supply, increase of interest rates, promotion of investment and export and retrenchment of workers.

The government has put in place policies and established to promote and coordinate investment activities in the country with a view to stimulate economic growth leading to the creation of the Zambia Development Agency (ZDA) Act of 2006, which is responsible for monitoring, the activities of SMEs in the country and is responsible for their development and establishing strategic partnerships. Further government enacted another Act called the Citizen Economic Empowerment Commission Act of 2006 that saw the creation of the Fund aimed at providing finances to SMEs in the country. Despite such efforts the country still faces major challenges to provide financial assistance to the sector in order to enhance industrialisation through SMEs.

The small and medium enterprises survey (2003-2004), indicated that from 1991 to 2001, Zambia experienced the most severe economic recession largely owing to public policy shifts. The drastic opening up of the domestic market to low cost and high quality foreign products made the hitherto protected and inefficient local producers to be uncompetitive. In order to stay afloat, most of enterprises were forced to restructure and reduction of labour ranked among the first options. Where downsizing was not attainable, most of the firms closed down. The result was a decline in the Gross Domestic Product (GDP) and employment, and in the absence of corresponding social protection measures, poverty increased drastically among Zambians. The continued deterioration in the performance of the economy and hence the living conditions in spite of the adoption of free market economic policies induced government to explore an alternative development strategy within the free market economic framework. In collaboration with the external and local cooperating partners, the Poverty Reduction Strategy Paper (PRSP) anchored on the Millennium Development Goals (MDGs), was adopted as the principal national policy. Through the poverty reduction strategy paper, Zambia hoped to attain the minimum social and economic pre-conditions necessary for take-off on to the path of sustainable development.

2. Literature Review

The experiences of developed economies in relation to the roles played by SMEs buttresses the fact that the relevance of SMEs cannot be overemphasized especially among the Less Developed Countries (LDCs) or rather Developing Countries. In order to highlight the significance of SMEs in relation to the growth and development of a given economy, SMEs have been variously referred to as the “engine of growth”. This stems from the fact that almost all countries that have focused on the SMEs sector and ensures its vibrancy have ended up succeeding in the significant reduction and its attendant enhancement in the quality and standard of living, reduction in crime rate, increase in per capita income as well as rapid growth in Gross Domestic Product (GDP) among other salutary effects.

In the European Union, micro, small and medium scale enterprises account for 99.9 percent of the 11.6 million businesses created in the bloc (World Bank, 2006a). In America, the United States, micro, small and medium scale enterprises created over 75 percent of the new jobs contributing 40 percent of Gross Domestic Product and 80 percent of the population got their first employment in the micro, small and medium scale enterprises (World Bank, 2000). In Japan, small and medium firms secured capital of up to one hundred million Japanese yen (US$ 925,926) and employees were involved in manufacturing.

In many countries in Africa, micro, small and medium enterprises have been at the forefront of accelerated economic growth (Nuwagaba, 2015). Most micro, small and medium enterprises in the Southern African Development Community (SADC) region employ at least about 50 employees depending on their size which reduces the burden of unemployment from states (Tshuma and Jari, 2013).

Operation of small and medium enterprises is however difficult in many African countries partly due to corruption, the more reason why at least 70 percent of small and medium enterprises reported corrupt practices as hindrance to their growth (World Bank, 2005). Most African economies were poor and corrupt and such practices made the operations of medium enterprises very difficult and noncompliant a factor responsible for circumnavigating regulatory requirements (World Bank, 2005). The same study revealed that Ethiopia had more than 73,000 micro, small and medium enterprises which employed more than 551,075 out of a total population of 87.1 million people persons but the survival of small and medium enterprises in Ethiopia remained a big challenge due to lack of political will and poor attitudes towards them. Generally there was a poor business environment (Devereux, 2010; Mader, and Winkler, 2013) for micro, small and medium enterprises to grow.

In Nigeria, the Nigerian bank for commerce and industry (NBCI) provided loans and equity investment to small businesses to help in the development of Micro, small and medium scale enterprises in the country (Anyanwu, 2001). In addition, the national economy recovery fund was established to promote micro, small and medium scale enterprises by providing medium to long term loans (5-10 years) to those in Agro-Allied industries, industrial support services mining, quarrying, equipment leasing and other ancillary projects. The Nigerian federal government provided their part contribution towards the project and the African development bank contributed the remaining counterpart fund (Izedomi, 2011). In addition, the formation of small and medium scale industries apex unit within the Central Bank of Nigeria assisted in the disbursement of World Bank $270 million loan to small scale entrepreneurs.

In Zambia, in 2014, of the 5,859,225 employed persons, 944,256 persons were working in the formal sector representing 16.1 percent while 4,914,969 persons were in the informal sector, representing 83.9 percent. In Luapula Province, of 411,845 employed persons, 25,044 were employed in the formal sector which represented 6.1 percent and 386,801 were employed in the informal sector which represented 93.9 percent (Zambia Labour force survey, 2014).

Earlier in 2012, the Bank of Zambia, showed that micro, small and medium enterprises provided sustainable economic growth through job creation, development of entrepreneurial skills and had a potential to contribute significantly to export earnings (Gondwe, 2012). However, provision of finance to the micro, small and medium enterprises sector in Zambia still remained a challenge and a survey conducted by the World Bank (2007) identified poor access to finance as a major impediment to investment and growth in Zambia.

2.1 Definition of micro, small and medium enterprise

Small and Medium Scale enterprises vary with culture and peculiar circumstances of the person attempting the definition. The definitions depend on the purpose and the policies which govern Micro, Small and Medium Enterprise sector in each country (Chishala, 2008). Three parameters generally apply, singly or in combination, capital investment, volume of production or turnover of business and the number of employees. This study has adopted the definitions that were recommended by the Ministry of Commerce Trade and Industry survey (MCTI survey, 2003) on Small and Medium enterprises which was carried out to update the definition of Small and Medium Scale Enterprises based on the capital investment, turnover of business and number of employees,.

2.1.1 Micro scale enterprises

A micro enterprise was defined (MCTI SME survey, 2003) as any business enterprise registered with the Registrar of companies whose;

(i) total investment excluding land and buildings shall be up to K80, 000 (U$D 8,000).

(ii) annual turnover was up to K150,000 (U$D 15,000).

(iii) number of employees was up to ten (10) person.

2.1.2 Small scale enterprises

A small enterprise was defined (MCTI SME survey, 2003) as any business enterprise registered with the Registrar of companies whose;

(i) total investment, excluding land and building for manufacturing and processing enterprises, was between K80,000 – K200, 000 (U$D 8,000 – 20,000) in plant and machinery, for trading and service providing enterprises shall K150,000 (U$D 15,000).

(ii) annual turnover was between K151,000 - K300,000 (U$D 15,100 -30,000).

(iii) number of employees was between eleven and forty nine (11- 50) persons.

2.1.3 Medium scale enterprises

A medium enterprise was defined (MCTI SME survey, 2003) as any business enterprise larger than a small enterprise registered with the Registrar of companies whose;

(i) total investment, excluding land and building for manufacturing and processing enterprises, was K201,000 – K500, 000 in plant and machinery, for trading and service providing was K151, 000 – K300,000 (U$D 15,100,000 – 30,000,000).

(ii) annual turnover was K300,000 - K800,000 (U$D 30,000 – 80,000).

(iii) number of employee between Fifty One and One Hundred (51 -100) persons.

2.1.4 Informal Enterprises

An informal enterprise was defined (MCTI SME survey, 2003) as any business enterprise not registered with the Registrar of companies whose;

(i) total investments excluding Land and Building was up to K50, 000 (U$D 5,000).

(ii) number of employees less than Ten (10) persons.

One major drawback in Zambia's quest for industrialisation development over the past years has been the absence of a strong, vibrant and virile SME sub-sector. Given a population of well over 13million people, vast productive and arable land, rich variety of mineral deposits, as well as enormous human and other natural resources, Zambia should have been a haven for Small and Medium Enterprises with maximum returns as it also has the location advantage as a marketing hub for the Central, Southern and East African Countries.

Instability due to frequent change of governments and high turnover had negatively affected the performance of primary institutions responsible for policy enunciation, monitoring and implementation resulting in distortions in the macroeconomic structure and its attendant low productivity. These and other problems constitute drawbacks to the development of SMEs, which to all intents and purposes provide the critical building blocks for sustainable industrialisation and economic growth. In developing countries like Zambia, there is the dire need to create an enabling environment for the nurturing and development of SMEs so that they could play the crucial roles expected of them in economic transformation. The key roles of SMEs include mobilization of domestic savings for investment, significant contribution to GDP, harnessing of local raw materials, employment creation, poverty reduction and alleviation, enhancement in standard of living, increase in per capita income, skills acquisition, advancement in technology and expert growth and diversification.

2.2 Financing of Small and Medium Scale Enterprises in Zambia

The Government has formulated and implemented legislative frameworks to create enabling environment for the development and promotion of micro, small and medium enterprises. Such instruments facilitated financing loans or equity participation and fiscal incentives designed to aid their growth and rapid development. It was on this basis that financial institutions such Zambia National Commercial Bank (ZANACO), Zambia National Building Society (ZNBS) and the Development Bank of Zambia (DBZ) were established through Acts of parliament from as far back as 1970 to provide financial services to micro, small and medium enterprises. Liberalisation of the public sector in 1991 provided financial services to MSMEs (ZSMES, 2003). The Small Industries Development Organisation (SIDO) Act of 1981 was enacted to enhance the contribution of the sector to the national economy. Other agencies and programmes were the Zambia Development Agency (ZDA), Industrial Cluster Development (ICD), Youth Empowerment (YE), Citizen Economic Empowerment Fund (CEEF), creation of Multi Facilities Economic Zones, Adoption of the Poverty Reduction Strategy Paper (PRSP, 2000) and the establishment of vision 2030 (GRZ, 2006), to enhance among other things the growth and development of MSMEs.

According to Gondwe (2012), commercial banks in Zambia had increased their support to realized MSME sector such that by end of December 2011, commercial banks financial support to Micro, Small and Medium Scale Enterprises had increased to 21 percent of total loans, an improvement from 17 percent in December, 2010. This was an increase of 68.9 percent or (K2,322.5 billion from K1,375.0 billion (U$D 232.25 billion from U$D 137.5 billion) in 2010.

2.3 Government Inadequacies towards Small and Medium Enterprises

According to Chisala (2008), macroeconomic reforms undertaken by the government of Zambia aimed at liberalisation of the economy and privatisation of state owned companies among others, had not benefited the sector. SMEs continued to experience constraints that hinder their growth in Zambia. The study revealed that following government inadequacies;

(i) inadequate policy framework thus the absence of a comprehensive policy framework to give direction to efforts and plans aimed at supporting the sector. The Zambia Development Agency Act of 2006, was far beyond the reach of most Small and Medium Enterprises. Under this Act, incentives were only granted to investors with qualifying assets of K5,000,000 (U$D 500,000),

(ii) difficulties in filling skills level capacity gaps for Small and Medium Enterprise by thegovernment,

(iii) ineffective and uncoordinated support schemes to effectively encourage Small and Medium Enterprise to meet both local and export markets,

(iv) inaccessibility to finance/or long term credits as only about 7.2 percent of Zambian Small and Medium Enterprise had accessed credit facility (MTCI: SME survey, 2004),

(v) time it takes to get a loan was too long often exceeding three months,

(vi) political interference in the granting of loans as most beneficiaries were being selected mainly based on their political affliation, and

(vii) (vii) creation of Multi-Facility Economic Zones, introduced to by the Japanese Government through International Corporation Agency (JICA) generally targeted large and hi-tech companies which inevitably excluded SMEs. The importation of cheap raw materials by companies investing in these facilities further injured SMEs who supply similar goods to the companies as they become uncompetitive in terms of pricing.

3. Discussions

3.1 Challenges of SMEs in Zambia

The fact that SMEs have not made the desired impact on the Zambian economy in spite of all the efforts and support of succeeding administrations and governments gives a cause for concern. It underscores the belief that there exists fundamental issues or challenges, which confront SMEs but which hitherto have either not been addressed at all or have not been wholesomely tackled. The study showed the following plethora of challenges, which are enormous, fundamental and far-reaching:

(i) lack of easy access to funding/credits, which can be traceable to the reluctance of banks to extend credit to them owing, to poor and inadequate documentation of business proposals, lack of collateral, high cost of administration and management of small loans and high interest rates.

(ii) Bureaucratic bottlenecks and inefficiency in the administration of incentives and support facilities provided by the government.

(iii) high incidence of multiplicity of regulatory agencies, taxes and levies that result in high cost of doing business and discourage entrepreneurs.

(iv) weakness in organisation, marketing, information-usage, processing and retrieval, personnel management, accounting records and processing, etc. arising from the dearth of such skills in most SMEs due to inadequate educational and technical background on the part of the SME promoters and their staff.

(v) inadequate, inefficient, and at times, non-functional infrastructural facilities, which tend to escalate costs of operation.

(vi) inability to meet stringent international quality standards, a subtle trade barrier set up by some developed countries in the guise of environmental or health standards. A relevant example is the impending ban of marine foods, vegetables, fruits and other agricultural products from Africa into the United States of America markets.

(vii) unfair trade practices characterised by the dumping and importation of substandard goods by unscrupulous businessmen. This situation is currently being aggravated by the effect of globalisation and trade liberalization, which make it difficult for SMEs to compete even in local/home markets.

(viii) lack of access to appropriate technology as well as near absence of research an Development.

(ix) big gap in entrepreneurship skills among SMEs.

3.2 Opportunities of SMEs in Zambia

The identified problems of SMEs notwithstanding their enormous depth, breadth and intensity, it is only fair and proper to acknowledge the fact that the government did not fold its arms to watch the SMEs wallow in the gamut of problems. Doubtless, the government fully appreciates the opportunities SMEs create for employment, their contributions to economic growth and development as well as the constraints and difficulties in their operating environment. These explain why in the past forty-five years or so, the government has established various support institutions and relief measures specially structured to render assistance and succour to minimize the constraints, which SMEs typically face if not to eliminate them. The support institutions established by the government range from specialized banks designed to focus on the funding of SMEs to agencies and departments all meant to give a flip to the fortunes of SMEs. The government has implemented a number of interventions aimed at enhancing SMEs performance in the subsector. These revealed the following interventions SMEs can use as opportunities;

(i) establishment of the Patent and Company Registration Agency (PACRA) in all provincial centres.
(ii) establishment of the Zambia Chamber of Small and Medium Size Business Association (ZCSMBA) regional office
(iii) Agriculture sector – contributes 20 percent of GDP due favourable agriculture policies. This is a priority sector for industrialisation strategy being implemented by the government.
    - establishment of cooperatives use as vehicle for accessing loans.
    - establishment of fresh milk collections centres for daily farmers.
    - establishment of the farm mechanization pack for subsistence farmers.
    - creation of aquaculture and fisheries fund in 2011, development of fisheries management plan and national aquaculture development plan – fish deficit of 35,000 metric tonnes.
(iv) Energy sector – energy sources includes; renewable, biomas, coal, petroleum and electricity. Zambia is a young and growing economy hence this an opportunity for SMEs
(v) Tourism sector – Zambia has 65,000 square kilometers of national parks and game management areas holds 40 percent of the water in Central and Southern Africa.
(vi) Mining sector – The coming on board of new mines and the expansion of existing ones and the increase in activities for small scale mining activities.
(vii) Infrastructure sector – This is another priority areas of the government enshrined in the vision 2030, opportunities in road network, energy generation, telecommunication.
(viii) Manufacturing sector – Contributes 11 percent of the country's GDP driven by the agro processing, textiles, metal processing, fertilizers, chemicals, explosives, construction materials such as cement.
(ix) Public private partnership (PPP) projects – The government has opened up the PPPs in four subsectors of the economy; health, transport, energy and agriculture.
(x) creation of new districts that supports growth of Small and Medium Enterprises.
(xi) improvement of road network.
(xii) establishment of micro-finance banks and other financial lending institutions with specific micro, small and medium enterprise packages Standard Chartered Bank, Indo Zambia Bank, Finance Bank, Africa Development Bank and entrepreneurs' financial centres.

Further, the government has spent colossal sums of money in the promotion of SMEs as shown in Table 1 with the highest being manufacturing (U$D 1,402,656,791) and the least consultancy(U$D 134).

4.0 Recommendations

Following the discussions and findings of the study, below are the recommendations:

(i) Introduction of training in entrepreneurship to SMEs through associations.
(ii) Introduction of entrepreneurship training programmes in the education curriculum at college and university levels.
(iii) Urgent need to formulate the fisheries sector policy, which will accelerate implementation of various aquaculture strategy.

(iv) Government should simplify the procedure and criterion for accessing of these finances from government established institutions such as CEEC.
(v) Introduction of tax incentives for local SMEs – currently this is only applied to foreign investors.
(vi) Introduction of a revolving fund to support SMEs involved in infrastructure development to acquire equipment.

Table 1: Total investment approvals and employment in Zambia for 1993 - 2006

Sectors	**Total Investment in MSMEs (US Dollars)**	**Total Employment**
Manufacturing	1,402,656,791	73,785
Agriculture	643,354,224	78,881
Service	748,636,802	15,759
Mining	485,301,725	15,117
Construction	271,696,890	11,190
Consultancy	943,032	134
Engineering	8,237,089	421
Financial Institutions	5,604,975	483
Fisheries	9,009,036	1,918
Health	10,340,799	659
Tourism	341,644,363	11,851
Transport	197,692,949	4,293

Source: ZDA, 2007

5.0 Conclusion

Given the crucial role SMEs play in the industrial and economic growth and development of developing countries like Zambia, the governments in Zambia cannot afford to relax in their efforts towards making the SME subsector very vibrant and productive. Apart from the government's concerted and relentless efforts towards revamping and sustaining to vibrancy of this all-important sub-sector, the private sector as well as professional bodies and associations should not relent in providing vital contributions to the development of the subsector. The capital market driven by the Lusaka Stock Exchange (LUSE) and Securities and Exchange Commission (SEC) have not only been expanding its facilities but also working to make it cost effective for SMEs to access funding from the market. Professional bodies and associations such as the various Chambers of Commerce, Engineering Institution of Zambia are vigorously pursuing, pushing and lobbying the government for improved welfare and a better and more enabling operating environment for the subsector.

6.0 References

Chisala C (2008) "Unlocking the potential of Zambian Micro, Small and Medium", pp 10-11.

Devereux M, Mader G and Minkler (2010 – 2013) *A Handbook for Entrepreneurs and Professionals.* Second Edition, pp. 50-53, London.

Citizen Economic Empowerment Commission Act, 2006.

Gondwe M (2012) “Importance of the Small and Medium Enterprise in Zambia”. Vol. 1 No.1, pp 1-3.

Government of the Republic of Zambia (2004) “MTCI Small and Medium Enterprises Suvery 2003-2004, final report, pp. 3-15.

Government of the Republic of Zambia (2006) “A prosperous middle-income nation by 2030”, pp. 23.

Izedomi P (2011) “Small and Medium Enterprises”. *Small Business Journal.* Businessday media, Lagos, pp. 20-21

Mader P and Winkler A (2013) “Rise and fall of microfinance in india”: The Andhra Pradesh crisis in perspective, strategic change, Vol. 22 No. 1-2, pp. 47-66.

Nuwagaba A (2015) “Enterprises (SMEs) in Zambia”. *International Journal of Economics, Finance and Management*, Vol. 4 No. 5, pp. 146-151

Small Enterprises Development Act, 1996.

World Development Report (2000 - 2006) World Bank.

Zambia Development Agency Act, 2006.

Small and Medium Enterprises and Industrialisation: The Case for Zambia

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Abstract

Small and Medium Entreprises (SMEs) have long been believed to be catalysts for growth and economic development both in developed and developing countries. In Zambia and many Southern African countries where the private sector is not well developed, SMEs are assumed to play a key role in indusrialisation. Various industrialization strategies have been tried, test and implemented by successive governments in Zambia and any other African countries, but with mixed results. In Zambia SMEs contribute greatly in job creation and country's GDP employing up to 50 percent of the working class by some estimates. Lack of affordable financing, coupled with lack of ownership of development process rooted in African culture has been cited as main causes of SMEs industrialization.

The purpose of the study is to find inform policy making on how SMEs can be a catalyst to economic development. The study report recommends support from financial system by way of low interest rates on borrowing by SMEs from formalized governmental and non-governmental organisations such as the Youth Empowerment Fund administered by the ministry of Youth and Sport, Citizen's Economic Empowerment Commission (CEEC). The study recommends some practical actions that the decision makers both in government and civil society coupled with the pronouncement by the Republican President Edgar Chagwa Lungu on the need to create 1 Million jobs through the Industrial Development Corporation (IDC) that can be taken alleviate poverty and enhance industrialization.

Key Words: Small and medium enterprises (SMEs), Industrialisation, Gross domestic Product (GDP), Industrial Development Corporation (IDC)

1. Introduction

Industrial development was in the past believed to occur when large corporations undertaking large investments and creating scale economies. The thinking then was that large corporations, with their large savings brought about by reduced cost of doing business and other economies of scale would continue to be the engine of development.

Even Schumpeter, the Germany industrialist in his memoir proclaimed that the future would come from large corporations. However, starting in the late 70s and early 80s, SMEs started to become more and more innovative and were flexible in terms of reducing costs.

Thus, they started providing intermediate goods and more efficiently than large corporations. Furthermore, due to increases in education levels, business skills and reduction in job security, entrepreneurial activities increased worldwide. It should also be noted that there were some experiments in the late 1980s in the form of establishment of business cooperatives. It should also be noted that SME development remained less than expected in transition countries until the end of 1990s. The definition of a small business enterprise in the Zambian context, as defined by the Small Enterprises Development Act of 1996 is any business enterprise -

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a. whose amount of total investment, excluding land and buildings, does not exceed

    i. in the case of manufacturing and processing enterprises, fifty million Kwacha (K50 Thousand) or (US$ 25,000) in plant and machinery; and

    ii. in the case of trading and service providing enterprises, ten million Kwacha (K10 Thousand) or (US$ 5,000);

b. whose annual turnover does not exceed eighty million Kwacha (K80 Thousand`) or (US$ 40,000); and

c. employing up to thirty (30) persons; provided that the values under paragraphs (a) and (b) may be varied by the Minister, by statutory instrument."

In Zambia, the SME phenomena blossomed in the early 1990s following government's liberalization of the economy when most large parastatals such as Zambia Consolidated Copper Mines (ZCCM), Zambia Consumer Buying Corporation (ZCBC), Metal Marketing Corporation (MEMACO) to mention just a few were either privatized of liquidated due to operational inefficiencies that culminated in their loss making. Since the early 1970s, Zambia's growth strategy was anchored on parastatal -led large scale enterprises promotion in all sectors of the economy.

However, the prolonged poor performance of the parastatal sector induced government to adopt a free market economic policy in 1991. In spite of the change in economic policy, the economy continued to decline resulting in drastic increases in unemployment and poverty levels.

This caused the government to, apart from liberalising the economy, explore structural realignment of the economy as a possible remedy to back-stopping and even reversing the decline in the economy, employment and living conditions.

Through the SED Act of 1996 and later on the PRSP, the SMEs sector was identified as such instrument on which basis a number of policy actions were developed. According to the Ministry of Commerce and Industries, 2007; Ministry of Finance, 2002 publications, Small and medium enterprises (SMEs) are very instrument for the development of an economy through for example creation of employment, increasing tax base for the country, improving incomes for the low earners among other benefits.

2. Problem Statement

SMEs have been rightly been viewed as a panacea for industrialization and economic development in many Asian countries and some African countries. However, in Zambia the story is different. Why is the status quo like this in the case of Zambia and what can be done to change the trend?

3. Literature Review

Various commentators such as Tshuma & Jari (2013) have contended that (SMEs) have overtime been at the forefront of accelerating economic growth in many countries and economic blocs.

In March 2016, Uganda which is a landlocked country and with similar geographical and demographical attributes to Zambia received a coveted youth business entrepreneur award. This has oiled and motivated the SME sector such that there are now over 400,000 entrepreneurs in all sectors of the economy. Nkongolo (2007) in his paper "SME Centered Industrialisation for inclusive and sustainable industrialization in Africa" identified 10 reasons why SME centred industrialization would be ideal for Africa:

1. SMEs enable better use of existing local capacity, thereby establishing the basis for sustained long-run growth, and the opportunity to expand that capacity in the future – we need to start with what we have;
2. They are naturally more labor intensive and central to job creation and contribute to a more equitable distribution of income.
3. SMEs provide an increasing measure of national self-reliance - the future of entrepreneurship in Africa should be in the hands of Africans themselves;
4. They are easier to start up as they require lower investment - SMEs are in the reach of Africa, and would enable them to take full ownership their development and management;
5. Because of their large number in different sectors in Africa there is likelihood to adapt new technologies in response to competitive pressure in domestic and regional (or international) markets;
6. They play the role of invisible colleges that impart tacit knowledge through 'On the Job Training Units' for various kind of labor force for the entire economy;
7. They focus on small markets – mostly domestic and regional markets (intraAfrica trade).
8. They are one of the push factors for foreign investors to invest in a particular country. The potential to be reliable suppliers is credited by foreign investors who may wish to outsource their non-core activities to local suppliers.
9. They are also necessary for the structural change of a country's economy, from agriculture-dependent economy to an industrial and service-oriented economy.
10. They expand economic space and develop capacities in various industrial sectors whose combined impact will have profound implications for long-term economic transformation.

Further, according to Thamas (1989) and Aymen (1988) in South Africa senarior, SMEs operates in every city and they provide employment for people and about 4 million jobs are created through this sector which in some cases may be regarded as informal sector and the formal sector just provides only 7 percent. Just as is the case in Zambia, the majority of the SMEs in South Africa operate in the informal sector and there are about 700,000 such business which contribute and their contribution ranges between 16 to 40 percent of the country's gross national product as pointed out by DeSmidt (1990) and Thamas (1989). Other commentators such as Krombergy (2005) have pointed that SMEs have played and continues to play a bigger role in the social economic development of the country. From previous studies that they conducted in South African SMEs, it was found out that they contribute 30 percent to gross national product considering SMEs that are registered with the government, though the percentage could be higher if you consider SMEs that could be operating but not formally registered because of fear to pay state taxes Skinner (2006).

In the case of Tanzania, SMEs have played a big role in the social and economic transformation of the country since its transition from a command economy of Mwalimu Julius Nyerere to a current market economy and they contribute about 60 percent to the gross national product as pointed out by Echengreen and Tong (2005) as well as Pyke et al., (2000). The country considers SME is viewed as one that employs at least 4 persons and with a capital of TZ shillings 5 million and the majority of the SMEs fall in the informal sector. It is however possible that you find some SMEs with capital of between 200-800 million employing above 49 employees, Hamisi (2011).

From such examples, Zambia as a country would look for ways of improving the SMEs market since it is evident from these studies, that they are can be a good source of jobs creation, taxes for the government among other benefits. According to UNIDO (2006), there is a strong relationship between existence of SMEs and contribution to a country's GDP and in the case of Tanzania they contribute about 35 percent and this would have be better if the SMEs are operating efficiently and a full friendly business environment, Calcopietro and Massawe (1999).

With reference to the Nigerian economy, it keeps growing amidst challenges, its informal sector which is composed of a lot of SMEs has also been growing, but with a lot of challenges mainly due to all the vices associated with harsh business environment for SMEs in the country (Okezie, Ihugba, Alex Odii, Njoku, 2014). The challenges that are being faced by entrepreneurs in Sub Saharan African countries cannot be underestimated and in most cases they are the same across the continent. Such challenges are; poor credit facilities which hinders Prospective entrepreneurs to easily access credit funding for their SMEs and those that are available charge higher interest rates of about more than 28 percent in additional to loan collateral which SMEs may not have (Okezie, Ihugba, Alex Odii, Njoku (2014), Obiajuru (2012), Agency Reporter, 2012).

The 1996 Zambia baseline survey on SMEs showed that the Zambian SMEs employ less than 10 employees and that 52 percent of all SME business activities are in rural areas of the country.

In SMEs sector, trading majorly account for 49 percent, manufacturing account for 41 percent while Services accounted for only 10 percent. These SMEs do help people to afford a descent livelihood. Most of the manufactured products in the SME sector include wood products, textile products, metal fabrication, food processing, light engineering leather products, handicrafts and ceramics etc. The service sector include simple building construction, passenger and goods transport restaurants, cleaning services, hair salons and barbershops, telecommunication services, services and business center. The trading sector is concentrated in agricultural inputs and produce, industrial products and consumable products.

To create 1,000,000 new formal sector jobs over the next five years, four growth sectors have been identified as having the greatest potential to achieve the objectives of promoting growth, employment, value addition and expanding Zambia's economic base. The four priority sectors are Agriculture, Manufacturing, Tourism, and Infrastructure. These sectors have the highest requirement for labour and the potential to be highly competitive. The distribution of potential direct jobs to be created is as follows:

- Agriculture – 550,000 (54%)
- Construction – 85,000 (8%)
- Manufacturing – 89,000 (9%)
- Tourism – 300,000 (29%)

Last updated on 4 October 2015

SMEs sector in Zambia has all sorts of business enterprises who deal in traditional manufacturing industrial sectors who produce for domestic consumption and the surplus for sale. Most businesses are small with features of sole proprietors and in some cases employing a few people and the incomes generated are primarily for looking after their homes.

Most MSMEs are further by characterized by the use of low level technology and are oriented towards local and less affluent market segments. As the Zambian economy was since the introduction of structural economic reforms and the country’s transition to a liberalized economy in 1991, this has helped greatly the development of the SMEs sector. The majority of SMEs in Zambia accounting over 90 percent operate in the informal sector (Government of the Republic of Zambia, 2011) and this seriously affects the economy in for example missing revenues in taxes. Table 1 shows the various SMEs businesses in Zambia.

A survey conducted by the World Bank on Enterprise Development in Zambia (2007) identified poor access to finance as a major impediment to investment and growth in Zambia. Only 16% of firms surveyed reported having a loan or line of credit from a financial institution, compared with 23% for the region and 35% for all countries surveyed.

Therefore, while Zambia’s cost of doing business index has progressively improved in recent years, access to finance continues to feature among the three key constraints to investment and growth.

Table 1: Business activities of SMEs in Zambia

Nature of Industry	Nature of Business
a) Manufacturing	1. Textile products
	2.Caprntry and other wood based business
	3. Light engineering and metal fabrication
	4. Food processing
	5. Leather products
	6. Handcrafts
	7. Processing of semi-precious stones
	8. Ceramics
	9. Essential oils
b) Trading	1. Consumable products
	2. Industrial products
	3. Agricultural inputs
	4. Printing
c) Services	1. Restraunts and food production
	2. Hair salons and barbershops
	3. Passengers and goods transport
	4. Telecommunication services
	5. Financial services
	6. Business centres
	7. Cleaning services
	8. Guest houses
	9. Building and construction
d) Mining	1. Small scale mining
	2. Small scale quarrying

Source: ZDA, 2007

Various industrialization strategies through usage of SMEs have been pursued to achieve economic development in many developing countries with marked success mostly in Asia, though not so much in Africa generally and Zambia in particular.

The paper outlines the role that SMEs can play in enhancing industrialization of a developing country; in this case Zambia considering the changing economic dynamics brought about by globalization. The paper concludes that among the myriad of reasons why SMEs have not impacted the Zambian economic landscape is that when business enterprises are established, the entrepreneurs are faced with a choice of whether to remain informal or register with Patents and Companies Registration Authority (PACRA).

There have been a lot of improvements made in the cost reducing strategies that have been implemented in the industrial structure and the development of new markets that have renewed interest in the small and medium size enterprises (SMEs) as an engine of development. Having started in the late 70s and early 80s, SMEs started to become more innovative and were flexible in terms of reducing costs. Thus they started providing intermediate goods more efficiently those large enterprises. Furthermore, due to increase in education levels, business and skills, entrepreneurial activities increased worldwide.

Further, available data for instance, Mbuta (2003) indicate that Literature reviewed show very low levels of formality as only 2 percent of SMEs were registered with PACRA. This could explain why only a few SMEs have had no access the incentives that government provided to the sector and hence their impact on industrialization of the country severely constrained forcing the country to import even the most basic of goods that could otherwise be produced by the SMEs if they were animated to produce and be counted as engines of industrialization.

4. Discussion

Other Factor Determinants to Business Performance of SMEs Apart from the influence of direct resources on the business performance of SMEs, indirect factors such as accessibility to quality infrastructure, type of economic activity engaged in, gender of entrepreneur, and age of business equally exert significant influence. As such it is necessary for policy makers to be aware of such influence and provide policy measures that will promote balanced development of SMEs in all areas. In the case of Zambia, the country is divided into nine administrative zones called provinces.

The level and rate of infrastructural and hence economic development in these provinces has been perceived to according to the 2003-2004 Zambia Small and Medium Enterprises Survey Ministry of Commerce, Trade and Industry, Lusaka. 33% be significantly skewed, which has been a source of concern to policy makers and the country as a whole. The skewness of infrastructure development is also responsible for the rural - urban divide among provinces in Zambia. While the survey revealed that 53 percent of enterprises were located in rural areas which finding broke the notion that the SMEs sector in Zambia is an urban phenomenon, the study also revealed that in comparison with the urban located SMEs, the profitability for the former was very low. In fact, hourly profits for rural SMEs constituted on average 20 percent of those located in the urban areas.

Inaccessibility of sufficient and high quality infrastructure is a major factor in profitability variations. Approximately 73 percent SMEs conduct their businesses in unauthorised premises. Inadequate premises for trading and production purposes of SMEs influence business performance. The survey identified that the most common location for conducting their business activities include the homesteads which exhibited the lowest hourly profits. However, even those trading from traditional designated markets experienced low profits while those who traded along the roadsides and mobile vans had the highest profits. Therefore, an absence of sufficient business premises and a lack of enforcement law appear to have affected the business performance of the SMEs sector.

Socio-Cultural Factors (Gender Role Stereotyping) Gender role stereotyping is also one of the factors that also affect business performance of enterprises. In line with this, the results show that the participation of women entrepreneurs in general in the SMEs sector was 46 percent. Further analysis on the participation of women entrepreneurs among the small and medium scale enterprises declined to 22 percent thereby confirming the notion that “women-run activities tend to be smaller than other business and that over half (57percent) of women-run businesses are one-worker activities”. Further, women-owned enterprises had dramatically lower hourly profits than their men-owned or multiple-owner counterparts.

Sector analysis of the results reveal that a greater proportion of female business owners constituting 46 percent concentrated in commerce while the figure was 58 percent for males. However, while the second most favoured sector for women was services and lastly manufacturing, for the men, it was manufacturing and then services. This also confirms the findings of the 1996 survey which reveal that women owners tended to group in activities such as agriculture-related production (except fish processing), malt and beer production, other beverage production, textile production (except garments), and vending. Men predominated in furniture making, fish processing, charcoal production, garment making, metal products, and the service areas of transport, repair, and construction.

The gender profile of Zambia's SMEs sector is consistent with that seen in other countries in the region. In all other countries studied, women owned roughly half of enterprises. Without exception however women-run enterprises tended to be

Capacity utilisation constitutes a major indicator of business performance. When asked the level of operations at which SMEs were operating especially those in manufacturing and services, almost all SMEs (95 percent) stated that they were operating at above 50 percent capacity. Business Growth When asked the performance of businesses from 2003 to 2004, a number of enterprises responded by stating that their businesses had registered some growth. In fact, the number of enterprises registering growth in business increased from 29.3 percent in 2003 to 31.5 percent in 2004. This reported growth was largely among small scale enterprises. By sector, more enterprises in trading recorded growth in business while manufacturing firms experienced stagnation. However, a decline was also recorded in the services sector. Furthermore, growth in business was recorded in the following provinces: Central, Eastern, Lusaka, and North – western, Southern and Western provinces. By gender, more businesses owned by men reported growth over the period while that of women declined.

Product Differentiation: The size of the list of products in a country is an indicator of its development. In the manufacturing sector for example, Zambia has the potential to produce more than 250 different types of products out of which less than 30 percent are produced. In the case of this survey, the list of goods and services produced by the SMEs sector has 53 products. Participation is the highest in the provision of foodstuffs followed by groceries, clothing, beverages and accommodation constituted the major items while paint, milk, public library and transport services constituted the least goods and services provided by the sector.

For instance, while the manufacturer of paint is only one, there were over a hundred SMEs engaged in foodstuff provision.

5. Conclusion

Industrialisation and economic development have been as much an economic as well as a politically sensitive matter in most developing countries. From the discussion above, it is evident that SMEs can contribute immensely to economic development and play a significant role in alleviating poverty levels in Zambia. However, there are many challenges that SMEs in Zambia face that impede their development and hence making it difficult for them to contribute to economic development. Among them are inadequate infrastructure, HIV and Aids, lack of social safety net, corruption etc

6. References

AFDB and OECD (2005) African economic outlook 2005: financing SME development in Africa, development center and African development bank, OECD, Paris.

Desmidt, M. (1988). The informal sector, in theory and practice: an examination of the informal activities in block c, site ckhayelitsha, Cape Town. Economic honors long paper, school of economics, university of Cape Town, Cape Town

FSD Zambia (2009). Finances national survey 2009. Dynamics of Zambia's changing financial landscape. Lusaka, Zambia: FSD Zambia.

Hamis, S (2011) Challenges and opportunities of Tanzanian SMEs in adapting supply chain management

Nkongolo, D (2007) SMEs/SMIs centered industrialization for inclusive and sustainable growth in Africa – How can Japan help?

OECD Publishing MoFNP, (2002), ZAMBIA-Poverty Reduction Strategy paper 2002 – 2004, MoFNP, Lusaka. MoFNP, (2006) Fifth National Development Plan 2006 – 2010: Broad Based Wealth and Job Creation through Citizenry Participation and Technological Advancement, Lusaka: MoFNP

Pyke, D., Robb, D., Farley, J (2000) manufacturing and supply chain management in china: a survey of state-, collective-, and privately-owned enterprises. Eur. mgmt. J., 18(6): pp. 577-89.

Republic of Zambia, (1996) Technical Education, Vocational and Entrepreneurship Training (TEVET) Policy, Lusaka.

Thamas, W, H (1989). South Africa's growing black market. Challenges for the 1990s. Speech at the spotlight on the black market conference, sponsored by the small business development center in Johannesburg, South Africa.

Tshuma, M.C and Jari, B. (2013) the informal sector as a source of household income: the case of Alice town in the Eastern Cape Province of South Africa, 5 (8). (Online). Available from: http://www.academicjournlas.org/jasd (Accessed May 2015)

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