PROCEEDINGS

of the

ENGINEERING INSTITUTION OF ZAMBIA 2023 CONFERENCE

Hosted by
The Engineering Institution of Zambia

Theme:

"Sustainable Economic Transformation and Job Creation Through Home-Grown Engineering Solutions."

ISBN: 978-9982-70-908-5

Thursday 20th to Saturday 22d April, 2023
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Foreword

We are pleased to welcome you to the 66th Engineering Institution of Zambia (EIZ) 2023 Annual Conference and Symposium (ACS) at Avani Victoria Falls Resort-Livingstone, a unique opportunity to engage and gather delegates for important discussions to advance the engineering profession. The ACS will be followed by the EIZ Annual General Meeting (AGM) on 22nd April, 2023.

This year's theme is "**Sustainable Economic Transformation and Job Creation Through Home-Grown Engineering Solutions**". It is hoped that this ACS will be a platform to gather and disseminate knowledge that will aim at pushing the engineering industry and academia to greater heights, giving us home-grown engineering solutions to transform the economy and create job opportunities for our country, the region, the continent and beyond.

The theme was chosen carefully, with the reason being to pay particular attention to the engineering professionals and academics about the importance of developing and strengthening the national economy through job creation using home-grown engineering solutions. Academics and engineering professionals have produced a lot of research on strengthening and development related to the engineering sector that has been previously mentioned. However, there is still many that has not been disseminated and widely publicized, so it is not accessible to the people who need it. On this basis, this ACS has become an event for academics and engineering professionals to present their research findings, as well as exchange information and deepen their research problems, and develop sustainable cooperation.

There are 24 peer reviewed research papers submitted in two parallel sessions. All the research papers in this *Book of Proceedings* were refereed through a triple-blind review selection process. By publishing this *Book of Proceedings*, this is expected to be useful and can be used as a reference in developing related research in the engineering sector.

The EIZ Editorial and Publications Committee would like to thank all parties involved in the publication of this *Book of Proceedings*.

Best Regards

Eng. Prof. John Siame
Chairperson, EIZ Editorial & Publications Committee
April 2023

Photovoltaic materials and challenges of PV technology deployment in Zambia - A critical review

Chiza L Nyirenda[1*]; Rudolph J Kashinga[2]

Abstract

Solar photovoltaic (PV) cells, commonly referred as solar cells, when exposed to sunlight generate voltage or current through a process of photovoltaic effect. They are widely used in various industries including the manufacture of solar panels, calculators, watches, powering of satellites in space just to mention but a few. They are basically devices that convert light energy into electrical energy through a process known as photo-voltaic effect. The basic characteristic of these materials which make them suitable for use in the manufacture of solar cells is that they are semiconductors with an optimal bandgap and are mostly doped with other elements like boron (B) and phosphorous (P). The most commonly used semiconductor material is silicon (Si), existing as either monocrystalline, polycrystalline or amorphous, and is classified as first generation. Second generation solar cell materials are basically polycrystalline thin film materials which are designed to reduce the cost of production and improve efficiency. Conversely, hybrid semiconductor materials comprising of copper (Cu), indium (I), gallium (G) and selenium (S), also known as copper indium gallium selenide (CIGS), are the most efficient in the category of polycrystalline thin film materials. Other polycrystalline materials are cadmium telluride (CdTe), amorphous silicon with an intrinsic layer of α-Si and gallium arsenide (GaAs). Gallium arsenide is one photovoltaic material which has high absorptivity and highly resistant to radiation, and is thus, used in concentrated systems as well as in space. Current research is exploring characteristics for such materials as perovskite, quantum dots, organic/polymer dye-sensitized materials, and many others, for suitability in specific environments. The rapidly decreasing costs and the gradual technological advancements in solar photovoltaic (PV) technologies, paradigm shift from fossil fuel-based power generation affecting climate change, have led to the widespread deployment of solar photovoltaic (PV) systems in Zambia. However, the performance of most of these systems has been with a lot of challenges hence making systems less reliable with a low overall output. This paper gives an overview of solar photovoltaic (PV) materials and the challenges faced by solar photovoltaic technology deployment in Zambia.

Keywords: Solar: Photovoltaic; photovoltaic effect; crystal structure; absorptivity

1.0 Introduction

Photovoltaics (PV) technologies, which directly convert solar energy into electricity offer a practical, sustainable and diverse renewable energy solution to the challenge of meeting the ever-

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increasing need for energy, globally. In recent years, the decreasing price of PV systems are owing to research and development in photovoltaic materials and optimization and have greatly improved. This has reduced the cost of PVs produced electricity to an extent that it can now compete favorably with the portion of consumer electricity prices in many countries worldwide. The scenario of "mains parity" has been reached (Goetzberger *et al.*, 2003).

Monocrystalline silicon usually produced through the Czhochralski process has a uniform single crystal molecular structure which is ideal for the transfer of electrons within the material. Polycrystalline silicon is produced through directional solidification casting process and has a molecular structure with grain boundaries which somehow impedes electron movement in the material. The second generation of solar cell materials are basically polycrystalline thin film materials aimed at reducing the cost of production and improved efficiency. The hybrid semiconductor material comprising of copper (Cu), indium (I), gallium (G) and selenium (S) also known as copper Indium gallium selenide (CIGS) is the most efficient in the category of polycrystalline thin film materials. The other polycrystalline materials are cadmium telluride (CdTe), amorphous silicon with an Intrinsic layer (α-Si) and gallium arsenide (GaAs). Gallium arsenide's very high absorptivity and high resistance to radiation makes it ideal for use in concentrated systems as well as in space (Mekhilef *et al.*, 2012; Polman *et al.*, 2016). There is progressive research and development into newer materials such as the behaviour of perovskite materials under various levels of temperature, nanostructured semiconductors i.e., quantum dots (Kramer *et al.*, 2015), organic/polymer materials and dye-sensitized materials (Suhaimi *et al.*, 2015). Solar cells are made of semiconductor materials. Given the broad solar spectrum, their fundamental efficiency limit is determined by factors such as crystal structure, Figure 1 (Polman *et al.*, 2016). Generally, solar cell fundamental conversion efficiency is determined by calculating the ratio of the maximum generated power to the incident power, as shown in equation 1 (Foster et al., 2009). Solar cells' power rating are measured under the Standard Test Conditions, where the incident light is described by the Air Mass (AM1.5) spectrum and has an irradiance (I_{in}) of 1000 W/m^2.

$$\eta = \frac{P_{max}}{I_{in}} = \frac{J_{mpp}V_{mpp}}{I_{in}} = \frac{J_{SC}V_{OC}FF}{I_{in}}, \qquad [1]$$

where η conversion efficiency, J_{SC} is the short-circuit current density, V_{OC} open circuit voltage, P_{max} Maximum power, FF is the fill factor, J_{mpp} short-circuit current density at maximum power point, V_{mpp} Open circuit Voltage at maximum power point and I_{in} is the irradiance. Typical external parameters of crystalline silicon solar cells are; $J_{SC} \approx 35$ mA/cm^2, V_{OC} up to 0.65 V and FF in the range 0.75 to 0.80. The conversion efficiency lies in the range of 17% to 18% (Crabtree et al., 2008; Khan et al., 2019).

Photons with energies below the band gap are not absorbed, whereas photons with energies above the band gap are not fully converted to electrical energy because of thermalization of charge carriers, as illustrated in Figure 1. Taking these two factors into account, ~45% of the incident spectrum integrated solar power remains for semiconductors with a band gap of 1.1 to 1.4 eV (Polman *et al.*, 2016).

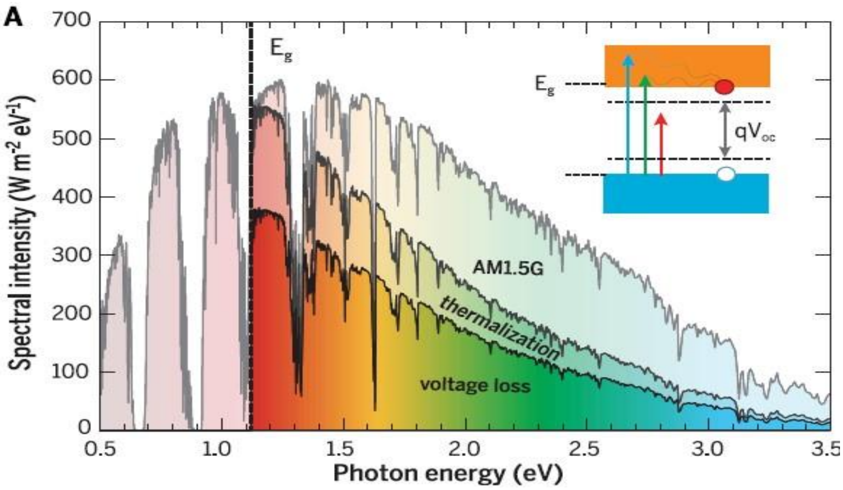


Figure 1: Fundamental solar cell efficiency limits on the solar spectrum (Polman et al.,2016).

2.0 Photovoltaic materials classification

2.1 Monocrystalline silicon material

Monocrystalline silicon is a high-quality type of silicon with uniform, single crystal molecular structure produced through the Czochralski process. It is more expensive but has higher efficieny, producing module effiencies of up to 18% (Goetzberger *et al.*, 2003; Polman *et al.*, 2016). Monocrystalline solar panels are space-efficient and produce 2 to 3 times more power than thin film technologies, but can be affected by shade and weather conditions (Goetzberger *et al.*, 2003). Theyhave a distict atomic structure and differ from polycrystalline silicon in their crystal structure (Goel *et al.*, 2016).

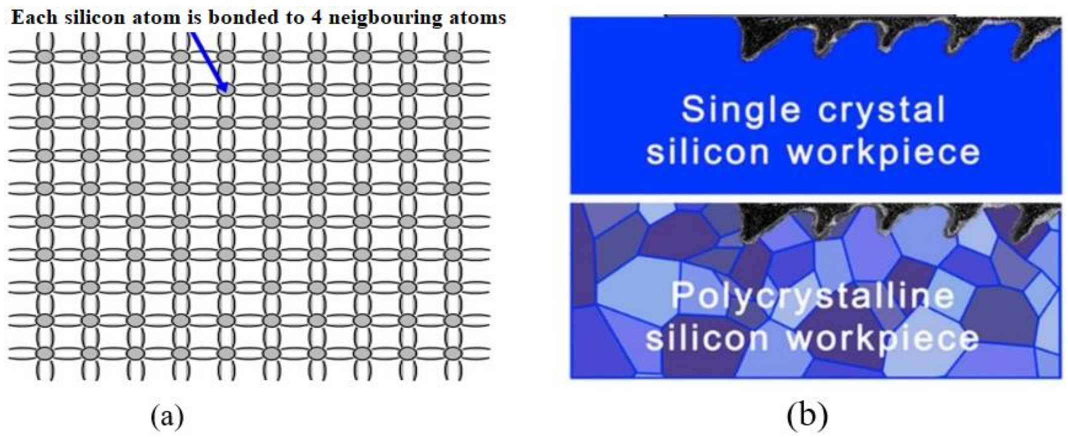
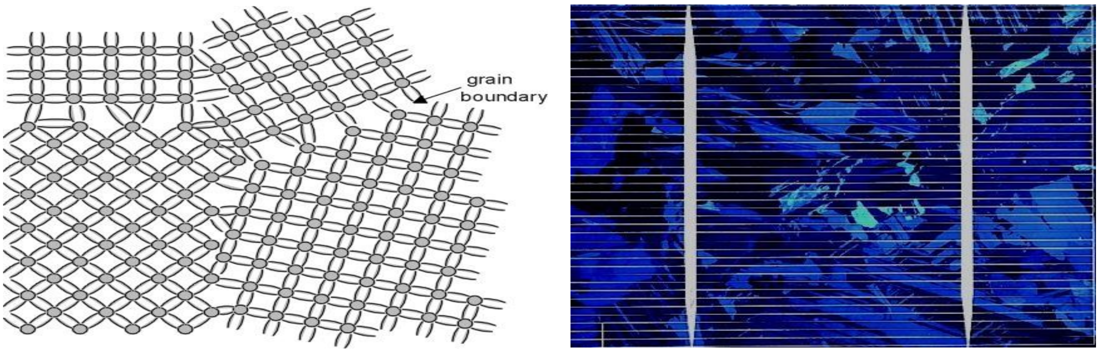


Figure 2: (a) Monocrystalline silicon atomic structure (Goetzberger et al., 2003) and an (b) illustration of the difference between single crystal (monocrystalline) and polycrystalline (Goel et al., 2016).

2.2 Polycrystalline silicon material

Polycrystalline silicon is produced through directional solidification casting and has a molecular structure with grain boundaries which can hinder electron movement in the material. It has lower efficiency than monocrystalline silicon, with modules of up to16% efficient. The atomic structure of polycrystalline silicon is shown in Figure 3 (a) along with a corresponding solar cell, Figure 3 (b) (Goetzberger *et al.*, 2003; Singh, 2013).

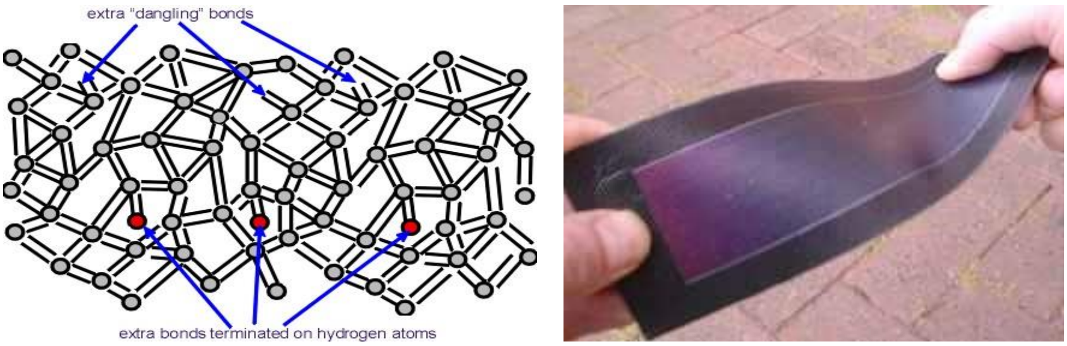


(a) *(b)*

Figure 3: Polycrystalline silicon atomic structure and corresponding solar cell (Goetzberger et al., 2003; Singh, 2013)

2.3 Amorphous silicon material

Amorphous silicon has extra defects in its molecular structure but has higher light absorption efficiency compared to monocrystalline and polycrystalline silicon. At an atomic scale, amorphous silicon has unbonded atoms and lacks long-range atomic order, as shown in Figure 4 (a) and a corresponding solar cell Figure 4 (b), (Cheng *et al.*, 2012). Amorphous silicon photovoltaic products are cheaper to produce than polycrystalline silicon products and have module efficiencies of up to 10% (Cheng *et al.*, 2012; Hsu *et al.*, 2012; Wang *et al.*, 2012).



(a) *(b)*

Figure 4: (a) Amorphous silicon material structure and (b) corresponding solar cell (Cheng et al., 2012)

3.0 Thin film materials

Thin film technology solar cell materials are basically polycrystalline and are aimed at reducing the cost of production and improving efficiency. There are three primary types of thin film solar cell materials on the market today: Amorphous silicon (a-Si) (Wang *et al.*, 2012; Misra *et al.*, 2013), cadmium telluride (CdTe) (Bao *et al.*, 2010; Zweibel, 2010) and copper indium gallium selenide (CIS/CIGS) (Singh *et al.*, 2014; Ramanujam and Singh, 2017). Gallium Arsenide (GaAs) is also a thin film photovoltaic material mainly used for space and concentrated system applications

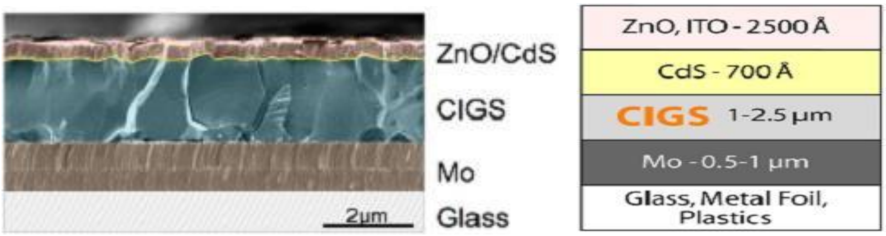
(Cheng *et al.*, 2012; Polman *et al.*, 2016).

3.1 Copper Indium Gallium selenide (CIGS) material

The most efficient material, in the category of polycrystalline thin film, is the hybrid semiconductor material comprising of copper (Cu), indium (I), gallium (G) and selenium (S), also known as copper indium gallium selenide (CIGS) (Singh *et al.*, 2014; Ramanujam and Singh, 2017). Copper indium selenide (CuInSe or CIS) is a ternary compound p-type absorber material belonging to the I– III–VI**2** family and crystallizes in the tetragonal chalcopyrite structure. The optical bandgap of this material can be tuned by varying the Ga/In ratio to match the solar spectrum (Hahn et al., 1953). The structures are shown in Figure 5.

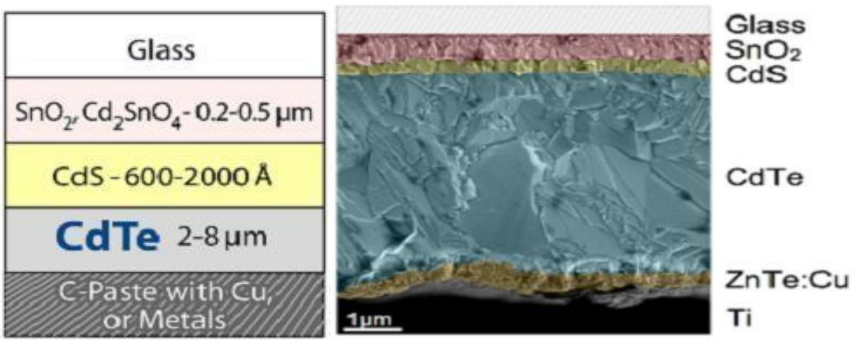
3.2 Cadmium Telluride (CdTe) material

This is polycrystalline binary semiconductor with a cubic zinc blende crystal structure material. Cadmium telluride material comprises a junction of n-doped cadmium sulfide, known as the window layer, on top of a p-doped layer of cadmium telluride, known as the absorber, with the structure as shown in Figure 6. A transparent conductive front contact covers the cadmium sulfide, while the CdTe is in contact with a conductive rear surface substrate (Bao *et al.*, 2010; Zweibel, 2010).



(a) *(b)*

Figure 5: CdTe material structure and configuration (Singh et al., 2014)



(a) *(b)*

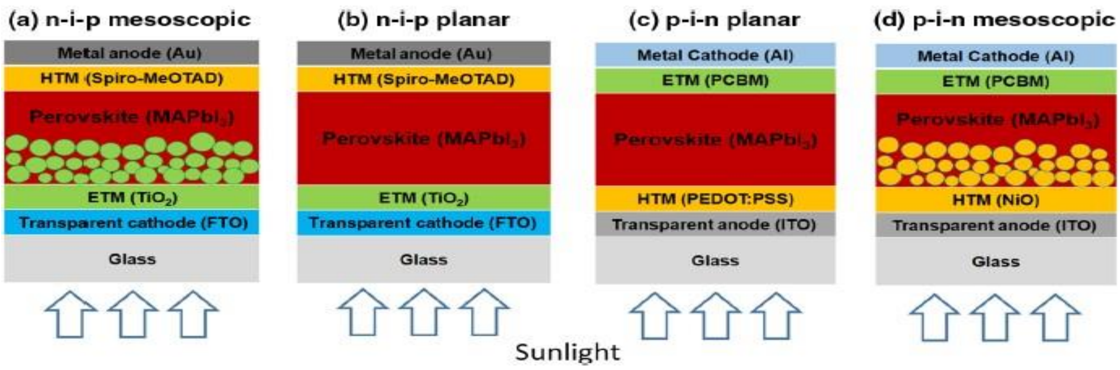
Figure 6: (a) CdTe material structure and (b) configuration (Singh, 2013)

4.0 New Photovoltaic materials

The challenge of meeting the growing energy demand while reducing its environmental impact is a pressing issue of the 21st century. Solar energy conversion devices offer a renewable energy source that can offset carbon emissions. Research and development into new materials is ongoing to improve efficiency, lower production costs, and reduce production's environmental impact**.**

4.1 Perovskite material

The perovskite material is originally derived from the calcium titanate ($CaTiO_3$) compound, which has the molecular structure of the type ABX_3. Perovskite materials have cubic lattice nested octahedral layered structures and the unique optical, thermal and electromagnetic properties. Perovskite materials used in solar cells are a kind of organic-inorganic metal halide compound with the perovskite structure. It is one of the most predominantly researched materials and has a structure which is a unique combination of methylammonium lead tri-iodide ($CH_3\ NH_3\ PbI_3$) chemically synthetic mineral and organic materials as shown in Figure 7. It has characteristics of both non-conductors and semiconductors and is a superconductor (Singh, 2013; Polman *et al.*, 2016; Sampaio and González, 2017).



(a) (b) (c) (d)

Figure 7: Perovskite material with its various configurations (Polman et al., 2016)

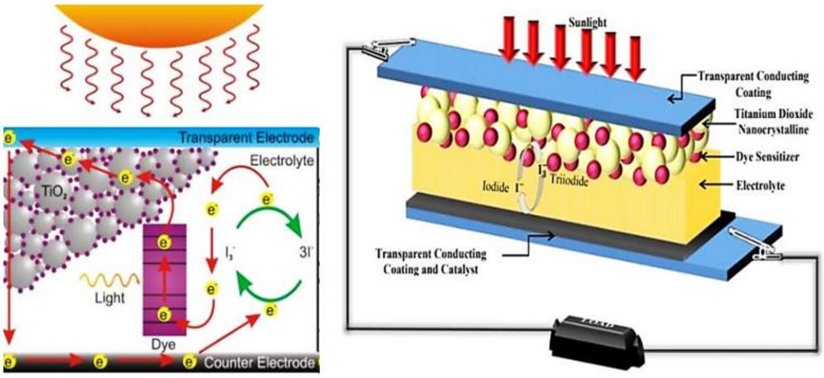
4.2 Dye-Sensitized material

Dye-sensitized solar cells (DSSCs) use a photoelectrochemical power generation process. They work by injecting electrons from a photoexcited dye to TiO2, transporting electrons to the conducting glass substrate, and regenerating the dye through electron transfer from a redox electrolyte (Suhaimi *et al.*, 2015). The absorber in DSSCs is a molecular dye, usually a ruthenium organometallic complex, instead of an extended solid semiconductor (Singh, 2013). This is shown in Figure 8.

4.3 Organic/polymeric materials

Recent developments in molecular or organic semiconductors and conducting polymers have shown substantial advances in the conversion efficiencies of PV cells. The great promise of organic PV's is that they can be produced at low cost in large volumes using well-established polymer coating technologies.

These materials are already on some commercial applications such as building integrated photovoltaics (BIPV) and domestic ornaments including organic thin film television screens. They operate on the concept of highest occupied molecular orbital (HOMO) (Machida *et al.*, 2010; Che *et al.*, 2012; Li *et al.*, 2018) and lowest unoccupied molecular orbital (LUMO) (Ding *et al.*, 2010; Sen *et al.*, 2012; Yang *et al.*, 2012) as shown in Figure 9.



(a) *(b)*

Figure 8: (a) Dye sensitized material scheme (Singh, 2013) and (b) principle of operation (Suhaimi, et al., 2015)

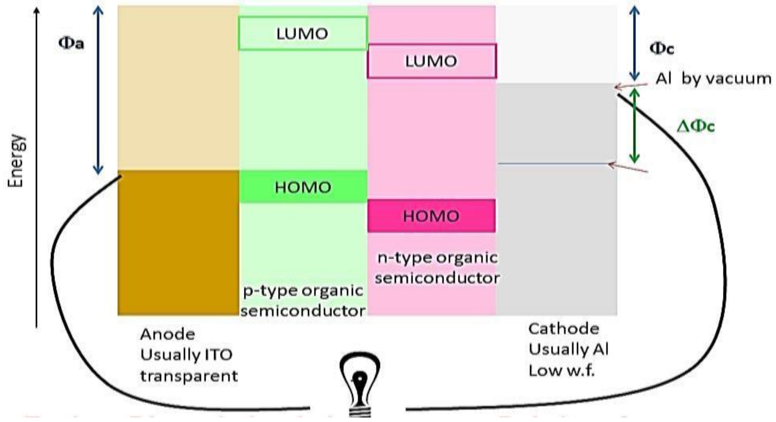


Figure 9: Organic solar cell materials HOMO/LUMO principle (Lopez et al., 2017)

4.4 Nano crystal materials

Current solar cell technology involving nanomaterials, as shown in Figure 10, have efficiencies ranging from 22% for first-generation solar cells to about 15% for second-generation solar cells. The Shockley–Queisser limit concerns the maximum theoretical limit for solar cells between 31% and 41%. Owing to miniaturized light trapping structures and enhanced absorption cross sections, solar devices may be designed with thicknesses well below the charge carrier diffusion lengths with maintained, or even altered and improved light harvesting efficiency. Nano crystal solar cells are those in which the substrate is coated with selected nano crystals like cadmium telluride (CdTe), copper indium gallium selenide (CIGS) or silicon (Choi *et al.*, 2011; Choi *et al.*, 2011).

5.0 Efficiency and design considerations

Solar energy devices have efficiencies ranging from 2% to 20% and are not very efficient or cheap. When choosing a solar panel for a specific application, important factors to consider are climate conditions, temperature effects on efficiency, and changes in solar insolation. The choice of solar panel is mainly based on its efficiency and the specific needs, rather than just basic factors.

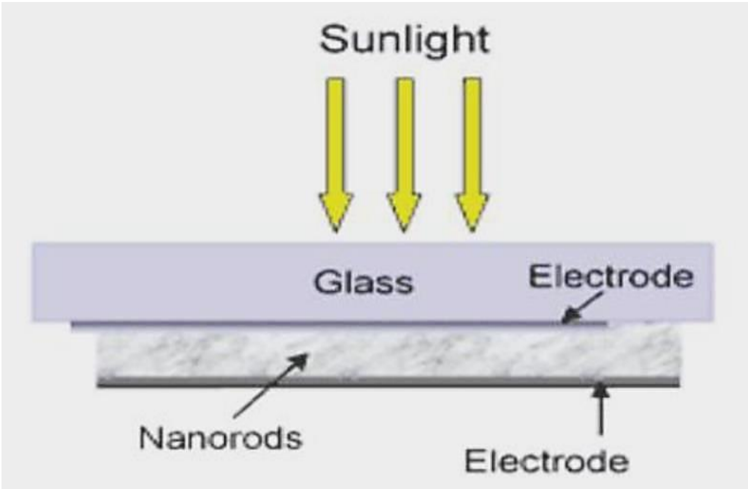


Figure 10: Nano integrated solar cell structure (Hudedmani et al., 2017)

6.0 Challenges of Photovoltaic technology deployment in Zambia

Most Sub-Saharan African countries are highly dependent of the hydroelectric power. This has resulted in about 80% of the population in this region still depending on traditional biomass as the main fuel for cooking (Polman *et al.*, 2015). Zambia is not an exception to this over-dependence on hydroelectric power despite it being affected by climate change and exhibiting challenges in the deployment of solar photovoltaics technologies (Rong *et al.*, 2018; Arizpe *et al.*, 2019). Zambia has a population of around 20 million people and is expected to grow to over 25 million by 2030. Currently Zambia's electrification rate stands at around 22%, an estimated 22% of the population had access to electricity (45% in urban areas and 3% in rural regions) (Mwanza *et al.*, 2017; Kachapulula-Mudenda *et al.*, 2018; McPherson *et al.*, 2018). The major challenges in the deployment of solar photovoltaic technologies in Zambia can be summarized as follows:-

6.1 Consumer awareness

The population, estimated at around 11%, either have or know someone who has, a small solar product. The vast majority of the urban population is likely to have some awareness of solar energy and workers from urban areas visiting rural regions may bring with them knowledge of solar products, or the products themselves. Overall, awareness in the technology has been estimated at around 44% of the population (Mwanza *et al.*, 2017; Kachapulula-Mudenda *et al.*, 2018; McPherson *et al.*, 2018).

6.2 Level of local skills and financial barriers

The high cost of renewable energy technology and a dispersed market result in difficulties in achieving economies of scale. Moreover, the small market size leads to inadequate bulk procurement, hindering successful deployment. Nationwide, there is low awareness about renewable energy, resulting in limited local skill capacity. Some training centers have been established, such as the Pulmani Renewable Energy Center in Kafue, and the University of Zambia has announced plans to establish solar applied energy laboratories (Gorkaltseva and Sinkala, 2017; Kachapulula-Mudenda *et al.*, 2018).

6.3 Policy and regulatory hindrances

Small-scale electrical power producers face challenges in connecting to and accessing the grid network. Additionally, there are insufficient incentives that drive renewable energy development among these producers. In Zambia, there is a shortage of fair competition in the energy sector, which is essential in attracting independent power producers. Furthermore, the policy, legal, and institutional framework that promotes renewable energy production and integration is not fully implemented (Creutzig *et al.*, 2017; Eberhard *et al.*, 2017; Dobrotkova *et al.*, 2018; Lyambai, 2018)

6.4 Institutional barriers

In Zambia, there is currently limited capability to evaluate technical, financial, and economic proposals, as well as market development and marketing of renewable energy projects. The distribution and supply of renewable energy equipment is located in inaccessible areas, resulting in limited coordination, according to Gorkaltseva and Sinkala (2017) and Makai and Chowdhury (2017).

6.5 Technical limitations

There is a shortage of technical capacity for the design, installation, operation, management, and maintenance of renewable energy systems in Zambia. Additionally, the standards for energy performance, manufacture, installation, and maintenance are lacking, and there is a lack of local manufacturing and/or assembly of renewable energy technology components, as reported by Gorkaltseva and Sinkala (2017).

7.0 Conclusion

Research in solar photovoltaic materials, presented herein, is still continuously ongoing. The focus appears to be more on the development of new materials and improvement of the existing ones with a view to improving efficiency. Particularly, optimizations in terms of variant heterostructures and combinations have mostly been aimed at achieving reduced cost and improving performance. In Zambia, since most of the solar photovoltaic installations are deemed not reliable owing to their poor performance which results from, among other things, the quality of the solar photovoltaic panels and the quality of installations. More research attention is therefore necessary to look into among other aspects, the basic performance evaluation of installed plants or units. This will establish the actual factors contributing to the poor performance and corrective measures will then be explored. It is also noteworthy that there exists a wide knowledge gap on solar photovoltaics in Zambia. Hence, research to establish critical factors that affect solar photovoltaics’ performance, such as physical verification of panel tilt angles as opposed to relying on the standard latitudes’ specification, need to be undertaken.

Recommendations:

1) In the Zambian household applications, capital cost of installation appears to be one of the drawbacks. This mostly arises from the high cost of batteries. Future research needs to look into the extent to which battery reuse/recycle can be achieved using cheap and locally available materials.

2) Future research needs to look in to the extent to which performance could be enhanced by mechanisms to rotate solar panels so as to continuously change the orientation of panel following the position of the sun, to optimize energy capturing.

3) Future research needs to look into disposal of solar photovoltaic products. Particularly, effects of constituent materials in panels, inverters and batteries, need to be understood. This will inform safe disposal, particularly, at the end of life.

4) Need for future research to consider policy change and legal framework to consider households' excess power generated (from solar) to be bought by the national utility company.

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Design and control of an advanced process controller on a copper leaching continuous stirred tank reactor

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Abstract

An advanced process controller (APC) is designed and simulated using Matlab/ Simulink®, for controlling temperature in a copper leach continuous stirred tank reactor (CSTR). The study is conducted was leaching reactors at Kansanshi mine. Non-linear control of the CSTR was assessed to understand the response when subjected to process disturbances. The model predictive controller (MPC) and the plant proportional derivative controller (PID) are compared. The simulation was done by introducing a disturbance and then observing the rise time, settling time and overshoot. The results indicate that the modeled MPC controller performs better than the PID controller.

Keywords: MPC, APC, Leaching, PID, Temperature Control.

1.0 Introduction

Advanced process control loops are automated changes to the process that are programmed to correct for the size of the out-of-control measurement. The advances in process technology has led to the development of new highly advanced control systems that offers highly efficient and effective ways to control systems in all engineering fields (Gernaey, et al., 2012). However, some mining industries have not had these technologies for many years as they are still running their operations manually. Advanced control systems offer great advantages to process systems such as giving real time values of process parameters (Temperature, Pressure, pH, density etc.), monitoring and manipulating of all process parameters, alarms that notify if process becomes unstable, safety instrumented system that ensure the safety of the system, personnel and equipment.

Generally, single-loop proportional-integral-derivative (PID) controllers, despite strong interactions between the loops, achieve industrial CSTR control. Single-loop PID controllers do not easily allow for any trade-off between the control objectives and constraint limits. Therefore, if one of the loops reaches a maximum limit constraint such as process disturbances, the other loops cannot attempt to offset the resulting set-point error (King, 2016). Varieties of multivariable controllers such as model predictive controllers (MPC) were developed to achieve the optimal

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trade-off between the control objectives and improvements in product quality, throughput, and power consumption.

The overall objective was to design an additional advanced controller that would increase process response and efficiency in comparison to the existing PID control setup. This was accomplished by performing and carrying out material and energy balance, designing the PID and MPC controllers, simulating, and performing controller tuning.

1.1 Model of the CSTR

Continuous stirred tank reactors (CSTRs) are units frequently used in chemical industry. From the system theory point of view, CSTRs belong to the class of nonlinear systems. Their mathematical models are described by sets of nonlinear differential equations (NDEs) (Dostal, et al., 2015). In this paper, the leach CSTR control strategy was based on the fact that concentrations of components of reactions taking place in the reactor depend on the feed temperature. The main product copper concentration was considered as the primary controlled variable, and, the reactor temperature as the secondary controlled variable.

1.1.1 Component Balance for the reactor

The volume of the reactor is assumed to be constant and the expression is simplified. Constant reactor volume implies that the volumetric flows in and out of the reactor are equal (Leirpoll, et al., 2013). The form of the component balance is expressed in equation (1).

$$\frac{dC_A}{dt} = (C_{A,f} - C_A)\frac{F_f}{V} - k_0 C_A e^{(\frac{-Ea}{RT})} \tag{1}$$

Where the terms are defined in Table 1.

1.1.2 Energy Balance for the reactor

The dynamic energy balance in enthalpy can be written as;

$$\frac{dH_r}{dt} = H_f - H + Q \tag{2}$$

Where H_r is the enthalpy for the reactor, H_f is the enthalpy of the feed stream, H is the enthalpy of the outlet stream and Q is the heat transferred from the reactor. It is assumed that the change in internal energy in the system is so big that the other energy forms can be neglected (kinetic energy, potential energy). The reactor volume, V is constant, the reactor pressure, p is constant, the system performs no work, W, on the surroundings (shaft work, electrical work) and that transferred heat to the reactor is through the jacket (Leirpoll, et al., 2013). The final expression for energy balance is expressed as equation (3) below.

$$\frac{dT}{dt} = \frac{F_f}{V}(T_f - T) - \frac{k_0 C_A}{\rho C_p} e^{\frac{-Ea}{RT}} \Delta_{rx} H + \frac{UA}{V \rho C_p}(T_j - T) \tag{3}$$

Table 1: Reactor model Parameters

Symbol	Unit	Description
C_A	0.87725mol/m^3	Concentration of component A in the reactor
$C_{A,f}$	0.658mol/m^3	Concentration of component A in the in feed stream
T_f	350K	Temperature of the feed
V	100m^3	Volume of the reactor
T_j	300K	Temperature of the jacket
$N_{A,f}$	mol/h	Molar feed rate of component A to the reactor
N_A	mol/h	Molar feed rate of component A out of the reactor
r_A	mol/m^3h	Reaction rate of component A
k_0	$7.2*10^{10}$1/h	Parameter in Arrhenius' equation
E_a	72747kj/kmol	Energy of activation
R	8.314kj//kmol K	Gas constant
T	324K	Temperature of the reactor
F_f	100m^3/h	Volumetric flow rate
ρ	1000kg/m^3	Density of mixture
ΔH	$5*10^4$kj/h	Flow of enthalpy out of the reactor
C_p	0.239kj/K	Heat Capacity
U	10000W/m^2-K	Overall Heat Transfer
A	5m^2	Area

1.2 Model of MPC Controller

MPC is an advanced control method that uses process models derived from the past process behavior to predict future process behavior. The predictions are used to control process units dynamically at optimum steady state targets (Robinson & Cima, 2007). MPC enables multivariable (10 x 10 x 10) closed-loop control, with dynamic constraint enforcement, explicit dynamic models to manage complex dynamic interactions and predictive disturbance rejection. It allows simplified use of integrated control with simplified integration to available measurements and output signals in a robust control processor (Allen, 2016). Predictive control describes an approach to control design and not a specific algorithm. The approach can then be interpreted to define an algorithm suitable for a specific process.

State Space Modelling in MPC

A simple state space model is given by;

$$\begin{aligned} x_{k+1} &= Ax_k + Bu_k \\ y_k &= Cx_k + Du_k + d_k \end{aligned} \quad (4)$$

Where; x is a State vector, u is the Vector of dimensionless Input variables, y is the Vector of dimensionless Output variables, d is the Disturbance and k + 1 = 1^{st} value in the prediction vector.

A one-step ahead prediction is used recursively to find an n-step ahead prediction and the general description of the n-step ahead prediction is given in equation (5).

Using Matrix multiplication, the state prediction is expressed as;

$$\underrightarrow{x_{k+1}} = \begin{bmatrix} A \\ A^2 \\ \vdots \\ A^n \end{bmatrix} x_k = \begin{bmatrix} B & 0 & \cdots & 0 \\ AB & B & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ A^{n-1}B & A^{n-2}B & \cdots & B \end{bmatrix} \begin{bmatrix} u_{k|k} \\ u_{k+1|k} \\ \vdots \\ u_{k+n-1|k} \end{bmatrix}$$

Similarly, the matrix multiplication output prediction is given as;

$$\underrightarrow{y_{k+1}} = \begin{bmatrix} CA \\ CA^2 \\ \vdots \\ CA^n \end{bmatrix} x_k = \begin{bmatrix} CB & 0 & \cdots & 0 \\ CAB & CB & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ CA^{n-1}B & CA^{n-2}B & \cdots & CB \end{bmatrix} \begin{bmatrix} u_{k|k} \\ u_{k+1|k} \\ \vdots \\ u_{k+n-1|k} \end{bmatrix} + \begin{bmatrix} d_k \\ d_k \\ \vdots \\ d_k \end{bmatrix}$$

$$x_{k+n} = A^n x_k + A^{n-1}Bu_k + A^{n-2}Bu_{k+1} + ... + ABu_{k+n-2} + Bu_{k+n-1} \quad (5)$$

The output prediction is given by equation (6);

$$y_{k+n} = CA^n x_k + C(A^{n-1}Bu_k + A^{n-2}Bu_{k+1} + ... + ABu_{k+n-2} + Bu_{k+n-1}) + d_k \quad (6)$$

1.3 PID Cascade Control

Cascade control is a hierarchy of primary and secondary control loops comprised of two ordinary PID controllers. The inner secondary loop has a traditional feedback structure, and it is nested inside the outer primary loop (Dostal, et al., 2015). Cascade control strategy seeks to improve the disturbance rejection performance of the process variable. Success in a cascade design depends on the measurement and control of an "early warning" 2nd process variable, which is normally measured with a sensor. The 2nd process variable responds quickly to disturbances before the 1st process variable and the final control element, hence giving a better output variable (Dostal, et al., 2015).

The primary controller determining the set point for the secondary (inner) control-loop is a PID controller with an adjustable gain. For the secondary controller, the procedure is based on its factorization on linear and nonlinear parts used. The inner loop has the effect of reducing the lag in the outer loop, with the result that the cascade system responds more quickly with a higher frequency of oscillation. The control action for the inner loop is often proportional with the gain set to a high value. The rationale for the use of proportional control rather than two- or three-mode control is that tuning is simplified and any offset associated with proportional control of the inner loop can be handled by the presence of integral action in the primary controller. The gain of the secondary controller should be set to a high value to give a tight inner loop that responds quickly to load disturbance; however, the gain should not be so high that the inner loop is unstable. Although the primary control loop can provide stable control even when the inner loop is unstable, it is considered unwise to have an unstable inner loop because the system will go unstable if the primary controller is placed in manual operation or if there is a break in the outer loop (Coughanowr & LeBlanc , 2009).

2.0 Material and Methods

The controllers were designed in Matlab/ Simulink®, using experimental data. The main operational variables were the feed temperature, feed concentration, and feed mass flow rate. Figure 1 shows the configuration of the variables in the control design with different control loops. Fixed variables were volume of the reactor, density of the mixture, heat capacity, and flow of Arrhenius value, the area and the overall heat transfer. The manipulated variables for the controller were the leach feed mass flow rate, feed concentration and the feed temperature. State variable was the reactor concentration, whilst the controlled variable was the reactor temperature. Disturbance variables were the changes in leach feed temperature and concentration. Both controllers had three output parameters (Feed mass flow rate, feed concentration and feed temperature) and one input parameter (reactor temperature).

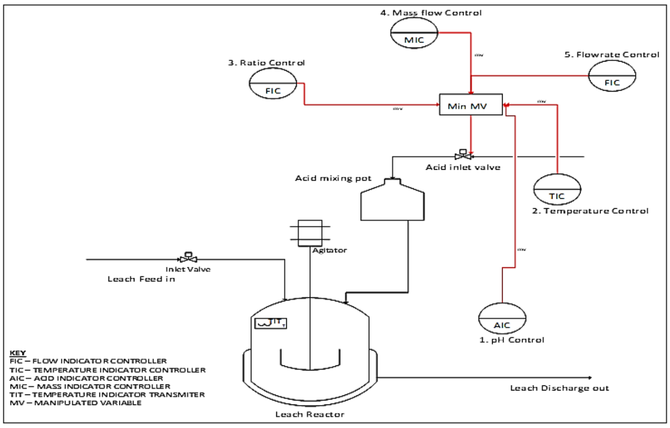

Figure 1: Continuous Stirred Tank Reactor existing setup with PID loops at Kansanshi Mine.

Simulation Conditions

Simulation time was 5 min and sampling rate at 0.1s, A step change introduced at *t* = 3 min from initial temperature of 300K to 320K to observe set point tracking, Disturbances were introduced (change in leach feed temperature and mass flow rate) at *t* = 3 min to observe the reaction in the process variable, Other simulation conditions that were done involved, changing the initial leach feed temperature thereby operating the reactor at extremely high temperatures and at extremely low temperatures.

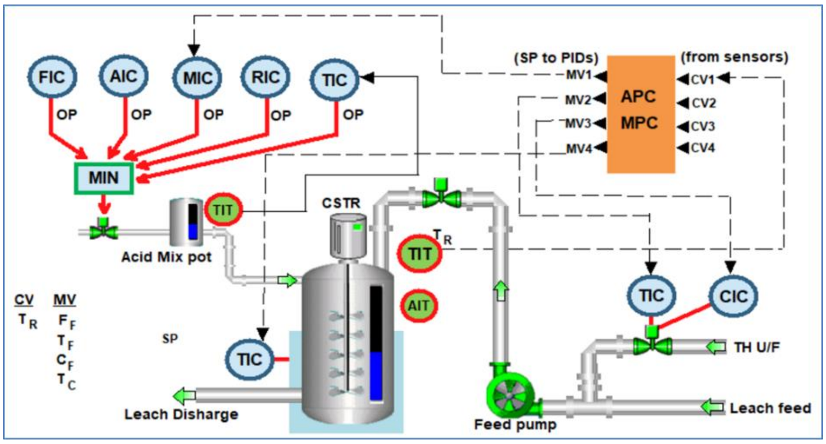

Figure 2: Designed MPC block system configuration.

3.0 Results and Discussion

The objective of this study was to model and understand the application of controllers in different cases. The simulation aimed to observe the response of the PID and MPC controllers to different conditions of feed temperature, flow rate, and concentration. Figure 3 and Figure 4 show the set point tracking and disturbance rejection results, respectively. After conducting three trials, specific performance parameters were evaluated, including % overshoot and settling time, using statistical functions such as confidence intervals, standard deviation, and others. The results show that the MPC controller has a tighter confidence interval for overshoots and a faster settling time of 0.466 minutes compared to the PID's 0.83 minutes, indicating a higher reliability and quicker stabilization time for the MPC.

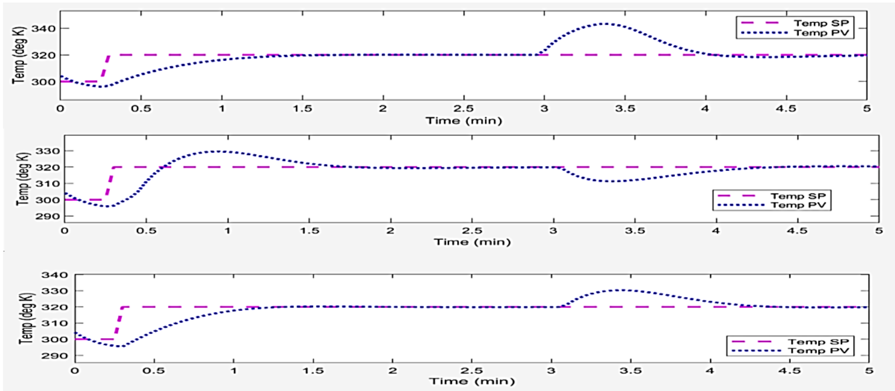

Figure 3: PID controller simulation results for trial 1, 2 & 3

The results in Table 2 show that the MPC controller outperforms the PID controller in terms of stability, with an average overshoot of 3.9 compared to 15.67 for the PID. However, the PID has a faster rise time, averaging 0.7 minutes compared to 1.43 minutes for the MPC. On the other hand, the MPC has a faster settling time, indicating a quicker response to stabilize.

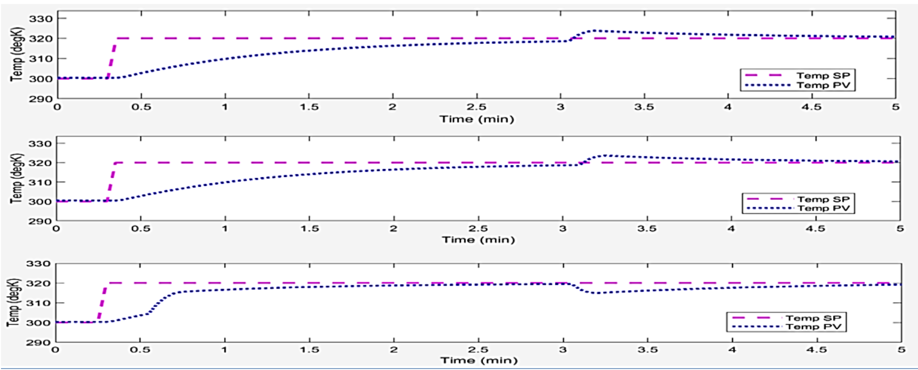

Figure 4: MPC controller simulation results for trial 1, 2 & 3.

Table 2: Performance Comparison between MPC and PID.

	MPC			PID		
Test No.	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**
Temperature SP	320	320	320	320	320	320
Rise time (min)	1.7	1.8	0.8	0.8	0.5	0.8
Peak time (min)	3.1	3.3	3.4	3.4	3.3	3.4
Settling time (min)	0.4	0.4	0.6	0.8	0.8	0.9
Overshoot	3.1	3.3	-5.3	21	14	-12

3.1 Process Capability Analysis

A process capability analysis was conducted to further assess performance. The lower specification limit (LSL) was set at 45 deg. C, the upper specification limit at 51 deg. C, and the target temperature at 48 deg. C. The cpk values, StDev (overall) and the mean were compared. Comparing the three charts, the MPC controller produced the highest cpk value of 3.5, followed by PID at 2.10. Figure 5a shows the capability analysis for the MPC controller, with the highest frequency in the target region and a low standard deviation. The PID process capability results shown in Figure 5b have a fair frequency range with a lower cpk value of 2.10. Figure 5c shows a summary report on the process capability analysis conducted on the plant data. The highest frequency does not sit in the target region and has a high standard deviation and a low cpk value of -3.10, indicating poor performance.

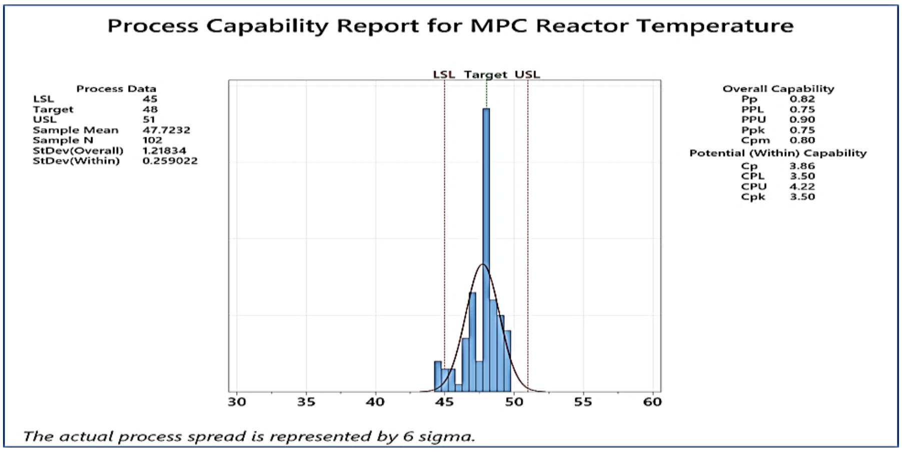

Figure 5a: Process capability report for MPC controller.

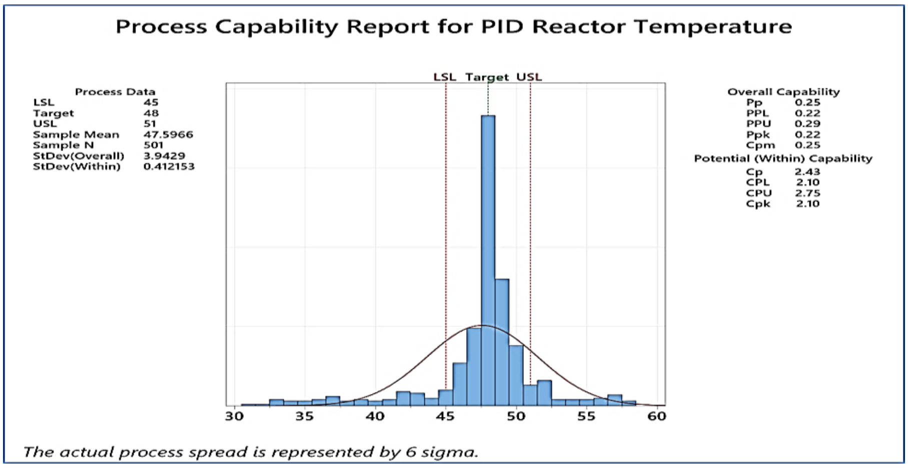

Figure 5b: Process capability report for PID controller

4.0 Conclusion

Results indicate that the MPC controller performs better in terms of disturbance rejection and set point tracking compared to the PID controller. The MPC controller showed less fluctuations and better response in rejecting big fluctuations after changing the feed temperature. The process capability analysis and confidence interval results also show that the MPC controller outperforms the other.

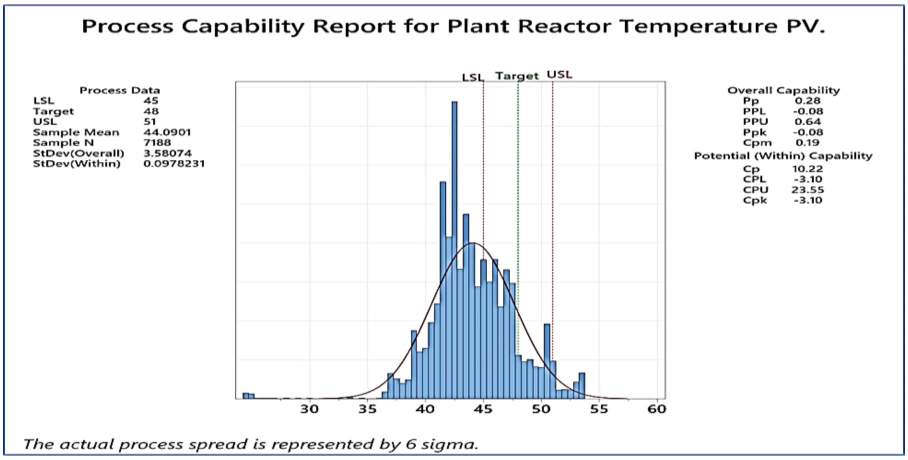

Figure 5c: Process capability report for plant data.

The MPC controller has a lower standard deviation (1.21) and overshoot (0.37) than the plant controller (3.581 and 6.47, respectively) and the PID controller (3.94 and 7.67, respectively). The MPC controller also has a faster rise time (1.43) and settling time (0.47) compared to the other controllers.

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Towards a conceptual framework for building resilience for risk reduction in the Built environment

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Abstract

Zambia in the recent past has had increasing temperatures, flash floods, droughts and landslides as natural disasters in some parts of the country while fires are the most common man-made disaster experienced in the built environment yet the same building standards are used for all design plan approvals and construction across Zambia's ten provinces. The differences in potential risks show that there is need to customize the standards based on potential risks. Through a literature review a framework is developed to guide design and construction of buildings so that they are resilient. The framework developed a six step process that focuses on the nature of the development, its location, management of potentials risks, the process and product to be developed and finally the capture of lessons leant to ensure that the standards are updated and relevant.

Keywords: building, construction, designs, resilient, Zambia.

1. Introduction

Disasters are on the rise, both in terms of frequency and magnitude at a global level. For the sustenance of human life, flora and fauna there have to be measures for mitigation, minimization or elimination. Of concern is how the natural and man-made disasters affect the built environment. Zambia has in the recent past had flash floods, fires, droughts and experienced landslides which have been termed as disasters by the Disaster management Unit (DMMU). The Sendai Framework for Disaster Risk Reduction 2015 – 2030 emphasizes the need to manage risk rather than disasters. The concept and practice of reducing risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (Turnbull et al, 2013) is key. Moreover, the country's' risk profile provides projects floods and droughts for the period 2050-2100 making the need for risk reduction dire. Risk Reduction is the taking of precautionary measures to reduce the likelihood of a loss or to reduce the severity of a possible loss. For the built environment the fundamental starting point is building regulation which will then inform design and construction. This will in turn address sustainability development goals 11 –sustainable cities and communities as well as SDG 13-climate action (UNDP, 2012). Building Regulation defines how a new building or alteration is to be built so that it is structurally safe, protected from risk of fire, energy efficient etc. and has adequate ventilation for its purpose. This also includes regulating for resilience which in essence gets buildings to be able to withstand or recover quickly from any difficult conditions such as

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floods, energy issues, water management, ventilation, fires, earth quarks, tremors and the like.. Figure 1 shows the possible resilience actions and measures (Madini and Jackson, 2009) of potential risks..

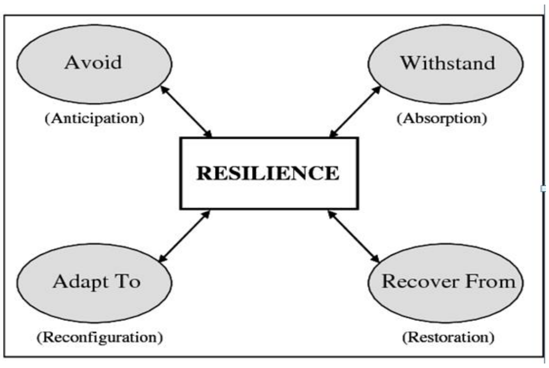

Figure 1Many faces of resilience (Madini and Jackson, 2009)

A risk factor is basically anything that amplifies the occurrence of a risk. Risk factors underlying disasters are climate change, environmental degradation, globalized economic development, globalized economic development, poverty and inequality, poorly-planned and managed urban Development and weak governance (iiamjunetv, 2017). Poverty and inequality, poorly-planned and managed urban development and weak governance are specific areas the built environment can participate in actively. Climate change can increase disaster risk in a variety of ways – by altering the frequency and intensity of hazards events, affecting vulnerability to hazards, and changing exposure patterns. Environmental degradation is both a driver and consequence of disasters, as it reduces the capacity of the environment to meet social and ecological needs. While globalized economic development has resulted in increased division between the rich and poor on a global scale contributing to poverty and inequality. Poverty is both a driver and consequence of disasters, and the processes that further disaster risk result in inequality. From a governance perspective; weak governance has resulted in investment environments in which public sector actors are unable or unwilling to assume their roles and responsibilities in protecting rights, providing basic services and public services. This in turn contributes to having poorly-planned and managed urban development. The latter is characterized by a new wave of urbanization unfolding in hazard-exposed countries and with it, new opportunities for resilient investment emerge. Many of the underlying risk factors are man-man and therein the solution lies with man. However, in building resilience in the built environment both natural and manmade risks have to be managed for the desired results to be achieved. This study was a desk review to answer specific questions that are needed for resilience to be achieved as follows:

- What are the hazards of concern in Zambia’s built environment for resilience?
- How can the identified hazards be mitigated?
- Who should be involved in promoting resilience in the built environment?
- What should be the areas of focus for identified stakeholders?
- What mechanism can be formulated to promote resilience in the built environment?

1.1 Nature of risks and disasters

The built environment can be affected by several risks; man-made or natural. Man-made risks include fires, pollution (land, air and water) and technology. Natural risks include droughts, floods, volcanoes, landslides, endemics, pandemics, tornadoes, cyclones and others. The approach is to minimize or eliminate the effects of natural disasters and mitigation of man-made risks. For the built environment this means that old building regulations cannot be maintained if they do not offer solutions to future problems. This would also follow that designs, materials and techniques used in the built environment should be responsive to future needs of resilience. In the Zambian context we currently have the same standards in terms of regulation for areas that experience flooding, droughts, and landslides. This approach is also true for construction in or near industrial areas and mining areas or water bodies when there is evidence that deterioration of the built environment and elements to be with stood differ. While it would be ideal to have a resilient built environment, barriers also need to be considered.

1.2 Barriers to resilient built environment

The barriers to a resilient built environment have basically been classified as physical, social, economic and technical. Physical barriers include aspects such as climate change and poor quality construction. For social barriers poverty, rapid population growth, corruption, construction on unsafe sites and growth of growth of informal settlements. Economic barriers include poor funding at local and municipal levels and financial limitations in meeting regulations is also noted. The technical barriers include shortage of qualified personnel and failure to apply knowledge to practices. For most developing countries economic, financial and technical barriers are very severe. It is proposed that barriers be overcome and building regulations be formulated to reduce risks in the built environment.

1.3 Building regulation as a means of risks reduction

Building regulation has proven a remarkably powerful tool for increasing people's safety and resilience and limiting the risk that they face (Cerè et al, 2017). Resilience ensures energy and water independent, use of renewable resources and their storage, reduction of environmental effects and community support. This can be done at different stages namely planning of developments, development of resilient standards and implementation (Tembo, 2016, 2018). Planning of developments is cardinal in averting disasters. For instance areas that are prone to flooding can be avoided during the development process or measures put in place to avoid loss of human life and property. Planning of developments can include Supervision of land use and prevent construction in unsafe locations not only for floods but other anticipated hazards. A step further from the planning is the development of resilient standards. The development of resilient standards aids in the provision of standards that are able to reduce foreseeable risks. For instance water harvesting can be part of designs in drought prone areas, fire resistant materials of designs in buildings and designs that guard against floods or at the least configuration and adaptation of a building.

Once developments of the proposed resilient standards are done, the next step is the implementation of these standards. This would include risk based implementation of regulations for permits and inspections. This would help in ensuring that there is:

- Consistency in plan reviews and inspections
- Focusing of resources on higher risk building projects
- Focus on builders with history of non-compliance
- Process simplification for lower risk construction in the local context
- Shift design risks & liability to the sectors with the skills, competencies and experience e.g. private firms

All the above-mentioned procedures would be done in an environment that fosters resilience. This should include **t**raining of professionals in resilient practices, adequate remuneration of professionals e.g. to prevent corruption and assistance with preparation and mobilization during disasters by coordinating actions (Tembo, 2016). Most times there is detachment of disaster planning and management hence those planning for disasters may not improve on their planning. The next section briefly discusses the methodology used in this research.

2. Methods

A rapid review was done for about two months (Grant, 2009). This type of review answers a narrow question. In this case the main question was the procedure/process to achieve resilience in the built environment. Due to the limited time taken to review, sources of information are limited nevertheless the selection of what to include is based on relevance and as to whether the literature answers the questions as indicated in the introduction section of this paper. The analysis is mainly descriptive in nature (Khangura et al 2012). The steps that were followed for conducting the rapid review include 1. defining a research question, 2. searching for research evidence, 3. Critically appraise the information sources, 4. synthesize the evidence, 5. identify applicability and 6. write-up of findings (Dobbins, 2017). The next section presents the results of the review.

3. Results

3.1 Zambia's risk profile and possible solutions

Zambia's country risk profile provides a comprehensive view of hazard, risk and uncertainties for floods and droughts in a changing climate, with projections for the period 2050-2100 (Rudari et al.2018). This entails that the major hazards are droughts and floods (see figure 2). So this provides hazards from two extremes for natural hazards. Landslides and sink holes are another hazard in some parts of the country (NHA, 2016). For man-made hazards fire is becoming a problem in the built environment for major cities. Additionally, pollution especially in mining areas has been seen to contribute to the built environment both directly and indirectly. Indirectly, use of unsuitable construction materials especially aggregate from mining activities is also contributing directly by emissions that may pollute buildings and compromise the structural stability of buildings. Tembo, Ziko and Sakala note in 2019 an increase in temperatures by 1 to 2 degrees Celsius of the past 20 years. This has been as a result of man’s activities and results in reduced thermo-comfort for occupants of building.

Flooding is an overflowing of water onto land that is normally dry. Flood resilient construction is an important aspect of flood risk management. The idea is to make spaces for and also be able to live with floods (Proverbs and Lamond, 2019). Flooding can cause a range of damage to urban settlements, including the threat to personal safety when normally dry areas are submerged, leading to the need to escape from buildings. The US congressional research (2019) outline improved drainage, vegetated landscapes, and stabilized walls, flood resistant materials, constructed barriers and flood plain/path zoning as built environment solutions for flooding aside from having minimum distances from flood paths. The general recommendation for planning is to increase activities for use as you move away from the flood path or plain. Flooding can damage foundations, destruct structural walls and flooring; as well as increase the risk of the building to de-attach from its foundations from the downstream forces applied (Cere et al, 2017). Droughts on the other hand are when there is extreme dryness. Measures that can be taken in the built environment include conservation of water in homes, agricultural or industrial processes, access new water sources, and manage drought on a watershed level (GWPEA, 2016). The measures are mainly bordered around water harvesting and storage. Additionally, facilities and activities can be designed to use less or recycled water.

Observed consequences in mining and industrial areas are corrosion of metals such as roofing, wearing of paints and staining. Special paints can be used on both walls and roofs at times even on plumbing installations. The use of more resistance and durable materials is generally encouraged in such areas to mitigate the effects of things like sulphur attacks resulting in acidic rain. Landslides are also becoming common. Landslides do not occur only as a single event but it is also associated with other hazards like floods and earthquakes (Bera, 2020). These can be prevented from attacking ones property, by adding nets, retaining walls, and planting tough vegetation. It is not advisable to remove vegetation in land slide prone areas to prevent further erosion. Additionally, in the waste case scenario sandbags can be added in exposed areas.

Fire resilience is the capacity of a building to resist to, adapt to and recover from a fire and resume to its essential functions in a timely. Studies show that by 2050, 1.6 billion people living in more than 970 cities will be regularly exposed to extreme high temperatures (UN, 2021). Fire impacts to the environment come from both natural and human sources. Human sources include negligence or use of incorrect or improper design or poor workmanship while natural sources could be from high temperature, volcanoes and the like. Temperature increase is mainly due to climate change resulting from increased carbon emissions for which the construction industry accounts for 38%. The temperatures are expected to increase beyond what is being experiencing now especially in cities (Mohammed et al 2022). This entails that the thermal comfort which sometimes can be fatal due to heat strokes need to be considered in building designs. Building should have both passive and active sustainable systems to promote thermal comfort. Interventions such as green areas, orientation of buildings, high-rise rooms, and large openings improve ventilation and should be encouraged. Additionally, green roofs and reflective surfaces can be used decrease temperatures within and outside buildings.

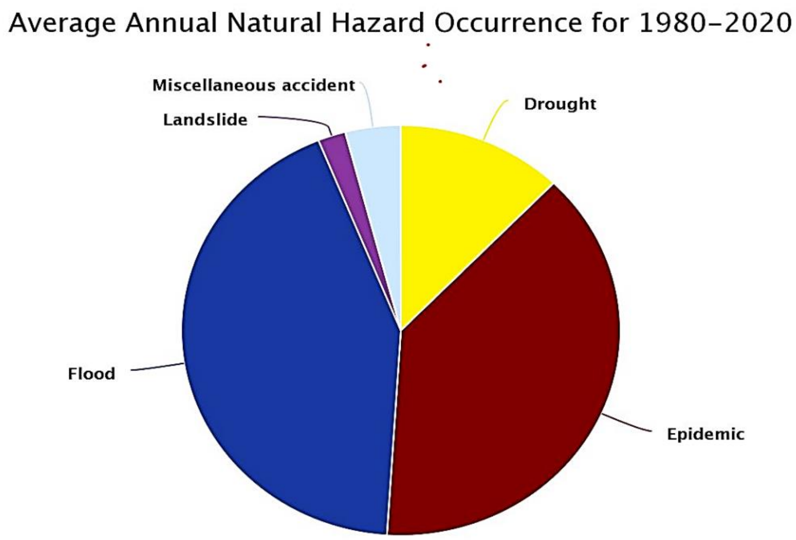

Figure 2 Zambia's risk profile (Source: https://climateknowledgeportal.worldbank.org/country/zambia/vulnerability)

3.2 Participants and areas of involvement and focus

Table 1 shows the nature of stakeholders to be involved in projects, their role and areas of focus in the resilience agenda. Professional consultants and government are seen as key stakeholders as they are in a position to drive most of the processes going by their involvement. Nevertheless all stakeholders are important as there none involvement results in all being affected. For instance, client can only use resilient materials that have been manufactured in that way once they are prescribed by a consultant/client.

Table 1. Stakeholders and their roles

Stakeholders	**Areas of focus during life of standards and regulations**	**Role In Resilience**	**Possible Areas Of Involvement during project life cycle**
Government	planning of developments, development of resilient standards and implementation	Formulation of policy and standards for resilience	Planning, design, construction and operational phase
Developer	implementation	Uphold resilience provisions	Planning, design, construction
Manufacturer/supplier	Manufacturing according to standard	supplier Use of sustainable material processing and manufacturing	Construction and demolition
Client	planning of developments, and implementation	Decides and approves materials and design	Planning, design, construction operation
Buyer/end user/ communities	Implementation of standards, feedback on standards	Maintenance and feedback of provided standards	Operation phase
Contractor	Implementation of standards, feedback on standards	Material purchase and installation	Design and construction, maintenance
Consultant	planning of developments, development of resilient standards and implementation	Design, advise on materials, maintenance procedures	Design and construction, maintenance and demolition

3.3. Process of resilience in the Built Environment

Figure 1 show the process of achieving resilience in the built environment. The process incorporates the proposed development in terms of the nature of construction to be embarked on. Secondly resilience parameters to be considered are also identified based on the location e.g. floods, landslides, high temperatures etc. Stakeholders would contribute to Planning of developments, development of resilient standards & implementation monitoring. During planning and implementation of the project those involved should have necessary skill and knowledge in various aspects such as planning, materials, manufacturing, use, construction etc. Once in use such facilities should be able to influence future projects with the capture of lessons learnt.

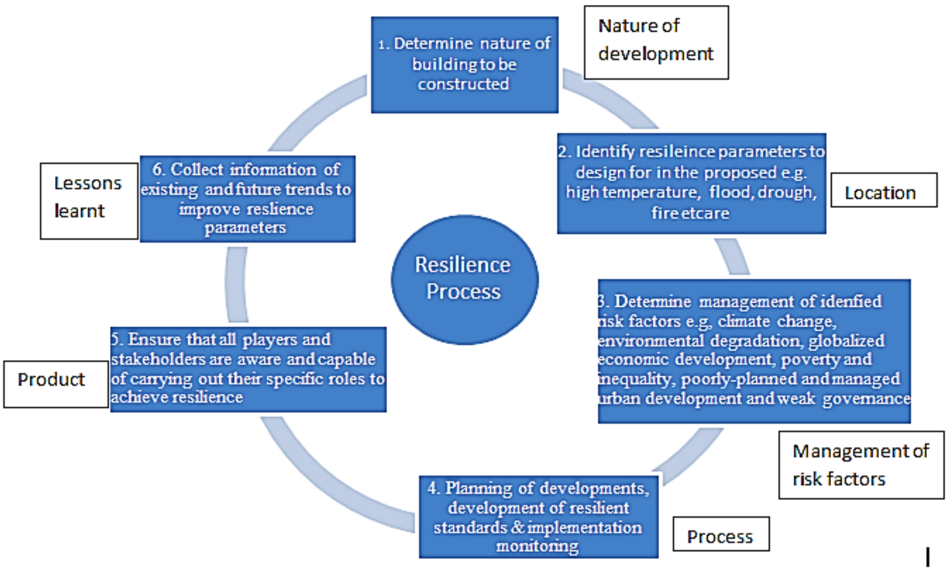

Figure 2. Process for achieving resilience in the built Environment

4. Discussion

Resilience is about bouncing back from risky, adverse situations. This may be achieved from the perceptive of anticipation, absorption, reconfiguration or restoration (Figure 1). The most desirable in the built environment is anticipation of risk factors (Figure 2 step 2) as they can be identified and managed. This implies that planning, development and implementation (Figure 2 step 3&4) of what is anticipated is actually possible. The built environments have various players and stakeholders (to be identified in stepwho have various roles to play as shown in Table1. Citizens in the various communities of various nations who may themselves be the players and stakeholder in a project would want certain parameters that need to be addressed resilience wise such as floods, droughts, fire, landslides, and high temperatures as examples. This means that the needed standards and policies needed to be in place. Standards and policies need to be developed for accommodated observed resilience parameters (Figure 2 step 4). Once this is done implementation has to be done to ensure that plans are achieved. This by implication needs skilled and knowledgeable people in the fight for a resilient built environment to ensure that a resilient product is constructed ((Figure 2 step 5). In the operation phase of the product, information has to be collected as a way of monitoring performance so as to have information feeding into future designs, policies and standards (Figure 2 step 6). The study’s main finding is that designs and standards should not be generic but be a response to various risks in the built environment.

5. Conclusion

Resilient buildings give confidence to users and owners for the safety and assurance of future benefits to both property and humans. Various stakeholders and professionals have various contributions that are key for the attainment of a resilient built environment. The key areas are planning of developments, development of resilient standards and implementation. After which lessons learnt have to be documented. Planning and development of standards must be done in due consideration of resilient parameter such as floods, fire, drought, landslides and others. A six stage conceptual framework was formulated that focuses on the nature of the development, its location, management of potentials risks, the process and product to be developed and finally the capture of lessons leant to ensure that the standards are updated and relevant The implication of this is that standards are not supposed to be uniform but specific to resilient parameters identified. Future studies should focus on the various provinces and areas within Zambia and map out the specific risks and the possible standards that need to be developed in those provinces and areas so as to have resilient buildings.

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The adaptive capacity for water supply and sanitation services provision under climate change: The case of Mulonga Water Supply and Sanitation Company in Chingola, Zambia.

Osward Mukosha[1]

Abstract

To sustainably provide water supply and sanitation services in changing climatic conditions, there is need to develop adaptive capacity for the effects that climate change will have on the water supply and sanitation systems. Those managing and designing water supply and sanitation services systems need to understand climate change and its effects, and the impacts these effects will have on water supply and sanitation installations and service provision. Such understanding will ensure delivery of climate resilient water supply and sanitation services. The paper assesses the adaptive capacity for water supply and sanitation services provision under climate change at Mulonga Water Supply and Sanitation Company in Chingola on the Copperbelt Province of Zambia. It uses a case study with the help of a questionnaire containing statements which are showing adaptive capacity indicators. The statements include awareness of climate related events that affect water supply and sanitation operations, employees undergoing training on the impacts of climate change on water supply and sanitation operations and employees' understanding of measures to address climate change. The paper finds that while all employees (100%) participating in the survey acknowledges that climate related events are affecting water supply and sanitation operations, only 14% acknowledges trained awareness of climate change impacts on water supply and sanitation operations and 60% did not understand measures to address climate change impacts on water supply and sanitation operations. The paper concludes that the adaptive capacity of water supply and sanitation operations under climate change is low and recommends that climate change knowledge acquisition be embarked on by training employees and collaborating with Institutions of higher learning and Climate Change Consulting Firms.

Keywords: Adaptive, Capacity, Change, Climate, Resilient,

1.0 Introduction

Climate Change is now understood and accepted as one of the most prominent environmental challenges the world is facing today (Howard *et al.,* 2016). In most parts of the world, the effects of climate change are manifesting and are impacting on many sectors of national economies. The water supply and sanitation sector is among the sectors that are being impacted by the effects of climate change (Muller, 2011). Lopez *et al.* (2011) stated that many specialists have recognized that the quantity and quality of water will be the main problems for societies and the environments

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in the face of climate change. Operations of water supply and sanitation systems will become increasingly more prone to the expected effects of climate change.

The World Health Organization technical report, WHO (2009) indicates that of all the effects of climate change, floods and droughts will affect the water supply and sanitation sector more. It indicated that flooding of river basins will affect intakes of water supply facilities that can take several days and even years to repair. For sanitation facilities, the report indicated that flooding will cause a breakdown in services, which will pose as a source of diseases that are transmitted by contaminated water through the spread of human excreta in the surrounding environment.

Given that water is a basic human need, and climate change is likely to threaten the enjoyment of the basic human rights to water and sanitation (The UN, 2020; Sarker and Ahmed, 2015), the urgency for institutions providing water and sanitation services to build adaptive capacity to the imminent effects of climate change on water supply and sanitation systems is eminent. Institutions providing water supply and sanitation services need to start to assess what impacts climate change will have on their systems and what the technical, operational and financial implications will be on service delivery (Danilenko *et al.*, 2010).

In climate change discourses, adaptive capacity is defined as the capacity of systems, institutions, people, and different living things to adjust to possible harm, to make the most of opportunities, or to react to results of climate change (IPCC, 2014). With regards to water supply and sanitation services system, it might be understood as the capacity of the system to keep up or improve levels of service delivery despite climate change. Adaptive capacity is, consequently, to a great extent attributed to the ability of Managers within the Company to handle the likely challenges and recognize the seriousness of the dangers, plan reasonable strategies and execute those (Azhoni *et al.*, 2018). By building adaptive capacity to climate change, water supply and sanitation services provision will become resilient even with climate change, and eventually have the option to utilize the opportunity that climate change will present.

1.1 Climate Change and the Water Sector

Climate Change, is a change in the average climate or climate variability that persist over an extended period, usually 30 years or more (Riedy, 2016). Climate Change effects have become evident in different places in the world and are projected to become more frequent and intense. The most important effects of climate change include melting of glaciers, rising sea level, rising temperatures leading to global warming, intense heat waves, droughts, wind storms and storm surges, floods, changing precipitation and shifting rain seasons, among others (IPCC, 2014; Bertule *et al.*, 2018).

For the water sector, climate change will fundamentally affect the worldwide water supplies and may bring about water shortage (IPCC 2013; 2014; Filho, 2012). Floods can damage water supply intake infrastructure that can take years to repair and cause service disruptions of sanitation facilities which can cause water borne and water related diseases. Droughts can lead to drying up of water sources causing people to cover longer distances to access drinking water (Shrestha *et al.*, 2014), water service disruptions and water rationing.

Climate Change adaptation is the process of preparing for actual, or projected, changes in climate averages and extremes. It is building adaptive capacity of the individual, groups or organization by increasing their ability to adapt to changes and transforming this capacity into actions by implementing adaptation decisions (Huntjens *et al.*, 2011). Bednar *et al.* (2018) pointed out that the process involves five stages of identifying climate change impacts, assessing risks and exposure, deliberating adaptation options, implementing adaptation options and monitoring the adaptation options

2.0 Method

In April to May 2021, a study was conducted at Mulonga Water Supply and Sanitation Company in Chingola Zambia, to evaluate the Company's preparedness for climate change effects on water supply and sanitation service provision and to identify adaptation options the Company can take in the face of changing climatic conditions. A structured questionnaire was used to address the study objectives. Forty (40) technical employees from the company were purposively sampled to respond to the questionnaire and 28 legitimate responses were obtained, a response rate of 70%. The questionnaire was carefully developed to contain statements which showed adaptive capacity indicators, that is, knowledge base and awareness of climate change impacts on water supply and sanitation, training and understanding climate change, collaboration on climate change with experts, financial capacity, and adaptation activities that can be taken to address potential impacts of climate change (Pardoe *et al*., 2018; Danilenko *et al*., 2010). Quantitative data from the structured questionnaire were analyzed using excel. The data have been presented in bar charts expressed in percentages. The following parts gives the results obtained:

2.1 Awareness of climate change impacts on water supply and sanitation operations

All 28 (100%) respondents who took part in this study stated that they were aware of climate change taking place. This means that climate change is not a new subject to the respondents who took part in this study as all of them were fully aware of the phenomenon taking place.

2.2 Impacts of weather-related events experienced at the company over last 10 years

Figure 1 below shows impacts of weather-related events experienced at the company over last 10 years

Figure 1 shows the distribution of respondents who took part in this study by their knowledge on events that have affected the water sector in the past 10 years. The majority of the respondents stated deteriorating raw water quality (78.57%), interruption of operations (71.43%) and flooding of water/sanitation facilities and decreased water quantity (67.86%) as the main weather related events that have affected the Water Utility Companies. 39.29% reported damage to water and sanitation infrastructure

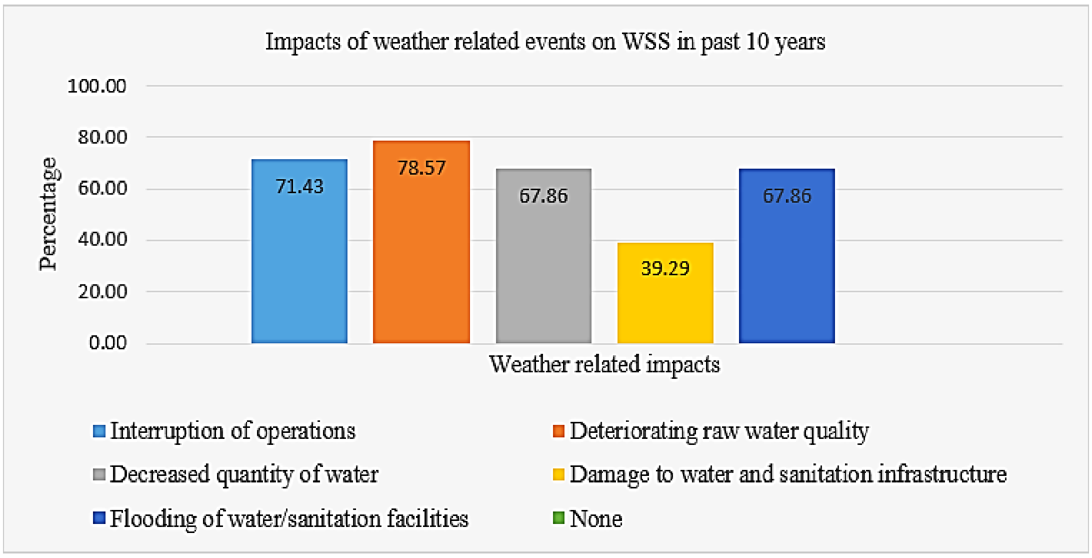

Figure 1: Impacts of weather-related events in the company over the last 10 years

2.3 Status of Capacity in Climate Change issues within the utility

Figure 2 shows employees capacity status in climate change issues at the Company

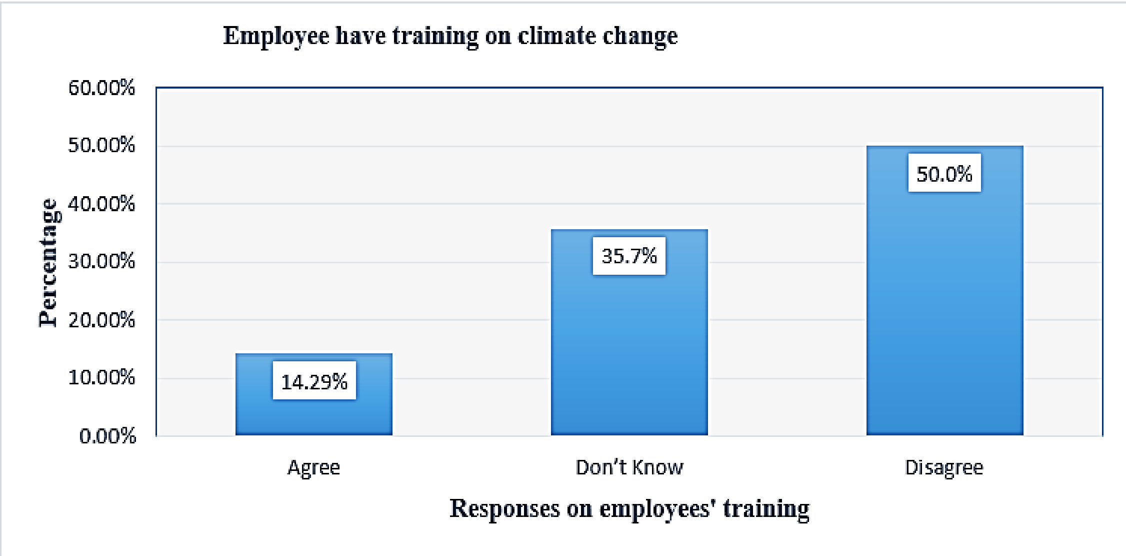

Figure 2: Employee's awareness of training on climate change at the institution

The findings presented in figure 2 above indicate that most of the respondents (50%) who took part in the study stated that there were no training that had taken place on climate change in the organization. Further, 35.7% of respondents did not even know if at all there was any trainings that took place. This result is in agreement with the findings of Ludwig et al. (2009) at Umgeni water where employees' level of trained awareness of climate change was low. This can be overcome by the respondents' organization engaging with climate experts or consulting firms to have employees trained on climate change and its potential impacts on water supply and sanitation. Nyamwanza (2017) similarly noted that such coordination and collaboration is vital for enhancing learning and ultimately building the resilience of the institution to climatic variability and change.

2.4 Employees Awareness of measures to address Climate Change

Figure 3 shows employees understanding of measures to address climate change

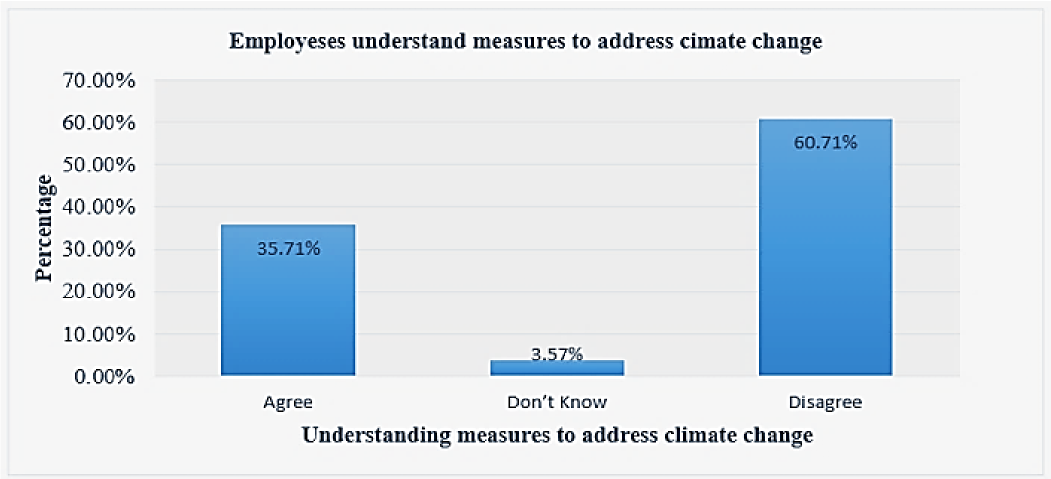

Figure 3: Employees understanding of measures to address climate change

In light of the findings of this study, as shown in figure 3 above, the vast majority of the respondents (60%) who participated in this investigation stated that the employees in operations did not understand measures for addressing climate change. This could be true as most of the respondents were aware of climate change but stated that they had not received any training on matters relating to climate change.

2.5 Options to address climate change impacts on WSS systems

Figure 4 shows options to address climate change impacts on water supply and sanitation systems

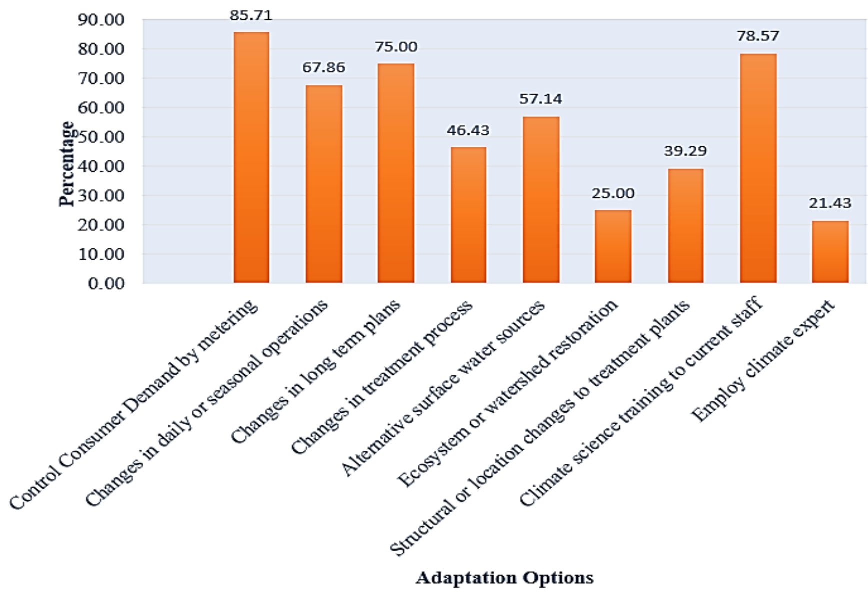

Figure 4: Options to address climate change impacts on water supply and sanitation systems

When given some set of adaptation options the institution can take to adapt to climate change, 85.71% (24) of respondents indicated the need to control consumer demand by metering customer points, followed by 78.57 % (22) who stressed the need to undergo training in climate science and a further 75 % (21) said there is need to change long term planning to incorporate climate change. Only 21.43 % (6) felt recruiting climate expert would help, and 25% (7) of the respondents indicated ecosystem or watershed restoration can help address the impacts of climate change on the water supply and sanitation system. These findings are shown in figure 4 above.

3.0 Conclusion

The study assessed the adaptive capacity for water supply and sanitation service delivery under climate change at Mulonga Water Supply and Sanitation Company Limited in Chingola. It was embarked on in order to fill the information gap on the adaptive capacity for water supply and sanitation service delivery under climate change. Such capacity is required for delivery of resilient water supply and sanitation services in the face of climate change. From the data analyzed, the following conclusions have been arrived at:

The respondents expressed awareness of climate change happening and that it will have consequences on their systems. But there is low capacity on aspects of Climate Change among technical personnel in the utility as observed on the lack of informed knowledge of climate change from either formal training, climate experts like universities, consulting firms or the National Meteorological Department. The same was true regarding collaboration with expert institutions. Regarding measures the institution can take to address potential climate change impacts, controlling of consumer point consumption, training staff in climate science and changes to long term planning to incorporate climate change emerged as most probable strategies the respondents identified.

4.0 Recommendations

There is need to embark on climate change knowledge acquisition by training staff so that they gain proper understanding of climate change issues. Such training will help the organization to devise measures to address climate change concerns from an informed perspective. The Company needs to enhance collaboration with other organizations such as Universities, National Meteorological Department and other Consulting Firms specialized in climate science knowledge so that the understanding of climate change among its employees is enhanced. There is need to explore other options available for climate change adaptation for the water sector to ensure climate resilient service delivery.

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Barriers to STEM education hindering the advancement of innovation and sustainable development

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Abstract

STEM education is an approach to learning and development, integrating the areas of science, technology, engineering and mathematics. The progression of the STEM education curriculum in Zambia started in December, 2019 and for this resolve, a transitional curriculum was planned based on the Zambia Educational Curriculum Framework of 2013. STEM education is necessary to facilitate quality education which has a potential to promote economic development, international competitiveness and job creation. The quality of education is key to equipping the younger generations with the knowledge and skills to address present and future socio-economic and environmental challenges, such as global climate change, digitalization and globalization. Therefore, learners should experience an education that reflects this reality and STEM educational schools have an important role to help achieve this objective. In this sense, STEM education should provide an opportunity that supports innovative and sustainability development. However, despite the many strides that have been made so far in the implementation of STEM education in schools, the rolling out of the programme has faced a number of challenges in spear heading Innovation and Sustainable Development (ISD). This paper discusses some of the key barriers preventing the integration of ISD in schools and these have been deliberated under two subjects namely innovation and sustainable development. Therefore under innovation, barriers covering themes such as informal and social support structures, formal environment, risk aversion, shared vision among others have been considered. Further, under sustainable development barriers such as educational structure, school curriculum and teacher education among others have also been pondered.

Keywords: Integrating, development, competitiveness digitalization, globalization

1.0 Introduction

1.1 Background

The need for quality and relevant education has gained global popularity. The establishment of Science, Technology, Engineering and Mathematics (STEM) Education in Zambia is a response to this call and in line with the Zambia Educational Curriculum Framework of 2013 which focused on producing learners who are self-motivated, creative, confident and productive (Oliver et al., 2022). It also focuses on producing individuals who are holistic, independent learners with values, skills and knowledge to enable them to succeed in life (Oliver *et al*. 2022). STEM is an approach

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to learning and development, integrating the areas of science, technology, engineering and mathematics. These four fields share an emphasis on innovation, problem-solving, critical thinking and sustainability and together they make up a popular and fast-growing industry (*Ibid)*.

The development of the STEM education curriculum in Zambia started in December, 2019 when the Ministry of General Education was given cabinet approval to commence the implementation of the STEM curriculum in fifty-two (52) pilot secondary schools (Magasu, *et al*. 2022). For this purpose, a transitional curriculum was designed based on the Zambia Educational Curriculum Framework of 2013. According to Ismail (2018), STEM education is necessary to facilitate economic development, international competitiveness and job creation. It should be noted that quality education is key to equipping the younger generation with the knowledge and skills to address present and future socio-economic and environmental concepts, such as global climate change, digitalization and globalization (Magasu, *et al*. 2022). This entails that learners should be exposed to schools that reflect the reality of these challenges, and STEM schools should be such. In this sense, STEM education should be seen as an innovative approach to education as it features extensively within the global landscape of educational policy and reforms. According to Ercan, *et al. (*2020), this approach not only addresses the aims of policy reforms, such as ensuring competency in mathematics and science, but also emphasizes that it is no longer sufficient for modern citizens to understand science and mathematics; their knowledge must be integrated with technology and engineering.

In view of the above, STEM education uses a learner-centered, approach to develop the learner's self-direction, problem solving, collaboration and project management. It also drives innovation through creating, designing and producing solutions to real-world problems and uses real-world challenges as entry points for integration of STEM disciplines which also promote sustainable development (Oliver, *et al*. 2022). Sustainable development is measured by many as the only way to avert environmental and social disaster (Brundtland, 2019).

On the other hand, innovation in education promotes the introduction of more technology into the classroom to create a blended classroom where students experience technology as they would in the real world. However, STEM education for sustainable development conversely provides a complete and transformational education which addresses learning content and outcomes, instruction and the learning environment. STEM education for sustainable development encourages children and youth to draw on their STEM competence and the process of science as a key basis for reasonable action in the world. Knowledge, skills, and understanding of science, technology, engineering, and mathematical phenomena are vital to helping students understand global problems and support actions in society that address these challenges in a meaningful and knowledge-based way (Oliver, *et al.* 2022).

Despite the many strides that have been made so far in the implementation of STEM education, the rolling out of the programme has faced a number of challenges in spear heading Innovation and Sustainable Development (ISD) in schools (Kirkland and Sutch, 2009). Further, integration of ISD in schools has been poor. An important question therefore is, "What are the barriers preventing the integration of ISD?" It is therefore argued here that addressing ISD barriers would go a long way in the integration of ISD in schools under general education.

2.0 Barriers to STEM educational affecting the advancement of innovation and sustainable development

Barriers to STEM educational are discussed under two themes namely innovation and sustainable development. Section 2.1 highlights the challenges faced in rolling out STEM education focusing on the promotion of innovation.

2.1 Barriers to STEM educational limiting promotion of innovation

There is evidently a wide variety of innovative teaching and learning practices across the education sector. However, the imperative to support this innovation is not clear and new approaches to teaching and learning need to be fostered to respond to the changing context with which education interacts (Kirkland and Sutch, 2009). It is becoming widely understood that end-user innovation is a crucial approach to developing new practices and approaches. This recognizes that the practice of creating solutions to individual problems, on an individual level, is an act of innovation. But also, that learning from these individual acts can support wider, system-level innovation – not through rolling-out the innovation that occurred at an individual level, but by supporting greater numbers of local level 'end-user innovators.'

Studies have examined barriers to innovation and increasingly they have highlighted the interactivity of factors that are considered barriers to innovation (Madeira *et.al*. 2017).However, there is a significant body of research, of what the barriers affecting change are, but not necessarily the process by which they happen. At the core of successful innovation in schools is the relationship between the innovations: the capacity and disposition of the innovator, and the environment in which the innovation occurs. The relationships among these areas are unique to each school and each innovation.

In identifying barriers to educational innovation, this paper draws on existing literature to discuss a number of existing barriers to innovation in schools. According to (Kirkland and Sutch, 2009) , the barriers are frequently intertwined, rather than attempting to create strict categories, these are deliberated under the following seven key themes emerging from the literature:

i. Informal and social support structures

ii. Formal environment

iii. Risk aversion

iv. Shared vision

v. Leadership

vi. Change management

2.1.1 Informal and social support structures

Information only becomes knowledge through a social process (Becta, 2009). Unfortunately, this social process may be sieved out by the school and the transformation may not be achieved. This was also observed by Zhao and Frank who highlighted that *"...the informal social organization of the school filters many of the factors that affect transformation of information into knowledge"*

(Zhao and Frank, 2003, p830).

A significant part of the immediate context of the innovation and the innovator is the informal social support structure. This social environment plays an important role in the success of innovations, providing an existing context for innovations with which to engage. This social environment offers resources in the form of social capital to support innovative practice but equally presents pervasive beliefs and practices which act as barriers to innovation (Frank *et al*., 2004).

The informal social support structure that is being characterized in this section goes to create the culture within which the innovator works and, as such, influences their ability to adopt and develop new practices. It takes into account such relationships as those between teachers and peers, friends and learners.

Initially, the atmosphere of a school influences the motivation to innovate. In reviewing innovative practice in schools, Becta (2009) found that there may be an anti-culture which prevents people from trying new things. Equally the innovation unit's survey of teachers highlighted that teachers may be motivated to engage in change in response to peer encouragement (Innovation Unit, 2008).

Sutch *et al* (2008) underline the importance of the informal environment for teachers to discuss innovations. This is not only to share visions, reasons and motivations for innovation, but also to openly share successes and failures of particular initiatives. This may happen within the school environment or as part of learning networks away from the physical or geographical context of their school.

The support resulting from a cohesive social network can be underpinned by a sense of feeling part of a team and being 'all in it together'. Scrimshaw (2004) found that staff who felt part of a whole showed a willingness to learn from and support each other. In understanding the impact of a school's social environment on the generation and dissemination of innovative practice, it is also important to recognize the uniqueness of the extent of social support structure for each respective school.

2.1.2 Formal environment

The formal environment can be seen as the administrative infrastructure of a school. This includes its formal policies and structures. As well as its place in supporting teaching and learning practice, this formal environment plays an equally important role in supporting innovation, particularly through setting the formal context that gives permission for teachers to innovate (Kirkland and Sutch, 2009). This 'permission giving' can be through the development of formal structures of support and mandates to innovate, but also through the inferred importance of particular elements of teaching practice.

In terms of supporting innovation, the formal environment is largely responsible for ensuring teachers' access to resources. A lack of technical support also constrains teachers' capacity and disposition to engage in technological innovations (Jones, 2004). Equally where an effective infrastructure ensures that technological problems and glitches are easily fixed, it results in increased teacher motivation to use technology (Jones, 2004). Good access to technology-based resources has also been shown to enable teachers to innovatively develop their use of ICT in the classroom (*Ibid*.). While access to resources and technical support is important, such access has to be balanced with effective policies to support the use of resources in the classroom (Zhao, *et al*., 2003). For example, a teacher may be inhibited in engaging with internet-based resources if the school has blocked access to them. School infrastructure can be seen to play a central role in ensuring that teachers are effectively resourced when implementing technology-based innovations.

Formal environments can provide a vital means for practitioners to share perceptions, motivations, and experiences to support innovation. Sutch, *et al*. (2008) highlight that space for sharing practice in school supports the development of ideas and supports the sharing of knowledge across the school. Innovations can happen at the intersection of disciplines and the problem may reside in one domain of expertise and the solution may reside in another. Providing mechanisms to support teachers and learners to interact with ideas from across disciplines is often within the control of the formal structures. Providing opportunities to support cross-subject teaching affords the sharing of disciplines in this way, as does finding formal links to experts outside of the school grounds: experts in the local community, industry and academia. School administrators can also release teachers to collaborate with professionals from other disciplines which can support the generation of transformative innovations (Sutch, *et al.* 2009, Becta, 2009). These approaches are difficult for teachers to coordinate (beyond the personal level) without the support of the formal environment supported by the school administration.

There is an important role within the formal environment for innovation and exploration, especially with respect to other activities that have perceived importance within the formal structure of the school. Core factors such as job stress, workload, and class sizes have been seen to influence a teacher's capacity and disposition to innovate. Frank *et al*. (2004), in examining how these factors affect computer use by teachers, found class size to be the most statistically significant factor.

2.1.3 Risk aversion

A number of research programmes have attempted to ascertain the capacities and dispositions of an innovator in order to understand how these qualities can best be looked after. Across the literature, risk aversion is a key factor that inhibits the ability to innovate and as such has implications for the magnitude to which any educational setting has the appropriate enabling conditions for innovation.

Teachers need to feel they are permitted to innovate and this is not because they are particularly timid or lack confidence in their ability, but because there is a risk involved and all effective innovators understand this. A wide-range of concerns which can inhibit teachers from engaging in educational innovations could include: risk of failure, risk of wasting time, risk of expenditure that couldn't be justified, and risk of criticism from parents, inspectors, government official or students (Sutch, *et al*. 2008).Iterative change management cycles are seen as central to supporting risk-taking on a micro level for a variety of reasons. This is crucial to support teachers to make informed decisions about the risk involved in an innovation. If one is evaluating, learning from mistakes, negotiating, listening and exit strategies are in place, then risks become calculated ones. Even when the stakes are high, one can learn and move the organization forward. In essence, risk cannot be avoided. However, risk that arising from work that has not been properly thought through and shared should be avoided if possible.

2.1.4 Shared vision

In education the starting point and the end point are connected (Cordingley and Bell 2007). Shared perceptions of the aims and requirements of an innovation are important aspects of innovation in education. Both from a resource and practice perspective, yet equally important, is a shared understanding of the aims of the innovation: the creation of a shared vision. A teacher's perception of educational practices associated with an innovation can influence the success of an innovation. Zhao, *et al*. (2003) found that teachers who were more reflective and aware of their academic beliefs were more successful in implementing their own innovations. Core to this was that they used technology in a way that was dependable with their teaching practice. Teachers who attempted to use an innovative technology that required them to teach in a way that was significantly different to their normal classroom practice were less successful.

Teachers' involvement in developing shared visions for the school supports their understanding of the aims of the school, the 'direction of travel' and the reasons for change. These three combined, support the affordance of teacher ownership of the reasons to change practice and from there a greater involvement in owning the process of change. Therefore, by providing opportunities to teachers to participate in the formulation process of the school vision, multiple innovations can be fostered to move towards ownership of the change process (Sutch, *et al.*, 2008).

2.1.5 School leadership

School leadership can have a significant impact on a teacher's motivation to innovate. Leadership is also important in supporting teachers to engage in innovative practice. This can be through creating an atmosphere conducive to innovation, characterized by distributed leadership, supportive and inclusive management, and a culture where failure is accepted as part of the innovation process (Innovation Unit, 2008). Building a culture of transformative innovation premised upon creativity is not, clearly, simply about 'letting go' and waiting to see what ideas bubble up. Instead, transformative innovation requires significant hard work, team building and leadership. Being able to find ways to look at challenges and opportunities beyond the classroom then, is a useful way for developing an understanding of reasons to innovate, but also to interact with ideas from different domains (Kirkland and Sutch, 2009).

Leadership at an organizational level supports two important sides of innovation: the creation of ideas and effective management processes of testing and turning innovative ideas into reality (Becta, 2009). Management style has been shown to support individual creativity, which plays an important role in sparking innovation (*Ibid*). Equally leadership also has strong responsibility for leading and ensuring the effective change management processes detailed below are in place and successful. Leadership style plays an important role in overcoming barriers to innovation in schools. As Doherty *et al. (*2013) suggested polarized leaderships in an organization, whether excessively bureaucratic or too flexible, can be equally damaging. Rather Sutch, *et al*. (2008) suggests that a clear sense of central management is needed for transformative innovation, but one which develops 'distribution of autonomy to diverse groups and individuals'. Such distributed leadership plays a vital role in establishing an atmosphere conducive to innovation. It can enable and empower staff at all levels can support team morale (Scrimshaw, 2004) and create a shared responsibility for innovation (Becta, 2009)

2.1.6 Change management strategies

Change management strategy can be defined as a plan on how to make something different. In business, a change management strategy describes specific ways in which an organization will address such things as changes in the supply chain, inventory requirements, scheduling or project scope.

Research suggests that innovation in schools works best when it is a continuous process that relies on the involvement of staff at all levels of the institution (Rogers 1995, Sutch, *et al.* 2008). Becta suggests that" *...institutional members need to understand why change is necessary to be motivated to embrace it. Ideally they also need to feel involved in developing the solution"* (Becta, 2009). To involve members requires an effective system of change management that is capable of supporting institutional level change, while enabling innovators on a micro level. Kenny argues that flexible project management cycles are well placed to manage innovation in schools. He suggests a cycle of development akin to an action research cycle, underlining the importance of evaluation, documentation of learning and disseminating progress to the rest of the organization (Kenny, 2003).

Effective change management also has a role to play in supporting members of staff in the adoption of innovations, particularly when they originate outside of the school context. An important factor in the success of an innovation is the degree to which it is aligned with the school culture and value of a school (Zhao, *et al*. 2003, Sutch, *et al*. (2008).

2.2 Barriers to STEM education limiting promotion of sustainable development

This section discusses the barriers to STEM education which limit the promotion of sustainable development.

2.2.1 Educational structure

As observed under leadership, securing top level school management support is seen as critical to addressing poor implementation of sustainable development concept (Wei Quan, 2013). Further, Verhulst and Lambrechts (2015) indicated that barriers that prevent a systemic integration of sustainability development in school structures include: (1) lack of awareness of sustainability (2) the structure within school administration and (3) lack of resources available. Educational structure may hinder sustainable development in schools and this could be attributed to increased capsule of education as highlighted by McArdle-Clinton (2010) who stated that:

"The concept of education as product and students as consumer impacts on education, on students and educational practitioners. Education conceived as product, makes for pedagogy of confinement which limits the creativity of students and inhibits any achievement by them beyond the limits which have been set for them and this has a potential to prevent sustained development in schools.. This ideological intent shapes education as an industry - the largest single industry in the world - where students are processed as inputs and awarded a qualification, the educational value of which is in serious doubt" (McArdle-*Clinton, 2010, p. 1-2).*

2.2.2 School curriculum

Jackson (1968) has suggested that the integration of sustainability into education can be influenced by the hidden school curriculum. The hidden school curriculum refers to the messages sent by an individual teacher, lecturer or institution to students, often unconsciously and covertly about what they ought to think and how to behave. A key way in which the hidden curriculum is made manifest is through the ethos and values of the educational institution (*Ibid*). Winter and Cotton (2012) have indicated that embedding sustainability content in the education system curriculum in the United Kingdom was met with extensive indifference and strong resistance.

2.2.3 Teacher Education

In 2014, the UN Decade of Education for Sustainable Development came to an end. A significant part of this decade focused on redirecting teacher education towards sustainability. To date, education for sustainability is not mainstreamed in any pre-service teacher education programmes (Babiuk, 2014). Babiuk (2014) also outlined that reorienting teacher education towards sustainability requires overcoming two challenges namely lack of leadership and splitting of education faculties.

Yavetz, *et al*. (2013) found that student teachers had a poor understanding of the environment, highlighting the need to integrate sustainability into teacher education. Research conducted in Sweden involving 3299 secondary teachers showed that participants did not have a holistic understanding of sustainable development, while 70% of teachers highlighted that they needed training in sustainable development Borga, *et al*. (2014). To enhance teachers' knowledge of sustainable development, Matthies (2015) posited that continuous teacher education is a key aspect in terms of obtaining greater education for sustainable development effectiveness.

2.2.4 Resistance to Change

Vales (2007), has posited resistance to change as one of the main obstacles to implementing sustainable development in schools. Similarly, as indicated by Chen and Komph (2012), the main reason curriculum change is a failure or only accomplishes surface change is due to teacher resistance to the change. One of the many barriers relevant to both individual and organizational change is a failure to distinguish the need for change (Heifetz and Linsky, 2002). If educators do not understand and appreciate the need for change, their interest in upholding the status quo will take priority over their willingness to accept change (Greenberg and Baron, 2000). Both Fullan (2001) and Greenberg and Baron (2000) support the view that, habit, past experience, a sense of security from doing things in familiar ways, disrupting well-established professional and instructional patterns can also result in a fear of the unknown. Rather than working to develop new strategies, it is simply easier to continue teaching using the status quo (Greenberg and Baron, 2000).

3.0 Conclusions and Recommendations.

In order to promote integration of STEM education in schools, there is need to address a number of challenges affecting innovation and sustainable development. Therefore, the District Education Board Secretary's office, school administrators including Ministry of Education officials should take keen interest in resolving some of the key challenges effecting the effective implementation of STEM education in schools. Prominently, addressing barriers is a prerequisite to the implementation of education that would promote innovation and sustainable development in schools and the nation at large. Addressing challenges would therefore facilitate quality education leading to economic development, international competitiveness and job creation for the country. Consequently, quality education is key to preparing younger generation with the knowledge and skills to address present and future socio-economic and environmental challenges, such as global climate change.

Further, the STEM education approach adds value to educating young people because it provides the fundamentals to understanding how to develop innovate and sustainability mindsets for social good. Thus, knowledge, skills and understanding of science, technology, engineering, and mathematics phenomena can also help students to understand global problems and support actions in society that address these challenges in a meaningful and knowledge-based way

Based on the challenges reported in this study, the following are the proposed recommendations that could help address some of the challenges underlined under innovation and sustainability development;

i. Since STEM education is practical in nature, the government through the Ministry of Education should equip STEM schools with appropriate teaching and learning materials such as laptops, internet facilities, tools and other materials.
ii. Teachers should be well trained to understand the STEM curriculum so that it is implemented accordingly
iii. Key stakeholders such as the Examinations Council of Zambia, Universities and Colleges of Education and the Engineering Institution of Zambia should be engaged at planning level
iv. To develop a system at school level that support practitioners across the education system to articulate their perception of the requirements for any innovation and sustainability ideas.
v. Investigate the role of innovation and sustainability development intermediaries as organizations that can best foster dialogue and collaboration across disciplines and contexts of practice.

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Energy Efficiency and Renewable Energy Interventions for Sustained Development

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Abstract

The Paris Agreement provides a prospect for nations to strengthen their global response to the threat of climate change. The resolve provides an unprecedented international determination to act on climate change and its mitigation by focusing on decarbonization of the energy system, given that it accounts for almost two-thirds of Greenhouse Gas (GHG) emissions worldwide. Subsequently, the intervention of Renewable Energy and Energy Efficiency could significantly reduce the effects of climate change. Development of energy efficiency and renewable energy technologies can decrease the demand and supply of energy generated from fossil fuels such as natural gas, oil and coal-fired power plants offering a number of multiple benefits cutting across a number of sectors such as electricity, health and national economic development as a whole. However, maximizing the benefits would demand deliberate investment in the two sectors. This approach was also observed during the 2022 United Nations Climate Change Conference (COP27) held from 6th to 18th November 2022 in Sharm El-Sheikh, Egypt emphasizing on the need to invest in energy efficiency and renewable energy to limit global warming (Kosolapova, 2022). Energy efficiency and renewable energy are critical pillars for attaining sustainable development providing an opportunity to exploit measures that are energy efficient and renewable energy resources. However, despite the two concepts being the mainstays of sustained development, renewable energy is normally inclined to have a higher profile than energy efficiency actions despite the fact that renewable energy development requires a higher initial capital cost. To exploit the benefits derived from the interventions of the two concepts, the paper attempts to discuss the common barriers to effective implementation of energy efficiency measures which include the lack of information and awareness of potential benefits, a failure to emphasize good energy management, lack of technical capacity to identify any technology and financing barriers.

Keywords: Mitigation, greenhouse, investment, decarbonization, sustainable

1.0 Introduction

1.1 Definitions: efficiency, energy efficiency and renewable energy

Efficiency can be defined as being able to accomplish something with the least waste of time and effort or competency in performance or accomplishment of or ability to accomplish a job with a

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minimum expenditure of time and effort. In terms of machines, it can also mean the ratio of the work done or energy developed by a machine, engine, etc., to the energy supplied to it, usually expressed as a percentage (Kariger B.and Fierro F., 1995).On the other hand, energy efficiency is understood to mean the utilization of energy in the most cost-effective manner to carry out a manufacturing process or provide a service, whereby energy waste is minimized and the overall consumption of primary energy resources is reduced (UNIDO, 2020).In other words, energy efficient practices or systems will seek to use less energy while conducting any energy-dependent activity: at the same time, the corresponding (negative) environmental impacts of energy consumption are minimized. In terms of renewable energy, it can be defined as energy derived from natural sources that are replenished at a higher rate than they are consumed (IRENA, 2017). Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us.

Energy efficiency and renewable energy are critical interventions for achieving sustainable energy and the two concepts must be developed concurrently to stabilize and reduce carbon dioxide emission (American Council for an Energy-Efficient Economy, 2007). Further, based on the definitions of the two concepts, the duo are interconnected bearing in mind that energy efficiency deals with utilizing the existing energy irrespective of renewable or non-renewable, judiciously that is, getting the work done with less expenditure of energy without the loss of quality while renewable energy is defined as a type of energy which is inexhaustible.

1.2 Interventions of energy efficiency and renewable energy to reduce effects of climate change

Historically, the Paris Agreement provides an opportunity for countries to strengthen the global response to the threat of climate change by keeping a century global temperature rise to below 2 degrees Celsius and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (United Nations Framework Convention on Climate Change, 2015).Therefore, the Paris Agreement reflects on an unprecedented international determination to act on climate change. The focus of climate change mitigation must be on the decarbonization of the energy system, given that it accounts for almost two-thirds of Greenhouse Gas (GHG) emissions worldwide (IPCC, 2022). Consequently, for the world to avoid catastrophic climate change, countries need to pursue energy decarbonization. In realizing the decarbonization of the global energy system, renewables would account for about half of the total emission reduction by 2050, with another 46% from increased energy efficiency and electrification (IRENA, 2017). Refer to figure 1 for details. Accordingly, the involvement of renewable energy and energy efficiency would result in higher utilization of renewable energy, a faster reduction in energy intensity and a lower cost for the energy system. These interventions have significant environmental and societal benefits, such as lowering levels of air pollution and the avoidance of adverse health effects caused by pollutants.

Crucially, improved energy efficiency reduces total energy demand, allowing the share of renewables in the energy mix to grow faster. Renewable Energy and Energy Efficiency (RE/EE) can deliver the lion's share of the emission reductions needed to decarbonize the global energy system, 90% of this energy-related reduction in CO_2 emissions can be achieved by expanding deployment of RE/EE

(IRENA, 2017). Refer to figure 1 for details.

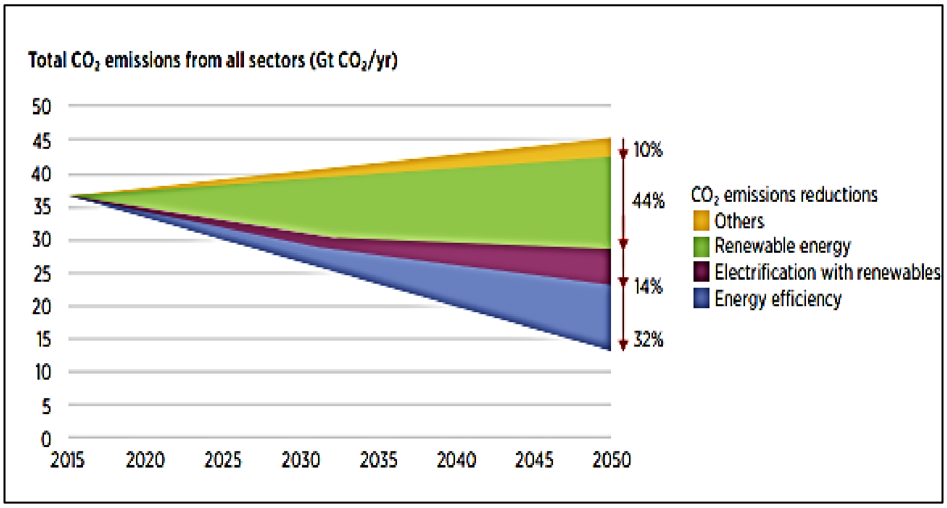

Figure 1: CO_2 emission reduction potential by technology (Source: Based on IRENA analysis: IEA and IRENA, 2017)

It is important to note that to realize the benefits of effective intervention of RE/EE, there is need to deliberately invest in the two sectors to accomplish the environmental and societal benefits. Energy efficiency and renewable energy investments can produce significant benefits and these include lowering fuel and electricity costs, increased grid reliability, better air quality and public health, and creation of more job opportunities. This strategy was also observed during the 2022 United Nations Climate Change Conference (COP27) which took place from 6th to 18th November 2022 in Sharm El-Sheikh, Egypt whose theme was to deliver for people and the planet. The meeting brought together world leaders, the UN Foundation and other influential climate change advocates to put a spotlight on climate changes issues. During the meeting, Mike Thornton, the Chief Executive at Energy Saving made a keynote speech emphasizing on the need to invest in energy efficiency and renewable energy to limit global warming

"COP27 provides an opportunity to transform words into actions and put delivery as the focus in Sharm El Sheikh. We must therefore see a focus and attention on the fundamental climate policy gaps that remain focused on limiting the global temperature rise by moving away from fossil fuels through reducing energy demand and scaling up renewable energy production which are critical solutions to both the energy crisis and achieving net zero for the long-term. Therefore, ambitious investment in energy efficiency, low carbon heating and renewable energy is clear practical steps to reduce severe impact of climate change" (Kosolapova, 2022, p 14).

However, maximizing interventions requires a greater understanding of the potential that exists at the various economic sectors and technology levels. It is therefore critical to understand a system-wide perspective looking at the inter-linkages between technologies and sectors such as developing smart and well-designed initiatives to realize the opportunities of RE/EE technologies across and within all sectors of the energy system. Thus, the system-wide perspective looking at the interactions and interventions between RE and EE would go a long way in improving the sustainability of energy development. Sustainable energy development can be defined as the development of obtaining, distributing, and exploiting the energy sector and is based on sustainability principles (Golušin *et al.*, 2013).

Sustainable energy development is important considering that when non-renewable energy sources are burned daily for energy for example fossil fuels (e.g., coal, natural gas and oil), they are not only harmful to the planet, but they are also unsustainable as finite resources. Sustainability refers to the concept that all people can meet their basic needs infinitely, without compromising future generations. As a consequence, harmonizing the concept of sustainability is imperative to observe when it comes to renewable energy sources, considering that it is generally more efficient than non-renewable energy sources. For example, energy derived from wind, the sun, and hydro turbines can be reused without relying on an exhaustible or finite element as compared to non-renewable energy sources, where we may have to factor in the product after the electricity has been produced.

2.0 Energy efficiency and renewable energy involvement: a critical tool for sustainable development

Renewable energy technologies tend to have a higher profile than energy efficiency actions. This is mainly for the obvious reason that they are more visible as new installations and are perceived as more "cutting-edge" technologies. This occurs even though they often have higher initial capital costs than energy efficiency measures and may have less favourable operating costs too (United Nations Industrial Development Organization, 2000). For example, solar PV or solar water heating panels on a public building raises the awareness of renewable energy use in the building to users and other members of the public.

Therefore, the assumed increased awareness of renewable energy may be used to stimulate awareness of energy efficiency by introducing energy efficiency measures simultaneously with a new renewable energy installation. As renewable energy installation has a significant capital cost, people can become more sensitive to the idea of "wasting" the energy from the system, especially if they feel a strong level of ownership of the renewable energy system. In addition, a renewable energy system supplier/installer could make recommendations on how to use the energy produced in the most efficient manner, so that the output from the system could be used to generate the most benefit in terms of services to the end-users. This is often a good opportunity to introduce demand-side energy savings measures. Consequently, from the national economic development perspective, a switch to renewables could go a long way in supporting sustainable development which could help reduce dependency on fossil fuels.

In view of the above, it can be inferred that there is an intimate connection between energy efficiency, renewable energy and sustainable development. A society seeking sustainable development ideally must utilize only energy resources which cause no environmental impact and use them efficiently without waste. Sustainable development is essentially about improving the quality of life in a way that can be sustained, economically and environmentally, over the long term supported by the institutional structure of the country (Adams, 2006). In order to provide sustained development, sustainable energy is critical in providing energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable energy sources are most often regarded as including all renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bio-energy, and tidal power. Further, it also includes technologies that improve energy efficiency and these technologies are essential contributors to sustainable energy as they generally contribute to world energy security, reducing dependence on fossil fuel resources and providing opportunities for mitigating greenhouse gases. As such, sustainable energy promotes sustainability. It can therefore be established that energy efficiency and renewable energy are critical pillars of sustainable energy and both concepts must be developed concurrently in order to stabilize and reduce carbon dioxide emissions (American Council for an Energy-Efficient Economy, 2007).

3.0 Benefits of energy efficiency and renewable energy deployment

Deployment of energy efficiency and renewable energy technologies can reduce the demand and supply of energy generated from fossil fuels such as natural gas, oil and coal-fired power plants. Electricity savings and renewable energy generation can offer the basis for estimating the many benefits of energy efficiency and renewable energy to the electricity sector, to emissions and public health including to the economy as a whole (Mulholland, 2021). The multiple benefits of energy efficiency and renewable energy are depicted in Figure 2.

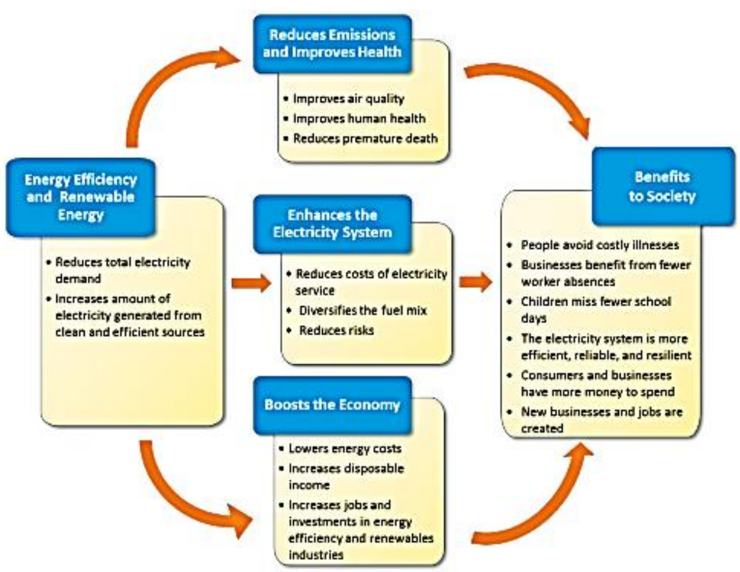

Figure 2: The multiple benefits of energy efficiency and renewable energy (Source: U.S. Environmental Protection Agency - State and Local Energy and Environment Program, 2018)

Figure 2 outlines the multiple benefits of energy efficiency and renewable energy. These are further deliberated in the section below under the three themes namely electricity system benefits, emissions and health benefits and economic benefits:

3.1 Electricity system benefits

Energy efficiency and renewable energy activities in combination with demand response measures can help protect electricity producers and consumers from the costs of adding new capacity to the power system and from energy supply disruptions, volatile energy prices and security risks.

3.2 Emissions and health benefits

Fossil fuel-based electricity generation is a source of air pollution that poses risks to human health, including respiratory illness from fine-particle pollution and ground-level ozone (USEPA, 2022). The burning of fossil fuels for electricity is also the largest source of Greenhouse Gas (GHG) emissions from human activities, contributing to global climate change. Improving energy efficiency and increasing the use of renewable energy can reduce fossil fuel-based generation and the associated adverse health and environmental consequences.

3.3 Economic benefits

Many of the electricity power system can yield overall economic benefits to a nation. These benefits include savings in energy and fuel costs for consumers, businesses and the government at large.

4.0 Energy efficient measures

Energy efficiency measures are best promoted in a strategic and integrated manner to use more efficient energy technologies and management practices within the context of an energy efficiency programs (US Department of Energy, 2018). Further these measures can be split into supply-side and demand-side activities. Supply-side interventions are typically technical or management interventions, which are implemented by generators, grid operators and/or energy distributors, i.e. on the utility side of the meter or fuel pump. While demand-side interventions address aspects of energy efficiency, which can be implemented and achieved through changes in operating procedures and technologies by a household or energy user i.e. on the customer’s side of the meter. According to US Department of Energy (2018), typical examples for supply-side and demand-side activities are provided as follows:

4.1 Supply side activities

The following energy efficient measures activities are covered on the supply side:

i. More efficient generation/conversion, these include the following:

- Minimizing waste heat generation and recovering waste heat to an economic maximum;
- Improving maintenance practices;
- Utilizing equipment that has been manufactured to the best modern standards of efficiency, e.g. electric motors, steam and gas turbines, transformers, boilers;

- Applying modern process technologies including clean coal processes;
- Cogeneration (particularly where this can be combined with biomass fuel from a renewable source, e.g. bagasse, or with the utilization of waste heat);
- Better control systems and metering of key operating parameters.

ii. More efficient transmission and distribution systems, including:

- Closer and improved control of existing systems, e.g. better balancing of phases, voltage regulation, power factor improvement, SCADA systems for better routine data acquisition and analysis;
- Increased use of distributed generation;
- Higher transmission voltages;
- State-of-the-art technologies such as low-loss transformers, fibre optics for data acquisition, smart metering, etc.

4.2 Demand side activities

On demand side activities, the following energy efficient measures are considered:

i. More efficient equipment and appliances in all sectors, e.g. motors, boilers, furnaces, industrial dryers, pumps, compressors, lighting, domestic appliances, air conditioning systems. This is particularly important for equipment that is operated over long periods or continuously.

ii. Improved maintenance of all equipment.

iii. Improved metering of fuel, electricity and steam flows and of key operating parameters such as temperatures.

iv. Control and energy system optimization, often made practical by the improved metering mentioned above. This can include variable speed drives for electric motors, thermostats in buildings and industrial equipment, ripple control, smart appliances and power factor improvement.

v. Behavioral change on the part of the energy user, such as:

- Monitoring energy efficiencies in major energy-consuming industrial processes and equipment to ensure design operating parameters and performance are respected.
- Reporting leaks and equipment failures systematically, e.g. in industrial plants, and checking the cost incurred through such deficiencies to ensure priority attention is given to repairs and replacement.
- Changes in work practices such as working from home and/or flexi -time.

- Changes in equipment usage both at home and in the office, such as switching off appliances which are not needed and avoiding excessive use of "standby mode" for many types of equipment.
- Electricity load shifting by industrial or commercial energy users is a demand-side intervention but it has implications for improving energy efficiency of the grid network that supplies the electricity (supply-side). This is because peak loads can be reduced if electricity demand is spread out over a longer time period or if it is moved to another time of the day. Since many electricity systems are forced to operate their least efficient generators to meet peak demand, this allows them to reduce the use of lower efficiency generating equipment in favour of greater use of their more efficient equipment over a longer period of time.
- Choosing different modes of transport, e.g. public transport versus cars for individuals, rail versus road for freight, where such alternatives are available.

5.0 Common barriers to implementation of energy efficiency measures

Despite the fact that energy efficiency appears to make good sense in many situations—both in terms of cost savings and reductions in environmental damage—it is often very difficult to get managers of companies as well as individuals households to take action. It is even more difficult to achieve effective implementation over a long period of time. All stakeholders are inclined to accept the status quo, which is usually a less efficient scenario, and only respond in terms of energy efficiency once a crisis forces the issue, such as in the case of insufficient energy supplies. For private firms, other priorities are often quoted, such as capital investments to increase plant capacity and market share, leaving no funds for energy efficiency expenditures.

This inherent inertia against acting to improve energy efficiency is reinforced by numerous institutional, financial and technical barriers to energy efficiency programmes, either real or perceived. Some of the common barriers to implementation of energy efficiency measures commonly encountered in Zambia are explained as follows:

5.1 Lack of awareness and information

This barrier is the most common problem as easy access to relevant information is typically lacking. Generally, there is a lack of awareness of proven energy efficiency measures and programs. Therefore, company managers would frequently have observed stating that they have a particular problem that is adversely affecting their energy efficiency, yet the problem they are facing might have been resolved in other locations or areas. The information might not have been well disseminated and the users are simply unaware of energy efficiency measures or their benefits to their company. The energy customers need to be informed of the availability of efficient equipment and the respective energy cost savings and their positive environmental impacts from proper adoption. Sometimes the information to customers is incorrectly perceived as being an attempt by power utility companies to restrict their energy use or deny them the right to energy, or manipulation by power companies to make higher profits. Thus, industry trade associations could play a positive role in encouraging the sharing of relevant information.

Further, raising awareness of energy consumption and related aspects of energy efficiency amongst consumers/users could also be encouraged. For example, awareness programs could cover many topics, from training of energy professionals to appliance labeling and consumer education for the domestic sector. Furthermore, learning institutions like colleges and universities could be encouraged to develop competences at professional levels (e.g., air conditioning and heating engineers) for implementation of energy efficiency interventions. Support for technology research and development by learning institutions and especially for the demonstration of proven technologies to increase energy efficiency can also be encouraged.

5.2 Lack of initiatives to emphasize energy management

This hurdle is particularly significant for the industrial and commercial sectors. Since energy management is an ongoing process, it is necessary that it becomes part of total management system. Most industries in developing countries have management systems that address production, accounting, maintenance, environment and safety, but many do not include energy management as part of their management systems (Schulze *et.al*, 2015).As energy management requires knowledge and skills base, medium and small industries often claim to have no staff resources to undertake energy management responsibilities. While this must be true for many organizations, it may be possible to cover some aspects of energy management by using part-time workforce where a full-time person may not always be necessary.

5.3 Lack of technical capacity to identify, evaluate and implement energy efficiency actions

There is a lack of qualified individuals and organizations to identify energy efficiency projects in many establishments. Required skills include the ability to carry out energy audits, analyze performance data, from which opportunities to implement effective actions can be evaluated and properly justified in terms of the benefits achievable compared with the costs involved. This barrier is particularly relevant and some organizations may address this barrier by offering services to conduct energy audits or advising clients on energy efficiency measures which is a logical next step towards raising energy awareness. According to United Nations Industrial Development Organization (2000), these service organizations need to possess or acquire the following qualities and competencies:

i. Have a knowledge and understanding of energy efficiency systems and opportunities

ii. Be aware of proper financial evaluation techniques and be experienced in analyzing rates of

iii. Demonstrate the quality and comprehensiveness of their work

iv. Have knowledge of the production and safety constraints of the client plant/company. A lack of technical capacity within such service organizations could result in an incorrect assessment and misdirected measures, which would be counterproductive. Further, there is need for training at a national level and for a technical certification scheme in order to improve technical capabilities and provide incentives for acquiring official qualifications.

5.4 Financial and investment barriers

The cost of implementing energy efficiency measures in industry, commercial or residential sectors is sometimes said to be a barrier to effective energy efficiency. However, it is often observed that management would have no dedicated teams within their organizations to evaluate energy efficiency measures properly and may not appreciate that no-cost/low-cost measures are available that require very little capital to implement. Most of the time , the lack of awareness of potential benefits from energy efficiency actions prevents management from doing the no-cost measures first and using the cost savings to build up capital for reinvestment later in energy efficiency. In certain cases, of course, there are companies that really do not have devoted funds to undertake even modest investments, even though the measures might have very short payback periods.

For instance, energy suppliers may need to invest in upgrading to more efficient electricity generators or transmission lines, while energy users may need to upgrade to more efficient appliances or install capacitors banks to improve power factors (and hence reduce the power needed for induction motors (US Department of Energy,2018).Unfortunately, these investments may not be made because there is a genuine lack of capital and interest rates on loans may not be favourable to justify borrowing.

5.5 Technology barriers

While great progress in attaining energy efficiency improvements is usually made by cultivating energy management, there will be occasions, a real need for confronting deficiencies from a technology point of view. A barrier may be stumbled upon because of a lack of availability of high efficiency equipment made to good modern standards. Furthermore, there may also be insufficient cooperation amongst researchers or research organizations, making it challenging to build effective energy efficiency research, development and demonstration programs. Thus, even where research may have been effectively conducted there can be difficulty in transferring research prototypes into industrial scale working products (US Department of Energy, 2018). Sometimes this is due to absence of more energy efficient technologies and it is perhaps more likely that weak marketing strategies exhibited by equipment manufacturers or importers are contributing to the problem, particularly where these do not address the inertia of customers who are unwilling to move away from outdated and traditional products. Lack of confidence in local installers of new technologies can also be a barrier. Certainly, poor marketing strategies will do little to promote efficient energy use even though better technologies might actually be available.

6.0 Progress made to date to drive Energy Efficiency (EE) and Demand-Side Management (DSM)

Table 1 shows an overview of initiatives already underway and measures that Zambia has considered to drive the DSM and EE agenda. Further, the Table also shows how EE has been applied in certain specific sectors and how EE has improved in energy use and saving of electricity costs.

Table 1: Progress made to date to drive Energy Efficiency (EE) and Demand-Side Management (DSM) in Zambia: Source - Power Africa (2017).

Demand-Side Management			
Measure	**Objective**	**Status**	**Implication**
Power Factor surcharge for maximum demand customers	Reduce capacity demand (kVA) while delivering the same power. Under this framework, large power consumers operating an average monthly power factor below 0.92 would be required to pay a surcharge over and above their normal bill	Framework approved, but consumers have been given time to make the requisite investments in power factor correction equipment and/or replace equipment that falls below specification	Mines will need to invest CAPEX to improve their electric systems
Time of use tariff	Reduce maximum demand at peak time by discounting the highest maximum demand charge by 50%	On track – in place, but low adoption rate (this is voluntary). The reason for low adoption is that Zambia's low tariffs provide little incentive to move to TOU tariff. In addition, the design of the TOU framework may need review	TBO
Energy Efficiency Program			
Incandescent light ban (Statutory Instrument (SI) number 74 of 2016)	Reduce consumption Use of energy saving lights (e.g. LED bulbs) will reduce lighting consumption	Illegal to use the products in Zambia for either domestic or industrial applications	Estimated savings of up to 200 MW annually. Under this program, ZESCO has been distributing 5 million free LEDs at a cost of $20 Million
Energy efficiency in buildings	Reduce consumption replacing geysers with solar water heaters	On track – pilot completed driven by ERB, looking to scaleup	Installation of solar water heating, and cool roof painting during a controlled study at the University Teaching Hospital reduced total electric energy consumption by 67 percent. Taj Pamodzi Hotel drew up an investment plan covering LED lighting, replacement of the AC chiller, and solar water heaters replacing the oil boiler after the audit, hotel management using. The hotel expects to reduce energy use by 38 percent (electric and thermal)

7.0 Conclusion

The Paris Agreement provides an opportunity for countries to strengthen their global response to the threat of climate change and the focus of climate change mitigation which must focus on decarbonization of the energy system given that it accounts for almost two-thirds of Greenhouse Gas (GHG) emissions worldwide. Consequently, the involvement of Renewable Energy and Energy Efficiency measures would result in higher utilization of renewable energy, a faster reduction in energy intensity and a lower cost for the energy system which can significantly benefit the environmental and society at large. These benefits could include lowering levels of air pollution and the avoidance of adverse health effects caused by pollutants.

Barriers to achieving a good level of energy efficiency improvement have been highlighted however, out of the underlined barriers, the failure to practice good energy management is typically one of the most important factors for enterprises. Improving energy management is almost always a low-cost action that achieves valuable benefits in the short term which could also contribute to enterprise profits in the long term.

Energy efficiency measures can be split into supply and demand-side activities and the benefits principally cover two critical factors which include Environmental critical for lowering greenhouse gas (GHG) emissions and other pollutants and Economic, significant in lowering individual utility bills, create jobs, and help stabilize electricity prices and volatility.

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Power generation and control of a hybrid self-powering induction generator (HSPIG)

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Abstract

Induction generators are increasingly being used in non-conventional energy systems such as wind, micro/mini hydro, etc. The advantages of using an induction generator instead of a synchronous generator are well known. The self-excitation squirrel cage induction generator (SEIG) is frequently considered as the most economical solution for powering customers isolated from the utility grid by wind energy because it derives its excitation from its own output terminal and neither an exciter nor voltage regulator is required. This paper presents an indigenous study for the development of a Hybrid Self- Powering Induction Generator (HSPIG) by manipulating the prime mover and output systems.

Keywords: Self- excited squirrel cage induction generator, back -to -back converter, hybrid, prime mover, capacitor bank.

1. Introduction

The increasing rate of the depletion of conventional energy sources has given rise to an increased emphasis on renewable energy sources such as wind, mini/micro-hydro, etc. for electrical power generation. An increasing rate of the depletion of conventional energy sources and the degradation of environmental conditions has given rise to an increased emphasis on renewable energy sources, particularly after the increases in fuel prices during the 1970s. Use of an induction machine as a generator is becoming more and more popular for the renewable sources (Bansal, Bhatti & Kothari, 2003 and Bansal, Kothari & Bhatti, 2000).

This paper presents an overview of the three-phase self- exciting induction generator (SEIG); its working principle. In this case we substitute the wind turbine for a motor which is coupled with the shaft of the rotor. The main focus of this paper is to design a system that can power and control the synchronous speed of the motor which shall be coupled with the rotor shaft in the stead of hydro or wind turbines. The power required for this system shall be obtained a fraction obtained from the generator's load output.

The system comprises of a back- to- back, AC-DC-AC converter makes up the ***Feedback system*** at the bottom side of the system. While AC-DC-AC (capacitor bank and battery) and cyclo converter (thyristor powered) ***Self- powering unit*** at the upper side of the proposed generator.

To attain such stable system of power control across the system, capacitor banks have been

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introduced as shown in Figures 2 and 3.

2. Classification of Induction Generators

On the basis of rotor construction, induction generators are two types (i.e., the wound rotor induction generator and squirrel cage induction generator). Depending upon the prime movers used (constant speed or variable speed) and their locations (near to the power network or at isolated places), generating schemes can be broadly classified as under:

A. Constant-Speed Constant Frequency (CSCF)

In this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch and/or generator characteristics. An induction generator can operate on an infinite busbar at a slip of 1% to 5% above the synchronous speed. Induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problems, and are economical.

B. Variable-Speed Constant Frequency (VSCF)

The variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation. Popular schemes to obtain constant frequency output from variable speed are the ***AC- DC- AC Link*** (Singh, 1995 and Dezza, Geriando & Perini, 1995) and ***Double Output Induction Generator (DOIG)***. (Vicatos & Teqopoulos, 1989 and Salameh & Kazda, 1986).

C. Variable-Speed Variable Frequency (VSVF)

With variable prime mover speed, the performance of synchronous generators can be affected. For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads, which are essentially frequency insensitive. This scheme is gaining importance for stand-alone wind power applications:Bansal, R. C., Bhatti, T. S., & Kothari, D. P. (2003) and Bansal, R. C., Kothari, D. P., & Bhatti, T. S. (2000, Nov 30-Dec 2) further information is cited in: **Khan, P. K. S., & Chatterjee, J. K. (1998, p. 27, 813-832)**.

The basic theme for this paper is a presentation of an overview of SEIG in isolated applications in order to make the generator that is self-powering. Hence the name "Hybrid."

3. Process of Self-Excitation and Voltage Build-up in SEIG

According to Besant & Potter (1935) and Levy (1997), self-excitation phenomenon induction machines, although known for more than a half century, are still a subject of considerable attention. The interest in this topic is primarily the application of SEIG in isolated power systems. Physical background of the self-excitation process has been described in considerable depth.

When an induction machine is driven at a speed greater than the synchronous speed (negative slip) by means of an external prime mover, the direction of induced torque is reversed and theoretically it starts working as an induction generator. (Bansal, 2005). The machine draws a current, which lags the voltage by more than 90^o. (Bansal, 2005). This means that real power flows out of the machine but the machine needs the reactive power. To build up voltage across the generator terminals, excitations must be provided by some means; therefore, the induction generator can work in two modes (i.e., grid connected and isolated mode). In case of a grid-connected mode, the induction generator can draw reactive power either from the grid (but it will place a burden on the grid) or by connecting a capacitor bank across the generator terminals. (Bansal, Bhatti & Kothari, 2001; Murthy, 1986 and Bansal, Kothari, & Bhatti, 2000). For an isolated mode, there must be a suitable capacitor bank connected across the generator terminals. This phenomenon is known as capacitor self-excitation and the induction generator is called a “SEIG.” This mechanism is proposed to be applied at the upper side of the generator to provide reactive power for the motor which acts as primary mover coupled with the generator shaft in place of a turbine. This is necessary to provide enough reactive power for the starting torque of the motor- generator shaft coupling. The process of voltage build-up in an induction generator is very much similar to that of a dc generator. There must be a suitable value of residual magnetism present in the rotor. In the absence of a proper value of residual magnetism, the voltage will not build up. So, it is desirable to maintain a high level of residual magnetism, as it does ease the process of machine excitation. (Bansal, 2005).

4. Modelling the Autonomous Hybrid Self-Powering Induction Generator

When a physical system (or device) is disturbed by an external forcing function, the disturbance causes the system variables to undergo a transient variation. An induction machine is inherently non-linear, and this nonlinear behaviour can be significantly reduced by mixing a proportion of the output signal with the input signal. (Oriahi & Egwaile, 2017). From the simple feedback scheme of Figure1a, it can be deduced that:

$$Ge = fo \quad (1)$$

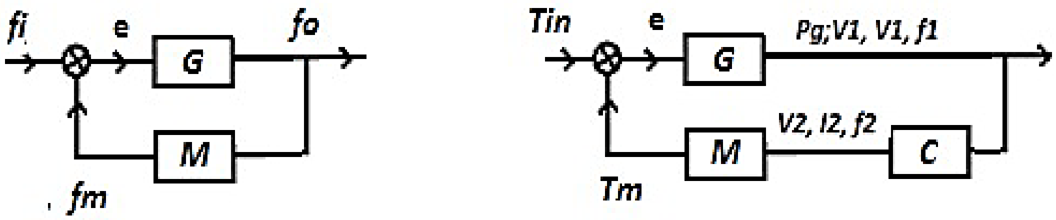
where $e = (fi – fm)$ (2),

$$fm = Mfo \quad (3)$$

Hence:

$$fo/fi = (1 + GM) \quad (4)$$

In Figure 1, ***G*** is the system. ***M***, is the feedback element and ***e*** is the error signal which acts to minimize the error. Clearly, if the product, ***GM***, called the “open loop gain,” can be made high compared to 1, the resulting “closed loop gain”, will be essentially independent of ***G***.



(a) The Simple Squirrel cage generator. (b) The Modified Squirrel cage generator.

Figure 1: System equation in Block diagram form (Source: Oriahi & Egwaile, 2017).

In this simple system, ***fi***, ***fo*** and ***fm*** are all of the same unit. However, for a system that has more than one variable, the equation implied by ***Ge = fo*** cannot possibly be correct since **H** is depicted as a constant multiplier. In order for us to use a figure such as this, we must add a component ***C*** in the feedback loop, as shown (Figure1b), which enables us to construct the input signal we can apply to ***M***.

$$(Tin - Tm)\omega_1 = Pg \tag{5}$$

In mathematical form,

$$Tm \times \omega_2(1 - s) = Pmech \tag{6}$$

where (in equations (5) and (6):

Tin is the mechanical torque applied on the prime mover by wind power, in this case the motor,

Tm is the braking torque of the motor,

Pg is the total mechanical energy converted into electrical energy in the generator output per phase,

ω_1 is the rotational speed of the prime mover,

$Pmech$ is the power converted into mechanical motion in the motor, and

ω_2 is the rotational speed of the motor and s is the slip.

The component ***C***, may take the form of a *cyclo-* converter, that takes power at one voltage and frequency and delivers it at another voltage and frequency, or in the form of a back -to -back AC/DC/AC converter that does essentially the same in just about two stages.

In the back -to -back converter shown in Figure 2, the grid side converter (***Cg***) accepts AC power from the generator and converts it to DC power, while the motor-side converter (***Cm***) commutates the DC voltage into alternating current at the desired frequency. The performance characteristics of the squirrel cage motor may be evaluated on per phase basis using a T -network. The idea of a current source driving current directly into the rotor circuit of an induction motor, when suitably excited and driven by an external prime mover, forms the basis of the circuit model of the self-regulated SEIG as shown in Figure 4. The power captured from the turbine (replaced by a motor coupled with the generator's shaft) drives the SEIG to generate electrical energy. Part of this energy is passed through an AC/DC/AC converter to the induction motor (IM) which returns it as electromagnetic torque in the form of current to regulate the current source. (Oriahi & Egwaile, 2017).

$$P_{in} = V_t I_s cos <_{I_s}^{V_t} = \frac{V_t^2}{|Z_t+Z_s+Z_c|} \quad (7)$$

The total energy at the generator output per phase is given by the relation, given by the relation,

$$P_g = \frac{|Z_c|}{|Z_t+Z_s+Z_c|} \quad P_{in} = \frac{|Z_c|}{|Z_t+Z_s+Z_c|^2} \times V_t^2 = |Z_c| \times I_s^2 \quad (8)$$

In (8) $Z_t = Z_m \| Z_{tm} = R_t + jX_{t'}$ $Z_s = R_s + jX_s$ and $Z_c = -jX_c$.. If a fraction of the output voltage is applied to the motor winding, we can infer that power delivered to the motor per phase is;

$$P_g = \frac{|Z_c|}{|Z_t+Z_s+Z_c|^2} \times \left(\frac{f_1}{f_2}\right)^2 V_t = \left(\frac{f_1}{f_2}\right)^2 pg \quad (9)$$

Where $\frac{f_1}{f_2}$ is the ratio of input and output supply frequencies.

The power converted into mechanical motion in motor is:

$$P_{mech} = \frac{R_r(1-s)/s}{|Z_t'+Z_r|^2} P_m \quad (10)$$

where $Z_t' = Z_m \| Z_{sr} = R_t' + jX_{t'}$ and $Z_r = \frac{R_r}{s} + jX_r = R_r + \frac{R_r(1-s)}{s} + jX_r$

Using equation (5) and (6), we get $P_g = \left[T_{in}\omega_1 - \frac{\omega_1 R_r(1-s)/s}{\omega_2(1-2)|Z_t'+Z_r|^2} P_m\right]$ (11)

Substituting for P_m from (9), we get

$$P_g = \left[1 + \frac{\omega_1 R_r(1-s)/s}{\omega_2(1-2)|Z_t'+Z_r|^2} \left(\frac{f_1}{f_2}\right)^2\right] = T_{in}\omega_1 \quad (12)$$

from which: $T_{in} = \frac{P_g}{\omega_1}\left[1 + n^3 \frac{R_r/s}{|Z_t'+Z_r|^2}\right]$ (13)

where $n = \frac{\omega_1}{\omega_2} = \frac{f_1}{f_2}$

Unlike a traditional induction machine, the characteristics of SEIG depend not only on the applied stator voltage, but also on the injected rotor voltage. The amplitude and phase angle of the AC voltage measured at the grid terminals changes as the real and reactive power control vary. The reactive power at the grid terminals can be generated or absorbed by a back to back converter and exchanged between the converter and the grid through the generator.

Now, it is important to note that in this proposed Hybrid Self- Powering Induction Generator, the upper AC/DC/AC converter derives power from the generator only after the system has fully been excited enough to capture power through the rotating motor which is in this proposal is the prime mover coupled with the generator shaft. After the induction machine (IM) is fully excited, the prime mover powered by the battery and capacitor bank at the *DC- Link* of AC/DC/AC converter at the upper side through the cyclo- converter is switched. These are two major components that makes it possible for the system to sustain itself without application of external source e.g. grid power while the induction machine is. The battery in the AC/DC/AC converter, provide startup power while the capacitor bank provides reactive power to the prime mover when the generator is loaded and or during transient state. The same applies to the AC/DC/Ac converter at the bottom side of the generator. The amount of reactive power required to produce the torque to put into motion the prime mover is mitigated by the self- excitation phenomena.

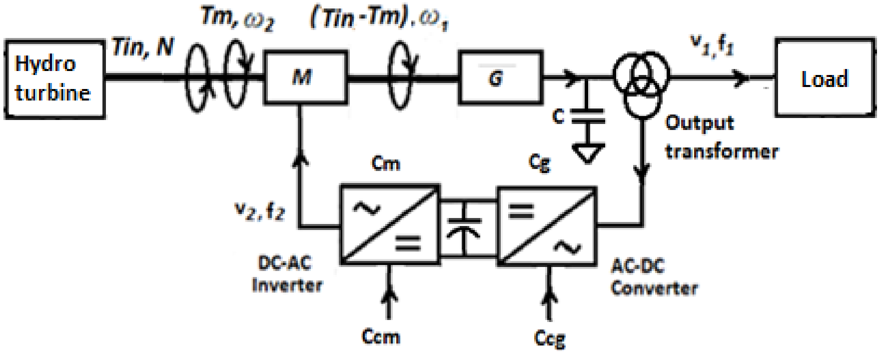


Figure2: The Circuit Diagram of a Cage Motor Controlled Self- Excited Squirrel Cage Generator.

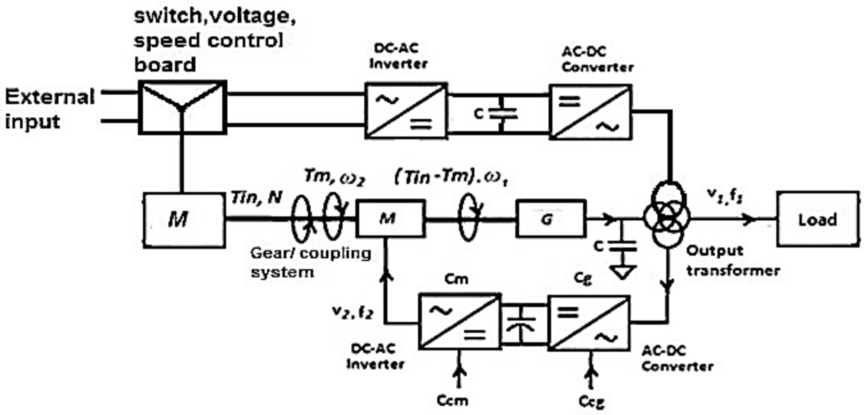


Figure 3: The Proposed Circuit Diadram of a Cage Controlled Hybrid Self- Powering Induction Generator.

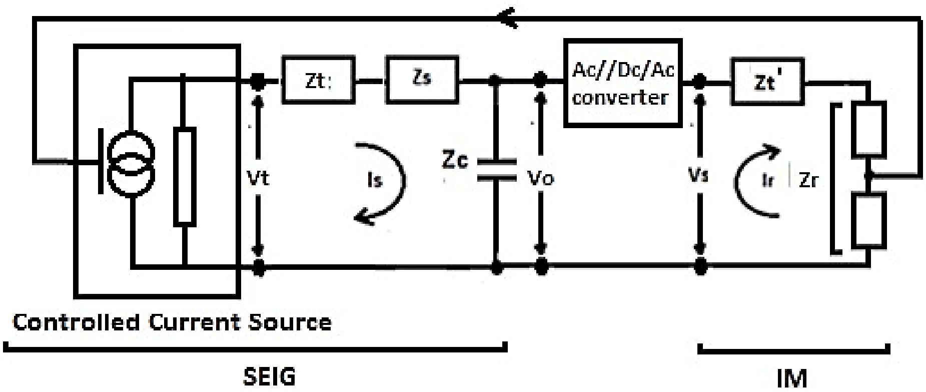


Figure 4: The Per Phase Equivalent circuit of the composite SEIG.

5. Modelling the Back- To- Back Converter

The back-to-back converter consists essentially of a controlled rectifier (T1) and an inverse parallel controlled rectifier (T2). The grid side converter is used to generate or absorb the grid electrical power and stores it as fixed Dc in a capacitor, while the motor side converter inverts the stored energy into alternating current Ac at desired voltage and frequency. The control circuit constructs the control signal to the grid side converter (Ccg) by pulse angle modulation box, PAM, while the motor side converter constructs the control signal to the motor side converter (Ccm) by pulse width modulation box, PWM. A second level control system is added as shown for user control purposes. The controller should provide a rapid and accurate response from the reference voltages and currents. This information is fully presented. (Oriahi & Egwaile, 2017).

Data on the modelling of a back- to- back converter and the simulation of the SEIG used in this hybrid system is presented in the original paper of by Oriahi and Egwaile (2017) on which this system is railed.

6. Steady-State and Performance Analysis

Steady-state analysis of SEIG is of interest, both from the design and operational points of view. In an isolated power system, both the terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance, and load impedance. (Bansal, 2005).

7. Transient/ Dynamic Analysis

Many articles have appeared on the transient/dynamic analysis of SEIG. Shridhar, Singh and Jha, (1995) and Tandon, Murthy and Berg (1984), and most of the transient studies of induction generators are related to voltage build-up due to self-excitation and load perturbation. In this study the transient performance of short-shunt SEIG is presented and it is seen that it can sustain severe switching transients, has good overload capacity, and can re-excite over no load after loss of excitation. It is also observed that except for the most unusual circumstances (the short circuit across the machine terminals across the series capacitor), the short-shunt SEIG supplies adequate fault current to enable over current protective device operation. The voltage build-up of SEIG due to switching of the three-phase capacitor bank at rated speed at no load has also been studied. It is observed that depending on the machine parameters, the generator voltage builds up from small voltage due to residual magnetism to its rated value in nearly 1 s. Transient analysis of SEIG feeding an induction motor (IM) has been investigated to analyse the suitability of the SEIG to sudden switching, such as starting of the IM. (Bansal, 2005).

8. Voltage- Control Aspects

The need for reactive power support and poor voltage regulation are the two major drawbacks of induction generators and also load, which is generally inductive in nature, require the supply of reactive power. Unbalanced reactive power operation results in voltage variation. Capacitance requirements and the selection of capacitors of the SEIG have been discussed. (Bansal, 2005).

A fixed capacitor alone, cannot provide the adequate amount of reactive power needed by the induction generator at all possible speeds and loading conditions. Even if fixed capacitors are used to provide the average value, self-excitation may result in undue or over voltages. Static Var Compensators (SVCs) have been used in conventional power systems and can also be used conveniently in isolated power systems where continuous and fast control of reactive power is required. SVC has fast response and continuous control of reactive power and offers a large number of advantages over conventional reactive power compensation schemes. (Bansal, 2005).

Capacitor Bank

Capacitor Bank is a combination of numerous capacitors of similar rating that are joined in parallel or series with one another to collect electrical energy. The resulting bank is then used to counteract or correct a power factor lag or phase shift in an AC power supply. They can also be utilized in a DC power supply to step up the total amount of stored energy or to step up the ripple current capacity of the power supply. Capacitor banks are generally used for:

- Power Factor Correction
- Reactive Power Compensation

The sizing of capacitor banks for the three-phase squirrel cage induction generator, operating on an electric distribution network, is essential: ***Eudinei O. Silva1, Wagner E. Vanço2, and Geraldo C. Guimarães.***

Induction Generator Operating on the Electric Network

In order that the asynchronous squirrel cage motor operates as a generator, the speed of the rotor should surpass the synchronous speed (of the electric distribution network) when acting as a generator, the end result is a negative slippage. This therefore means that the induction motor will produce a negative torque, and as such will operate as a generator with respect to producing energy, the induction generator should receive reactive energy, which may come from the power grid or from a capacitor bank, as illustrated in Figure 5: ***Eudinei O. Silva1, Wagner E. Vanço2, and Geraldo C. Guimarães.***

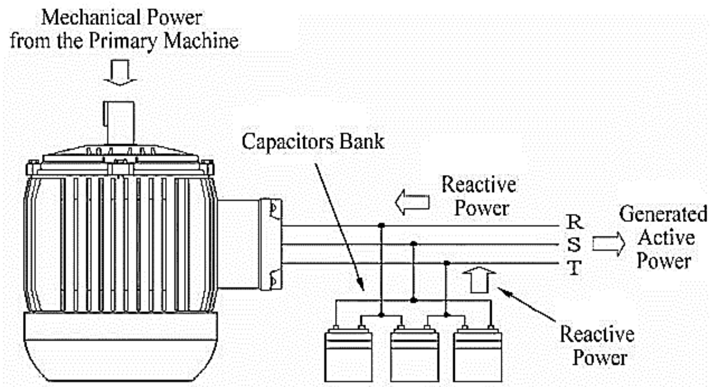


Figure 1: Capacitor bank connection on induction generator.

9. Conclusion

Induction motors have become common in the generation of electric energy in off-grid setups. The technology of self-exciting induction generators has a capability of running merely depending on the reactive power stored in the capacitor until the desired synchronous speed is reached for the induction machine to generate electric power.

The Hybrid Self- Powering Induction Generator (HSPIG) runs on the concept of Self- Exciting Induction Generators which are commonly used in wind power generation schemes. An alteration has been done to the system; the wind turbine is replaced by a motor which is coupled with the rotor shaft to act as prime mover. While the generator is fully exited, the prime mover is switched on so that the generator can produce real power to be distribute to the load. The power by which the prime mover is fed, is drawn from the storage unit in the upper AC/DC/AC converter comprising of a battery and capacitor bank in the upper AC/DC/AC converter. Once the generator attains maximum power generation capacity and load is connected, part of the power at the load output is directed to the upper AC/DC/AC converter to charge the battery and capacitor bank as illustrated in "*The proposed circuit diagram of a Cage motor-controlled hybrid self-powering induction generator*." Aback to back AC converter has been proposed for use in the feedback motor control system to control synchronization of the induction machine by regulating the generator output and frequency.

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Study on the Properties of Blast-Furnace Slag Cement Concrete Subjected to Accelerated Curing

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Abstract

The precast concrete industry uses accelerated curing methods for quick production of concrete units. In these products, autogenous shrinkage and drying shrinkage occur during and after accelerated curing. This causes thermal cracks due to both heating and cement hydration at early age, then drying shrinkage when precast concrete products are demoulded or installed on site. Use of ground granulated blast-furnace slag cement (BFS) improves concrete strength development during accelerated curing but poses a challenge of increased shrinkage. In this paper, mechanical and shrinkage properties of standard cured concrete and concrete subjected to accelerated curing are compared. Two types of blast-furnace slag cements with different fineness were used as main mineral admixture with other additives such as limestone powder, gypsums with two different types of fineness. One-day accelerated curing cycle consisting of three hours' delay period, heating to 65°C, and peak temperature maintained for three hours and finally cooling, was adopted. Increment in gypsum fineness showed increase in concrete expansion at one day for both sealed and accelerated cured concrete. In drying condition, similar shrinkage was observed where addition of gypsum provided slightly lower shrinkage and this may help to reduce cracking of concrete. Limestone powder improved concrete strength at early age. The difference in blast furnace cement fineness did not have significant differences in compressive strengths especially at 28 days.

Keywords: Accelerated curing; ground granulated blast-furnace slag cement; autogenous shrinkage; drying shrinkage

1. Introduction

BFS is an industrial byproduct in the manufacture of steel. It is one of the supplementary cementitious materials that has been used in concrete to help reduce Ordinary Portland cement (OPC) usage. OPC has negative environmental impact during its production (Sheikibrahim, *et al.* 2018). There are different types of BFS distinguished basically by their fineness that are available for use in different concrete works. BFS with fineness 4000 has been widely used in precast concrete industry. Its addition in concrete improves concrete properties such as workability; durability and water tightness. Increase in concrete resistance to salt damage and restraining the alkali–silica reaction using BFS have also been reported in literature by Jeon, *et al.* (2006) and (Suresh and Nagaraju, 2015). Therefore, replacement of BFS in concrete is generally dependent on

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the size and use for the concrete structure, (Nagao and Suzuki, 2015). Steam curing is a widely used accelerated curing method in precast concrete industry. In this method, it has been proven that there is significant increase in early strength of concrete when BFS is added, (Bhanumathidas and Kalidas, 2004). In addition, minor mineral admixtures such as limestone powder or gypsum are also incorporated in concrete to improve concrete workability, strength development and durability in accelerated cured concrete. (Esping, 2008).

During accelerated curing, concrete undergoes volume changes due to external temperature, heat of cement hydration and autogenous shrinkage. When BFS with 4000cm^2/g is used, high shrinkage has been observed due to its fineness. Reported by Saito et al.., autogenous shrinkage of concrete may be reduced by modifying blast furnace slag fineness used and content of gypsum in the binder (Saito, *et al.*, 2011). Recently BFS with specific surface area of at least 2,750 and less than 3, 500cm^2/g was developed for low heat slag cement and was then utilized as a concrete additive, JIS R 5210 (2009). However, little experiment data are available on shrinkage during and after accelerated curing using this type of BFS. Thus, the focus of this study was on investigating mechanical properties of concrete at early and later age of BFS 3000 in relation to the widely used BFS 4000. Thermal properties of BFS 3000 in semi-adiabatic condition and effect of minor mineral admixture on cement hydration was evaluated. The extent of autogenous shrinkage and drying shrinkage to provide experimental data sets on concrete crack resistance at early and later age was also conducted.

2. Materials and Test Methods

2.1 Concrete Materials

Table 1 provides the physical and chemical properties of binder materials used in this study. The main binders were Ordinary Portland Cement (N) and Ground Granulated Blast-furnace slag cements (BFS). Commercially produced Ordinary Portland cement conformed to the requirements of Japanese standard, JIS R 5210 (2009). Two different types of commercially produced BFS used were classified as BFS 3000 and BFS 4000. This is based on their fineness and conformed to Japanese standard, JIS A 6206 (2013). Limestone Powder (LSP) and two different types of anhydrous gypsum fineness namely, Normal Gypsum (GYP) and Fine Gypsum (F.GYP) were other mineral admixtures incorporated in concrete. Six mix proportions for each type of BFS cement were proposed. The percentage replacement of cement and mineral admixtures contents by mass of OPC for each concrete mix proportion are shown in Table 2. Air-entraining agent (AE); and air-entraining and water-reducing agent (AEWR) were used to produce entrained air and improve workability.

Crushed coarse and fine aggregates used were sandstone and river sand. Coarse aggregates had 20mm maximum grain size with 2.64g/cm^3 specific gravity. River sand had 2.59g/cm^3 specific gravity, 2.55% water absorption and 2.83 fineness modulus.

2.2 Mix proportions of concrete

The general composition of six mix proportions used in the experiments with varying mineral admixture contents are tabulated in Table 3. Target slump and air content were 15±2.5cm and 4.5±1.0%, respectively.

Table 1: Physical and chemical analysis results of cementitious materials

Cementitious Materials	Density (g/cm^3)	Fineness (cm^2/g)	Chemical composition (%)								
			ig-loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
OPC (N)	3.16	3200	0.94	20.84	5.49	3.07	63.89	1.97	2.4	0.4	0.32
BFS 3000	2.90	3350	0.25	34.01	14.28	0.33	42.61	6.23	-	0.2	0.35
BFS 4000	2.90	4580	0.09	33.90	14.16	0.30	42.92	6.24	-	0.19	0.32
LSP	2.71	7420	43.40	-	0.08	-	55.3	0.23	0.0	-	-
GYP	2.90	4100	1.10	0.90	0.20	0.10	39.7	0.10	58.0	-	-
F. GYP	2.90	9680	1.10	0.90	0.20	0.10	39.7	0.10	58.0	-	-

Table 2: Binder content percent by mass per cubic metre of concrete

Proportion	Blending (%)					Total (%) by mass
	N	BFS	LSP	GYP	F. GYP	
N+BFS	75	25.00	-	-	-	100
N+BFS+GYP	75	23.25	-	1.75	-	100
N+BFS+F.GYP	75	23.25	-	-	1.75	100
N+BFS+LSP	75	22.50	2.50	-	-	100
N+BFS+LSP+GYP	75	20.75	2.50	1.75	-	100
N+BFS+LSP+F.GYP	75	20.75	2.50	-	1.75	100

Table 3: Mix proportions of concrete

Proportion	W/B (%)	s/a (%)	Amounts of contents (kg/m^3)								Chemical Admixture AEWR (B X %)
				Binder (B)							
			Water	N	BFS	LSP	GYP	F. GYP	S	G	
N+BFS	50	47	175	262.5	87.5	-	-	-	812	933	1.0
N+BFS+GYP	50	47	175	262.5	81.4	-	6.1	-	812	933	1.0
N+BFS+F.GYP	50	47	175	262.5	81.4	-	-	6.1	812	933	1.0
N+BFS+LSP	50	47	175	262.5	78.6	8.6	-	-	811	933	1.0
N+BFS+LSP+GYP	50	47	175	262.5	72.6	8.6	6.1	-	811	933	1.0
N+BFS+LSP+F.GYP	50	47	175	262.5	72.6	8.6	-	6.1	811	933	1.0

2.3 Test methods

A pan type concrete mixer was used for all concrete mix proportions and batching was conducted according to the mix designs and as specified in Japanese standard (JIS A1119, 2014). Air-entraining agent (AE) and water-reducing agent (AEWR) were used in all the mix proportions. AEWR dosage was kept constant as recommended by the manufacturer whilst AE was varied to achieve target concrete air content. Fresh concrete properties such as slump, air content and temperature were measured just after casting in accordance with Japanese standards (JIS A 1101, 1975; JIS A1115, 2014; JIS A1118, 2011 and JIS A1156, 2014). Strain and temperature were measured throughout the experiments using transducer strain gauges installed in central portion of 100x100x400mm beam mold and connected to a data logger as shown in Figure 1. Compressive strength tests conforming to Japanese standard (JIS A1108, 2006), were conducted using (100mm diameter and 200mm height) cylinder molds. Temperature rise due to heat of cement hydration under semi-adiabatic condition was measured in cubic moulds with internal dimensions of 200mm made of foamed polystyrene of 200mm thick. Setting time of concrete was determined according to Japanese standard (JIS A 1147, 2007).

After casting, all specimens were sealed and stored in a temperature-controlled room at 20°C and 80% relative humidity (RH). Some selected beams, and cylinder specimens for 1, 7 and 14 days' compressive strength tests were then subjected to high temperature curing 3 hours after casting time. Figure 2 shows the target ambient temperature profile used in the experiments which was similar to a typical steam curing process in general precast concrete factories. In this study, steam was not applied. The remaining beam and cylinder moulds were kept in temperature-controlled room at 20°C and 80% RH, strain and temperature was measured in beam specimens as well. Accelerated curing was conducted on three mix proportions on the same day. Thus, twelve mix proportions were cast and cured on four different days.

After 24 hours, all specimens were demoulded. The accelerated cured specimens were then subjected to drying condition in a different temperature-controlled room at 20°C and RH 60% for drying shrinkage measurement in beams specimens and compressive strength tests in cylinder specimens. Autogenous shrinkage was measured in beam specimens which were sealed with aluminum adhesive tape and stored in temperature control room at 20°C. The storage condition for both sealed and in drying condition of beam specimens are shown in Figure 3. Cylinder specimens for 28 days' compressive strength test were stored in water at 20°C.

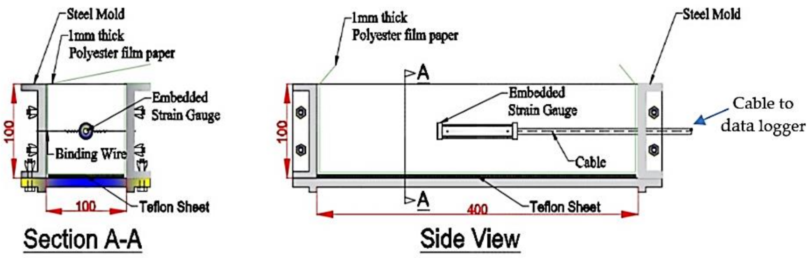

Figure 1: Beam concrete mold for shrinkage measurement

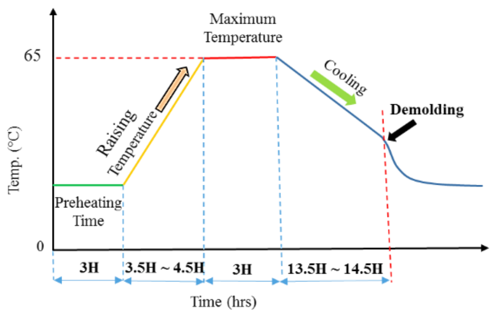

Figure 2: Target temperature history for accelerated concrete curing

Figure 3: Shrinkage measurement for Autogenous (Left hand side) and Drying Shrinkage (Right hand side)

3. Results

3.1 Fresh Properties of Concrete

Table 4 below shows the results of the fresh properties for all the mix proportions. Similar results were obtained in the mix proportions.

Table 4: Results for fresh concrete properties

Mix Proportion	Slump (cm)		Air Content (%)		Temperature (°C)	
	BFS 3000	BFS 4000	BFS 3000	BFS 4000	BFS 3000	BFS 4000
N+BFS	19.3	19.2	5.8	5.5	18.5	28.0
N+BFS+GYP	19.0	19.7	5.5	6.4	19.5	28.5
N+BFS+F.GYP	18.2	19.2	5.6	4.8	20.0	28.5
N+BFS+LSP	17.7	20.7	4.4	6.5	19.0	26.5
N+BFS+LSP+GYP	18.5	20.5	4.5	5.4	19.0	26.0
N+BFS+LSP+F.GYP	19.4	20.0	4.6	5.0	20.0	26.0

3.2 Results for setting time of concrete

Table 5 provides concrete setting time test results obtained. As reported in previous studies, the use of GGBFS generally retards setting time of concrete (Mahmoud, 2013). Furthermore, the extent of concrete setting time retardation depends on many factors such as fineness and composition of the SCM and the level of replacement used, amount and composition of the Portland cement or blended cement (particularly its alkali content), water-to-cementitious materials ratio (w/cm), and temperature of concrete (Mahmoud, 2013 and Sadaqat, *et al*., 2014). The results obtained showed similar trend of longer setting times. In this study, the observed initial setting time of each mixture was taken as the starting point of autogenous shrinkage measurement.

Table 5: Setting time of concrete

Mix Proportion	Initial setting time (hrs)		Final setting time (hrs)	
	BFS 3000	BFS 4000	BFS 3000	BFS 4000
N+BFS	7.03	5.70	10.42	7.50
N+BFS+GYP	6.83	5.21	9.83	7.25
N+BFS+F.GYP	7.36	5.27	9.90	7.57
N+BFS+LSP	6.38	5.92	9.27	8.65
N+BFS+LSP+GYP	6.93	5.80	9.58	8.25
N+BFS+LSP+F.GYP	6.64	5.60	9.58	8.15

3.3 Accelerated Temperature History

Figure 4 shows typical accelerated temperature history observed in all mix proportions with the similar temperature rise of about 20°C/hour. Though the heating temperatures were not exactly same, all the mix proportions were heated within the recommended temperatures recommended in the America Concrete Institute (AC1 51 7.2R-87, 1992). During the constant maximum heating, all the mix proportions reached a target temperature of 65°C. At start of cooling, all the concrete specimens were kept inside a closed oven to prevent high temperature difference in concrete and surrounding that would have led to cracking due to thermal shock. During this period, there was no automated cooling system installed in the chamber. Considering this chamber condition, cooling of concrete specimens was still achieved in similar temperature decreasing rate of 1.8°C/hour on average. This cooling rate was also within the recommended rate in AC1 51 7.2R-87 (1992) of about 2°C/hour.

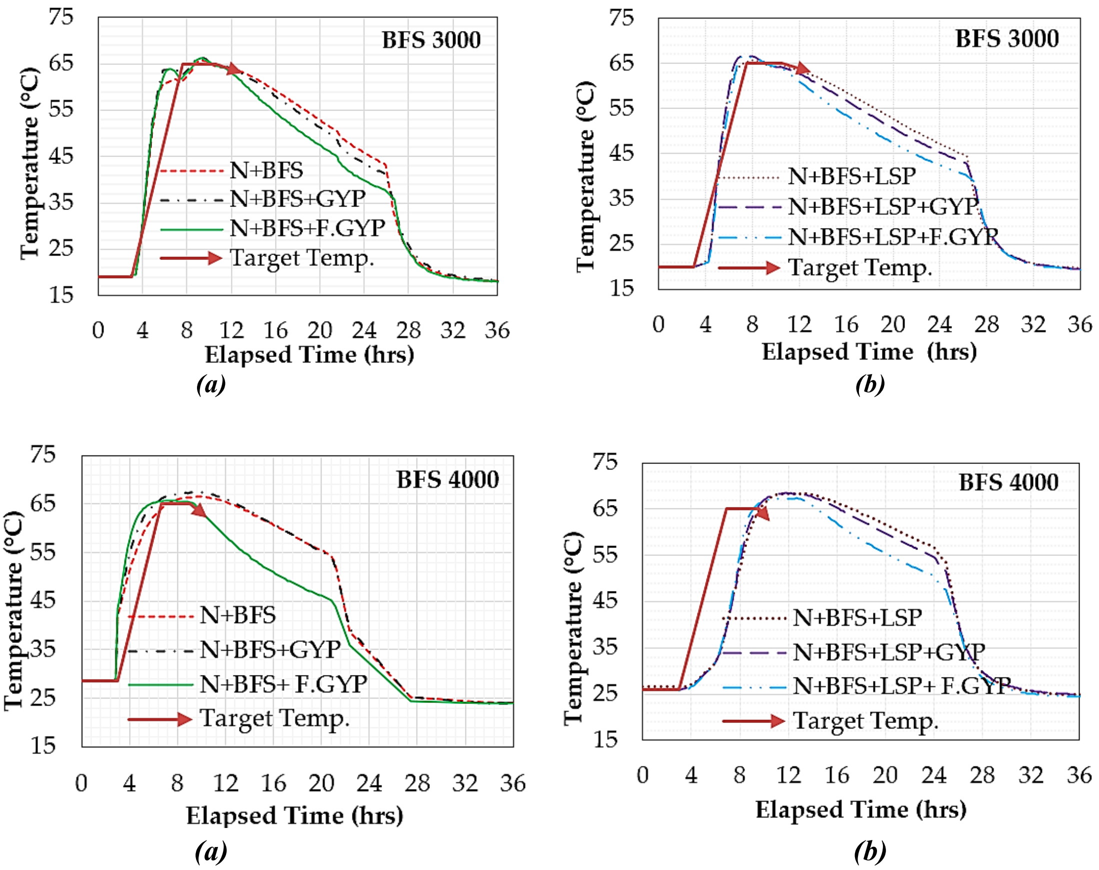

Figure 4: Temperature history for accelerated curing in BFS 3000 and BFS 4000

3.4 Compressive strength test results

Compressive strength results for accelerated cured concrete obtained are shown in Table 6 water cured compressive strength at 28 days. Higher 1-day compressive strength for accelerated cured concrete specimens was observed for specimens containing limestone powder. The trend for strength remained generally the same even for the 28 days' compressive strength of specimens cured under water. When BFS 3000 was used, strength development after accelerated curing was slower than BFS 4000. Addition of limestone powder in BFS 3000 showed more effect in strength improvement compared to BFS 4000. Amongst the specimens containing limestone powder, similar strength values from 1 day to 14 days' results was observed in both BFS types which showed an average of 13.5% more compressive strength compared with concrete mixes with N+BFS. At 28 days, mix proportions containing N+BFS+LSP+F.GYP had highest compressive strength. In this case, fine gypsum contributed to strength development in concrete at 28 days under water. It was also observed that the increase of fineness of BFS did not have significant influence in compressive especially at 28 days. Thus, BFS 4000 may be used if early strength is needed for demolding.

Table 6: Compressive strength at 1 day, 7 days and 14 days for accelerated cured BFS 3000 and BFS 4000; and 28 days for water cured concrete

Age (days)	Compressive Strength (N/mm^2) - Accelerated cured concrete					
	N+BFS	N+BFS+GYP	N+BFS+F.GYP	N+BFS+LSP	N+BFS+LSP+GYP	N+BFS+LSP+F.GYP
1	19.2	19.5	18.9	23.5	23.3	22.0
7	26.1	25.0	24.1	31.3	32.4	31.1
14	30.6	29.2	27.3	34.7	35.7	34.1
Compressive Strength (N/mm^2) - Water cured concrete						
	N+BFS	N+BFS+GYP	N+BFS+F.GYP	N+BFS+LSP	N+BFS+LSP+GYP	N+BFS+LSP+F.GYP
28	37.1	39.1	37.2	41.6	42.0	45.2

3.5 Autogenous and Drying Shrinkage – Sealed and Accelerated Cured Concrete

In the experiments conducted, total strain which is the sum of thermal strain and autogenous shrinkage strain was observed. To obtain autogenous shrinkage, coefficient of heat expansion of concrete was assumed to be $10x10^{-6}$/°C, Japan Concrete Institute (JCI, 2016). Thus, autogenous strain was calculated as the difference between total strain and thermal strain. The observed autogenous shrinkage in sealed concrete specimens at 20°C containing BFS 3000 and some for BFS 4000 are presented in Figures 5 and 6. Note that only mix proportions containing LSP for BFS 4000 were prepared for autogenous shrinkage measurement. Mix proportions containing gypsum showed higher expansion at early age. Additionally, increment in gypsum fineness showed more expansion. Similar shrinkage at later age in all mix proportions was observed. Figures 7 and 8, show autogenous shrinkage and drying shrinkage during and after accelerated curing. Mix proportions containing gypsum showed higher expansion during accelerated curing and slightly lower shrinkage after accelerated curing with fine gypsum showing similar behavior observed in sealed specimens in Figures 5 and 6. In this condition again, all mix proportions showed similar shrinkage values at later age.

3.6 Heat of cement hydration of the concrete - semi adiabatic condition

Cement hydration in concrete is an exothermic reaction and causes temperature rise in concrete. This property is responsible for thermal cracking in concrete members and has influence on shrinkage properties. There is generally a relationship between the extent of rise in temperature on the type and content of cementitious materials in concrete.

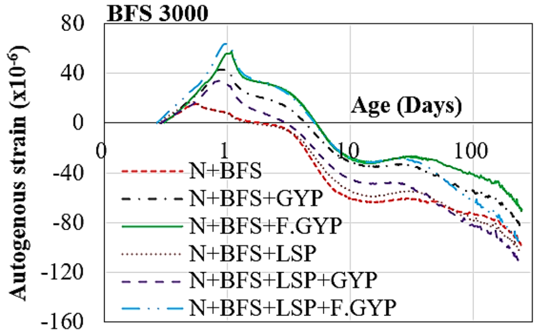

Figure 5: Autogenous shrinkage – BFS 3000

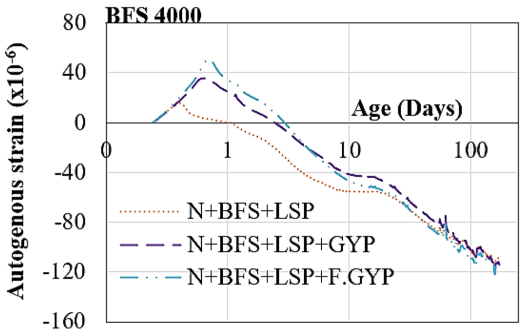

Figure 6: Autogenous shrinkage – BFS 4000

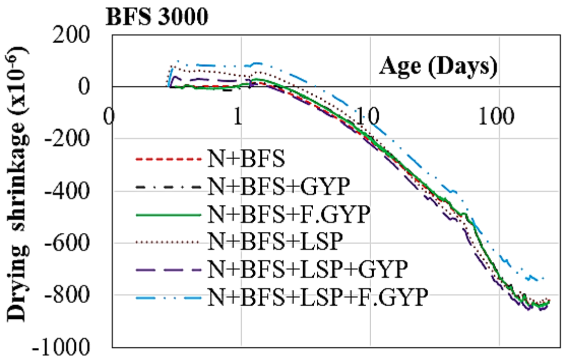

Figure 7: Drying shrinkage – BFS 3000

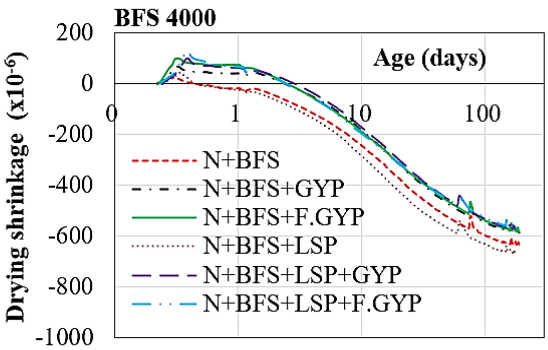

Figure 8: Drying shrinkage – BFS 4000

To establish the general behavior of this concrete property, temperature rise due to cement hydration in semi-adiabatic condition was conducted on N+BFS and N+BFS+LSP+F.GYP containing BFS 3000. This also, enabled to check the effect of adding LSP and F.GYP on rise in concrete temperature. The observed results are shown in Figure 4 (a) and (b). The results obtained were then used to predict adiabatic temperature rise of concrete using Equation (1). This equation is based on simple thermal insulation test on the relationship between semi-adiabatic temperature rise and adiabatic temperature rise proposed from the previous research, Yasuyuki (2002).

$$\rho CVT' - Sh\theta = \rho CV\theta' \quad (1)$$

Where: $\boldsymbol{\rho}$= Density of the sample specimen (kg/m^3), $\boldsymbol{C}$ = Specific heat capacity of concrete taken as (1.05KJ/kg°C), **V** = Volume of the sample specimen (m^3), **S** = Surface area of the sample specimen (m^2), $\boldsymbol{h}$ = Heat transfer coefficient (W/m^2 °C), $\boldsymbol{T}$ = Temperature gradient existing between the sample specimen and ambient room temperature, $\boldsymbol{\theta}$ = Adiabatic temperature state.

Predicted parameters using experiment data from Equation (1) were then used to generate constants in JCI model Equation (2) shown below. Graphs obtained are also presented in Figure 9 (a) and (b), Japan Concrete Institute, JCI (2016). The derived constants from Equation (2) are given in Table 7. Test results obtained indicated that addition of limestone powder and fine gypsum contributed to faster and higher predicted adiabatic temperature rise and ultimate temperature rise, (Suresh and Nagaraju, 2015 and Bonavetti, *et al.*, 2013).

$$Q(t) = Q_\infty[1 - exp\{-r_{AT}(t - t_{0,Q})^{SAT}\}] \quad (2)$$

Where: **t** = Age in days, **Q (t)** = Adiabatic temperature rise at t (ºC), $\boldsymbol{Q_\infty}$ = Ultimate adiabatic temperature rise (ºC), $\boldsymbol{r_{AT}, S_{AT}}$ = Parameters representing rate of adiabatic temperature rise, $\boldsymbol{t_{0,Q}}$ = Age at starting of temperature rise.

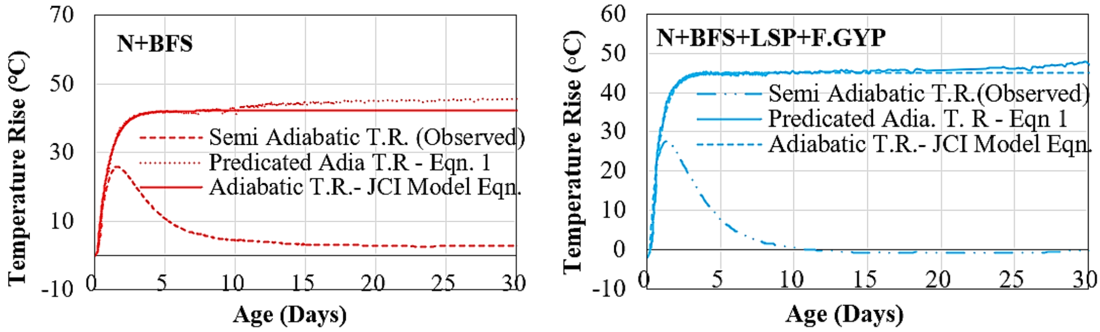

Figure 9: Observed semi adiabatic and predicated adiabatic temperature rise in BFS 3000

Table 7: Adiabatic temperature rise properties of BFS 3000 concrete

Mix Proportion	W/B (%)	Q_∞ (°C)	r_{AT}	S_{AT}	$t_{0,Q}$
N+BFS	50	42.14	1.179	1.0	0.183
N+BFS+LSP+F.GYP	50	45.14	1.378	1.0	0.177

4. Discussions

Fresh concrete properties such as slump play various roles in precast concrete just like in other types of concrete. In the study, the results obtained showed increased slumps values which are typical when blast furnace cement is used. This may help in ease of casting and finishing the concrete units. In addition, setting time of concrete has been used in precast concrete in determining the start time for accelerated curing though generally the delay period 2 to 5 hours has been employed in many precast companies (Deogekar, *et al*., 2013). In this study, setting time was used as the start of measurement for autogenous shrinkage, Japan Concrete Institute, JCI (2016) and 3 hours was adopted despite of longer setting times observed in mix proportions. The main function of accelerated curing of concrete as mentioned earlier is to enhance early strength. Thus, the concrete strength at demoulding in this case, at one day is important in the production of concrete units. Use of both types of blast furnace slag cements in all mix proportions produced concrete with higher strength which satisfied the minimum required strength as recommended in previous research, (Nagao and Suzuki, 2015). On the other hand, the influence of introducing other additives such as limestone powder showed more effect on strength gain especially with decrease in blast furnace slag cement as observed at 7 and 14 days. This may also help to have good concrete strength for dispatching of precast concrete units from precast yard to installation site that generally takes place 14 days after demoulding. During accelerated curing, more expansion was observed in the mix proportions containing limestone powder and gypsum. The Increment in fineness of gypsum showed even greater expansion. Thus, this combination of limestone powder and fine gypsum may be helpful in acting as expansive agents for such mix proportions as this effect showed slight reduction in the drying shrinkage at later age. It was also observed that the increase in fineness of blast furnace slag cement showed slight reduction in the drying shrinkage which may help in cracking resistance when a concrete unit is in service. However, the difference of about 200µm in drying shrinkage was not so significant to show major cracking tendency between the two types of cements. Adiabatic temperature rise in concrete has been used to assess the rate of cement hydration for some purpose related to cracking. Generally, the addition of supplementary cementitious materials such as blast furnace slag cement has been used to reduce rise in temperature in concrete. In this study, the rise in temperature was used to check the effect of using additives such as limestone powder and fine gypsum. The results showed slight increased rate of concrete strength and rise in temperature when the two additives were used.

5. Conclusions

The study investigated on the fresh, mechanical and shrinkage properties of concrete made with BFS 3000 and BFS 4000 cement as main mineral admixtures and subjected to accelerated curing by heating. Based on the results from the laboratory tests, conclusions were drawn and summarized as follows:

1) Fine gypsum contributed to higher expansion at early age in sealed and accelerated cured concrete. Combination of limestone powder and fine gypsum had highest expansion in concrete.

2) Limestone powder contributed to increased compressive strength of concrete at early age whilst gypsum addition showed significant influence on concrete strength at 28 days.

3) There was insignificant difference in compressive strength especially at 28 days between two types of slag cements even when additives such as limestone powder and gypsum were used.

4) Similar drying shrinkage was observed at later age. Concrete containing fine gypsum showed slightly lower shrinkage which may help in cracking resistance.

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Design of Geo Radar Telemetry power alerting Prototype

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Abstract

Geotechnical radar systems real time network monitoring contributes to more sustainable mining operations. The most important considerations are the ability to monitor and receive real-time notifications from critical systems (i.e., Geotechnical ground monitoring radars). The safety of any individual is critical in the industry's application, particularly in open pit mines where many high wall movement accidents occur and result in fatalities at times. This paper describes the design and development of a telemetry system that will send real-time radar power status (ON/OFF) notifications to network administrators. This means that if the radar goes offline for any reasons, the OAM (Operations, Administration, and Monitoring Center) will be alerted in real time as compared to the traditional SNMP.

The VHF two-way radio system is integrated with the Geo radar system solely for status monitoring, this is tested alongside ubiquity SNMP wi-fi network. The two systems under study are telemetry using VHF two-way radio and SNMP that utilizes ubiquity wi-fi network. This paper does not dive into the technical operation of the Geo radar system, the framework allows for continuous monitoring of ground movement detection of radar systems (in the case of the Barrick Lumwana mine, Zambia).

The results for the performance warnings of the telemetry access points collectively accounted for a response alert time of 0.29% compared to the SNMP system that registered a total of 99.71% of the total response time of 691499ms. The results derived from the VHF 2-way radio telemetry prototype show that this system performs better than the traditional SNMP network monitoring system. Telemetry communications, in this sense, is a foundational platform technology required to reduce environmental impacts and improve worker health and safety. Private wireless communications will be a critical enabler of the data revolution that will power the mining industry's green shift.

Keywords: Network Telemetry, Simple network monitoring protocol (SNMP), Very high frequency (VHF), Geo Radar.

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1. Introduction

Network monitoring is the network management function that collects information(Wekhande, 2006). Data for network management applications is collected by network monitoring applications. The purpose of network monitoring is to gather useful information from various parts of the network so that the network can be managed and controlled using the data collected (Wekhande, 2006). Most network devices are in remote locations. Because these devices do not typically have directly connected terminals, network management applications cannot easily monitor their statuses.

Telemetry is becoming increasingly important for the efficient detection and timely response to network state changes, such as radar device uptime/downtime alerts. The current pull-based data collection mechanism used by the traditional simple network monitoring protocol (SNMP), on average, network operators collect SNMP data every 5 to 30 minutes, which affects network visibility (Svoboda et al., 2016).

The idea behind a telemetry network using VHF 2-way radio is to "push the data" rather than "pull the data." The VHF 2-way radio network telemetry prototype collects and transmits device alert status (uptime/downtime) in near-real time, while SNMP uses a combination of Pull and push communications between network devices and the network management system.

The purpose of this paper is to build and compare a VHF 2-way radio radar telemetry system with SNMP polling. The results are then populated for both systems. The goal of introducing VHF 2-way radio network telemetry is to benefit application development for effective network monitoring and diagnosis that will lead to sustainable mining. The network engineers will be kept up to date on the device's status and the reasons for failure. This, in turn, will shorten the time required to fix the problem.

1.1 Geotechnical Radar

The Geo radars offers reliable, innovative and comprehensive solutions for proactive and reactive monitoring of slope displacements in open pit mines. From very slow movements to rapid displacements, the radar system offers solutions for instabilities. Figure 1 below shows the geo radar systems architecture.

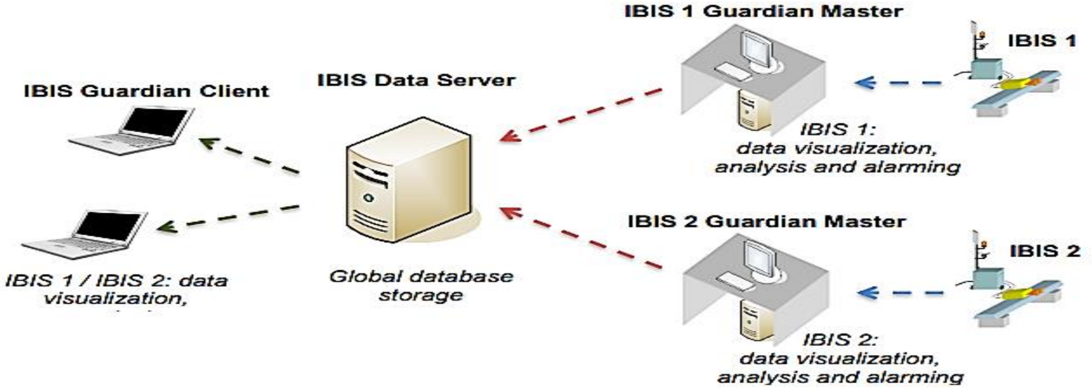

Fig. 1: Geo Rader system architecture

2. Related work

The Network monitoring has been the subject of numerous research. Since it is easy to collect network traffic statistics in real time, or at least very close to real time, most of them were built on wired networks(Wekhande, 2006). These studies have the drawback of being difficult to apply to wireless networks. The problems highlighted in these studies must be overcome in order to acquire the same level of detail in wireless networks as in wired networks. Recently, however, industry and academic institutions have both suggested solutions for network monitoring(Johnson, 2009.; Series and Science, 2018). Existing solutions, however, primarily concentrate on balancing expressiveness, accuracy, speed, and scalability (Paolucci et al., 2018; Svoboda et al., 2016). For instance, systems like NetQRE (Yu et al., 2013) and others can enable a variety of queries using stream processors operating on general-purpose CPUs, but doing so comes at a significant expense in terms of bandwidth and processing. Although they can only support lower packet speeds, telemetry systems like Chimera and Gigascope (Martin-Flatin, 1999) are expressive in nature since they encompass a broad variety of telemetry elements. This is so that the stream processor, which in these systems can become a bottleneck, can process all packets.

3. System components (Radar 1 and radar 2)

The radar prototype setup for both Radar 1 and Radar 2 is shown in figure 2. The radars are in different parts of the pit to monitor any high wall earth movements.

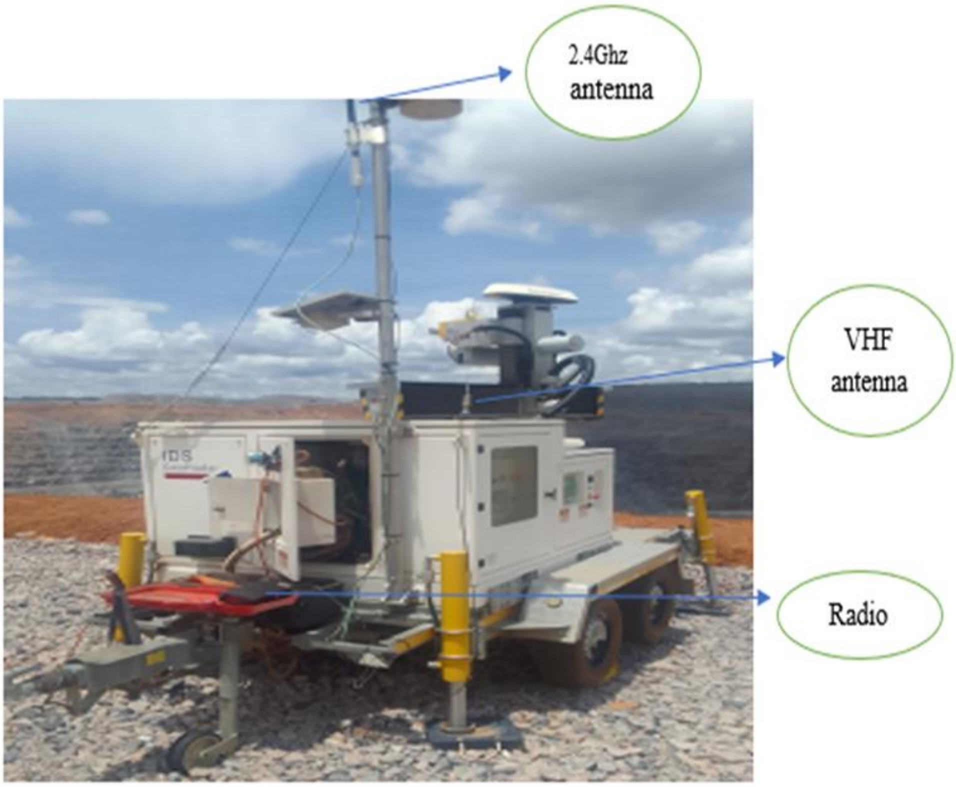

Fig. 2: Geotech Radar

3.1 Geotechnical Radar system implementation

In the execution of the telemetry with VHF 2-way radio, the setup was done as follows: For each of the two prototype radars, an SRD 12 VDC SL C Relay was linked and wired with the 12V switched battery from the radio rear accessory pin 7 which is SW+ and pin 8, PWRGND negative. GPIO pin 20 (5V) is connected to the input control part of the relay.

The relay is connected in a normally closed state to continuously monitor and transmit the GPIO configured 5V control signal. Any power cut to the relay will stop the 5v signal to the control Arduino connected monitoring radio. The control voltage is being transmitted through the VHF whip antenna. Figure shows a circuit of the geo radar system with inbuilt batteries and solar charge regulators. The relay is powered via 12VDC from the batteries. Below is a circuit diagram.

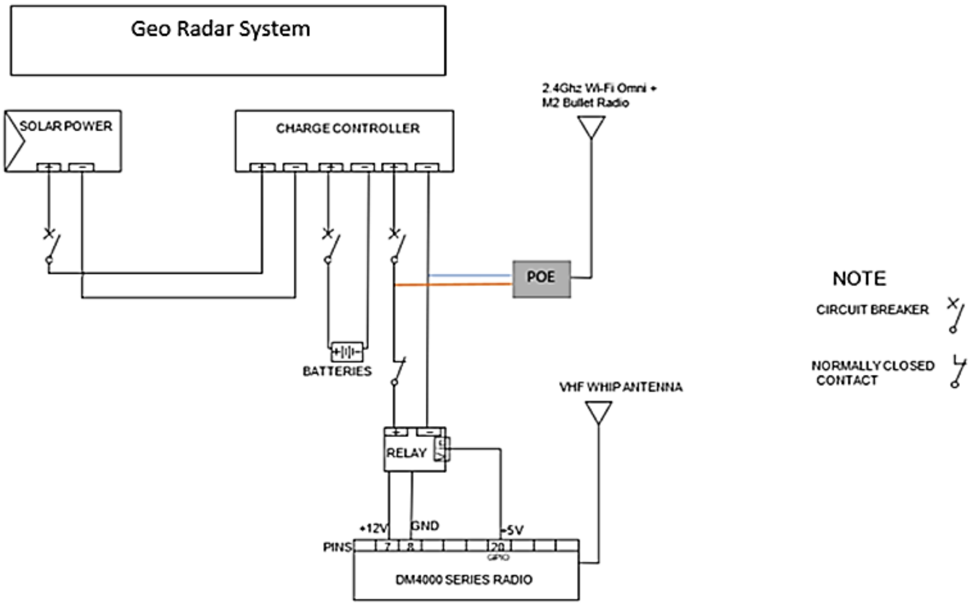

Fig. 3: Connection layout

4. Results

In this section, the results of the measurements are presented.

4.1 Telemetry

Results for radar 1 and radar 2 are shown below after five random sampling for each.

4.1.1 Geo radar.

Table 1 shows the test samples that were carried, the time, name of the radar, status, and the average time.

Table 1: Geo radar 1

Sample	Time	Name	Status	Response	Avg.
1	16:34:01.173 16:34:01.595	RADAR 1	OFF ON	422	211
2	16:34:10.501 16:34:10.923	RADAR 1	ON OFF	431	215
3	16:34:11.345 16:34:11.720	RADAR 1	OFF ON	375	188
4	16:34:33.235 16:34:33.610	RADAR	ON OFF	375	188
5	16:34:34.829 16:34:35.251	RADAR 1	OFF ON	422	211

Table 2: Geo radar 2

Sample	Time	Name	Status	Response	Avg.
1	16:26:26.028. 16:26:26.403	RADAR 2	OFF ON	375	188
2	16:20:34.877 16:20:35.252	RADAR 2	ON OFF	375	188
3	16:20:36.096 16:20:36.471	RADAR 2	ON OFF	375	188
4	16:26:45.856 16:26:46.278	RADAR 2	ON OFF	422	211
5	16:26:47.075 16:26:47.497	RADAR 2	OFF ON	422	211

4.2 SNMP

SNMP results for radar 1 and radar 2 are presented below.

4.2.1 Geo radar 1

Table 3 shows some results for SNMP for radar 1.

Table 3: Geo radar 1

Sample	Time	Name	Status	Response	Avg.
1	15:20:29 15:24:56	RADAR 1	ON OFF	267000	133500
2	15:27:29 15:27:52	RADAR 1	ON OFF	23000	11500
3	15:31:59 15:33:44	RADAR 1	ON OFF	105000	52500
4	15:51:53 15:52:27	RADAR 1	ON OFF	34000	17000
5	16:43:30 16:44:20	RADAR 1	ON OFF	50000	25000

4.2.2 Geo radar 2

Table 4 below shows some results for SNMP for radar 2.

Table 4: Geo radar 2

Sample	Time	Name	Status	Response	Avg.
1	13:24:10 13:25:59	RADAR 2	ON OFF	109000	54500
2	13:31:29 13:32:59	RADAR 2	ON OFF	90000	45000
3	13:43:59 13:47:29	RADAR 2	ON OFF	210000	105000
4	13:04:40 13:13:40	RADAR 2	ON OFF	540000	270000
5	16:15:00 16:16:00	RADAR 2	ON OFF	60000	30000

5. Comparisons between telemetry and SNMP

Figure 3 shows a summarized response time alert comparison of the SNMP system and VHF 2-Way radio system. The first simulation percentage of VHF two-way radio radar 1 telemetry recorded 0.15% and radar 2 telemetry registered 0.14%.

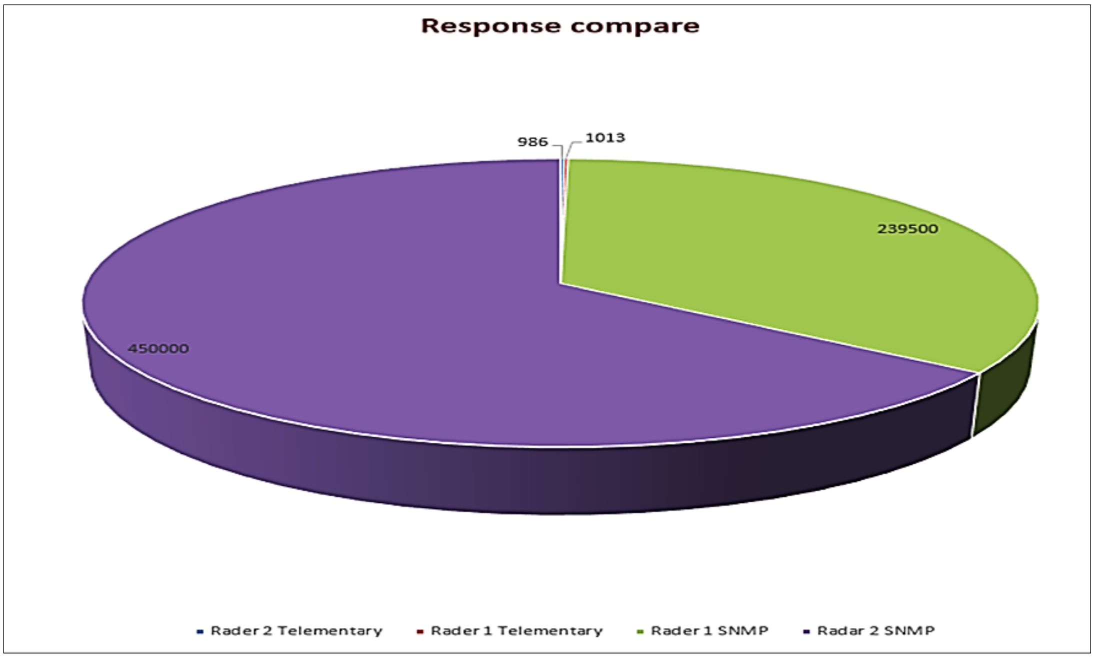

Fig. 3: Summary response

In the second Prototype simulation carried out, radar 1 SNMP simulation recorded 65.08% of response alert time while radar 2 SNMP simulation records 34.63% of the response time. This translated a total of 1999ms for radar telemetry and a total of 744000ms for SNMP. The telemetry monitoring system further accounted for a system response alert time decrease of 34392.2%.

6. Conclusions

In this paper, a near real-time device Wi-Fi network uptime/downtime alerts using telemetry with VHF 2-way radio has been presented. According to the results in section 4, the telemetry prototype built in this study performed better as compared to the SNMP system.

The telemetry with VHF two-way radio system has shown to be more efficient in providing near real-time Wi-Fi network power alerts. The collection of real-time monitoring data helps to immediately evaluate and react quickly to the alerting current events.

The framework will help mitigate and reduce some open pit mine occupational incidents but timely monitoring the radar systems. This will in turn bring about sustainable mining, value addition, economic development and empowerment.

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Groundwater assessment in unplanned settlement: A case study of Musonda Compound in Kitwe

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Abstract

Analysis and visualization of water resources data is a pedestal for building resilience and influencing adaptation strategies in fighting negative effects of climate change which affect access to safe drinking water and sanitation. In this paper we present the results of an investigation of groundwater levels and quality from Hand-dug wells in Musonda Compound, an unplanned settlement located in Kitwe City. The research was carried out to compare the quality groundwater with the set limits of drinking water by Zambia Bureau of Standards (ZABS), establish groundwater flow direction and quantify the rate at which groundwater was changing, as well as to check whether there was a correlation between the observation well contamination and distance to the nearest pit latrine. Groundwater Potential heads were processed to estimate groundwater flow direction and the rate at which the water table was changing. The spatial distribution maps for groundwater quality and groundwater potential heads were derived using Inverse Distance Weighting method. The results revealed that groundwater was generally contaminated as compared with the limits of drinking water quality set by ZABS. The correlation analysis showed that there is a negligible relation between the minimum distance to pit latrine and the water quality. The correlation coefficients were found to be: 0.22 for nitrates, 0.02 for Total Coliforms (TC) and 0.07 for Fecal Coliforms (FC). Further, Groundwater Potential heads (derived from groundwater levels during the period of observation) revealed that the water table was decreasing at an average rate of **0.35cm/day** and the flow direction was towards East and South-Eastern part of the project area.

Keywords: **Musonda Compound, Climate Change, Groundwater Quality, Groundwater Potential head, Pit Latrines, Hand-dug wells, Kitwe City**

1. Introduction

Groundwater resources in Zambia are variable both in quantity and quality across the country but a national groundwater resources assessment and mapping program is presently not in place (Chongo et al 2013 and Mpamba et al, 2008). Groundwater levels and quality measurements from observation wells are the principal source of information about the hydrologic stresses such as climate change acting on aquifers and how the stresses affect groundwater recharge, storage and discharge (Heath, 1983, Healy & Cook, 2002; Brassington, 2007; Subramanya, 2010 and

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Phiri, 2018). Measurement coupled with analysis of groundwater levels and quality provide the most fundamental indicator of the status of groundwater resource and is critical for managing water resources. According to the 8th National Development Plan (MFNP, 2022) Zambia made progress towards increasing access to water and sanitation. However, the objective to improve the water and sanitation sector as envisaged in the 8th National Development Plan (MFNP, 2022) can be hampered if monitoring water resources and sanitation services are not taken into serious consideration.

In Zambia, groundwater is an important source of water. Nkhuwa et al (2015) states that in Zambia groundwater forms the most important source of water in urban, peri-urban and rural areas, and in some cases 100% of the water demand is met by groundwater supply. However, considering the growing demand of groundwater (MoFNP, 2011), the increase in impermeable surfaces coupled with the impact of climate change (especially resulting from increase of droughts), groundwater supply is bound to decrease. The impact of climate change can be understood by analyzing groundwater levels and quality from observation wells.

Analysis of groundwater levels and quality especially in phreatic aquifer is simple and insensitive to the mechanism by which the water flows through the unsaturated zone (Bureau of Rural Sciences, 2007; Healy & Cook, 2002). The method is cheaper to implement as aquifer parameters are obtained passively under natural flow conditions without stressing the aquifer (Bureau of Rural Sciences, 2007; Powers & Shevenell, 2000).

The aim was to compare the quality groundwater with the set limits of drinking water by ZABS, establish groundwater flow direction as well as to check whether there was a correlation between the observation well contamination and distance to the nearest pit latrine in Musonda Compound in Kitwe City of Zambia. This study was conducted to highlight the importance of the measurements and analysis of groundwater levels and quality so as to encourage a more comprehensive systematic approach to the long-term collection of groundwater data in the water and sanitation sector of the nation.

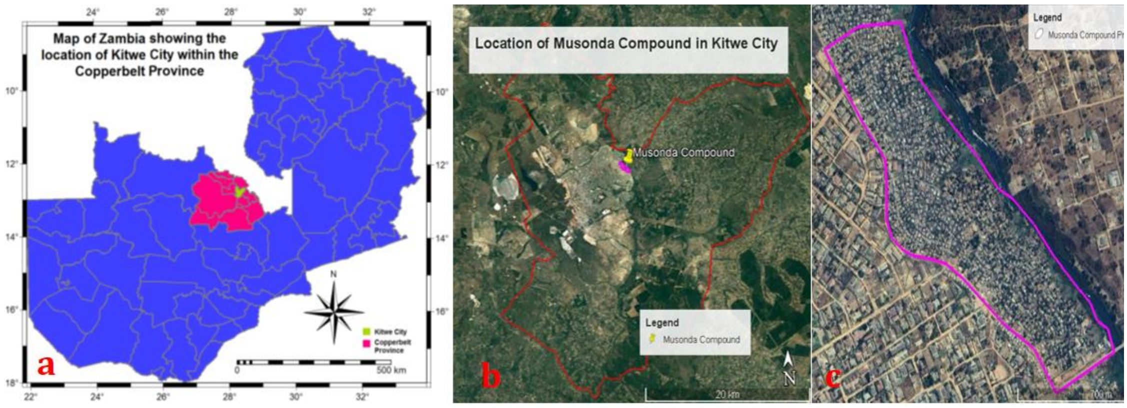
2. MATERIALS AND METHODS

2.1 Study Area

Musonda compound is an unplanned settlement in Zambia's Kitwe District (Figure 1) with an area of about 48 hectares. It has over 80 hand-dug wells and over 40 pit latrines. Majority of the people in the area have resorted to groundwater as their main source of water because they are unable to afford piped water from the local water utility company. The use of dry sanitation and open dumping of waste indiscriminately in the area pose a threat to the quality of groundwater in the area and the health of the community.

2.2 Groundwater Sampling and Laboratory Tests

A total of 80 hand-dug wells, 51 pit latrines and a total of 14 dump sites were identified within Musonda compound. This was done by surveying the area and identifying residents using the hand-dug well water source. From the identified wells, 23 were selected as observational wells for measuring the depth of groundwater while 10 sampling wells were selected from the 23 observational wells for water quality tests. The observation wells were selected in such way to cover the project area evenly within the constraints the budget.



(a) *(b)* *(c)*

Fig. 1: (a) Location of Kitwe City in Zambia (b) Location of Musonda Compound in Kitwe City (c) Musonda Compound Project Area

The depth of water table was recorded twice a week from 15th March to 29th June 2022 using a steel tape. Ground surface elevation was measured using the Differential Global Position System (DGPS) with a geodetic reference surface WGS 84. Total hydraulic head is the summation of Pressure head, Velocity head and Elevation head. But for groundwater, velocity head is negligible and further at the water table surface, Pressure head is zero (Heath, 1983; Brassington, 2007; Subramanya, 2010). Therefore, for groundwater in a phreatic aquifer Total hydraulic head (Groundwater Potential head) is basically equal to the Elevation head at the water table surface. This means that Groundwater Potential head is equal to Elevation of the ground surface minus depth of groundwater (Equation 1):

$$GWP = z - d \qquad (1)$$

Where;

$GWP = Groundwater\ Potential\ head,$

$z = Ground\ Surface\ Elevation$

$d = Depth\ of\ Groundwater\ table$

Under homogeneous and isotropic conditions, the flow of groundwater in an aquifer is from a high to low Groundwater Potential head. Further, trend analysis of Groundwater Potential head can be used to estimate groundwater recharge in the concentration limb and groundwater discharge in the recession limb of the groundwater hydrograph (Healy & Cook, 2002; Brassington, 2007; Subramanya, 2010.)

Sampling of water quality from the ten observation wells was carried out once every month from April to July 2022. The samples were carried in cooler boxes to the Copperbelt University

Environmental Engineering Laboratory, within two to four hours of sample collection, for analysis of the following parameters: Turbidity, Total Suspended Solids (TSS), conductivity, Sulphates, Nitrate, pH, Chloride, TDS, Total Coliforms (TC) and Fecal Coliforms (FC). The parameters were tested using standard laboratory procedure in accordance with the American Public Health Association (Baird, *et al*. 2017). Groundwater quality results were compared with the Zambia Bureau of Standards (ZABS, 2001) of drinking water. The minimum distance from well to pit latrine was also measured using a measuring tape for the 10 water quality observation wells.

2.3 Groundwater Analysis

Trend and spatial analyses were carried on observed groundwater data. A correlation analysis was done to establish whether or not the distance from well to pit latrine had a bearing on groundwater quality, as it is common knowledge that percolation of chemical and microbial contaminants from pit latrines can contaminate groundwater. For spatial analysis, observed field data was processed using Inverse Distance Weighting, a deterministic spatial interpolation method, to estimate values at unvisited locations. In this case, it was assumed that the groundwater aquifer was homogeneous and isotropic in nature. Equation 2 was applied for calculating the value for unknown location, using Inverse Distance Weighted (IDW) Interpolation:

$$Z = \frac{\sum_{i=1}^{n} Z_i * W_i}{\sum_{i=1}^{n} W_i} \qquad (2)$$

where,

$Z = Value\ for\ the\ unknown\ point$

$n = Number\ of\ points\ considered\ for\ calculating\ Z$

$Z_i = Value\ at\ a\ known\ point\ i$

$W_i = Weight\ for\ known\ point\ i$

Given by

$$W_i = \frac{1}{d_i^P} \qquad (3)$$

where,

$d = distance\ to\ a\ known\ point\ i$

$p = Power\ value\ which\ optimises\ the\ estimation\ of\ Z\ values$

Equations 2 and 3 were implemented in QGIS software. Inverse Distance Weighted (IDW) Interpolation assumes that points which are close to each other are more alike than those that are farther apart. That is, the measured values closest to the prediction location have more influence on the predicted value than those farther away. The assumption is true for homogeneous and isotropic conditions.

3. RESULTS & DISCUSION

From the results obtained, it was observed that on average the quality of water in the observation wells was within the limits of drinking water quality set by **ZABS (2001)** except for the Turbidity, TC, FC and TSS, Table 1. This means the water from the wells after disinfection treatment, by boiling or use of chlorine, can be a source of potable water.

Table 1: Water Quality Test Average Values

ObsWell	ObsW1	ObsW3	ObsW8	ObsW10	ObsW12	ObsW14	ObsW15	ObsW20	ObsW21	ObsW23	*ZABS Maximum Limit*
Temp, °C	25.7	25.7	25.8	25.1	26.1	25.5	25.6	25.6	26.3	25.7	***25***
Conductivity, µS/cm	806.6	514.0	967.8	867.0	263.8	381.4	454.8	181.7	241.2	148.0	***1500***
Turbidity, NTU	6.3	5.2	6.5	63.8	2.9	69.8	55.9	2.7	4.1	1.0	***5***
TSS, mg/L	29.2	32.4	33.0	74.8	9.0	30.6	84.0	28.8	29.6	31.2	***50***
TDS,mg/L	403.3	257.0	483.9	433.5	131.9	190.7	227.4	90.8	120.6	74.0	***1000***
Sulphate,mg/L	89.8	56.8	86.4	51.2	53.4	28.2	41.6	37.0	53.0	37.6	***400***
PH	7.2	6.9	7.0	7.5	6.6	7.1	7.2	6.2	6.0	6.2	***8***
Nitrate, mg/L	0.4	1.4	2.0	0.8	0.6	0.6	0.5	0.6	0.4	0.7	***250***
Chlorides, mg/L	75.1	80.7	129.4	122.0	58.1	74.2	71.4	90.4	58.8	52.7	***10***
Total Coliforms,CFU/100mL	644.2	16.4	10.4	635.8	238.0	80.2	18.6	493.4	653.0	628.2	***10***
Feacal Coliforms, CFU/100mL	6.8	2.3	1.0	3.0	5.0	2.3	2.3	23.8	27.3	11.5	***0***

As an illustration of groundwater quality spatial distribution, the figure below shows a visualized spatial distribution of the fecal coliform count.

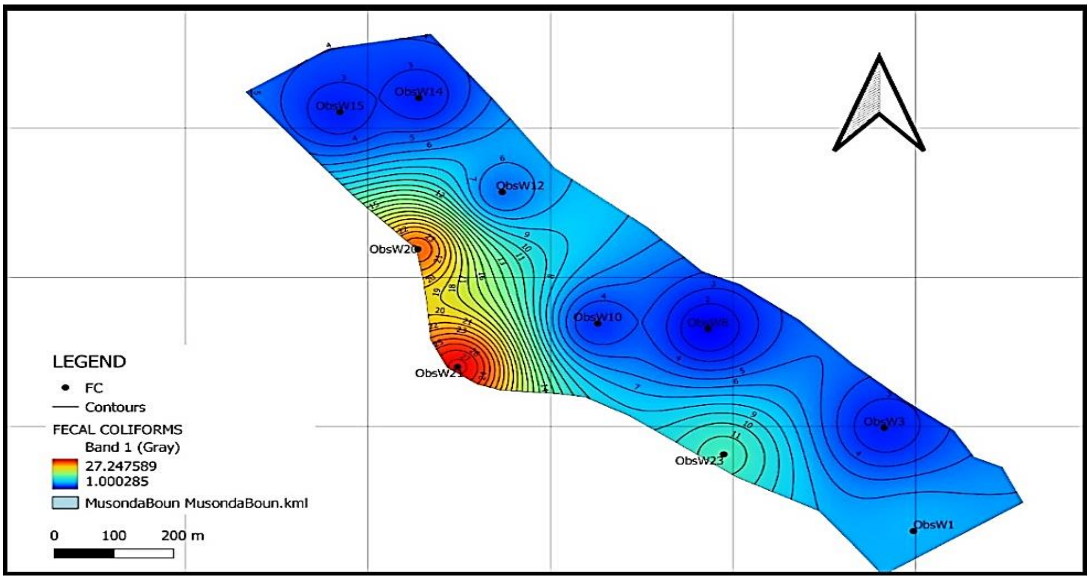


Fig. 2: Spatial distribution of Fecal Coliforms map

Regression analysis was carried out on the minimum distance to pit latrine in relation to Nitrates, FC and TC. In each case the **Coefficient of Correlation** (**R^2**) was found to be less than 0.5 which is far less than 1 as shown in the table 2.

Table 2 shows that the correlation between the independent (distance) and dependent (groundwater quality) variables is low. Therefore, minimum distance between the pit latrine and observation wells in Musonda Compound have negligible effect on groundwater quality. For illustration purposes FC correlation results are given the in Figure 3

Table 2: Correlation Coefficients (R^2) of the minimum distance between the pit latrine and observation wells

Groundwater Quality Parameter of Observation Well	**Fecal Coliforms**	**Total Coliforms**	**Nitrates**
Correlation Coefficient with minimum distance to Pit Latrine	0.07	0.02	0.22

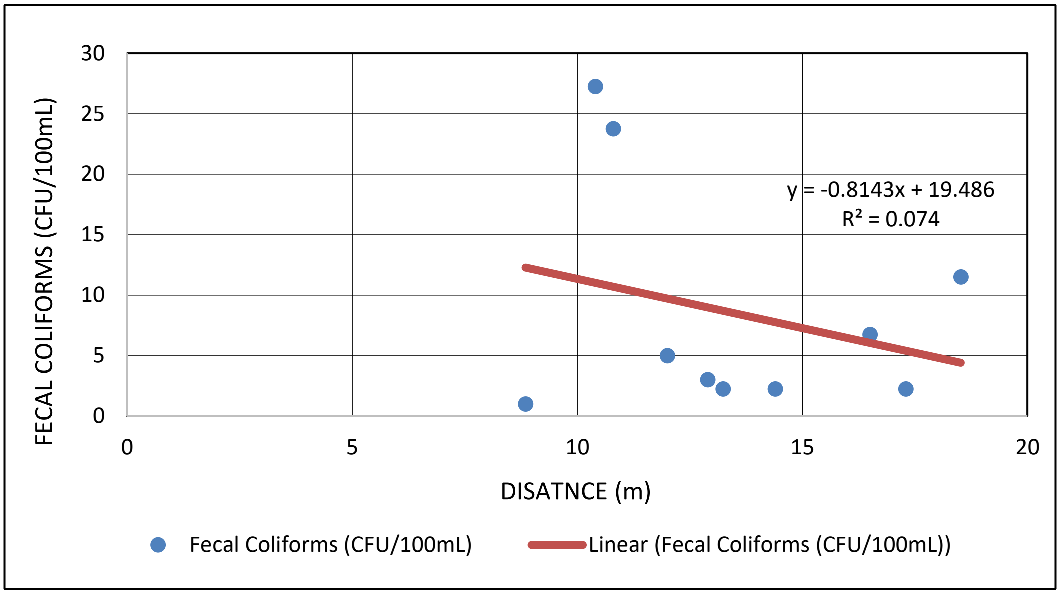


Fig. 3: Correlation between Fecal coliforms and distance to pit latrines.

The correlation coefficient values as seen above were not significant hence the degree of contamination of the wells could not be attributed to the proximity to the pit latrines. It was observed that the sanitary condition in the settlement was very poor due to numerous open dump sites, water flowing in various parts of the settlement and open defecation in some parts of the settlement. It was also observed that groundwater could be contaminated by the method of drawing water from the wells which involves a container that is kept at the well site which was not regularly cleaned or carefully placed.

A trend analysis of groundwater potential head (i.e., height of water table above the WGS 84 datum) is as shown in Figure 4. The chart displays the trend of the groundwater potential head over a period of 5 months, from March to July 2022 (see Appendix 1 for details of field observations). The trend depicts that the groundwater potential head was reducing with time and this was expected as the months in which the study was carried out were moving from the wet to the dry season i.e., in the recession limb of the hydrograph.

The average discharge rate per day was calculated based on the groundwater potential head data. The rate at which the groundwater table drops is shown by the drop of groundwater potential head as shown in Figure 4. For the period of observation, the rate at which the groundwater table was decreasing based on the average values of the groundwater potential head was estimated at **0.35cm/day, given by the gradient of the equation of best fit for the Average Values for Groundwater Potential Heads (Figure 4)**. With continuous observation this value can be used as the basis of comparison in determining seasonal variation and ultimately the impact of climate change on groundwater.

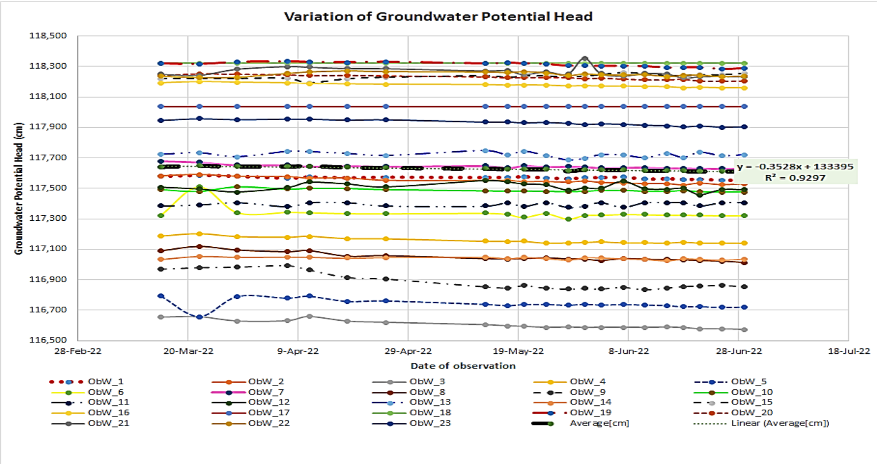


Fig. 4: Variation of Groundwater Potential head with time

Groundwater potential head contours were generated to give the indication of groundwater flow direction (fig. 5). The values ranged from 1166m to 1183m above sea level. Groundwater moves from high to low potential head. From Figure 5., it can be seen that the direction of flow of groundwater was generally towards the Eastern and South Eastern part of the project area.

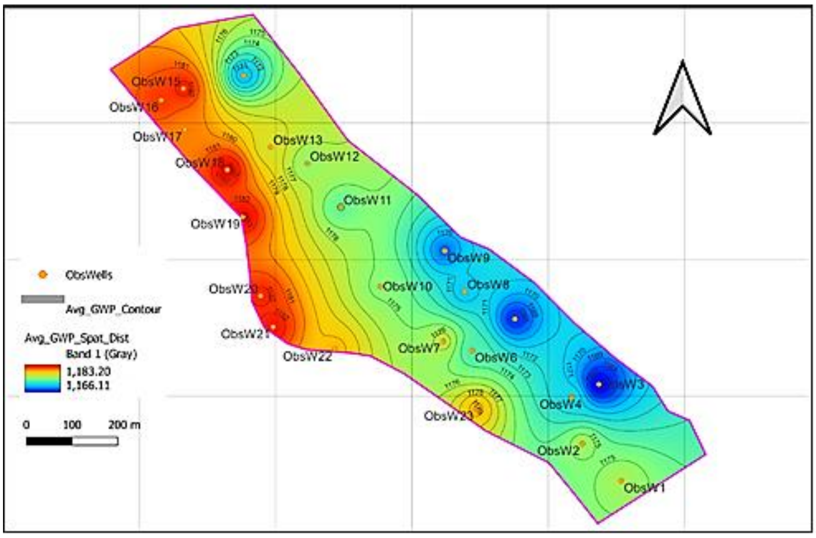


Fig 5: Spatial distribution of Groundwater Potential Head

4. Conclusion

Within the constraints of time and financial resources, the project was successfully carried out and the following conclusions can be made:

Groundwater in Musonda Compound is generally contaminated and therefore needs treatment (especially boiling or disinfection) before consumption.

The contamination of groundwater cannot be attributed to proximity of hand-dug wells to pit latrines. The correlation analysis between the minimum distance of hand-dug well to pit latrine and the groundwater quality gave correlation coefficients of: 0.22 for Nitrates, 0.02 for TC and 0.07 for FC. Therefore, the minimum distance between the pit latrine and observation wells in Musonda Compound have negligible effect on groundwater quality. However, the method of drawing water from the wells which involves a container that is kept at the well site is possible source of contamination.

A trend analysis of groundwater potential head revealed that the water table was decreasing at an average rate of 0.35cm/day during the during the observation period. A spatial analysis of groundwater potential head revealed that groundwater flow direction was towards East and South-Eastern part of the project area.

This study was carried out within the constraints of an academic calendar and therefore, a complete hydrological year was not covered. However, even if a complete hydrological year was not covered, the observed results give an indication of groundwater status during the recession period. With continuous observation the findings can be used as the basis of comparison in determining seasonal variations and later on the impact of climate change on groundwater.

5. Acknowledgement

We wish to thank Musonda Compound residents for allowing us to use their hand-dug wells for groundwater observations. We also want to thank the Reviewers for the comments and suggestion that have brought the best out of the research work to the public.

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7. Appendix 1: Groundwater Potential Head Data

Well_Point	ObW_1	ObW_2	ObW_3	ObW_4	ObW_5	ObW_6	ObW_7	ObW_8	ObW_9	ObW_10	ObW_11	ObW_12	ObW_13	ObW_14	ObW_15	ObW_16	ObW_17	ObW_18	ObW_19	ObW_20	ObW_21	ObW_22	ObW_23		
Altitude (m)	1,176.943	1,176.627	1,167.332	1,173.024	1,168.889	1,175.530	1,177.740	1,174.481	1,173.696	1,176.016	1,174.063	1,175.741	1,178.067	1,171.722	1,182.991	1,182.288	1,180.363	1,183.215	1,184.636	1,183.205	1,184.653	1,182.894	1,180.285		
Altitude (cm)	117,694.3	117,662.7	116,733.2	117,302.4	116,888.9	117,553.0	117,774.0	117,448.1	117,369.6	117,601.6	117,406.3	117,574.1	117,806.7	117,172.2	118,299.1	118,228.8	118,036.3	118,321.5	118,463.6	118,320.5	118,465.3	118,289.4	118,028.5		
	GroundwaterPotentialHead (cm)																								
Date	ObW_1	ObW_2	ObW_3	ObW_4	ObW_5	ObW_6	ObW_7	ObW_8	ObW_9	ObW_10	ObW_11	ObW_12	ObW_13	ObW_14	ObW_15	ObW_16	ObW_17	ObW_18	ObW_19	ObW_20	ObW_21	ObW_22	ObW_23	Average[cm]	Average[m]
15-Mar-22	117,578.7	117,581.9	116,654.2	117,186.2	116,795.9	117,322.0	117,678.7	117,088.1	116,969.4	117,491.6	117,385.0	117,508.3	117,722.0	117,033.5	118,219.8	118,192.2	118,036.3	118,321.5	118,317.8	118,239.8	118,249.2	118,235.2	117,946.8	117,641.5	1,176.415
22-Mar-22	117,584.6	117,590.3	116,657.3	117,200.9	116,658.0	117,511.5	117,671.1	117,117.3	116,978.4	117,478.3	117,391.6	117,495.6	117,732.8	117,053.6	118,220.9	118,199.9	118,036.3	118,321.5	118,314.9	118,252.0	118,242.5	118,227.2	117,958.2	117,647.6	1,176.476
29-Mar-22	117,579.0	117,579.2	116,629.0	117,182.7	116,791.4	117,341.7	117,652.9	117,093.8	116,982.1	117,510.9	117,406.3	117,476.1	117,706.8	117,047.9	118,220.8	118,196.1	118,036.3	118,321.5	118,328.9	118,248.5	118,282.4	118,228.9	117,952.2	117,643.3	1,176.433
7-Apr-22	117,566.1	117,576.6	116,630.9	117,178.7	116,780.4	117,344.0	117,653.0	117,083.4	116,991.5	117,494.9	117,380.9	117,505.3	117,742.0	117,049.1	118,220.7	118,191.9	118,036.3	118,321.5	118,331.3	118,245.1	118,298.4	118,253.1	117,956.2	117,644.8	1,176.448
11-Apr-22	117,574.4	117,567.0	116,658.3	117,184.6	116,792.4	117,341.7	117,644.3	117,090.1	116,963.4	117,499.6	117,406.3	117,541.3	117,739.7	117,048.0	118,191.2	118,187.3	118,036.3	118,321.5	118,328.9	118,239.5	118,294.5	118,262.9	117,955.5	117,646.5	1,176.465
18-Apr-22	117,568.4	117,567.6	116,628.0	117,169.9	116,758.5	117,335.7	117,647.0	117,053.1	116,914.7	117,498.9	117,406.3	117,530.0	117,728.4	117,041.8	118,218.2	118,184.7	118,036.3	118,321.5	118,325.9	118,241.1	118,286.2	118,270.0	117,949.0	117,638.3	1,176.383
25-Apr-22	117,573.2	117,552.6	116,620.5	117,168.6	116,761.7	117,334.3	117,643.7	117,057.1	116,905.1	117,491.1	117,385.2	117,509.6	117,714.7	117,045.9	118,228.1	118,182.3	118,036.3	118,321.5	118,329.3	118,238.5	118,285.0	118,265.5	117,951.4	117,634.8	1,176.348
13-May-22	117,570.4	117,551.8	116,604.3	117,153.3	116,738.7	117,338.0	117,647.3	117,038.4	116,855.1	117,482.6	117,384.1	117,553.4	117,747.3	117,048.5	118,237.6	118,179.3	118,036.3	118,321.5	118,318.9	118,231.1	118,270.7	118,262.9	117,935.0	117,630.7	1,176.307
17-May-22	117,571.7	117,552.3	116,598.0	117,152.6	116,730.0	117,330.7	117,634.0	117,036.4	116,847.1	117,480.9	117,406.3	117,544.2	117,717.6	117,037.5	118,227.3	118,176.5	118,036.3	118,321.5	118,322.7	118,225.1	118,273.8	118,258.5	117,935.2	117,626.8	1,176.268
20-May-22	117,575.7	117,544.0	116,594.0	117,152.9	116,737.7	117,310.0	117,648.0	117,039.1	116,862.4	117,481.6	117,382.6	117,530.0	117,743.4	117,046.5	118,235.9	118,177.7	118,036.3	118,321.5	118,318.9	118,227.1	118,247.2	118,264.9	117,929.8	117,626.4	1,176.264
24-May-22	117,568.0	117,544.0	116,587.3	117,141.9	116,738.4	117,335.0	117,641.7	117,043.4	116,846.4	117,479.3	117,406.3	117,523.6	117,713.7	117,039.5	118,236.6	118,176.3	118,036.3	118,321.5	118,314.5	118,227.1	118,265.2	118,257.2	117,932.8	117,625.0	1,176.250
28-May-22	117,562.4	117,541.0	116,589.3	117,143.3	116,733.4	117,300.0	117,643.0	117,036.4	116,840.4	117,477.3	117,375.9	117,487.0	117,685.4	117,029.5	118,228.6	118,170.7	118,036.3	118,321.5	118,303.9	118,226.8	118,250.5	118,239.9	117,926.2	117,615.1	1,176.151
31-May-22	117,569.0	117,547.3	116,587.0	117,145.6	116,739.4	117,323.0	117,641.7	117,035.4	116,843.5	117,479.6	117,383.4	117,502.7	117,694.7	117,044.5	118,237.6	118,172.3	118,036.3	118,321.5	118,304.7	118,220.1	118,352.8	118,249.9	117,917.8	117,623.9	1,176.239
3-Jun-22	117,570.1	117,539.0	116,588.0	117,149.6	116,735.0	117,325.0	117,634.7	117,026.9	116,840.7	117,485.6	117,406.3	117,499.6	117,720.4	117,043.8	118,244.0	118,169.7	118,036.3	118,321.5	118,302.1	118,221.8	118,253.6	118,245.3	117,922.0	117,620.9	1,176.209
7-Jun-22	117,573.4	117,534.3	116,588.5	117,143.6	116,737.1	117,330.3	117,637.1	117,037.9	116,851.7	117,486.6	117,376.6	117,547.7	117,718.4	117,037.8	118,259.4	118,169.5	118,036.3	118,321.5	118,303.2	118,217.5	118,238.0	118,243.5	117,919.8	117,622.2	1,176.222
11-Jun-22	117,560.2	117,531.3	116,587.3	117,143.5	116,735.2	117,328.3	117,637.7	117,034.3	116,836.3	117,479.9	117,406.3	117,498.2	117,700.0	117,034.3	118,251.5	118,167.7	118,036.3	118,321.5	118,300.3	118,212.0	118,254.1	118,245.6	117,912.8	117,618.0	1,176.180
15-Jun-22	117,562.4	117,530.6	116,589.1	117,142.3	116,730.1	117,325.7	117,633.0	117,033.1	116,847.5	117,478.9	117,406.3	117,494.2	117,726.7	117,024.9	118,238.9	118,165.5	118,036.3	118,321.5	118,290.9	118,212.3	118,251.2	118,233.5	117,910.2	117,616.7	1,176.167
18-Jun-22	117,557.8	117,522.3	116,586.0	117,147.6	116,723.0	117,325.3	117,632.7	117,030.8	116,856.7	117,484.9	117,406.3	117,499.3	117,701.7	117,037.8	118,237.7	118,159.8	118,036.3	118,321.5	118,292.3	118,215.5	118,225.2	118,241.9	117,901.4	117,615.0	1,176.150
21-Jun-22	117,558.9	117,534.2	116,578.5	117,142.3	116,723.3	117,324.0	117,631.0	117,026.8	116,860.4	117,476.9	117,384.6	117,457.2	117,736.5	117,034.8	118,244.4	118,161.7	118,036.3	118,321.5	118,292.5	118,204.3	118,233.3	118,241.9	117,907.4	117,613.6	1,176.136
25-Jun-22	117,552.4	117,523.9	116,577.8	117,142.7	116,718.8	117,321.3	117,628.9	117,022.6	116,863.9	117,474.7	117,406.3	117,491.6	117,713.0	117,029.3	118,244.2	118,158.6	118,036.3	118,321.5	118,281.8	118,202.8	118,235.2	118,233.3	117,900.0	117,612.2	1,176.122
29-Jun-22	117,553.0	117,530.4	116,573.5	117,141.3	116,720.4	117,321.2	117,628.7	117,013.4	116,855.9	117,476.1	117,406.3	117,490.3	117,720.2	117,036.3	118,253.2	118,158.5	118,036.3	118,321.5	118,287.8	118,204.6	118,233.4	118,236.5	117,902.1	117,613.1	1,176.131

Wedge sliding analysis of rock slopes subjected to surcharge load conditions in open pit mines

Victor Mwango Bowa[1]

Abstract

Wedge rock slope failure is a common and big problem in many open pit mines around the world. These failures are induced by slope geometry, geological structures, ground water, dynamic forces, shear strength parameters, lithology and open pit operations as documented in various literature. However, the influence of surcharge load (Dump, Sump, Head frame, service erections) in inducing slope failure has received limited attention in the available literature. Nonetheless, wedge failure induced by surcharge load (Dump, Sump, Head frame, service erections) is never the thing of the past in several commercial dams, highways, and surface mine slopes around the world. In this article, a vigorous analytical model for analysing the stability of the potential wedge rock slope failure induced by surcharge load is presented. This encompasses transforming the existing analytical model for estimating the factor of safety of the rock slope subjected to wedge failure by incorporating variable surcharge load. Additionally, a real wedge slope instability at Nkana open pits' Area K allegedly induced by the surcharge case history is studied in order to exemplify the efficiency of the proposed analytical model. The study results designate that the existence of variable surcharge load has a straight effect on the worked-out factor of safety of the rock slope subjected to wedge failure. The obtained results necessitate that the offered analytical model is able to deliver a vigorous analytical model for the stability analyses of the rock slope susceptible to wedge failure considering the presence of variable surcharge load.

Keywords: Open pit mines, Wedge slope failure, Surcharge load, Improved analytical model, Factor of safety

1. Introduction

A wedge forms when two intersecting surfaces (such as beddings, faults and joints) meet in the specified dip directions and there is movement in the wedge polygon formed. Wedge slope failure happens when the shear stresses on the slope exceed the shear strength of the rock mass. Wedge failure is a thorn in the flesh (Marcos et al., 2013; LV et al.,2017 citations) in most open pit mines across the world because among many other adverse effects, it disrupts normal open pit operations. When wedge failure occurs, particular attention is paid to the slope that has experienced failure to remove the waste that may have fallen and this affects the normal operations on the pit. Sometimes, the fallen waste rock may be so massive that it can lead to loss of assets and human life and also increases the cost of mining. Slope failure is induced by many factors and among other factors are; dynamic forces, slope geometry, geological structures, lithology, ground water, surface mining operations and shear strength parameters (Bisleshana, 2009; Bowa, 2019; Bowa and Kasanda 2020, Doumbouya et al., 2020). However, this paper

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concentrated much on the effects of surcharge load as a factor inducing wedge failure. There are various causes of these surcharge loads. Some of which are: due to the creation of in-pit waste dumps and sumps, headgears, service erections and parking of excavation equipment on the benches and at or around the crest of the slope (Hossain, 2011; Yan 2015; Bowa, 2020). These external loads exert an additional stress to the slope. For instance, where a wedge exists and depending on the magnitude of the load exerting stress and the shear strength parameters and by the help of gravity, the wedge may fail. Surcharge load in open pit mines is so detrimental that if much attention is not paid to it, open pits may continue running at huge losses. It does not only affect the economy of the mine but also has an adverse effect on the aesthetic view. In this paper, a case history of wedge slope instability at Nkana open pits' Area K induced by the presence of surcharge load was studied. The presence of surcharge load exerted negative influences on mining economics at Nkana open pits' Area K by creating risks for operational continuity and miners' safety. This is caused as a result of mining the pit advancing towards the head frame. Figure 1 below show the satellite view of the mine and location of Area K.

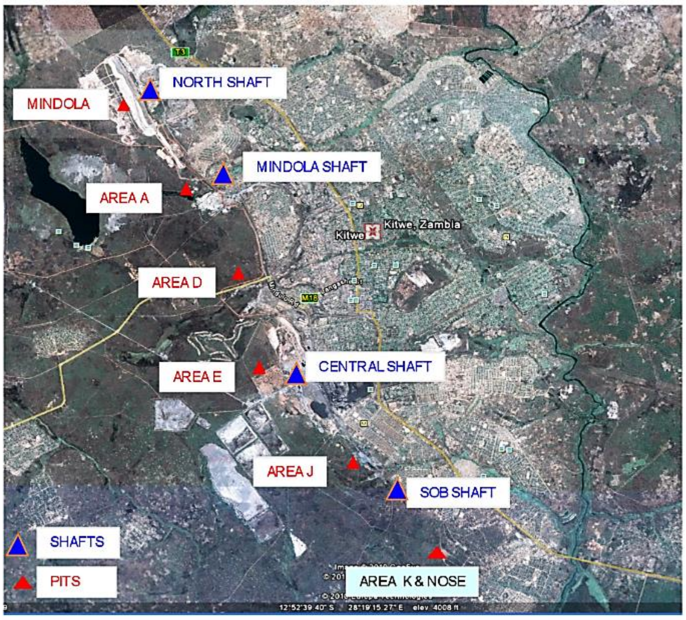


Fig.1: Satellite view of Nkana open pit showing Area K and Nose

The main objective of this paper is to modify the existing analytical model for estimating the factor of safety of the mine slope subjected to wedge failure in an open pit by incorporating the effects of surcharge load. The specific objective are to conduct parametric analyses on the stability of an open pit mine slope subjected to surcharge load conditions. The structure of this paper is organized as follows. The case history and material for the slope with potential wedge slope failure induced by surcharge load for Nkana open pits' Area K are presented as a case study. Then the analytical model formulations for the wedge failure induced by the presence of surcharge load based on the limit equilibrium are derived, and the parametric analysis considering variations of surcharge load quantities is conducted. Thereafter, the results obtained are discussed in detail. The conclusion is arrived at based on the results. This research work provides additional literature on wedge failure induced by surcharge load using an improved analytical method on case studies, and adds on the limited literature on this kind of failure mechanism.

2. Case history and material

A typical rock slope subjected to wedge failure allegedly to have occurred due to the presence surcharge load at the Nkana open pits' Area K is shown in Figure 2.

Fig. 2: Nkana open pit Area K wedge failure

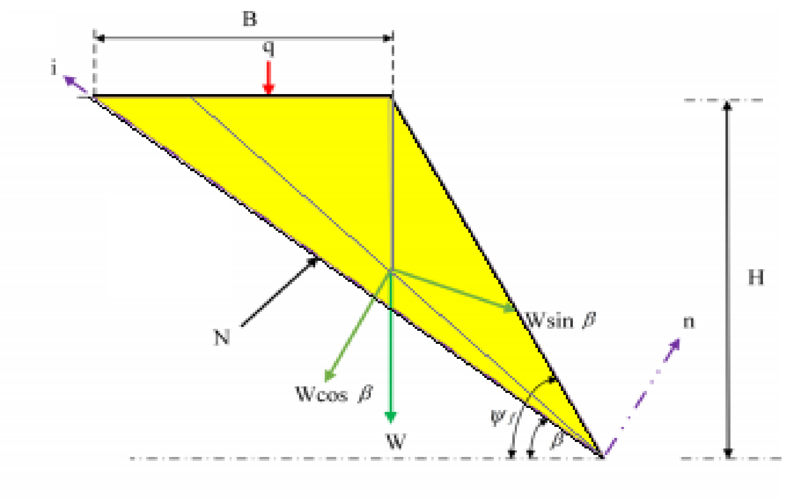
3. Analytical formulation

The data collected from the historical Nkana open pit -Area K wedge failure is summarized in Table 1, the particular wedge selected is not subjected to water and any seismic activities such as earthquakes and blasting. It is alleged that wedge failure only occurred due to the presence of surcharge forces (q), the slope geometry, and the weight of the wedge block (W). Conceptual geometrical view of the wedge failure induced by the presence of surcharge load is shown in Figure 3. Figure 3(a) is a vertical plane view, and Figure 3(b) shows the transverse section to *i* direction.

Table 1: Data of slope parameters

Rock density (MN/m^3)		0.025
Internal friction angle (Deg)		32
Cohesion (MPa)		0.226
Overall slope (Deg)		30 – 45
Average bench height (m)		15
Pit design	Berm width (m)	10
	Slope face (Deg)	75
Pit depth (m)		330
Dip/Dip Direction of joint plane, J_1 (Deg)		60/205
Dip/Dip Direction of joint plane, J_2 (Deg)		65/150
Primary material cover		Weak shales, sandstones and dolomites

(a)



(b)

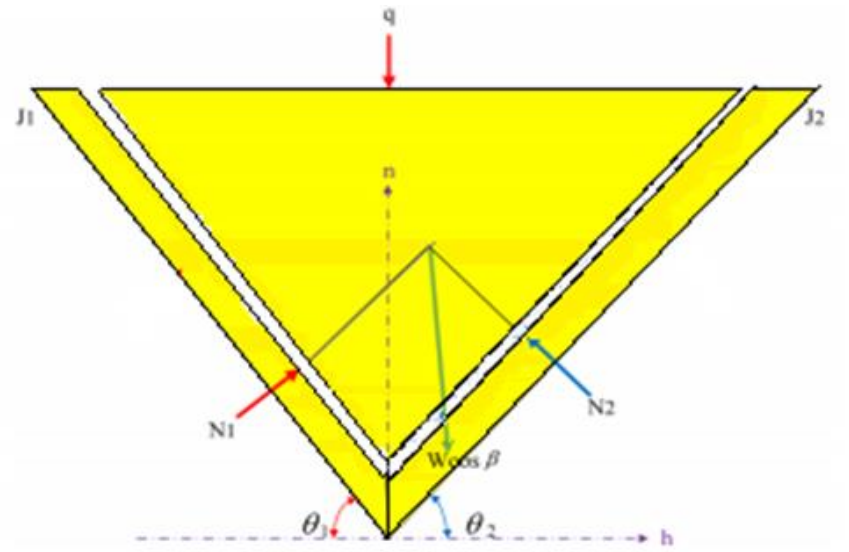


Fig. 3: Geometry of wedge used for stability analysis: a) vertical plane view, b) transverse section to i direction.

Where: θ – Internal friction angle, H – Bench height, ψ_f – Slope face angle, J– Dip of joint plane, N– Normal force, B– Wedge horizontal distance, β – Overall slope angle, i- direction n-line of intersection

The joints J_1 and J_2 forming the wedge are dry i.e., there are no uplift forces, also that the slope is not supported by any bolts, factors that induced wedge sliding are mainly, surcharge load denoted by ***q*,** weight of the wedge ***W***, slope geometry and shear strength parameters. These factors are used to come up with an expression for resolving the Factor of Safety (FoS) of the slope as shown in Eq. (1)

$$\text{FoS} = \frac{Restraining\ forces}{Activating\ forces} \tag{1}$$

Restraining forces are those forces that are trying to hold the wedge to prevent failure and activating forces are those forces that are pushing the wedge to slide. All the forces on the wedge are resolved individually as shown in Eqs. (2) and (3):

$$N_1 = \frac{WCos\beta Sin\theta_2 + qCos\beta}{\text{Sin}\ (\theta_1 + \theta_2)} \tag{2}$$

$$N_2 = \frac{WCos\beta Sin\theta_1 + qCos\beta}{\text{Sin}\ (\theta_1 + \theta_2)} \tag{3}$$

N_1 and N_2 are normal forces acting on planes of joints J_1 and J_2 respectively. The restraining forces and activating forces are resolved by Eqs. (4) and (5) respectively.

$$\text{Restraining forces} = N_1 tan\emptyset . J_1 + N_2 tan\emptyset . J_2 + c_1 . J_1 + c_2 . J_2 \tag{4}$$

$$\text{Activating forces} = W\ \text{Sin}\,\beta + qB\ \text{Sin}\,\beta$$

$$= (W + qB)\ \text{Sin}\,\beta \tag{5}$$

Substituting Eqs. (4) and (5) into Eq. (1), FoS is resolved by Eq. (6)

$$FoS = \frac{N_1 tan\emptyset . J_1 + N_2 tan\emptyset . J_2 + c_1 . J_1 + c_2 . J_2}{(W + qB)\ Sin\,\beta} \tag{6}$$

And replacing Eqs. (2) and (3) into Eq.(6) gives the expression in Eq. (7):

$$FoS = \frac{\left(\frac{WCos\beta Sin\theta_2 + qCos\beta}{\text{Sin}(\theta_1 + \theta_2)}\right) tan\emptyset J_1 + \left(\frac{\theta_1 + qCos\beta}{\text{Sin}(\theta_1 + \theta_2)}\right) tan\emptyset J_2 + c_1 . J_1 + c_2 . J_2}{(W + qB)\ Sin\,\beta} \tag{7}$$

But $W = \gamma V$ and taking $V = \frac{HB}{6}$ gives $W = \gamma H \frac{B}{6}$ (8)

Where C_1 and C_2, is the cohesion of Joints J_1 and joints J_2 and γ unit weight of the rockmass and V is Volume of the wedge.

The surcharge load q is resolved using Eq. (9).

$$q = \frac{qB}{2} \tag{9}$$

and the distance *B* can be derived as;

$$B = \frac{H}{tan\beta} - \frac{H}{tan\psi_f} = H(Cot\beta - Cot\psi) \tag{10}$$

Therefore; substituting equations (8), (9) and (10) into equation (7) gives:

$$FoS = \frac{\left(\frac{\gamma H \frac{H(\text{Cot}\,\beta - \cot\psi)}{6}\text{Cos}\,\beta\,\text{Sin}\,\theta_2 + \frac{qH(\text{Cot}\,\beta - \text{Cot}\,\psi)}{2}\text{Cos}\,\beta}{\text{Sin}(\theta_1+\theta_2)}\right)\tan\emptyset J_1}{\left(\gamma H \frac{H(\text{Cot}\,\beta - \text{Cot}\,\psi)}{6}\right) + qH(\text{Cot}\,\beta - \text{Cot}\,\psi)\,\text{Sin}\,\beta}$$

$$+ \frac{\left(\frac{\gamma H \frac{H(\text{Cot}\,\beta - \text{Cot}\,\psi)}{6}\text{Cos}\,\beta\,\text{Sin}\,\theta_2 + \frac{qH(\text{Cot}\,\beta - \text{Cot}\,\psi)}{2}\text{Cos}\,\beta}{\text{Sin}(\theta_1+\theta_2)}\right)\tan\emptyset J_2 + c_1^* J_1 + c_2^* J_2}{\left(\gamma H \frac{H(\text{Cot}\,\beta - \text{Cot}\,\psi)}{6}\right) + qH(\text{Cot}\,\beta - \text{Cot}\,\psi)\,\text{Sin}\,\beta} \quad (11)$$

Where; $c_1^* = \frac{c_1}{\gamma H}$ and $c_2^* = \frac{c_2}{\gamma H}$

3.1 Parametric analyses

In order to examine the wedge sliding on the slope, a model of the block was depicted from the field to clearly describe the particular region selected. Parametric analyses were conducted using the weight, cohesion, bench height, and slope angle. The angle of friction and variations of the obtained loaded skip in magnitudes of surcharge forces (i.e., Values progressing from q = 30 kN/m^2 to q = 120 kN/m^2 with a constant difference of 10 kN/m^2 between two consecutive values as indicated in Table 1). This was done in an effort to compute the factors of safety. The computed unit weight of the rock from the field that was used for the ten trials was the same: γ = 0.25 MN/m^3. In carrying out the stability analysis of the Nkana open pit mine's area K, the rock behaved as a Mohr Coulomb material in which the shear strength is expressed in terms of cohesion and angle of internal friction along the failure surface. The actual values of cohesion and angle of internal friction were $c = 0.226\,MPa$ and $\emptyset = 32°$ respectively, and these values remained unchanged throughout the calculations to determine the different factors of safety. The actual values of these two shear strength parameters are closely related to the geological conditions at the site, and the material cover was a mixture of weak shales, sandstones and dolomites.

3.1.1 Results

Figure 4 shows the graph for the factor of safety plotted against variations in the surcharge forces. Table 2 shows the obtained factor of safety for varying magnitudes of surcharge forces.

Table 2: Computed results of factor of safety against corresponding surcharge load

Surcharge load kN/m^2, (q)	Factor of Safety, (FoS)
120	0.9
110	1.0
100	1.1
90	1.2
80	1.3
70	1.4
60	1.5
50	1.6
40	1.7
30	1.8

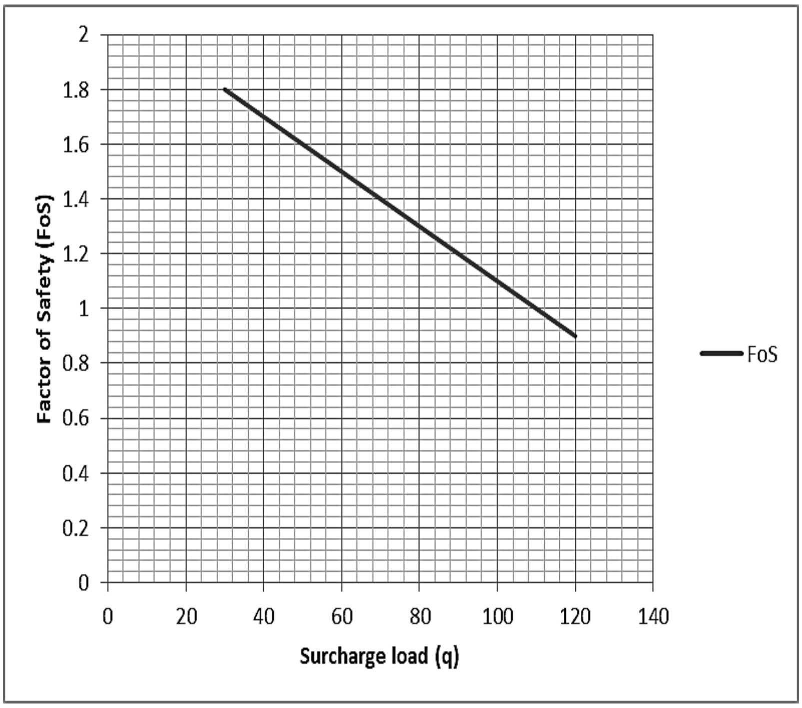


Fig. 4: Graph of the factor of safety against surcharge load.

4. Discussion

From the presented data, it is worthy of notice that each increase in the value of the surcharge load, caused a decrease in the final value of the factor of safety. Therefore, an increase in the amount of surcharge load on a rock slope decreases the slope's factor of safety and makes the rock slope more vulnerable to failure. Figure 4 clearly indicates that the factor of safety decreases with an increase in the amount of the surcharge load. From this analysis, it is clear that failure of the slope at Area K of Nkana open pit mine occurred due to the surcharge load created by the head frame which was too much stress to be overcome by the rock slope's shear strength. This is as a result of mining the pit advancing towards the head frame.

5. Conclusion

The study showed that surcharge load in open pit mines affects the factor of safety of rock slopes and eventually leads to slope failure. Study results indicates that an increase in the amount of surcharge creates a decrease in the value of the slope's factor of safety.

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Challenges in implementing government water and sanitation infrastructure development projects in Zambia -Project management teams

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Abstract

The Government of the Republic of Zambia (GRZ) has been funding water infrastructure projects through the different implementation methods and this has led to some of these projects not being completed. The study was motivated by a general perception that major water infrastructure projects funded by GRZ did not materialise. This study was therefore undertaken in order to determine the challenges that were faced by government in the implementation of water infrastructure development projects that were either abandoned, stalled or left incomplete. The study was carried out by interviewing different government and donor officers involved in the water infrastructure projects at different stages, literature review of the various books and reports and also observation of selected water infrastructure projects. The results indicated that the major challenges of implementation were the formation and operation of Project Management Teams, financial constraints and lengthy procurement process. It was therefore recommended that the Project Management Team should have fully dedicated team members to work on the project and have no government interference, government to fulfil its financial obligation to the projects and the procurement process to be revised to improve efficiency and effectiveness.

Keywords: Water infrastructure projects, project management team, government, challenges, implementation.

1. Introduction

Water and Sanitation infrastructure projects have been implemented throughout the world to develop the resource; however, the implementation of these projects comes with challenges (Korir, 2013). Ambulkar (2019), stated that the implementation stage is the most challenging as it is a stage of knowns and unknown.

The Government of the Republic of Zambia (GRZ) has been implementing water and sanitation infrastructure development projects and programs through the Ministry of Water Development and Sanitation (MWDS) and other line ministries. The water infrastructure projects have been prioritized in the different sectors such as water supply and sanitation as well as water harvesting structures such as dams used for the agricultural purposes to increase social benefits and to promote food security and poverty alleviation (MWDS, 2010). Despite these efforts, some of these projects have been abandoned or left incomplete posing a threat on investments. In the past

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10 years, a number of these projects have been abandoned at various stages of implementation. Therefore, this study was undertaken to establish challenges that impede on the implemention of water and sanitation projects funded by the Zambian government.

2. Material and Methods

The methods used were literature review, in-depth reviews and observation of sites.

2.1 Literature Review

An extensive literature review was conducted on water infrastructure development across the globe, regionally and in Zambia.

2.1.1 Water and Sanitation Infrastructure Development across the Globe

Globally, many governments have undertaken water infrastructure development projects in order to increase people's access to water for multipurpose use. Dams have been developed in Japan for multiple uses in collaboration with different users to enhance investment efficiency (Water Partners and Nihon Suido Consultants, 2017).

Angola, the Water Sector Institutional Development Project (WSIDP) was launched and implemented through the Ministry of Energy and Water, with the support of the World Bank (WB). Some of the project outputs were that over 100,000 urban households were to have water supply connections and over 1,000km of pipeline installed or rehabilitated (WB, 2019).

The Government of the Kingdom of Eswatini is implementing the Manzini Region Water Supply and Sanitation Project through the Eswatini Water Services Cooperation. This project aims to expand the water supply system and improve the sanitation infrastructure and hygiene services in the Manzini region. The project, funded by the AfDB and the government, is expected to end in 2023 but due to delays in implementation, the government will seek for extenstion of implementation period from the Bank (AfDB, 2022a).

2.1.2 Water and Sanitation Infrastructure Development Projects in Zambia

The development and management of water resources, provision of clean water supply and adequate sanitation is the responsibility of the MWDS implemented through the Department of Water Resources Development (DWRD) and the Department of Water Supply and Sanitation (DWSS) with support from cooperating partners via different water projects in line with the National Urban Water Supply and Sanitation Programme (NUWSSP 2011-2030) and the National Rural Water Supply and Sanitation Programme (NRWSSP 2021-2030), (MWDSEP, 2021).

The water infrastructure includes boreholes, dams, weirs, reservoirs, water reticulation systems, drainage, irrigation systems and hydropower systems (Spacey, 2017). Some of the notable big projects are the construction of the Mwomboshi Dam, Kafulafuta Dam, and Kariba Dam Rehabilitation Project, Itezhi-Tezhi Dam Upgrade, Kariba North Bank Upgrade, Millennium Challenge Water and Sanitation Improvement Project in Lusaka; and various water and sanitation projects across the country (Kopulande, 2021).

The Water Resources Development Project (WRDP) was one of the projects that involved the development of surface water in order to address the challenges of water for productive use. The project was executed by the DWRD with funding from the World Bank (WB). One of the project components was the construction and rehabilitation of 100 small-scale water resources infrastructure throughout the country (MWDSEP, 2018). Another project implemented by government with support from Southern African Development Community, Groundwater Management Institute (SADC-GMI), was the Groundwater Development Project to address water shortages in Chongwe township (MWDSEP, 2021).

2.1.3 Challenges in Implementing Water and Sanitation Infrastructure Projects

2.1.3.1. Financial

Finance seems to be a major problem in the water and sanitation sector, especially in developing countries, this is because of less funds apportioned to the sector and also the high price of implementing these projects. Therefore, governments implement water and sanitation infrastructure projects using different financing models and these models come with different challenges. Ruiters and Martji (2016) identified three models of implementation based on financing, namely; state financing model (100% government funding); hybrid financing model (mixed funding between the government and private) and private financing model (100% private). Due to limited public funds, governments take on debt and Public Private Partnership (PPP) to finance large water infrastructure projects (IWA, 2018).

2.1.3.2 Procurement Processes

Government procurement in the purchasing goods and services from the private sector, that the government needs. To procure these goods and services, taxpayers' money is used, therefore, specific regulations and procedures need to be followed (GMP, 2021). The complex and lengthy procurement processes in the government leads to most of these water projects delaying in implementation and also increase in costs from the time of tendering.

2.1.3.3 Project Management Team (PMT)

Project management is very critical in ensuring the success of water and sanitation infrastructure development projects. Therefore, the competency of the PMT is very crucial in any water project as it comprises different experts with various skills (Indeed, 2022). Tortagada (2014) explained that in the delivery of water services, the most important problem to deal with is the infrastructure, its management and operation. This acknowledges the importance of the PMT in successful water infrastructure development projects.

2.1.4 Specific Challenges Faced by Different Projects Across Africa

2.1.6.1. The Case of South Africa

Dithebe et al., (2019) highlighted that corruption, hostility, weak project structuring, high fiscal deficits by state government, cost recovery constraints, high credit risk for private financing and unreliable planning and procurement processes are major challenges affecting the success of financing water infrastructure projects in South Africa.

2.1.6.2. The Case of Kenya

The major challenges faced by the Kenyan government in the implementation of water and sanitation projects are lack of political will to address the water problems, insufficient allocation of funds in water and sanitation infrastructure projects, delays and failures to conduct monitoring and evaluation, and finally avoidance of applying new technological or implementation approaches (Korir, 2013).

2.1.6.3. The Case of Nigeria

In Nigeria, some of the challenges in implementing infrastructure projects were due to inaccurate costing and corruption, poor financial capacity by the government, incompetence and lack of knowledge, poor contracting and contractor practices and political interference which led to project failure (Eja and Ramegowda, 2019).

2.1.6.4. The Case of Zambia

Kopulande (2021) states that most of the government projects in Zambia implemented between 2011 and 2021 were either abandoned, rescoped downwards, or suspended due to non-payment of contractors and the only operational ones were those funded by cooperating partners and multilateral institutions. Despite some of the projects being funded by cooperating partners, challenges were faced as some were not completed. For example, the WRDP with funding from WB in which 100 dams were to be constructed or rehabilitated. From these 100 dams, 12 were tendered and only 10 were actually built or rehabilitated. However, there were no certificates issued of full completion (World Bank, 2019a).

According to World Bank (2019b), some of the challenges during implementation were due to the Provincial and District Water Officers not able to supervise the projects as they lacked staffing and financial resources as supervision and operational funding ended in quarter 2 of 2015, supervision by one consultant for contracts spread across the country was difficult, the capacity of the PMT was weak as it had high turnover of staff, it did not have full time dedicated staff to the project and it was also understaffed. There was weak contract management such as failure to complete works on time; failure to recover advance payment where contracts were terminated due to major foundation challenges. Further, there was weak inter-ministerial coordination at national, provincial and district level during implementation.

The Irrigation Development and Support Project implemented by the Ministry of Agriculture with support from World Bank constructed the Mwomboshi Dam in Chisamba, however the project incurred some financial challenges. At the time of project approval in April 2011, the loan amount was equivalent to USD115million, however by the end of November 2019, due to the loss in dollar exchange rate, the loan had a loss of USD10.5million. The actual cost of infrastructure exceeded the initial estimates leading to the irrigation infrastructure not being completed. GRZ also delayed to release the counterpart funding and cash compensation for the economic losses of Project Affected People (PAP) (World Bank, 2020).

Poor procurement procedures were also some of the challenges faced by the project implemented by the DWSS, Transforming Rural Livelihoods in Western Zambia – National Rural Water Supply and Sanitation Programme II. The poor procurement has led to delays in the completion of some water and sanitation infrastructure (AfDB, 2022b).

2.2 Data collection-Interviews and Observation

The researcher conducted interviews with both top management officials and operational engineers at the MWDS, Ministry of Agriculture (MoA), Ministry of Local Government and Rural Development (MLGRD) and other water development related sponsors, donors and financiers. For sampling, purposive sampling was used to select the project sites visited as well as respondents. Information was collected through in-depth interviews and questionnaires as well as observation.

In addition, the researcher visited four sites of projects to get a deeper understanding on selected Ministries Provinces Spending Agencies (MPSAs). This was done by observing the government role in the implementation and the project outputs.

3. Results

The results of the study are presented below.

3.1 Water infrastructure projects implemented by government in the past 10 years

The results from the government officers (n=21) revealed that the water development infrastructure projects implemented by the government departments in the past 10 years, showed that 7 projects were ongoing, 8 were successful and 7 had stalled

3.2 Procurement process for water infrastructure projects implemented by government

For projects with contractors and consultants, it was indicated that 61 percent had the contractors and consultants contracted by the government while 39 percent had them contracted by the project financier. The results from all the respondents indicated that all the procurement of equipment and materials was done by government with other partners just giving a no objection on the tender document and on the evaluation report before award of contracts

3.3 Reasons for stalled projects

The main reasons leading to stalled projects by the respondents (n=25) were long procurement procedures, lack of financial fulfilment, no dedicated PMT staff and interference from senior government officials. Others were government staff as sole PMT, contractors lacked capacity and experience, and poor incentive for government PMT.

3.4 Formation of PMTs in the water infrastructure projects that have stalled

The formation of the PMTs in stalled projects as stated by the government officers (n=21) revealed that 11 percent had all outsourced officers, 65 percent had government officers only while 24 percent of the officers indicated that the PMTs had both outsourced and government officers. From the PMTs that had government officers, 14 percent of the government officers were fully attached to the project while 86 percent were not fully attached to the project

The government officers further mentioned during the interviews that government officers on the PMT were either appointed by the Permanent Secretary or the Director of the department to work on the project. Some of the PMTs were outsourced and people who were to be part of the PMT had to apply individually or had to engaged as a consulting firm.

3.5 Proposed Implementation Model

The proposed model for effective implementation of water infrastructure development projects by government is one that has the following: -

a) The government gives its full financial obligation;
b) The PMT has officers that are dedicated to the project only and not involved with other government assignments. The PMT should operate independently from the government structure;
c) The implementation of the project has no interference from the superiors and leave the PMT to implement the project as described in the project implementation plan;
d) The procurement process does not take long.

4 Discussion

Other projects failed because the PMT had government officers who had to undertake other government duties thereby not dedicating a greater amount of their time to these projects and therefore their commitment to the project was affected. This is in line with Carroll (2022) who stated that the majority of failed projects was due to inexperienced project management and poor resource planning. She also indicated that most organisations do not prioritise project management.

The results have revealed that the procurement of the contractors and consultants as well as the equipment and machinery for the projects was mainly done by government whose procurement process is lengthy causing a delay in the implementation of projects. As evidenced from the literature review, procurement processes is one of the major challenges in water infrastructure projects. In Namibia, the NWSSP project is behind schedule as the procurement of consultancies for the project has delayed due to the procurement process (AfDB, 2022c). The procurement process of water infrastructure projects by government has highly contributed to the delay in the delivery of these projects leading to change in prices and projects not being completed as the allocated funds are not sufficient. This is because of the long bureaucracy of the government procurement process.

The challenges being faced by stalled projects is that the PMT had too much work as they had to undertake other government duties and there was also too much interference from the superiors. The formation of the government PMT was that of appointed by the Permanent Secretary or Director of the Department. Most of the successful projects had permanent staff on the PMT or the PMT was outsourced. In Zambia, according to World Bank (2019b), the capacity of the PMT was weak as it had high turnover of staff, did not have full time dedicated staff to the project and was also understaffed.

There were several models that were proposed and identified during the research. Maharjan (2019) explains that for successful infrastructure projects, the problems of government coordination, management and accountability need to be dealt with. Therefore, the ideal implementation model for water infrastructure projects is one where the government workers are solely dedicated to the project and resume the other duties after the completion of the project.

5 Conclusions

The general objective of the study to establish challenges faced in implementing Zambia water infrastructure development projects by government has been addressed and has been achieved through researcher observations as well as stakeholder verbal and written submissions outlined in the questionnaires administered.

The study, therefore, concluded the following:

(i) that the PMTs are ineffective as they comprise government employees as part of the team. This is because the government officers still had other government duties and did not have specific roles defined for them in the implementation of the projects;

(ii) that government projects, when implemented by a PMT that is independent from other government duties and has no interference from senior government officers, are usually successful;

(iii) that government procedure for procurement of goods and services was followed, however, the time taken for each process and clearance was very long leading to delays in implementation of the projects. This caused the projects to go beyond the project period.

6 Recommendations

For successful water infrastructure projects to be implemented by the government, this study recommends that: -

(i) the PMT be independent and have government officers who should be seconded full-time to the project for continuity and ownership after close of the project;

(ii) the PMT should comprise people who are qualified and with adequate experience thereby able to implement the project on time and within the budget;

(iii) the funds for the project from both the donor and government should be managed by the PMT;

(iv) Government to disburse its financial obligation on time and in the right amount;

(v) there should be no undue government in the implementation of the project; and

(vi) the procurement process should not take too long.

Therefore, strict adherence to the above outlined issues would certainly be classified as successful models for implementing water and sanitation infrastructure projects by the Zambian government.

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Opportunity for enhanced technological/engineering skills transfer - Ground Zero for home-grown engineering solutions

Gibson Mupeyo[1]

Abstract

Skills development is ground zero for achievement of socio-economic transformation for any nation. There is evidence which links industrialisation to levels of development in science, technology, and engineering skills. This paper proposes a framework for increasing levels of skilled human capital required for technological innovations anchored on engineering projects implementation. This is important for promoting the development of home-grown engineering solutions. It is realized that projects are a dormant laboratory where skills necessary for Zambia to attain world-class socio-economic transformation can be forged. The paper reviews the role of technology/engineering in industrialization. Furthermore, relevant legal/institutional framework which should provide an enabling environment for development of engineering skills in Zambia is given. Some deficiencies are observed in the existing skills development framework. Finally, a model for achieving skills development synergies among the Government, regulators and project parties is suggested.

Keywords: Home-grown, engineering solutions, skills, socio-economic transformation, technology

1. Introduction

There is good-will and understanding by Government that science, technology and engineering are essential for economic transformation.

The Minister of Commerce, Trade and Industry in Zambia stated:

> *We appreciate the role that science, technology, and innovation play in contributing to job creation, enhancing value addition, facilitating easy access to health care services, easing the cost of doing business as well as guaranteeing food security* (Mulenga, 2022).

Undisputedly, Zambia needs home-grown engineering solutions to address the socio-economic challenges (UNCTAD, 2022). This is the route that developed worlds have taken advantage of to escape from conditions of poor quality of life. Engineering technologies developed to respond to the needs of the local market will have value in sustaining the sector and the economy at large. It

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can also be argued that technologies developed for markets outside Zambia tend to only advantage the countries of origin and usually come at prohibitive cost.

It is, however, contended that to date, the levels and numbers of home-grown engineering solutions have not grown to sufficient proportion to impact the economy significantly. This is evidenced by the static and slowing down of Zambia's Global Innovation Index ranking between 2013 and 2020 (UNCTAD, 2022). It is important therefore that while there is a need to innovate, and convert the innovations into commercial products and services, Zambia needs to be systematic and methodical in developing and sustaining the skills underlying innovation. The theme of emphasis at this symposium is a timely call for engineers and scientists to be innovative.

One mode to develop and grow the present base of skills is to smartly tap into the existing technologies and make them the thinking pad and steppingstone for home-grown solutions.

2. Skills Development - Global and Country Context

Turoswski (2002) observed that technology and the transfer of engineering innovation are among the primary concerns for many countries across the globe. UNESCO prioritises engineering education and capacity building as the world heralds the dawn of the Fourth Industrial Revolution that will enable engineers tackle the challenges and effectively address the Sustainable Development Goals (UNESCO, 2021). The potential drivers of development on the African continent are engineers. The National Academy of Engineers identifies "Grand Engineering Challenges" that engineers of the 21st Century need to solve to improve livelihoods around the world. Furthermore, the Academy observes that "Africa is home to three countries globally" (Zimbabwe, the Democratic Republic of Congo and Zambia) that had "a lower Human Development Index (HDI)" in the recent past and perhaps even today "than in 1970" (Cilliers et al., 2011).

Therefore, the education and training of present and future engineers on the continent is critical for the economic emancipation of Africa in the 21st Century (Erinne, 2015); (UNCTAD, 2022)

Many countries have over several centuries leveraged on science and engineering to transform and sustain economies to the developed state (National Academy of Science, 2023). The engineering fraternity and the Government of Zambia should seek and follow, even better, the path to development that others before laid.

A Harvard sponsored research conducted by Sands and Bakthavachalam (2019) suggests that most of the world population lives in countries that are lagging in critical skills - developing economies with less investment in education and lifelong learning. Further, the research reveals that, out of the 60 countries studied - representing 80% of the world population, Africa lies in the last quartile in business, technology and data science skills. This situation dictates that Zambia, like many other developing countries, must focus on developing these skills – and use every opportunity to sharpen the skills if the country must be ready for significant technological transformation.

In the preamble to the UNESCO report, the UNESCO Director General stated:

> *Addressing sustainable development within the challenges of climate change, population growth and urbanization will require innovative engineering and technology-based solutions. Engineering capacity and competence - building activities are critical to ensuring that there is an adequate number of engineers capable and ready to work on global challenges. This is particularly important in Africa where the per capita number of engineering professionals is lower than in other regions of the world. In Swaziland for example, there is one engineering professional for more than 170,000 people, compared to United Kingdom where there is one engineering graduate for 1,100 people* (UNESCO, 2021).

According to the Engineering Institution of Zambia (EIZ) Secretariate report (2021) there were slightly above 65,000 registered engineering members in Zambia. The total number of the unregistered engineering cohorts is not known. Even if the total number of engineers in Zambia doubled to allow for those unregistered with EIZ, the overall total will still be a very small number in relation to the population of 19 million people compared to countries like Indonesia that produces more than 100,000 engineers every year. Data indicates that despite the known role that engineering plays to socio-economic transformation, there is a shortage of the skill in many countries, including Zambia. Continued skills development is still a challenge for the engineering sector.

Although Zambia's per capita number of engineering professionals is better than that of Eswatini (formerly Swaziland), the shortage of the numbers and quality of engineering skills does not inspire hope for increased numbers of home-grown solutions in the short to medium term.

2.1 A snap view of Skills Development

Published data on engineering skills development plans and achievements in Zambia is difficult to find. Scattered sources suggest that science and engineering graduates from institutions of learning in Zambia do not possess sufficient skills upon graduation due to inadequate infrastructure for training among other factors. Consequently, it is emphasised that the engineering education must prepare engineers to solve the challenges of the 21st Century (Siame, et al., 2016).

EIZ has been creating synergies with industry (mining, water, training institutions, etc.) to promote training and developing engineering skills in Zambia. EIZ has offered scholarships to ten (10) deserving candidates in 2021 to study engineering at undergraduate and diploma levels. EIZ reports further having commenced a flagship programme to mentor candidates in engineering skills with 35 on board (2021).

The efforts by EIZ should be commended as a step in the right direction. However, such efforts are only a drop in the ocean of what should be done as a country needing technological innovations to transform people's livelihoods.

3. Zambia's Developmental Needs - A Platform for Innovations Skills Development

To grow the right and sustainable technologies and the skills required for the Zambian society to develop, it is critical to understand the key needs of Zambia as a nation. According to the 8th National Development Plan, the greatest need is "socio-economic transformation for improved livelihoods" and attain prosperous middle-income nation status by the year 2030 through improvement in the strategic areas cited in Table 3.1:

Table 3.1: Strategic for Zambia's Development Agenda 2022-2026

Strategic Area	**Outcome**	**Strategy**
1. Economic Transformation and Job Creation	1. Industrial and diversified economy	1. Increase agricultural production and productivity
		2. Promote traditional and non-traditional minerals
		3. Promote value addition and manufacturing
		5. Improve transport logistics
2. Human and Social Development	1. Improved Education and Skills Development	1. Enhance access to equally, equitable and inclusive education
	4. Reduced Poverty, Vulnerability and Inequalities	4. Increasing access to decent and affordable housing
3. Environmental sustainability	1. Enhanced Mitigation and Adaptation to Climate Change	1. Strengthen climate change adaptation
	2. Sustainable Environment and Natural Resources Management	1. Promote integrated environmental management
4. Good Governance environment	2. Improved Rule of Law, Human Rights and Constitutionalism	2. Strengthen National data Information System

Source: (Parliamentary Select Committee, 2022)

Some of the Engineering solutions/innovations that may respond to these strategies include for example:

- Road pavement material research and innovation
- Mass transport for goods and people and traffic de-congesting solutions in cities
- Cost effective and less time-consuming housing building technology
- Food processing and value addition technologies
- Labour reducing cost-effective agricultural tillage equipment
- Cost effective irrigation equipment for small-scale farmers
- Research and innovation in home-grown power equipment technology
- ICTs for Data Information Systems

Top range engineering, research and innovation skills are required for impactful contribution to the above strategic areas. Without such skill it will not be possible to achieve the objective of improving people's socio-economic livelihoods.

4. Zambia's Legal/Institutional Framework for Engineering Matters

4.1 National Council for Construction

The National Council for Construction (NCC) provides for issues relating to construction, research, and development of the construction industry in Zambia. The NCC Act No.10. of 2020 reads in part:

> *An Act to provide for the promotion, development and regulation of the construction industry so as to promote economic growth and competitiveness and create sustainable employment; continue the existence of the National Council for Construction and provide for its functions; enhance contractor capacity development and technical compliance in the construction industry; collaborate with professional bodies engaged in activities in the construction industry; continue the existence of the Construction School and rename it as the National Construction School; provide for a complaints and appeals procedure; repeal the National Council for Construction Act, 2003; and provide for matters connected with, or incidental to, the foregoing.*

The following observations are made regarding the NCC Act No.10:

Article 31 provides for the registration of construction projects. The mandate of the Council for monitoring projects is limited to those registered under its Register (Article 32).

Article 54 provides for capacity building and professional development but appears to address the regulatory potential deficiencies of the NCC and reposits authority to the School of Construction for consultation regarding the needs for training and capacity building. The article states:

> *The Council may, in order to improve its regulatory capacity, facilitate capacity building and professional development courses for directors, technical staff and other officers, and shall develop standards, competence levels and certification requirements for officers, in consultation with the School and other appropriate authorities responsible for public sector training and development.*

It leaves out the role of other stakeholders (public and private sector) participating in skills development for the industry.

Article 54 also does not legally require or specify minimum targets for private sector and foreign players to build capacities and skills in the local industry in which they do business. This is a significant stumbling block to accelerated transformation of the engineering sector. It is noted though that, potentially, the Minister may pass a Statutory Instrument to provide for certain desired changes at his discretion.

4.2 Engineering Institution of Zambia Act

The Engineering Institution of Zambia (EIZ) Act No. 17 of 2010 provides for the formation of EIZ, registration of engineers and firms, and regulating professional conduct of its members practicing engineering in Zambia. The Act states in part:

> *An Act to continue the existence of the Engineering Institution of Zambia; provide for the registration of engineering professionals, engineering units and engineering organizations and regulate their professional conduct; repeal the Engineering Institution of Zambia Act,1992; and provide for matters connected with, or incidental to, the foregoing.*

Article 4 (g), of particular interest, is reproduced below:

> *promote the general advancement of science, engineering, technological and allied disciplines for the improvement of the quality of life*;

It is observed that the Act merely "promotes" and does not set out any minimum benchmarks, or require regulators to do so, by which science and engineering is advanced. There is need for the Act to breathe more life into the engineering practice to oblige stakeholders to provide programmes and targets for science and engineering advancement for the local professionals, in the areas of operation - projects, manufacturing, research, etc. The benchmarks will improve the chances of skills transfer from the foreign private sector to the local professionals who should use the skills to develop home-grown solutions.

4.3 Association of Consulting Engineers of Zambia

The EIZ Act also requires that Consulting Engineers practicing in Zambia should be registered with the Engineers' Registration Board (EngRB) and be members of the Association of Consulting Engineers of Zambia (ACEZ).

The objectives of ACEZ relevant to the discussion are:

> To promote the training and development of engineering personnel.
>
> To promote the advancement of the profession of Consulting Engineers.

In expanding the import of the first objective, the Constitution points (Article 2) in the direction of training bodies as a route for developing engineering professionals.

Nothing in the ACEZ Constitution, directly seeks to draw skills development based on the relationship with main actors in the engineering sector such as the contractors and the consulting firms practicing in Zambia. The closest ACEZ seems to stretch is to "confer with Associations representing Manufacturers, Contractors and other persons engaged in engineering works on matters of common interest (ACEZ, 2021)."

5. Proposed Solution for enhancing Skills Transfer

Zambia can leverage on projects being implemented in the country to improve the situation of skills shortage. It should be appreciated that projects are a field laboratory from which a spectrum of skills can potentially be forged and hardened. Engineering projects (e.g., hydropower, roads, water, irrigation) which involve several engineering skills applied on one site are a good case. These include:

- Civil Engineering
- Geotechnical Engineering
- Geomatic Engineering
- Mechanical Engineering
- Electrical Engineering
- Environmental Science/Engineering
- Control and Monitoring (e.g., SCADA)
- Hydropower Engineering
- Automotive Engineering
- Site Laboratory
- Manufacturing Workshops
- Project Management

There appears to be no legal requirement to entrench skills development at a project implementation level. Subsequently projects in Zambia are implemented with or without deliberate targets for skills development for the local engineers/staff. This should be changed.

The proposed solution shown in Figure 1 involves creating synergies among the following stakeholders: Government and regulating agents, project owners, consultants and contractors aimed at ensuring skills transfer are optimised at project level. Figure 1 illustrates how synergies can be leveraged by all stakeholders. The model suggests the following measures to be taken to operationalise it:

Legislature (GRZ) should enhance the provisions of the EIZ Act by including minimum targets for skills development in terms of numbers and expected quality to be attained by Project parties. There should of necessity be incentives, enshrined in the Act, awarded to those parties that perform compliantly to these provisions.

Empowered by statutory instruments, NCC and ACEZ should require submission of plans for skills development during registration of projects, contractors, and consultants applicable to the regulating agent. Reporting modalities should also be agreed upon. NCC and ACEZ should then monitor and evaluate skills development implementation ending with a report that rates the performance of contractors, consultants, and project owners at project close-out.

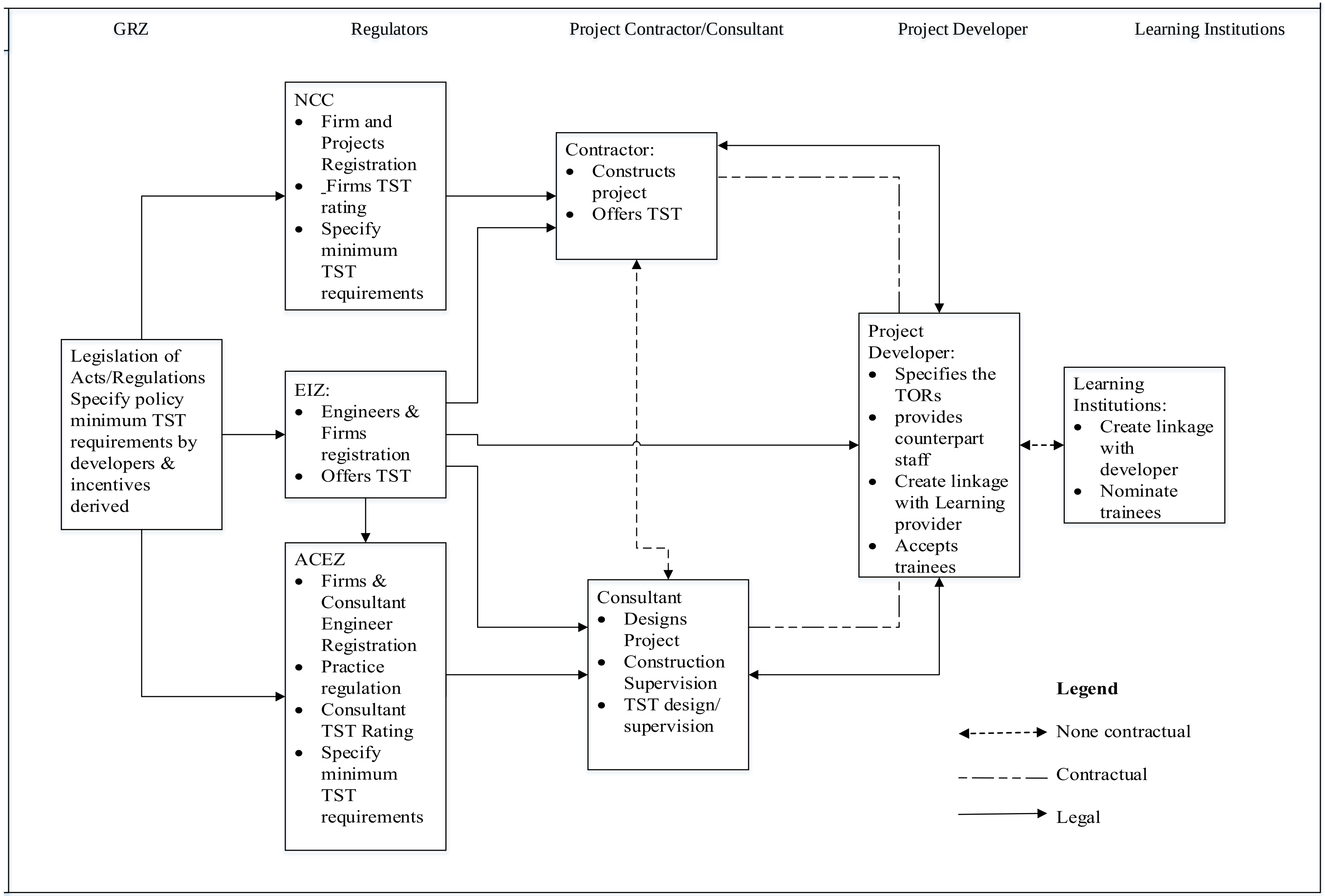

Figure 1: Proposed model for Technological Skills Transfer (TST) at project level in Zambia.

The project owners should be required to specify as part of the Employer's Requirements the minimum targets to be achieved by a project with respect to technical skills transfer (TST). Based on the requirements, the contractors and consultants should include plans which are subsequently submitted to regulating agents at registration. In cases where the consultant acts as the owner's engineer, the consultant would then be required to supervise the skills transfer programme during project implementation.

Project owners need to collaborate with learning institutions to supply the learners, in addition to owner's counterpart project staff, who should be imparted with skills during project implementation.

The model will provide great opportunities for students of engineering to tap into the super skills that are pooled in one project from foreign and local expertise. The model offers a cost-effective paradigm shift for skills transfer into Zambia. Armed with engineering skills through project real implementation, the students will bake to be able to offer solutions required for transforming the economy. The model will augment the efforts of GRZ to increase per capita number of engineering skills necessary to drive the economic agenda of improving livelihoods of Zambians. The model can fit in most projects of different types.

This is compared to a faculty of engineering at a university. It is interesting to know that such projects cover a long duration of time, typically 2-3 years for small projects and 5 years for large projects. Therefore, targeting graduates not yet in employment is ideal. By the time they complete this intensive skills development, they will be steamed with years of experience for applying in various economic activities.

6. Conclusion

Zambia like many other developing countries has a critical shortage of engineering/technological skills to bring socio-economic transformation to reality. The legal framework needs to be modified to require and incentivise stakeholders (Contractors, Consultants, Project Owners) to be objective about skills development during project implementation. Developing sufficient engineering/technological skills is ground zero for socio-economic transformation, leading to improved livelihoods. A model has been proposed to enhance the skills of engineers, especially those graduating from institutions of learning.

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On the effectiveness of the coarse grain CFD-DEM model for fluidization

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Abstract

In this paper the effectiveness of the coarse grain CFD-DEM model in the open source code MFIX is presented. The simulations are based on the small-scale fluidization challenge problem experimentation. Coarse grained CFD-DEM greatly cuts down computational cost which is the main challenge in conventional CFD-DEM. In this paper we demonstrate that such a model gives relatively accurate model predictions whilst cutting down on the computational time, The metrics used for validation include fluidization behavior, minimum fluidization velocity and mean particle velocity. For $2U_{mf}$, the bed does not fluidize in the absence of the coarse grain model meanwhile the predicted minimum fluidization velocity is 1.2 m/s and 1.4 m/s for statistical weights of w1, w4 and w8 respectively . Axial profiles of the bed voidage also demonstrate the need to include scaling laws of forces via coarse graining to get accurate predictions. Similarly, velocity profiles with and without the coarse grain model show appreciable differences. For a statistical weight of w4, there is a 14 per cent reduction in the wall clock time required to complete 1 second of physical time. However increasing the statistical weighting from 4 to 8, results in a decrease of 2.64 per cent in the simulation time, suggesting an optimum value.

Keywords: CFD-DEM, Coarse grain, Fluidization, Statistical weight, Validation

1. Introduction

Fluidization technology is commonly encountered in mineral processing and allied industries for operations such as air dense medium separation (Sahu, Biswal and Parida, 2009; Oshitani, Franks and Griffin, 2010), calcination, (Kunii and Levenspiel, 1991), roasting of sulfide ores (Kunii and Levenspiel, 1991), drying of solids (Kunii and Levenspiel, 1991) and pneumatic conveying of solids (Molerus, 1996) to mention a few. The technology offers several advantages over other gas-solid contactors including rapid mixing of solids and high heat and mass transfer rates (Grace, 1986) and is suitable for large-scale operations.

Despite the aforementioned inherent advantages, gas-solid flows in these devices are typically multi-scale and complicated making practical design and scale-up efforts quite challenging. Over the last century, scale up procedures have greatly advanced from heuristic to more fundamental ones encompassing advanced computational and experimental tools (Chew, LaMarche and Cocco, 2022).

For computational methods, the Computational Fluid Dynamics (CFD) coupled with the Discrete Element Method (DEM) abbreviated as CFD-DEM has proved to be a powerful tool in the study

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of fluidized beds and other gas-solid systems as evidenced by the exponential increase in publications on the subject (Gan *et al.,* 2020) . In the CFD-DEM model, the solid phase and the fluid phase are treated as discrete elements and continuum phase respectively. The continuum phase is modeled using the familiar Navier-Stokes equations whereas a force balance based on Newton's second law of motion gives the motion of the discrete particle elements. The particle to particle and particle to wall collisions can further be modeled as either soft sphere (Tsuji, Kawaguchi and Tanaka, 1993) or hard-sphere (Hoomans *et al.*, 1996).

A major drawback of the CFD-DEM model has been the relatively high computational cost especially for industrially relevant scale equipment due to the tracking of the individual particle motions. This, thus, places a restriction on the number of particles that can be simulated (Golshan *et al.*, 2020; Di Renzo, Napolitano and Di Maio, 2021). To cut down on the computational cost, coarse graining particle methods (CGPM) have been advanced. Different researchers have used different approaches for coarse graining. (Di Renzo, Napolitano and Di Maio, 2021). The philosophy behind this approach is to substitute the actual number of particles in a system by a smaller number of representative coarse grains using appropriate scaling laws to maintain the properties of the original particle system. The grain tracking realized using conventional DEM is referred to as coarse-grained CFD-DEM model i.e. CG CFD-DEM as applied to fluidization.

Application of the CG CFD-DEM model has attracted a great deal of interest lately and it has been used to simulate fluidization with regular spherical particles (Sakai *et al.*, 2014; Lu, Gopalan and Benyahia, 2017; Lin *et al.*, 2020; Jia *et al.*, 2021; Zhou and Zhao, 2021; Lungu, Siame and Mukosha, 2022), cohesive particles (Sakai *et al.*, 2012), irregular particles (Xu, Li and Gao, 2022; Zhou *et al.*, 2022), reactive flows (Lu *et al.*, 2020; Wang and Shen, 2022) and heat transfer (Lu *et al.*, 2017). Other applications include cyclone separators (Chu, Chen and Yu, 2016; Chu *et al.*, 2022; Li *et al.*, 2022; Napolitano, Renzo and Maio, 2022), pneumatic conveying (Sakai and Koshizuka, 2009) and spiral jet mill (Scott *et al.*, 2022). Despite the great strides made with CG CFD-DEM modeling, further development is still required for the approach to reach full maturity and be relevant for practical industrial design (Di Renzo, Napolitano and Di Maio, 2021) .

In this work, we test the effectiveness of the coarse graining approach by comparing numerical predictions with and without the coarse grain model invoked whereas in the latter case an equivalent particle size is used. The concept of the effectiveness of the CG CFD-DEM approach is adopted from the works of Sakai and co-workers (Sakai *et al.*, 2012, 2014) The simulation set-up is based on the small scale fluidization challenge problem (Gopalan *et al.,* 2016). The objective of this work can be thought of as a verification test.

2. Experimental set up

The small-scale fluidized bed is a rectangular acrylic column of 0.076 m thickness, 0.23 m width and 1.22 m height shown in Figure 1. The column was filled with 1.9 kg Nylon bead particles forming a bed of height 0.173 m at minimum fluidization condition. The bed is fluidized with air at ambient conditions at superficial gas velocities of approximately 2, 3 and 4 times the minimum fluidization velocity, U_{mf}. The measured physical and operating conditions are tabulated in Table 1.

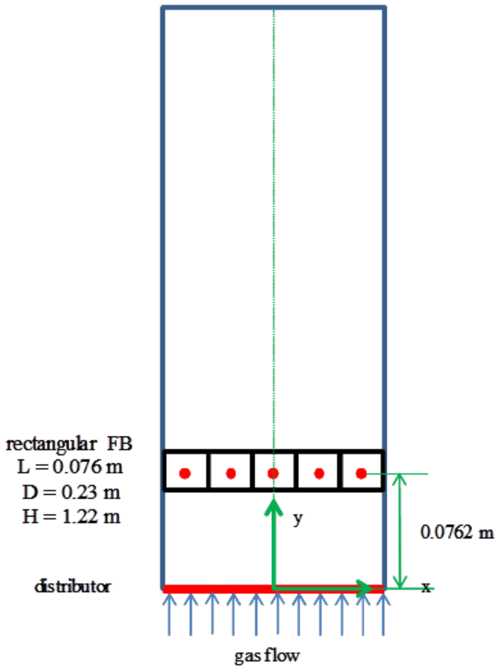

Fig 1: NETL SSCP1 experimental test rig

Table 1: Experimental and operating conditions

Discrete (particle) phase	***value(s)***
minimum fluidization velocity	1.05 m/s
void fraction at minimum fluidization	0.42
particle diameter	3.256 mm
particle density	1131 kg/m^3
sphericity	0.94
particle-particle restitution coefficient	0.84
particle-wall restitution coefficient	0.92
particle-wall friction coefficient	0.35
Continuous (fluid) phase	
temperature	293 K
pressure	101.325 kPa
viscosity	0.000019 Pa.s
density	1.2 kg/m^3
superficial gas velocities	2.19, 3.28, 4.38 m/s

Low frequency differential pressure measurements across the bed were acquired using the Rosemount 1151DP pressure measuring and transmitting device at a frequency of 1 Hz. In addition, high frequency pressure fluctuations were sampled at a frequency of 1 kHz with the Setra differential pressure instrument across the bed (0.0413 m – 0.3461 m).

Meanwhile the particle velocity measurements were acquired using the high-speed particle image velocimetry (HSPIV) with particle tracking from five sampling volumes of dimension

$0.0457 \times 0.0457 \times 0.003\ \mathrm{m}^3$. The center of the sampling volume is at an elevation of 0.0762 m from the distributor. The sampling frequencies for the HSPIV system were 1000, 1200 and 1500 frames/s respectively for the three superficial gas velocities. More details of the experimental set up can be found from (Gopalan *et al.*, 2016) and (Lungu, Siame and Mukosha, 2021; Musango, John and Lloyd, 2021).

3. Coarse-grained CFD-DEM model and simulation set up

The open source code MFIX was used to perform the coarse-grained CFD-DEM simulations. As aforementioned in Section 1, the rationale behind this model is to replace individual particles by a smaller number of representative elements or coarse grained particles. The relevant equations of the model (Lu et al., 2020) are given in Table 2.

Table 1: Coarse-grained CFD-DEM model

Gas phase continuity equation

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g\right) + \nabla \cdot \left(\varepsilon_g \rho_g \mathrm{v}_g\right) = 0$$

Gas phase momentum conservation

$$\frac{D}{Dt}\left(\varepsilon_g \rho_g \mathbf{v}_g\right) = \nabla \cdot \overline{\overline{\mathrm{S}}}_g + \varepsilon_g \rho_g \mathbf{g} - I_{g}$$

$$\overline{\overline{\mathrm{S}}}_g = -P_g \overline{\overline{I}} + \overline{\overline{\mathrm{T}}}_g$$

$$\overline{\overline{T}}_g = 2\mu_g \overline{\overline{D}}_g + \lambda_g \nabla . tr\left(\overline{\overline{D}}_g\right)\overline{\overline{I}}$$

$$\overline{\overline{D}}_g = \frac{1}{2}\left[\nabla \mathbf{v}_g + \left(\nabla \mathbf{v}_g\right)^{\mathrm{T}}\right]$$

mass of coarse-grained particle

$$m_{CGP} = m_p W$$

where m_{CGP}, m_p and W are the mass of the coarse-grained particle, mass of the individual particle and statistical weight respectively.

diameter of coarse-grained particle

$$d_{CGP} = d_p W^{1/3}$$

Tracking of the CGP is according to the force balance based on Newton's laws

$$m_{CGP}\frac{dv_{CGP}}{dt} = m_{CGP}\mathbf{g} - \frac{\pi}{6} d_{CGP}^3 \nabla P_g + \frac{\beta\left(\mathbf{v}_g\left(\mathbf{x}^i\right) - v_{CGP}\right)}{1-\varepsilon_f}\frac{\pi}{6} d_{CGP}^3 + \mathbf{F}_{CGP}$$

$$I_{CGP}\frac{d\omega_{CGP}}{dt} = \mathbf{T}_{CGP}$$

$$\beta = 18\mu\left(1-\varepsilon_s\right)\varepsilon_s \frac{F}{d_s^2}$$

$$F = \frac{10\varepsilon_s}{\left(1-\varepsilon_s\right)^2} + \left(1-\varepsilon_s\right)^2\left(1+1.5\varepsilon_s^{1/2}\right) + \frac{0.413 Re}{24\left(1-\varepsilon_s\right)^2}\left[\frac{\left(1-\varepsilon_s\right)^{-1} + 3\varepsilon_s\left(1-\varepsilon_s\right) + 8.4 Re^{-0.343}}{1+10^{3\varepsilon_s} Re^{-(1+4\varepsilon_s)/2}}\right]$$

The contact forces are resolved into the normal and tangential directions and computed using the soft sphere model

$$\mathbf{F}_{CGP-CGP}^{n} = \left(-k_n\delta_n + v_n\delta_n\right)\mathbf{n};\ \mathbf{F}_{CGP-CGP}^{t} = \min\begin{cases}\left(-k_t\delta_t + v_t\delta_t\right)\mathbf{t}\\ \mu_s \mathbf{F}_{CGP-CGP}^{n}\end{cases};\ \mathbf{F}_{CGP-CGP} = \mathbf{F}_{CGP-CGP}^{n} + \mathbf{F}_{CGP-CGP}^{t}$$

Effective restitution coefficient

$$e_{CGP} = \sqrt{1 + \left(e_p^2 - 1\right)W^{1/3}}$$

The pseudo 2D bed geometry was discretized using uniform Cartesian grids of approximately three particle diameters, which guarantees mesh independence. A statistical weight $W = 8$, was used for the base case CG CFD-DEM simulations resulting in 12065 tracked grains. Other set of simulations were also run with $W = 1$ i.e. original system with 96 527 particles and $W = 4$ resulting in 24 131 tracked coarse grains. The effectiveness of the coarse graining approach was tested by adopting particle size of 6.1212 e-03 mm which is equivalent to CG CFD-DEM with $W = 8$. The numerical simulations were set up to mimic as closely as possible the experimental conditions and run for a total of 25 seconds (physical time) on an Intel(R) Core (TM) i3 HP desktop machine. The start-up transients of the simulations subsided within the first 5 seconds and only data for the last 20 seconds were considered for post processing. The pressure drop and particle velocity transient data was extracted at a frequency of 1 kHz and stored for post processing.

4. Results and discussion

4.1 Fluidization behavior

Snapshots of fluidization patterns captured at 2.5 s, 7.5 s, 12.5 s and 25 s respectively for the 3 statistical weights at a superficial velocity of $2U_{mf}$ are displayed in Figure 2. There is no appreciable difference between conventional CFD-DEM with 96 527 particles and the CG CFD-DEM set up with 24 131 and 12 065 coarse grains respectively. Following Sakai et al (Sakai et al., 2014), the effectiveness of the coarse graining procedure was tested by simply replacing an equivalent coarse grain size for the case with $W = 8$ but without the coarse grain model invoked. At a superficial gas velocity of 2Umf, no fluidization occurred which is consistent with observations made by (Sakai et al., 2014) At higher superficial gas velocities of $3U_{mf}$ and $4U_{mf}$, the bed fluidized but significant differences were observed between the results with and without the coarse-grained model invoked as will be later on demonstrated. This clearly validates the coarse graining approach in simulating the macroscopic fluidization pattern in the qualitative sense at least.

4.2 Minimum fluidization velocity

The defluidization curves for the three statistical weights is shown in Figure 3 with the error bars representing the standard deviation of the pressure fluctuations. In the fluidized state, the fluctuations are intense due to the bubble and slug motion and they decrease as the fixed bed state is approached eventually leveling off to almost zero. As expected the averaged pressure drop variations in the fluidized state are small and start to rapidly decrease in the fixed bed state as the superficial gas velocity is gradually reduced. The magnitude of the fluctuations decrease with increasing statistical weight most likely brought about by the scaling of the drag and contact forces via the coarse graining approach. It is expected that lumping together individual particles into parcels will reduce the frequency of collisions leading to a reduction in the intensity of the pressure fluctuations and a similar observation has been made by Zhou and Zhao, 2021. It can also be deduced that without the coarse grain model invoked, accurate minimum fluidization behavior cannot be predicted since the bed does not fluidize at all for $U_g = 2U_{mf}$.

The coarse graining approach impacts the predicted minimum fluidization as can be seen from the defluidization curves. For w1, which converges to the conventional CFD-DEM approach, the predicted minimum fluidization velocity is 1.2 m/s, which is slightly lower than 1.4 m/s predicted by CG CFD-DEM $W = 4$ and $W = 8$ respectively.

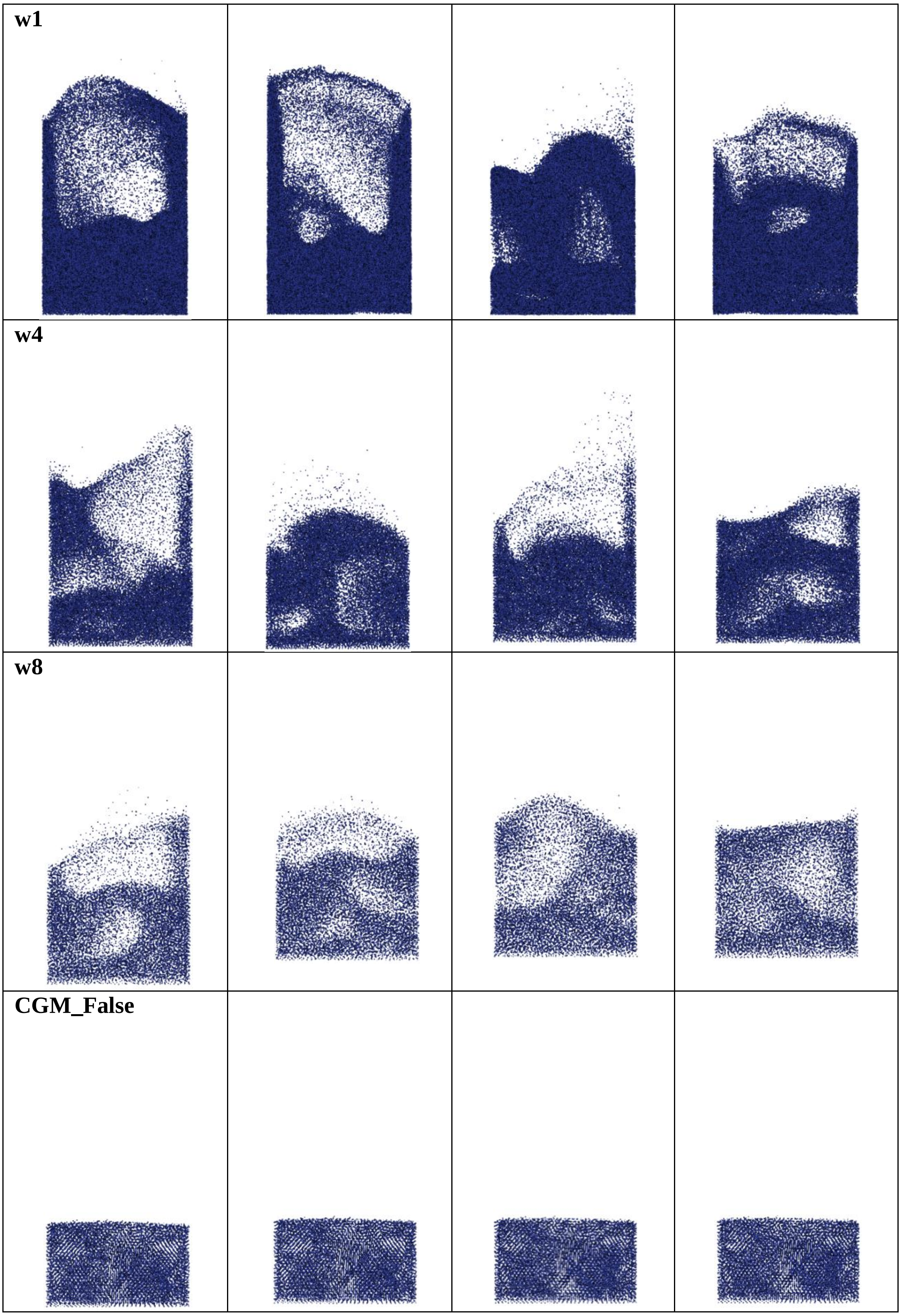

Fig 1 : Effect of statistical weight on instantaneous flow structures for a superficial gas velocity of $2U_{mf}$.

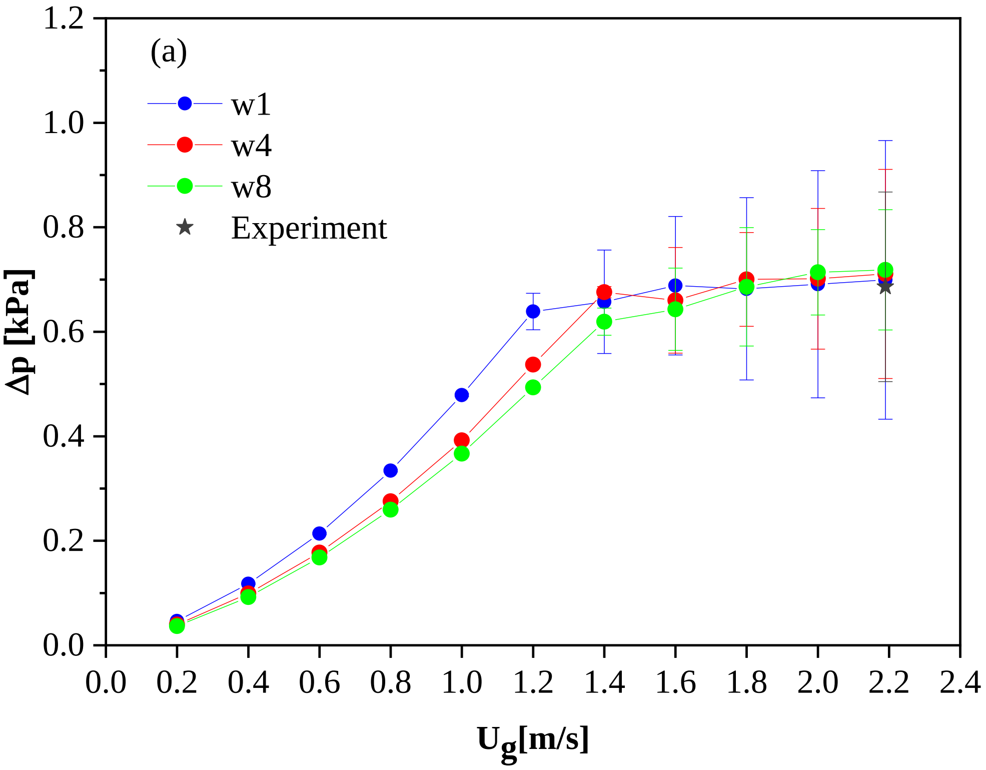

Fig 2: Defluidization curves for different statistical weightings.

4.3 Axial voidage profile

To explore further the effect of different statistical weights on model predictions, time averaged axial voidage profiles at different superficial gas velocities are compared in Figure 4. Simulations with the three statistical weights give similar predictions of low voidage in the dense bed that steady increases with increasing bed height eventually leveling off to unity in the freeboard. It can also be seen from the figure that the increase in bed height with increasing superficial gas velocity is well captured by all the simulations as expected because of the increased energy supplied to the bed by the fluidizing gas. Some slight differences however can be observed as well, for instance at $U_g = 2U_{mf}$, a slight decrease in the bed height is observed with increasing statistical weight although this is not as pronounced for $U_g = 3U_{mf}$. This explains the reducing tendency in the pressure fluctuations and average pressure drop with increasing statistical weight. For $U_g = 4U_{mf}$, the coarse grain model with $W = 4$ predicts slightly higher average voidage (or low solids hold up) for most bed heights relative to simulations with $W = 1$ and $W = 8$.

The voidage increases with increasing bed height and with superficial gas velocity as expected. Without coarse graining method applied, it can be seen from Figure 4 that the voidage profiles for $3U_{mf}$ and $4U_{mf}$ deviate significantly from the others once again reinforcing the need for scaling of relevant forces via coarse-graining,

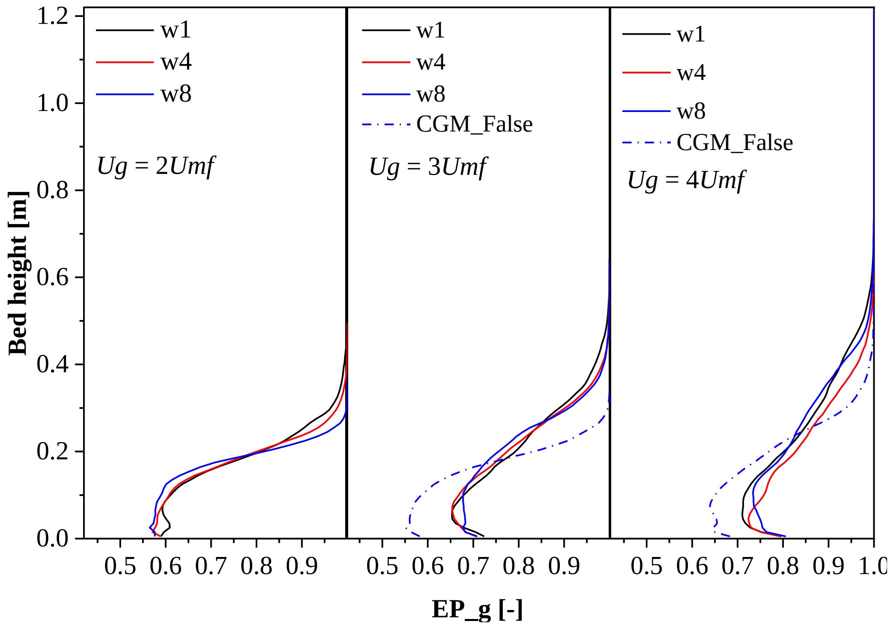

Fig 3: Spatially and time averaged axial voidage profiles for different statistical weights.

4.4 Velocity profiles

Figure 5 gives a comparison of the predicted mean particle velocity profiles using the coarse-grained CFD-DEM model with different statistical weighting and experiments with the HSPIV. It is inferred from the figure that the model is capable of qualitatively reproducing the experimental HSPIV particle velocity profiles for all the statistical weights tested. The over estimation of the horizontal particle velocity profile at superficial gas velocities of $3U_{mf}$ and $4U_{mf}$ increases for all the statistical weights but predictions with w8 seem to provide the optimum result due to the decreased fluctuation frequency of the coarse grains. Accurate prediction of the horizontal particle velocity has been challenging for this challenge problem (Lu, Gopalan and Benyahia, 2017; Agrawal et al., 2018; Liu and van Wachem, 2019; Musango, John and Lloyd, 2021) as well as previous problems (Breault et al., 2010). The use of heterogeneous drag correlations (Ayeni et al., 2016) and Energy Minimization Multi Scale (EMMS) based models (Musango, John and Lloyd, 2021) show promise in improving the horizontal particle velocity predictions.

The quantitative agreement between the coarse grain model using the three statistical weights and the HSPIV measurements for the mean vertical particle velocity at superficial velocities $3U_{mf}$ and $4U_{mf}$, Figure 5 (b) and Figure 5 (d), is much better in comparison to the horizontal profiles i.e. Figure 5 (a) and Figure 5 (c). This is because the vertical direction is the main flow direction in the pseudo 2D set up and thus strong particle velocity gradients are generated in this direction. Slight differences can be observed using different statistical weights but overall the accuracy of the prediction is acceptable.

The simulations without the CG CFD-DEM invoked give seemingly better horizontal particle velocity predictions but this is only due to the decreased fluctuation velocity and these results should be treated with caution. Corresponding vertical profiles from Figure 5 (b) and Figure 5(d) show significant under prediction and over prediction of the vertical component of the velocity in reference to the other statistical weights at the core and near the walls respectively.

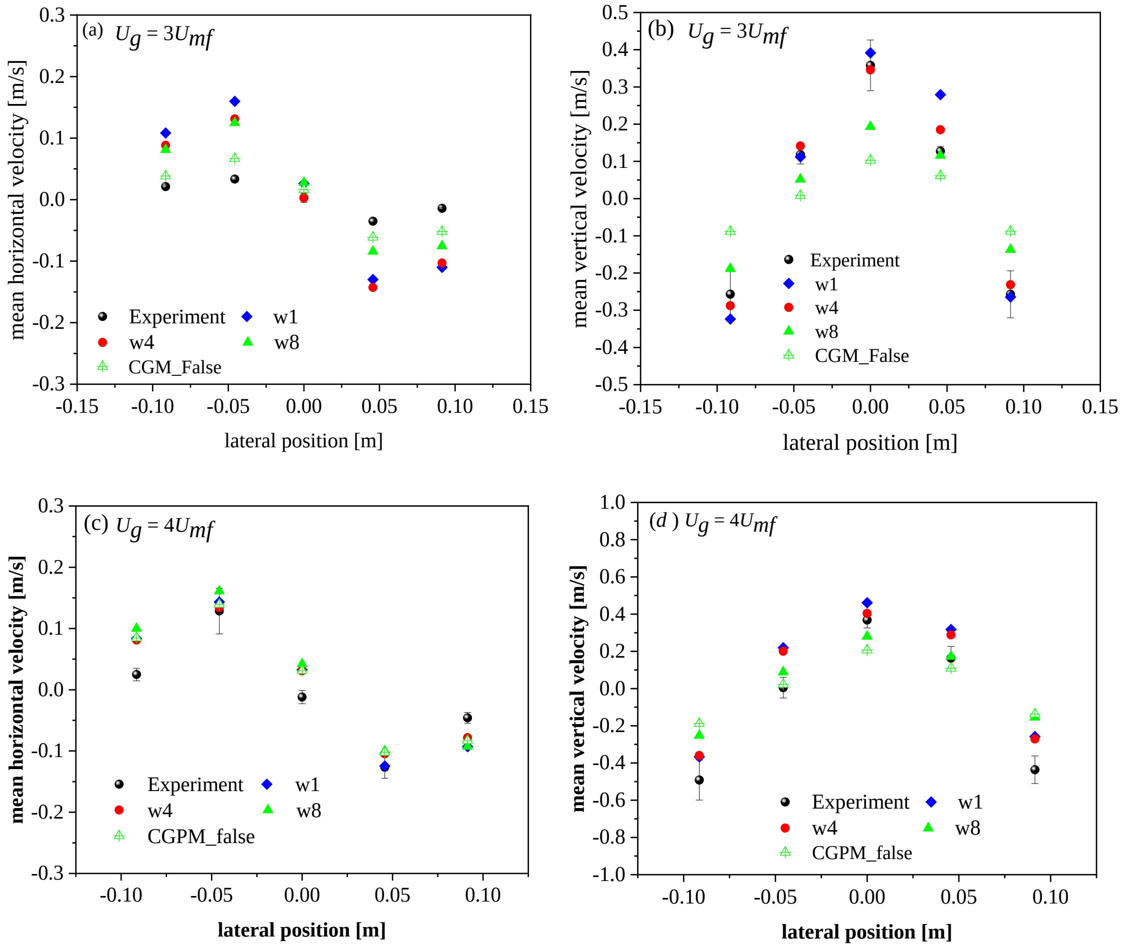

Fig 4 : Mean particle velocity profiles for different statistical weights.

4.5 Computational effort

The ultimate goal of coarse grain CFD-DEM model development is cutting down of the computational effort and ability to quickly set up a simulation and run it on a personal computer with minimal loss in accuracy. Figure 6 shows the typical wall clock time in hours required to simulate one second of physical time for the three statistical weights. When the statistical weight is increased from w1 to w4, there is a 14 per cent reduction in the wall clock time required to complete 1 second of physical time. However increasing the statistical weighting from 4 to 8, results in a paltry decrease by only 2.64 per cent in the simulation time. It should be noted that CFD-DEM based computations are inclusive of the CFD component and thus the overall computational time savings might not be as satisfactory despite gains from the DEM component. Moreover a relatively small grid size of about 3 particle diameters was used compared to who used a mesh size of about 5 particle diameters for the same set up. A further study is required to find methods of further reducing the computational time for this set up whilst maintaining the accuracy.

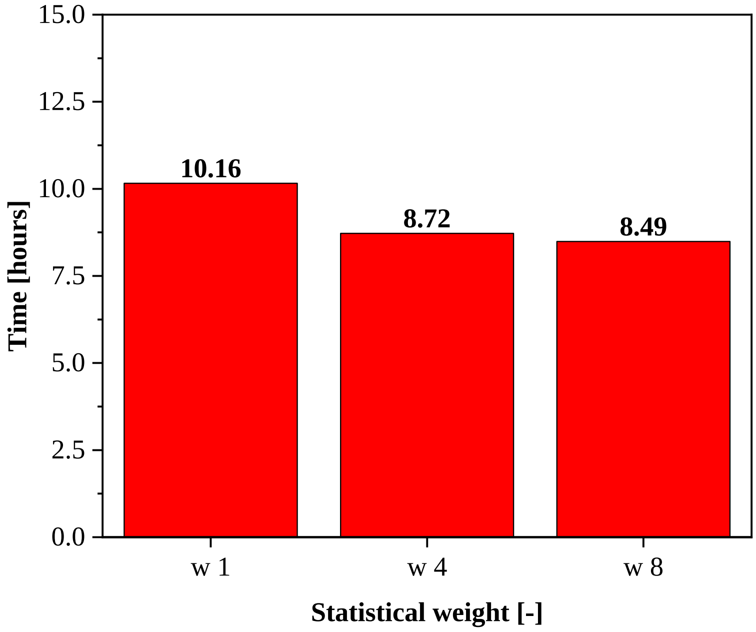

Fig 5: Wall clock time required to simulate one second of physical time.

5.0 Summary

In this paper, verification of the coarse-grained CFD-DEM model in the open source code MFIX is performed based on pressure drop and particle velocity experimental measurements from the small-scale challenge problem. Particular attention is paid to the statistical weight of the model predictions including the absence of coarse graining. The metrics used for validation include fluidization behavior, minimum fluidization velocity, axial time and spatially averaged voidage and mean particle velocity. For W =1, which converges to the conventional CFD-DEM approach, the predicted minimum fluidization velocity is 1.2 m/s, which is slightly lower than 1.4 m/s predicted by CG CFD-DEM with statistical weights of 4 and 8 respectively. The bed does not fluidize at all without the use of the coarse graining method.

Spatially and time averaged axial voidage profiles do not show significant differences for the three statistical weights but deviate significantly to the profiles from predictions without the use of coarse graining. Similarly, the profiles of the mean particle velocities for the coarse grain and conventional CFD-DEM models do not show significant differences with the exception when the coarse graining is false.

For a statistical weight of w4, there is a 14 per cent reduction in the wall clock time required to complete 1 second of physical time. However increasing the statistical weighting from 4 to 8, results in a decrease of 2.64 per cent in the simulation time, suggesting an optimum value.

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An assessment of the impacts of land use change on water quality and discharge: A case study of Chongwe River catchment

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Abstract

The Chongwe River catchment is sub-catchment that is within the Zambezi River basin that has been altered in both land-use patterns and hydrological ecosystems. This paper focused on assessing the impacts of Land Use/Land Cover classifications such as Agriculture, Urban areas, Forests and Grasslands and their impact on water quality and discharge in the Chongwe River Catchment. This study focused on five land use types, of which Agriculture land, Forest land, Built-up land and grasslands were analyzed and showed a significant correlation. Evidently noticeable changes have been observed in the land use patterns between 1980 and 2021, thus there was an observed increment in the Built-up lands and agricultural lands whereas there was a decrease in Forest land and Grasslands. It is in this context classified Land Use/Land Cover change (LULC) maps for years (1980,1990, 2000, 2010 and 2021) were generated through the aid of Arc-GIS software combined with remote sensing technology. Results between 1980 and 2021, showed that Agriculture lands increased from 0.91% to 11.01%, Built up land from 0.87% to 4.65%, whereas Forest lands decreased from 32.96% to 24.12%, Grasslands from 64.93% to 60.17% and Water bodies from 0.34% to 0.05%. Grab method for water sampling was used and samples laboratory tested thus according to the obtained water quality trend results, the water quality degraded over time. The results from the Man-Kendall test for pH, EC, TDS, Na, Cl and Mg showed an increasing trend and a decreasing trend for Temperature, Fe, K and $SO_4{}^{2-}$ over the catchment at the 4 sampling stations. This was mostly as a result of built-up lands and agricultural land in that there has been settlement land causing impervious surfaces, as well as the increase of surface run off from cultivated agriculture lands transporting chemical fertilizers to the river. Furthermore, Discharge levels in the dry season were observed to have been affected mostly by abstraction of water from the river for irrigation purposes and domestic uses. It was concluded that agriculture land was negatively correlated with discharge in dry seasons, whereas built up lands had a positive correlation.

Keywords: Discharge, Water Quality, Land Use/Land Cover (LULC), Geographical Information System (GIS), Remote sensing (RS)

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1. Introduction

The International Geosphere-Biosphere Program (IGBP) consists of two core types of research these are: Biosphere aspects of Hydrological Cycle (BAHC) and the Land Use Cover Change (LUCC). Research programs on the environmental effects of LUCC have brought about a positive result of regional sustainable development, Due to the fact that there has been an accelerating practice of urbanization and the unhindered spread of urban boundaries, the usage of land has drastically changed, consequently people's focus on the impact of natural resources, especially the quality and quantity of water resources (Szewranski, 2018). In addition, according to Muangthong, (2015), soil erosion is often amplified by changes in land use, affecting all links in the water cycle and increasing pollution from non-point sources in the basin. Thus, watersheds would be protected if the relationship between land use change and water quality is to be revealed, which poses to be greatly significant.

According to Bu, (2014), it has been proven that there is a significant correlation between land use and the quality of water. The land use that comes as a product of economic conditions and human activities are confidently correlated with the concentration of pollutants of the water (Bu, 2014). Griffith, (2002), further states that the quality of water is often discovered to be better in locations that are not developed such as woodlands that are natural. Regardless of that fact, the impact of changes in land use on water quality is not completely uniform. The water quality of the area of the study area can be affected by complex interactions between land use types, topography and socio-cultural. Agricultural land is generally the main source of pollutants in river water (Batbayar, 2019).

Further, Hess (2016), stated that deterioration of water quality due to Land Use/Land Cover often occurs in African countries, the fact that there is a problem with treatment facilities and backward economy, improper usage of land, and it can worsen water quality and threaten the sustainable development of the region. Therefore, assessing the correlation between land use change and water quality is very important as it helps to develop comprehensive management strategies and policies to reduce the intensive impact of land use on water quality.

1.1. Background: study area

The Chongwe River catchment is estimated to cover an area of about 5168.7 km^2 and is located in Zambia between latitude 1455'40" to 1543'19" S and longitude 28°13'53" to 2921'24" E as represented in Figure 1. The catchment covers multiple parts of Lusaka, Chisamba, Chongwe, Chibombo and Kafue districts. It also occupies about 45% of the city of Lusaka (Tena, 2019).

The Chongwe River Catchment is split into the upper, middle and lower parts. The most common land use type in the upper and middle half is agriculture and livestock produce. Approximately 6.5 km^2 of land is now being used for a variety of irrigation schemes in small- and large-scale farming. The main crops that are grown are groundnuts, maize, wheat, vegetables, cotton, flowers and horticultural crops. The other half is chiefly a Built-up area. The lower half is mostly forest and bushlands providing a natural habitat for animals and other wild creatures (Nguvulu, 2019).

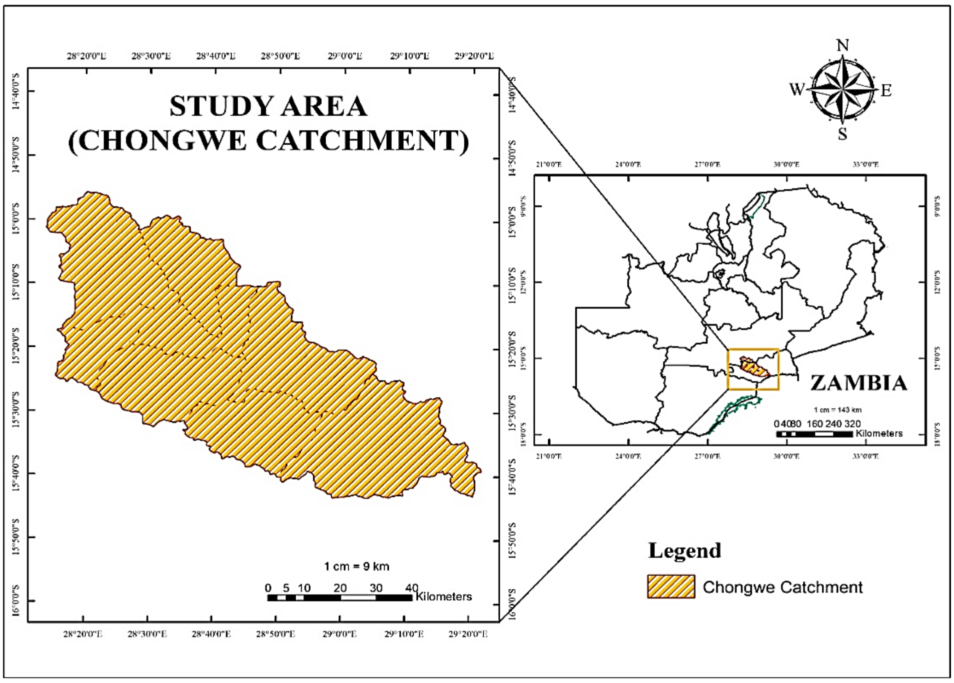

Figure 1: Location map of Chongwe River Catchment

2. Methodology

2.1. Methodology Flow Chart

The Research methodology was done according to the technical flow chart and techniques in Figure 2.

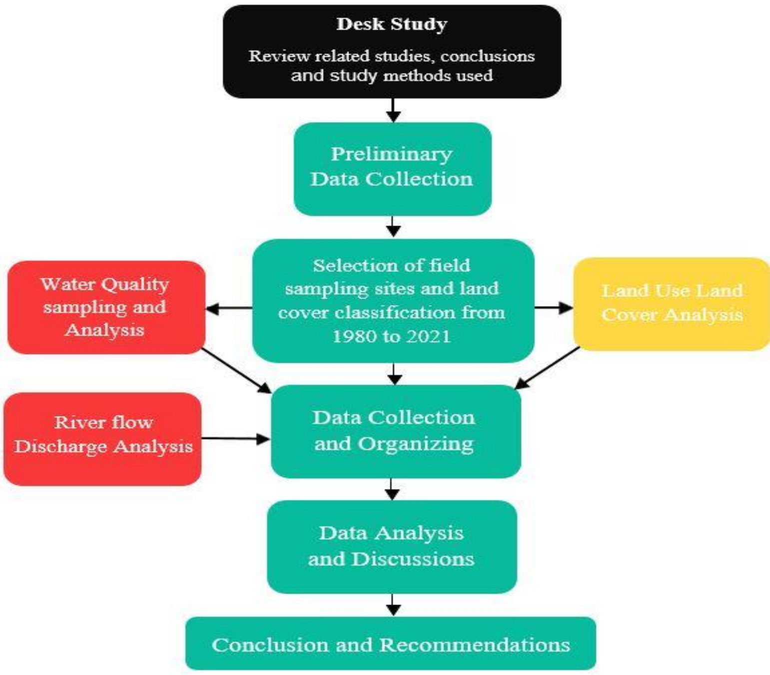

Figure 2: Research technical flow chart and techniques

2.2 Materials and methods

2.2.1 Land use land cover detection and analysis in the Chongwe River Catchment

Chongwe River Catchment was clipped out using a shape file of the catchment boundary. The method that was adopted for this task was supervised image classification which was carried out using Landsat 4-5 for 1980, 1990, 2000, 2010 and Landsat 8 for 2021. Supervised classification is centered around pattern recognition skills and Information that helps the system define statistical criteria or signatures for data classification. The Maximum Likelihood Classifier (MLC) parametric decision rule was used to carry out the image classification. The classification comprised a predefined scheme which included classes namely Forest lands, Grasslands, Agriculture lands, Built up areas and Water bodies. The scheme presented in Table 1 was based on field information.

Table 1: A description of the land use and land cover classes used in this research

Land Use/Land Cover Class	Cover Description
Forest Lands	Woodland, Forest Area, Dense trees, shrubs
Grasslands	Grasslands, Pasture land, small shrubs and Bareland
Agriculture Lands	Irrigation and Rain fed farms
Built Up Areas	Urban area, Building, Commercial, Industrial area, Airport, Road, Green houses, Residential Area, Sand Plain, Excavation sites and other related infrastructure
Water bodies	Reservoirs, Dams, Rivers/Streams, ponds, Wetland

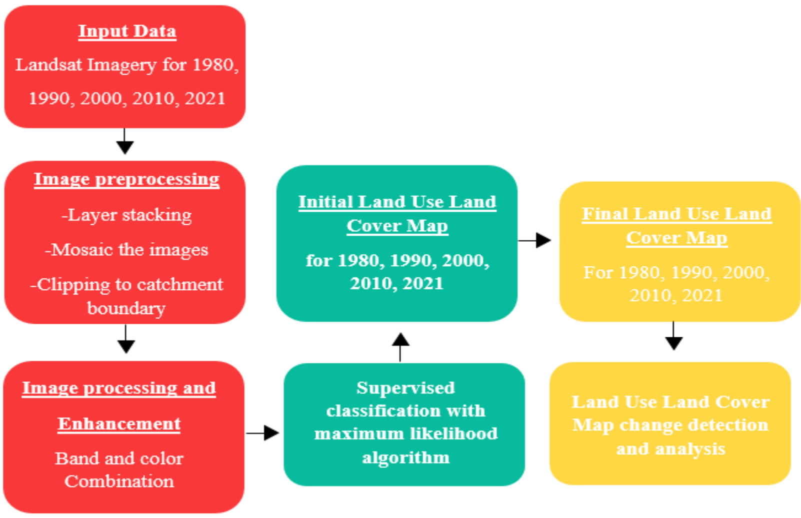

Figure 3: Flowchart for land use/land cover map analysis of Chongwe River catchment.

2.2.2 Water sampling and Analysis of physical, chemical and biological quality parameters

The water sampling and analysis were carried out in laboratory practice conditions that were credible, Zambian Standard (ZS), 2010. For the secondary data the tests were conducted quarterly per annum, which implies that data was collected once every three (3) months from the period of interest being between 2012 to 2021, at the same sampling sites of interest. The sampling carried out was considered because the results that were produced were comparable with the data set that that was provided by WARMA from 2012 to 2021.

2.2.3 Trend Analysis of water quality

The trend analysis of water quality was carried out with the Kendall's t test, when the value of ***S*** is positive in the trend test this means that there is an increasing trend and provided the value is negative it represents a decreasing trend. This test interprets that if:

H0: then there is no trend in the series

Ha: then is a trend in the series

If the computed p-value is lower than the significance level alpha = 0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha, but if the opposite occurs then the null hypothesis is not rejected. The Kendall's trend test was performed with the use of an extension of Microsoft Excel which is XL stat 2016.

Furthermore, the Man-Kendall trend test was carried out for all the sampling stations and the averages of the results were computed to have an overview of how the catchment at the 4 sampling sites has been behaving with respect to the water quality.

2.3 Measurement of river flow discharge

The gauge stations of interest in this study were station 5-016, 5-024 and 5-025 which are Ngwerere at Ngwerere weir, Chongwe-Ngwerere confluence and Chongwe at great east road bridge respectively as shown in Figure 4.

2.3.1 Station Rating Equations

For two stations it was impossible to use the wading method such as Chongwe bridge Great East Road and Ngwerere weir, therefore the stage method was employed. All gauge stations had gauge plates thus measuring stage data was the alternative route in which it required the use of stage/discharge rating equations for the various gauge stations.

The correlation between discharge and water level can be expressed with a Rating Equation. The rating curves usually conform with Equation (1):

$$Q = C \times (h + a)^N \tag{1}$$

Where:

Q = Discharge (m^3/s)

C = Calibration parameter (1)

h = Water level (m)

a = Water level at which discharge is zero (m)

N = Calibration parameter (1)

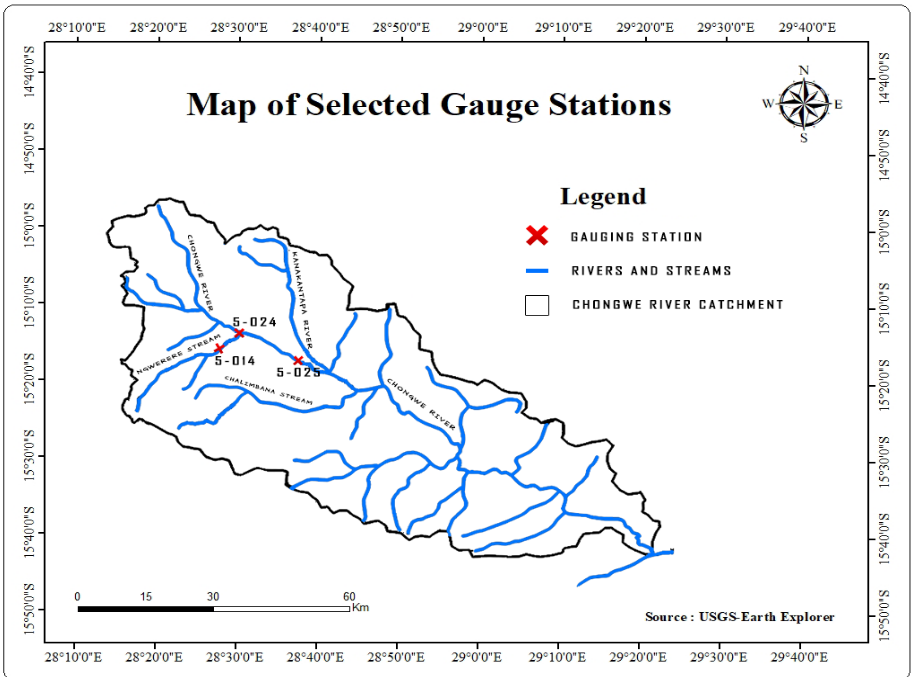

Figure 4: Map of selected gauge stations

3. Results and discussions

3.1 Land use/land cover classification

The following Land use/Land cover data was obtained from the analysis of Landsat images through the help of GIS and Remote sensing technology.

As shown in Figure 5 between 1980 and 2021, Agriculture lands increased from 0.91% to 11.01%, Built up land from 0.87% to 4.65%, whereas Forest lands decreased from 32.95% to 24.12%, Grasslands from 64.93% to 60.17% and Water bodies from 0.34% to 0.05%.

For all the years of interest, the increase in the Agricultural lands is due to the fact that there has been an increase in the Socio-economic activities and development of commercial irrigation farms based on field observation.

Furthermore, the increase of Built-up lands is as a result of the expansion of Lusaka City towards

Chongwe catchment. Lusaka City being the capital, attracts various socio-economic activities, thus Built-up lands are expected to continue increasing towards the Upper and the Central part of the catchment area.

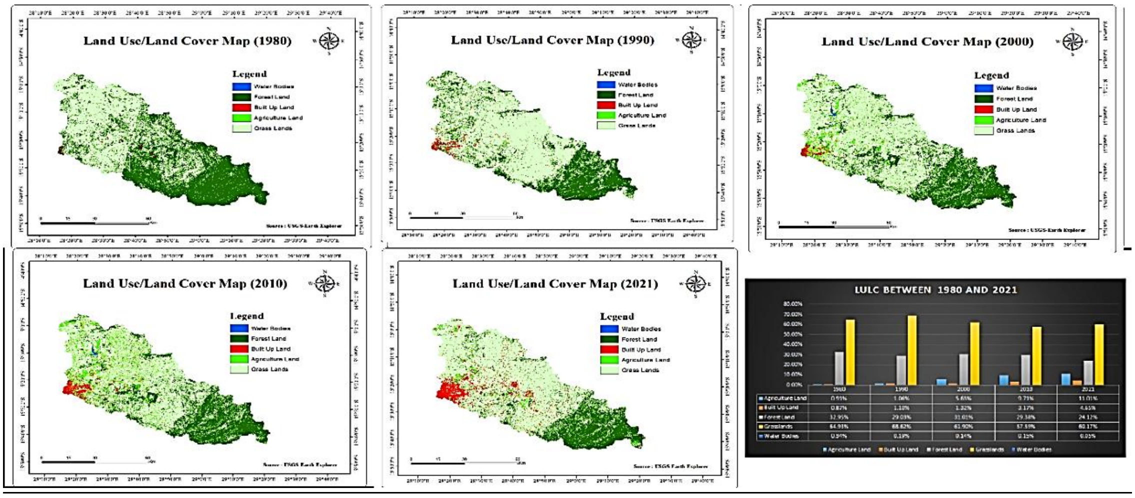

Figure 5: Land Use/Land Cover Maps for 1980,1990,2000,2010 and 2021

Forest lands have been reducing and can be related to the transformation of Forest lands into Built up lands and Agricultural land. Further, according to Hibajene (1994), it was stated that the Chongwe River Catchment supplies a substantial amount of charcoal to Lusaka city which can ultimately be the reason for the reduction in Forest land.

Grasslands fluctuating percentages is due to the fact that there have been common traditional farming practices where agriculture land has been transformed to grasslands and Vice-versa. Further, the leaving of land bare after deforestation caused the increase in grasslands between 1980 and 2021.

Lastly, Water body percentages have been decreasing and is related to the fact that there is a big conversion of farming that is rain fed to farming that is irrigation based.

3.2. Flow discharge results and analysis

According to Figure 6 there is an observation at the stations in the month of January, the increment in built up land and the concurrent decrease in forest land increased discharge in the Chongwe River catchment during the rainy season. In addition, the construction of buildings and roads increased the flow rate and ultimately increased the discharge of rivers, thus there is a positive correlation between the increase in discharge in the river and built areas.

The reduced river discharge in the dry seasons of October may be associated to increased built up land (domestic use) and agriculture land (irrigation). The year 1980 was observed to have had 0.91% of agriculture land and increased to 11.01% by 2021, based on these results we can correlate agriculture land to the drop in discharge levels that is as a result of abstraction, thus there is a negative correlation between Agriculture land and discharge.

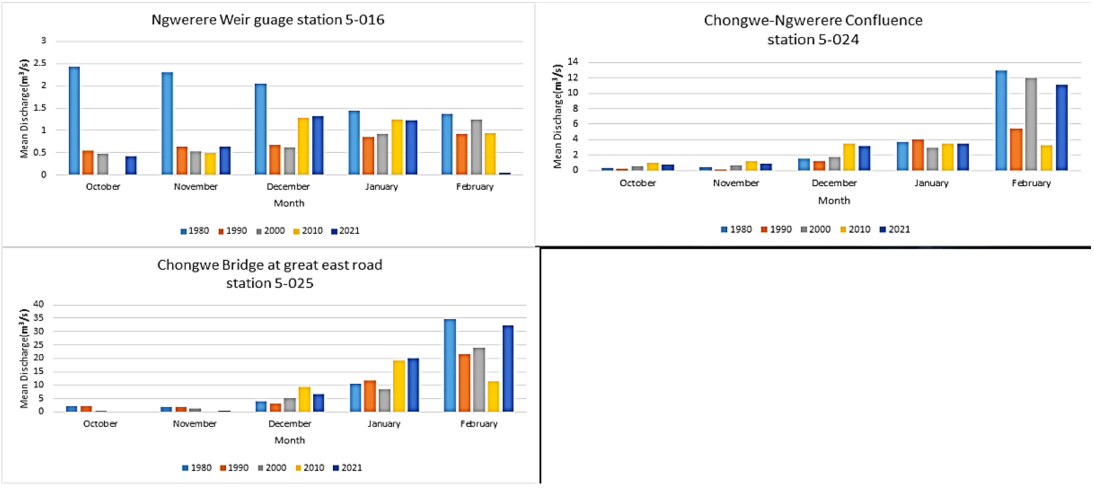

Figure 6: Histograms of gauge stations 5-016, 5-024 and 5-025

3.3. Water Quality Trend results and Analysis

Table 2 gives the results that were obtained from the water quality trend tests and analysis.

Table 2 The Man-Kendall trend based on averages for the 4 sampling stations

Parameter	S Value	Sen's slope	P Value	Comment
pH	3.25	-0.0315	0.690	No significant Trend
EC	1.5	56.72	0.865	No significant Trend
Temp	-7	-0.317	0.804	No significant Trend
TDS	1	107.5	0.432	No significant Trend
Na	13.25	18.128	0.349	No significant Trend
K	-9.5	-14.223	0.529	No significant Trend
Fe	-0.75	-10.055	0.902	No significant Trend
SO_4^{2-}	-0.75	-11.35	0.740	No significant Trend
Cl^-	4	5.671	0.611	No significant Trend
Mg	1.25	0.775	0.645	No significant Trend

Note: All for 2012 to 2021

i. Built Up Lands

According to the man Kendall results in Table 2 Cl, TDS and Electrical Conductivity gave a positive value of S meaning that there was an increase in each of the stated parameters over time. Therefore, the positive correlation between built up land and Cl, TDS and Electrical conductivity is attributed to the run off from construction sites as well as weathering of rocks from land. Further the increment of Chlorides in receiving waters maybe attributed to Road salts.

ii. Agricultural Lands

Further, Figure 5 shows and increase in agriculture land therefore, land clearing activities may have led to salinity problems in the river and the sediment run off from loose soils on cultivated land as well as decomposition of organic matter in the catchment may lead to acidic problems in the catchment. The results of this study support this statement that is we observe a reduction of the pH and Fe over time.

Also, according to this study, Na had been increasing over time this may be as a result of chemical fertilizers on agricultural land and the increase in surface run off also plays a role in the positive correlation of agriculture land with Na and Mg.

iii. Forest and grasslands

Forests and grasslands in relation to water quality depict a negative correlation. This revealed that as forest land increases, water quality degradation reduces and vice-versa. As Tu (2011) highlighted results that stated forest and grasslands are indicators for good water quality.

4. Conclusion

The correlation between Land use/Land cover change with discharge and water quality was determined and the main causes of the water quality deterioration and rapid reduction in discharge in dry season was determined, for water quality it was as a result of increase in agriculture land sediment run off from loose soils on cultivated land and for Built up lands the run off from construction sites, whereas for Discharge it was associated to the increased built up land (domestic use) and agriculture land (irrigation). The results from the study showed a positive correlation between land use change with water quality and Discharge.

Good management of water resources brings more certainty and efficiency in productivity across economic sectors and contributes to the health of the ecosystem thus contributing to Zambia's sustainable economic transformation.

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Pre-heater design at 500TPD sulphur burning plant

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Abstract

Konkola Copper Mines Plc (KCM), is one of the largest integrated copper producers in Africa. KCM's core product is copper. Sulphuric acid is a by-product from the smelting process but it is also produced as a primary product from elemental sulphur. The 500TPD sulphuric acid plant (SAP) employs the Contact-process in which molten sulphur is burned to form sulphur dioxide (SO_2), in the presence of pellets of a catalyst vanadium pentoxide (V_2O_5), to form sulphur trioxide (SO_3) at temperatures of 420^0C. In the months leading to December 2019, the 500 TPD SAP experienced low converter bed temperatures leading to high SO_2 emissions during start-ups leading to environmental hazards. The need for air heater was arrived at by the drop of bed temperatures in the converter during shutdowns. The fixed sulphur burner at the sulphur furnace, locks any changes on the burner at the sulphur furnace for air/fuel/sulphur and you can't change the diesel burner to heat up the catalytic converter. The effect brings a time-consuming effect and a very tedious process. The consequence would be to normally start up with relatively low converter temperatures. This creates a problem of pollution at plant start-up until converter bed temperatures reaches 425^0C where SO_3 formation is activated and exothermic reactions are promoted. Thus, the air heater is needed to heat up the catalytic converter while the plant is coming from these shutdowns to reduce on chances of pollution which was being caused by low converter bed temperatures. The KCM Smelter projects team zeroed in on design calculations using fundamental heat transfer equations to come up with a design of a Preheater. This paper discusses the preheater design steps.

Keywords: Sulphuric Acid, Converter, Temperature, Heat transfer, Preheater, Design.

1.0 Introduction

Konkola Copper Mines Plc, is one of the largest integrated copper producers in Africa. KCM's fully integrated operations include open pit mines, underground mines, leaching plant, smelter, refinery and sulphuric acid plants. The company produces several by-products, including sulphuric acid from the smelting process. The sulphuric acid can also be produced as a primary product from elemental sulphur burning. The acid is largely consumed in the leaching process at Tailings Leach Plant.

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Sulphuric acid is the world's largest-volume industrial chemical. The largest single use of Sulphuric acid is making fertilizers both super phosphate and ammonium sulphate accounting for nearly 60% of the total world consumption. It is also used in the leaching of metals such as copper.

The Sulphuric Acid Plant at KCM uses the Contact process which are of two types. The simpler type, the sulphur-burning contact plants, uses sulphur as the raw material and the other one uses the off gas stream containg sulphur dioxide (SO_2) gas from the smelting process to produce sulphuric acid.In both types the system employed is Double Conversion Double Absorption (DCDA) designed to achieve a conversion efficiency of 99.8%. In the sulphur burning type,molten sulphur is burned to form sulphur dioxide, which is cooled, then oxidized, usually in the presence of pellets of porous siliceous material impregnated with vanadium pentoxide and a potassium compound, to form sulphur trioxide at a temperature of 425 ^{o}C (Bed 1 temperaure).

2.0 Process description

The conversion of sulphur dioxide to trioxide is carried out in the Converter. The Converter contains four layers (bed or pass) of vanadium pentoxide catalyst. Gas from the Waste Heat Boiler is led to the first layer where a part of the sulphur dioxide is converted to trioxide. This being an exothermic reaction the temperature of the gas rises. The gas is cooled in the superheater and led to the second layer bed or pass of the Converter for further conversion of sulphur dioxide to trioxide, raising temperature of the gas. The gas is cooled in the Waste Heat recovery boiler part 2 and led to the third layer. After conversion in the third layer the gas is led to the tube side of the heat exchanger where it is cooled and led to the intermediate Absorption Tower (IAT). Here sulphur trioxide is absorbed in circulating 98.5% sulphuric acid. The gas is passed through candle type mist eliminators to remove any mist carried with the gas.

The sulphur trioxide free gas is heated to conversion temperature in the shell side of the heat exchanger and led to the fourth layer of the Converter. Here final conversion of sulphur dioxide to trioxide takes place and the gas goes to economiser, where it is cooled and then to Final Absorption Tower (FAT) where again sulphur trioxide gas is absorbed in 98.5% sulphuric acid. The gas is then passed through candle type mist eliminators and led to the atmosphere through a gas stack. (KCM 500TPD Manual-2007).

2.1 Sulphur burning and Converter Reactions

The basic equation for the start of sulphuric acid manufacture is the combustion of sulphur (S) with oxygen (O_2) in air to produce sulphur dioxide gas.

$$S\,(g) + O_2\,(g) \leftrightarrow SO_2\,(g) \qquad (1)$$

The most critical stage in the manufacture of sulphuric acid is the catalytic conversion of sulphur dioxide (SO_2) to sulphur trioxide (SO_3) using oxygen over vanadium pentoxide catalyst as shown in equation 2.

$$SO_2\,(g) + \tfrac{1}{2}O_2\,(g) \leftrightarrow SO_3\,(g) \qquad (2)$$

In order for the reaction to proceed, the catalyst must be heated up to its ignition temperature, typically 415 to 425 ^{o}C prior to introducing the sulphur dioxide containing gas. The catalyst operating temperature relates to optimum temperatures and strike temperature (to initiate self-sustaining reaction). Conventional vanadium pentoxide catalyst strike temperature is about 400^{o}C. The reaction between sulphur dioxide and oxygen to form sulphur trioxide is favoured in the temperature range of 425^{o}C to 440^{o}C. Since the reaction $SO_{2\ (g)}$ + ½ $O_{2\ (g)} \Rightarrow SO_{3\ (g)}$ is an exothermic reaction, the equilibrium at higher temperature than 450^{o}C is shifted toward forming $SO_{2\ (g).}$ Therefore, temperatures above 450 ^{o}C promote a reversible reaction leading to formation of sulphur dioxide. Similarly, temperatures below 400^{o}C result in incomplete conversion of sulphur dioxide to trioxide. (1850TPD SAP operating manual-2010). The bed temperatures are as follows:

Inlet to Bed 1 -425^{o}C	Outlet Bed 2-618^{o}C
Inlet to Bed 2 -440^{o}C	Outlet Bed 2-524^{o}C
Inlet to Bed 3-435^{o}C	Outlet Bed 3-464^{o}C
Inlet to Bed 4-410^{o}C	Outlet Bed 4-418^{o}C

After a plant restart in August 2019, efforts to ramp up production from 250t/day to 350+ t/day were met with operational challenges, one of them being high SO_2 stack emissions. SO_2 in stack averaged 8100 ppm against the target of 400 ppm. This increase in stack emissions to 8100ppm showed that there was incomplete conversion of SO_2 to SO_3 in the Converter. Combustion of molten sulphur takes place in the furnace where the sulphur is sprayed by sulphur gun in dry air to form SO_2.Once you fix a sulphur burner at the sulphur furnace in air/fuel/sulphur you can't change to diesel burner to heat up the catalytic converter because it is time consuming and it is a tedious process. Therefore, normally the plant would start up with relatively low converter temperatures. This had created a problem of pollution at plant start-up until converter bed temperatures reaches or crosses 400 ^{o}C where SO_3 formation is promoted. From minor shutdowns, the furnace temperatures will normally support the burning of atomized molten sulphur but the catalytic converter will not support the forward reaction ($SO_{2(g)}$ + ½ $O_{2(g)} \leftrightarrow SO_{3(g)}$) thereby sending sulphur dioxide straight to the main stack consequently polluting the environment.

Also,a number of boiler leaks had been experienced on the plant prior to the 2019 period which led to the poisoning of the vanadium pentoxide (catalyst) thereby reducing its efficiency and contributing to longer hours of heat-up before the plant could reach optimum bed temperatures thus contributing to pollution. The process gas needed longer residence time in the reactor (converter) for it to react due to catalyst fouling, poisoning coupled with low temperatures at plant startups. Plant data was studied and reviewed. For the period April to June 2019, Converter Beds 1, 2, 3 & 4 temperature difference between inlet and outlet averaged 140^{o}C, 40^{o}C, 48^{o}C, 5^{o}C respectively. Conversely for the period of August to December 2019, Bed temperatures difference (ΔT) averaged 100^{o}C, 54^{o}C, 50^{o}C, 35^{o}C for Beds 1, 2, 3 & 4 respectively. For Bed 4, it reached a peak temperature of 100^{o}C in the said period compared to average of 5^{o}C in April to June 2019.This data showed that the reactions shifted from Bed 1 to mostly bed 4. This led to incomplete conversion, seen also in stack emissions. The Converter /Reactor with Beds 1, 2, 3

&4 is shown in the Figure 1.

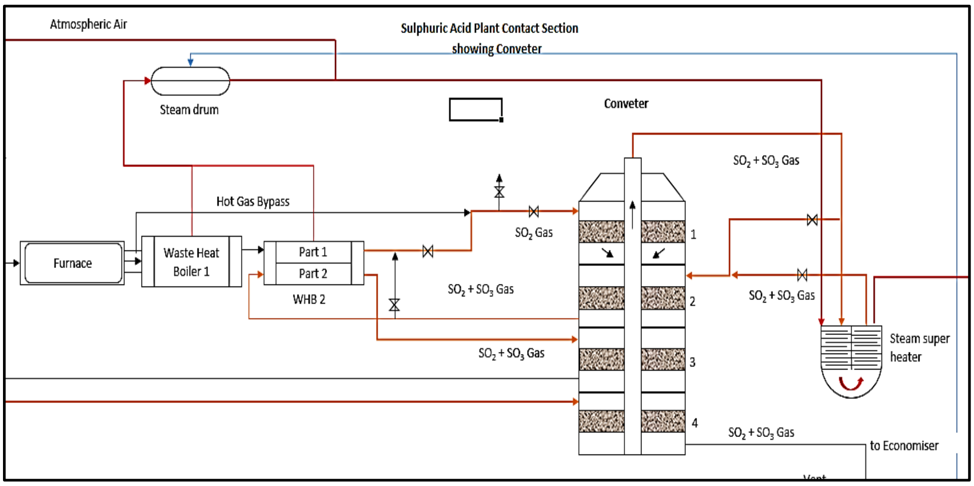

Figure 1: SAP Contact Section showing Catalytic Converter Beds 1-4

The need for air heater was arrived at by drop of bed temperatures in the Converter during minor shutdowns and subsequent start up. Thus, an air heater is needed to heat up the catalytic Converter while the plant is coming from minor shutdowns to reduce on chances of pollution which was being caused by low Converter bed temperatures. Usually, the sulphur furnace is able to maintain temperatures required for sulphur burning for up to 3 days.

A team was constituted to come up with a design of a Preheater that would ensure Bed 1 inlet temperatures were within the required temperature of 420-425^{o}C to facilitate complete conversion.

2.2 Pre-Heater

An air preheater (APH) is any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. They may be used alone or to replace a recuperative heat system or to replace a steam coil. There are two main types; recuperative and regenerative air heaters. Tubular or recuperative air pre-heaters are provided in boilers of medium and small range of steam generation. The arrangement of all these air pre-heaters differs with the design and the way they are combined for very high-capacity boilers. Regenerative air per-heaters are compact and can have a stationary or rotating hood. A combination of tubular and regenerative type of air pre-heaters is used in very high-capacity boilers .The tubular being used for primary air heating and the regenerative used for the secondary air heating. (Basheer, *et al*., 2018).

In the sulphuric acid plant, the heating of the catalyst beds as well as other items of equipment, prior to start-up is achieved using a pre-heat system. In sulphur burning plants a supplementary fuel may be burnt in the sulphur furnace for refractory brick curing and preheating the contact section of the acid. Pre-heat systems are used for start-up and on-line applications. Start-up preheaters provide necessary heat to raise the catalyst bed to its ignition temperature and up to 450^{o}C to 480^{o}C to heat other equipment prior to introduction of SO_2 gas and as such, do not operate continuously. On-line preheat systems are operated continuously during low SO_2

strengths to maintain the catalyst beds at ignition temperature. On-line systems are commonly used in metallurgical and acid regeneration plants.

The pre-heat system consists of a furnace, heat exchanger, combustion air and tempering air fan and stack. Natural gas or fuel oil is typically burned in the furnace and tempering air or recycle gas is added to cool the combustion gases to a suitable temperature before entering the heat exchanger. Heat is exchanged between the combustion gas and process gas before being discharged from a local stack.

3.0 Design of 500TPD Air Preheater

Calculations

The logarithmic mean temperature difference (also known as log mean temperature difference, LMTD) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers. The LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the double pipe exchanger. While designing an air-preheated the laws, which govern this process, should be well understood and thus should be used in this design, construction, testing and operation of the equipment.

Governing Equations:

$$m_c cp_c\left(T_{c,o} - T_{c,i}\right) = m_h cp_h\left(T_{h,o} - T_{h,i}\right) \quad (3)$$

Where;

Tc: Temperature of flue gas in K

$T_{c,out}$ =Temperature of air out of the pre-heater K(assumption).

$T_{h,in}$ = Temperature of water in the pre-heater K

m_h =Mass flow rate of Flue gas in kg/s

$m_{c\,=}$ Mass flow rate of air in Kg/s

cp_c: Specific Heat Capacity of Flue gas kj/kgK

cp_a = specific heat capacity of air in kj/kgK

$T_{h,out}$: Temperature of Flue gas out in K (Calculated)

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{In(\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (4)$$

Equation (4) is the unification equation in gas flow with heat transmission, which phenomenon can only be proved in higher gas flow iterations with infinite mathematical analysis.

- From first principles of the Logarithmic Temperature Value Mean (LMTD).

- Table 1&2 shows all the step-by-step calculations results on the determination of the flow characteristics and in flow simulation with actual values, Figure 2. It also shows the parametric design which the design is governed by.

$$Q = UA\,\Delta T \qquad (5)$$

Where:

Q is heat flowrate [W]

A is the heat flow area [m^2]

U is the overall heat transfer coefficient [$W.m^{-2}.K$]

ΔT is the temperature difference [K]

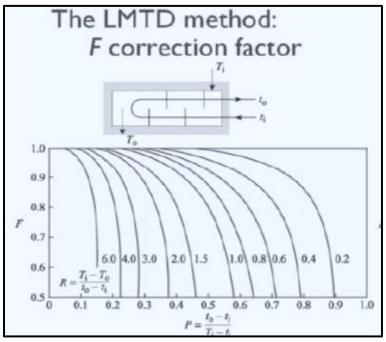

Figure 2: Flow characteristics and in flow simulation. (Source: Kraus and Bejan, 2003)

Calculations above have results to the determination of the flow characteristics and in the flow simulation with actual design reference values.

Table 1: Calculations of various parametric values

Calculations

Description	**UOM**		**Remarks/Formulae**
Current Preheater Capacity	m3/hr	100000	at IGV 20% opening
Combustion air	m3/hr	42000	at pressure 3200mmWC
Dilution Air	m3/hr	42000	at pressure 3200mmWC
Atomising air	m3/hr	500	at pressure 1bar
Atomisation temp diesel	°C	230	
Atomisation temp HFO	°C	400	
Pi		3.1416	
Hot air quantity at HAG outlet	Nm3/hr	36,540	
Cold air quantity to be heated from 30DegC to 425DegC	Nm3/hr	**36,143.2**	equivalent to **43,520 kg/m3 @ 30DegC**
Inlet Temp air	°C	30	Tc_i
Inlet Temp flue gas	°C	750	Th_i
Outlet Temp air	°C	425	Tc_o
Outlet Temp flue gas	°C	305	Th_o
By Comparison ratios		**5.5**	
volume requirement in 500TPD	m^3	**7683.1**	
Air for Shell side	m^3	**15457.6**	
Design basis	m^3	**15457.6**	
Specific heat capacity air	KJ/(KgK)	**1.01**	C_{ph}
Specific heat capacity flue gas	KJ/(KgK)	**1.1**	C_{pc}
Mass flow rate for air	Kg/hr	**43,520**	$m_C=[m_h*C_{ph}(T_{ho}-T_{hi})]/[C_{pc}(T_{co}-T_{ci})]$
Mass flow rate for flue gas	Kg/hr	36540	m_h
Height(h)	m	5.990	
Internal diameter(D)	m	1.450	
Outer diameter(D)	m	2.870	
outer diameter of 1 tube	m	0.0508	
Internal diameter of 1 tube	m	0.0466	
Tube thickness	m	0.0021	
No.of holes(n)		1,164	Pi *D*h*n
Tube flow Area	m2	1,021	
LMTD		299.304	=((Tho-Tci)-(Thi-Tco))/ln((Tho-Tci)/(Thi-Tco))
$(LMTD)_{cross}=F*(LMTD)_{counter}$			This Preheater is a cross flow Preheater where' F' is the correction factor

P thermal effectiveness		0.5	P=(Tco-Tci)/(Thi-Tco)
R		0.6	R=(Thi-Tho)/(Thi-Tci)
F		**0.900**	On assumption that one mixed phase(shell/flue gas) and unmixed(tube/SO2)
Therefore,$(LMTD)_{cross}$=F*$(LMTD)_{counter}$	^oC	269.37	=F*(LMTD)counter
U (Calculated Overall heat transfer coeff)	W.m2 ^oC	36.16	=AΔT/Q
U(as per standard tables)	W.m2 ^oC	40.00	
Q	KJ/Kg K	**1,866.7**	Q=UA*LMTD*F

3.1 Air Pre-Heater Design Summary.

Table 2: Design corrections and correction factors and solution determination for preheater.

V_2O_5 Properties		**Value**	**UoM**
Molar heat capacity,	Cv	127.7	J/mol.K
Pi	π	3.141592654	
Density	ρ	0.385	tons/m^3
Volume of Bed 1	V	18	m^3
Mass of Catalyst	M	6.93	tons
V_2O_5	RMM	181.88	g/mol
Number of moles		38102.0453	mols
Catalyst initial temp		25	
Catalyst final temp		430	
Overall heat	Q_o	1970580630	J
		1970.58	MJ
Overall heat transfer rate	q	26065.88	J/s
Area 1 under curve	A_1	810.00	
Area 2 under curve	A_2	1230.00	
Area 3 under curve	A_3	1905.00	
Heat Ratios	Q_1	404.61	MJ
	Q_2	614.40	MJ
	Q_3	951.57	MJ
		26065.88135	
AIR			
Air Volumetric flow rate		17381.7382	m^3/hr
density	ρ	1.2	kg/m^3
Air mass flow rate		20858.08584	kg/hr
Specific heat capacity	Cp	1010	J/kg.K
Heat rate	q	2106666.67	J/s
Flue Gas			
Flue gas mass flow		15000	kg/hr
Flue gas volumetric flow		12500.00	m^3/hr
density	ρ	1.2	kg/m^3
Specific heat capacity	Cp	1264	J/kg.K
Heat rate	q	2106666.67	J/s
LMTD			
		379.65	
		0.90	P
		1.11	R
Corrected LMTD	F=1	379.65	
AREA			
Overall Ht X Coeff		65.00	W/m^2 ^oC
Area of heat X		85.37	m^2
Tube outside diameter		0.04	
Wall thickness		0.004	
inner diameter		0.02	
Length of tube		3	m
		0.156	
Area of one tube		0.4	
No.of tubes		226.4	

shell single pass K		0.319	
shell single pass n		2.1	
Shell diameter		0.20	m
Bundle diameter		0.86	m
Tube pitch		0.05000	
Tube X sectional area		0.00031	m^2
Total flow area inside		0.00031	m^2

Air Pre-Heater Design Summary.

The parameters in the results in Table 3 indicate base lines limits and boarders of the design of the preheater. The dimensions are in cohort with the effects for which the reactions will be sustained in normal optimal operational feed.

Overall Ht X Coeff	65	$W/m^{2o}C$
Area of heat X	85.369033	m^2
Tube outside diameter	0.04	
Wall thickness	0.004	
inner diameter	0.02	
Length of tube	3	m
Area of one tube	0.3769911	
No.of tubes	226.44839	
shell single pass K	0.319	
shell single pass n	2.142	
Shell diameter	0.2	m
Bundle diameter	0.8573189	m
Tube pitch	0.05	
Tube X sectional area	0.0003142	m^2
Total flow area inside	0.0003142	m^2

Table 3: Inference of calculated dimensions and parameters

4.0 Conclusions and Recommendations

Correlation with overall balance:

Literature indicated that the catalytic reactor consists of heating units placed in between each bed to maintain the reactor temperature. This is reflected in the energy balance by the heat deficit of about 26.5MW in the outlet. Similar, to most heat demands around the converter unit, the high temperatures that are above the critical temperatures of water prevents saturated steam.

Based on the calculations and results obtained, the Preheater can be fabricated and installed as shown in the proposed flowchart in Figure 3.

The primary steps of the design have been followed, from the prior investigations extensively done on the LMTD with the Contact process in the beds 1 to 4 (the standard thermochemical process to produce sulfuric acid).

In order to be consistent with a conservative estimate, we have equated the results and drawn confirmations to reach equilibrium in a steady state environment of zero pollution and zero discharge. Efficiency of the preheater is above the desired economic benefits surpassing and averting expected environmental hazards. Figure 3 above shows the relevant and key components. It also suggests the configuration of the plant and also the best location point for design optimisation considering safety options.

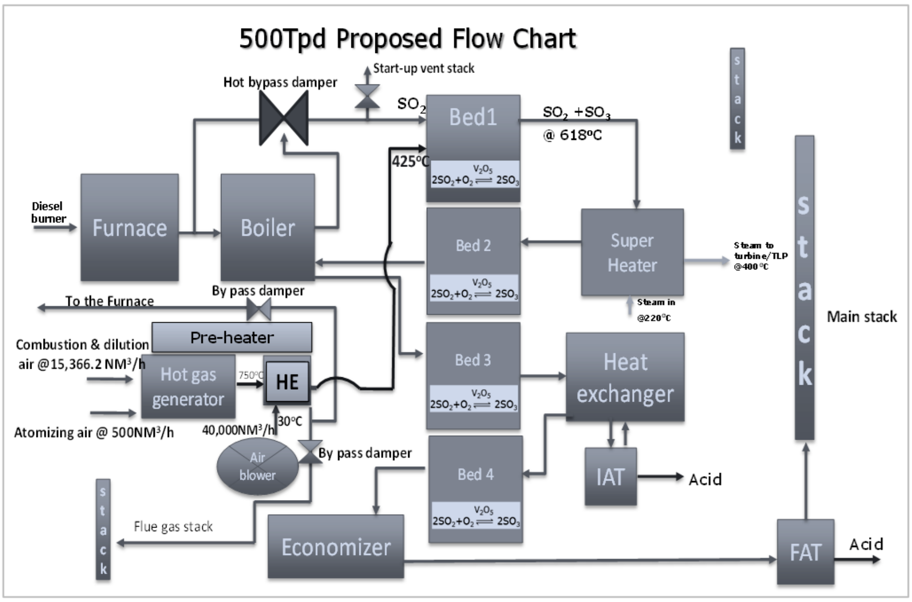

Figure 3: Proposed flowchart for installation of pre-heater

This paper has attempted and established an approach for the optimization and design of air preheater design with inline & staggered tube arrangement. This solves the poor performance of an air preheater in the 500TPD plant.

In the present work the performance of tubular air preheater is evaluated and found compliant with the latter being more thermally efficient. The selections, i.e. type of surface geometry for optimizing the design of air preheater is correct.

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Skills and technology for mineral scientists managing the future mine: A case of Zambia

Bunda Besa[1], Webby Banda[2]

Abstract

It is well established that the mining sector is and will continue, for a long time to be the main driver of the Zambian economy. Therefore, a skilled labour force is key in ensuring that Zambian natural resources are efficiently extracted. An increase in technology in the mining industry demands for skilled mineral scientists to undertake strategic roles and leadership. Therefore, there is a need to train students for the future mine which will be centred on the use of digital technology. In doing so, Zambia's two Universities (i.e., the University of Zambia (UNZA) and the Copperbelt University (CBU)) offering mining education need to realign their curriculums in this endeavour. There is a need to focus on training students to comprehend technologies that will be in high demand in the future mine. In this regard, this will support their problem-solving, communication, and critical-thinking abilities. Artificial intelligence, machine learning, and autonomous technologies provide many economic benefits for the mining industry through cost reduction and improved productivity and safety. Apart from the curriculums focusing on technology and operating practices, UNZA and CBU will need to introduce courses focused on talent and leadership, governance, and partnership with key stakeholders. This is because these skills are necessary for managing the future digital mine. To ensure that Zambia successfully trains and deploys mineral scientists for the future mine, they will be a need for triple helix synergies among government, industry, and training institutions.

Keywords: Artificial intelligence, machine learning, autonomous technologies, Future mine, skills

1. Introduction

The mining industry remains the mainstay of Zambia's economy and will continue to play an important role in the development of the country. Zambia is internationally recognised as a major producer of copper and cobalt. It is ranked as the world's eighth-largest producer of copper, generating 5% of the world's production (Figure 1), and the world's second-largest producer of cobalt (19.7%) as shown in Figure 2. Mining contributes significantly to GDP, revenue generation, employment, FDI, and export earnings of most mining countries. Therefore, a skilled labour force is key in ensuring that Zambia as well as other African countries benefits from its their natural resources. It is envisaged that mining companies also need to invest in young mineral scientists and recruit talented students through partnerships with universities.

It is a well-known fact that the economic development and social transformation of any nation

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are dependent upon the investment made in education and especially tertiary education. An increase in technology in the mining industry is demanding well-qualified mineral scientists to undertake strategic roles and leadership. This will support their problem-solving, communication, and critical-thinking abilities. Thus, there is a need to establish a symbiotic relationship among the government, tertiary institutions, and mining companies. Students should be willing and ready to learn beyond the lecture theatre so that they become more practical.

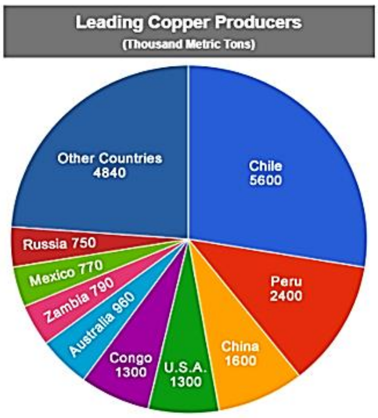


Fig. 1: Major world Copper producers (Source: https://geology.com/usgs/uses-of-copper/)

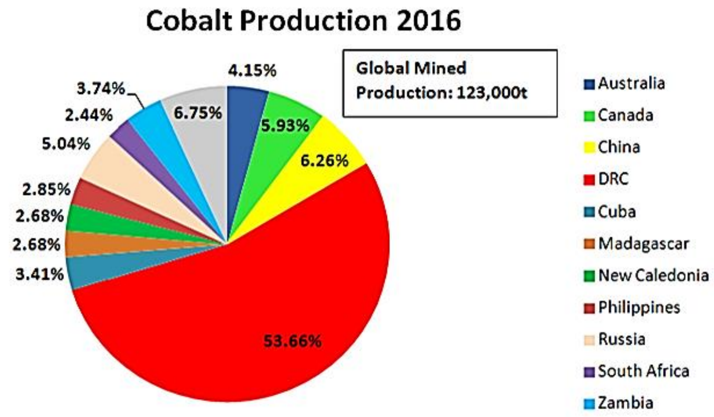


Fig. 2: Major world Cobalt producers (Source:* Mining.com, 2018*)

2. Principles of the future mine

Mining technology has evolved from using handheld tools to the use of large high-tech equipment. Recently, there has been a refocus of production away from labour to that anchored on mechanization. Smart mining systems, Automation, Artificial Intelligent (AI), Drone technology, etc. are advancing quickly, reshaping the workforce of the future and adjusting the abilities organizations are looking for in mineral scientists (Siau, 2017; Siau, 2018).

2.1 Autonomous Mining Systems

The application of Autonomous mining systems is a rapidly growing development in mechanization (Figure 3). Autonomous mining systems can drive mining efficiency, sustainably, safely, and cost-effectively (Dyson, 2017). Thus, technology has the power to significantly improve lives and enhance efficiency. Autonomous mining systems involve the use of machines, robots, and communication systems to conduct mining operations with minimal human involvement in the process (Roth, 2018). The use of autonomous mining systems requires a few highly skilled employees. Therefore, an Autonomous mining system can be viewed as an integral component of the future mine. It is envisioned that the future mine should be fully automated with smart technology, analytics, and machines that can interact with the rock and surrounding environment to collect analyze data to automatically produce useful outputs.

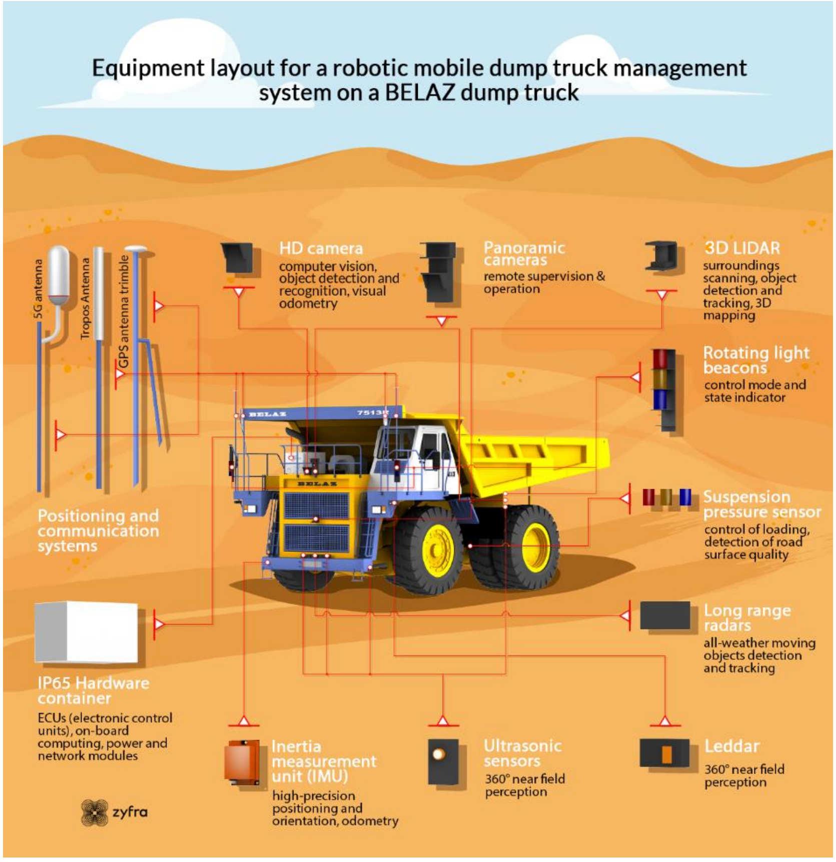


Fig. 3: Autonomous mining dump trucks (International Mining Journal, 2023)

2.2 Use of Artificial Intelligence (AI) in Mining

Artificial intelligence is a growing force in the global economy (Marr, 2016). Seventy percent of companies could adopt at least one type of AI technology by 2030, and that technology could add $13 trillion to the global economic output in the same time frame. Artificial intelligence shifts raw materials in mining from a people-oriented operation to a process-oriented one, which is critical to ensure appropriate health and safety conditions for the mineworkers, a high level of accuracy, error elimination, and a faster decision-making process. The benefits of AI include the following; faster decisions with greater accuracy, improved health and safety, boosting efficiency through error elimination, and smaller environmental footprint.

2.3 Use of Drones in Mining

The use of drones in mining is demonstrating excellent results by enabling much greater data collection, enhancing safety, and improving productivity (Figure 4). The popularity of drone technology across the mining industry has grown significantly in recent years. Some of the Drone applications in mining include the following;

(i) Site safety management e.g. drones can be deployed to collect data in areas where humans are not allowed to enter i.e. to collect data for hazard identification, security patrols etc.

(ii) Tailings dam management i.e., Drones are used to quickly get into the air and monitor the tailings dam for any leaks or potential fault points. They can also be used to check the level of the tailings dam. Additionally, drones enable operators to analyze tailings data, ensuring the tailings dam maintains structural integrity and supporting designs for expanding tailings dams where necessary.

(iii) Automatic surveying and mapping i.e., it involves mapping with a drone to produce all kinds of useful outputs like digital elevation models and 3D models;

(iv) Monitoring and inspection i.e., remote monitoring, mapping, and inspections to keep workers from dangerous working conditions

(v) Haulage road optimization i.e., Drones can facilitate this process by collecting a large amount of aerial data, covering wider areas more precisely, which can then be used by engineers for planning, designing, construction and maintenance of haul roads.

(vi) Stockpile management i.e. volumetric monitoring and measurement e.g., calculating how much material is left in a stockpile of overburden, ore, or other mining materials

Fig. 4: Use of Artificial Intelligence in underground mining

As mining becomes increasingly automated the skills gap gets wider. Therefore, there is a need to address this gap through investment in tertiary education. It is, therefore, necessary to attract and retain the required young talent and equip them with skills to enable them to operate the future mine. The mining industry needs to be forward-thinking and progressive to achieve this. Future mines will require a few employees with high skills in various aspects of automation, database management systems, data science, technology, etc.

3. Educational needs for the future mineral scientists

The speed of technological disruption and evolution is demanding more high-level responsiveness and innovation from organizations to retain their competitive advantage. Intelligent mines need specific skill sets, and understanding the current gap is crucial to prepare companies to plan their workforce and sustain competitive advantage strategically. According to research (Holland, 2018), there is a difference between what is being taught in some minerals engineering courses and what the current industry needs. Therefore, the fundamental questions are:

(i) Who will be running the mine of the future, and what skills will they need?

(ii) How can mining companies create an attractive workplace to capture young talents?

(iii) What changes will be necessary for the educational agenda to efficiently adapt and overcome the skills shortage in the mining industry

The following observations as regards the educational needs of future mineral scientists: (Siau, 2017; Siau, 2018)

(i) That there is a need for a different way of thinking about the mining as a business, Technological investment - particularly in IT and control systems;

(ii) It is unlikely that there will be major changes to the mechanics of mining and processing but the use of cleverer technology and automation of equipment is an attractive option.

The focus of the mining industry on zero harm will accelerate autonomous mining and the use of robotics. Sensor technology, big data, powerful computers, and complex algorithms will dominate the mining industry. Traditional mine planning will undergo revolutionary changes to accommodate new technologies. This will result in lower mining costs and improved efficiency. The future miner will be an office worker.

4. Essential Qualification for Mineral Scientists

Mineral Scientist's education efforts must include research and development engineers with the following essential qualifications:

(i) High-level technical skills;

(ii) Knowledge and ability to apply, optimize, and adapt to emerging technologies, especially digital technologies;

(iii) Data literacy and capacity of manipulating large datasets (sometimes Big Data) to manage efficiently and control systems;

(iv) The capacity of planning and operating mines with more socially acceptable surface footprints and environmental issues;

(v) Holistic knowledge about the full value chain of the mining operation, incorporating a systems-approach to planning and operations;

(vi) Use of risk-based techniques for planning, decision-making, and management; and

(vii) The capacity of working as a team member or leader of multidisciplinary groups.

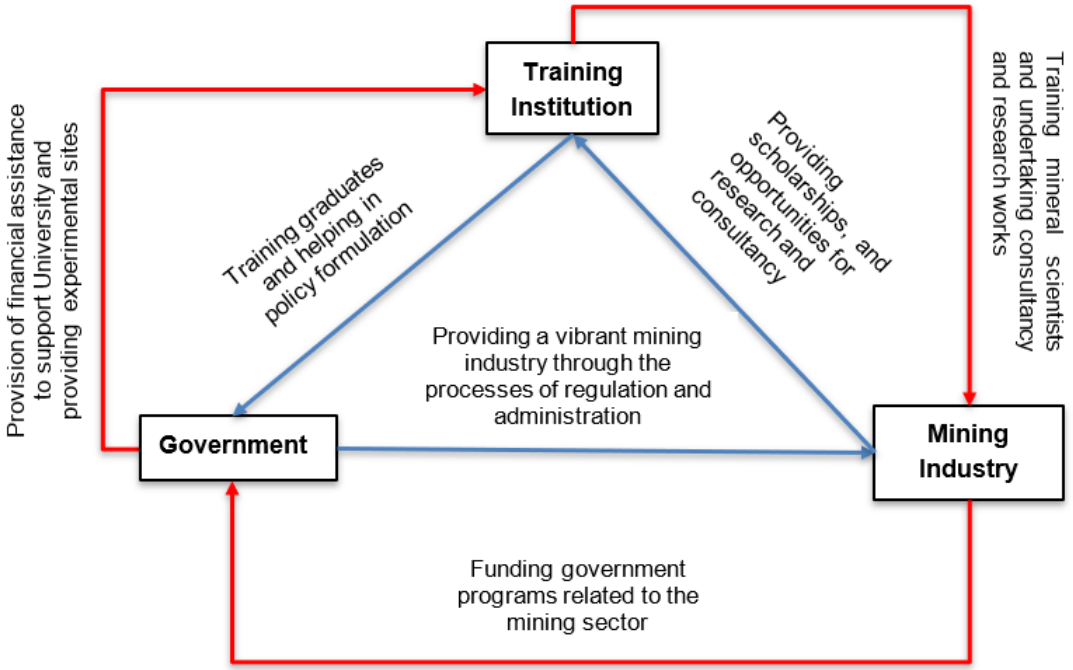
5. Zambia's preparedness to train mineral scientists for the future Mine

This Section discusses Zambia's preparedness to train mineral scientists for the future mine. Currently, two universities offer mining education, namely, the University of Zambia, School of Mines, and the Copperbelt University, School of Mines and Mineral Sciences. These two Universities are the primary source of graduates that serve the Zambian mining industry. The University of Zambia was established in 1966 and it is the oldest public university. The School of Mines was established in 1973 and has three Departments: Mining Engineering, Geology, and Metallurgical Engineering. The Copperbelt University on the other hand was established in 1987 as an offshoot of UNZA. The CBU departmental structure in the School of Mines and Mineral Sciences is similar to UNZA. In preparing graduates for the future digital mine, these two universities need to tailor their curriculum to produce graduates that are relevant for the future Mine. The key focus areas of the future mine will gravitate towards operating practices and technology, talent and leadership, partnerships with key stakeholders, and governance (Figure 5).

Fig. 5: Focus areas for the future mine (Holland, 2018)

The mining curricula of the two universities in the three disciplines are more inclined towards operating practices and few courses are offered in the areas of talent and leadership, partnerships with key stakeholders, and governance (Banda and Besa, 2021). However, even courses that speak to operational practices and technology will need to undergo restructuring to respond to the future needs of the mining industry. For instance, there is a need to include components of machine learning, big data, data science, and other courses that are essential for the digital mine. Although the future mine will heavily rely on operational practices and technology the mineral scientists must be trained in the area of governance to ensure that the technologies operate under the prescribed laws and regulations. Courses in talent and leadership will ensure that mineral scientists work in multidisciplinary teams to achieve the organizational objectives of future mines. Courses in talent and leadership will also equip mineral scientists with entrepreneurial skills to form their start-ups in the future. Additionally, courses in partnerships with key stakeholders are essential to ensure that mineral scientists working in the future digital mine can partner with other players including Original Equipment Manufacturers (OEMs), and other companies offering different technologies. These companies must be able to deploy technologies that respond to the needs of the mineral scientist in the future digital mines. Looking at this backdrop, the two Universities need to introduce some courses in governance, talent, and leadership, as well as partnerships to fully equip graduates with the skills of the future mine.

Apart from the curriculum, other challenges have impeded the two universities from offering high-quality mining education. Therefore, these need to be resolved now to ensure that the institutions produce graduates that will be relevant for the future mine. The challenges include the limited interaction between the training Institutions and the industry. However, this has started to change because the two Universities have developed programmes that they are now offering to the mining companies. However, this interaction should not only end at teaching but encapsulate collaborations that are centered on consultancy and research. The other challenge is the lack of laboratory infrastructure to support research and consultancy. Due to this fact, most mining companies prefer to engage foreign Universities for consultancy and research. The other challenge that the two Universities face is the limited interaction with the government. This has subsequently led to a drop in scholarships. In a rational sense, there is need for a triple helix synergy among the three players (Figure 6). Industry must be able to communicate with universities on the numbers and skills needed for graduates to successfully run mining enterprises. Secondly, the University must be able to feed this communication to the government to assist in Scholarships and funding of laboratory infrastructure. Lastly, the government should interact with mining companies for engaging in fundraising activities to raise finance to support the



Universities. The training institutions should also develop expert advice on issues of policy formulation that will lead to a vibrant mining sector

Fig. 6: Triple Helix synergy of training institutions, government and mining industry

6. Conclusions and Recommendations

In the near future, mining will undergo an immense transition from being conventional to being mechanized. At the heart of this mechanization, autonomous mining systems shall be fully embraced to increase the productivity, safety, and profit levels of mining ventures. The question is whether mining education institutions in Zambia have curricula that will meet the demands of the future mining industry. In meeting the skill sets of the future mine, Zambian mining institutions will need to establish state-of-the-art research centers and experimental mine sites, and incorporate courses in their curricula that meet the demands of the future mine. In achieving this, triple helix synergies of government-industry-mining companies need to be strengthened. There is a need to review Mining Curricula at UNZA and CBU to include topics such as machine learning, data science, and big data to manage the transition from the status quo to the digital mine. These areas will help to impart critical and analytical thinking, interpretation of data, and problem-solving skills to the graduates for the future Mine. Modern mining companies are capital- and technology-intensive, with complex processes and industrial systems. Prerequisites to succeed in the digital world and transform the next-generation mine include the capacity to enable technologies and systems engineering, and innovation. Although the future digital mine will be highly skewed toward operating practices and technology there is a need to focus on the other three areas to train graduates who will successfully manage the future mine as put forward by Holland (2018). Therefore, the two Universities need to include courses that are centered on governance, talent and leadership, and partnership with key stakeholders.

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Sustainable economic transformation through quality assured engineering projects: A Case study of biogas technology deployment by Verde Technology in Zambia

Patrick Mubanga[1] and Charles Zemba Moono[2]

Abstract

Over the recent years it has been observed that biogas technology as a source of power supply has been underutilised despite its numerous benefits. The low deployment of the technology can be attributed to a number of factors such as high upfront cost of installing biodigesters, limited access to credit facilities, insufficient numbers of skilled biodigester experts to mention a few. It is against this background that this paper discusses the challenges faced during the deployment of biogas technology by a company called Verde Technology Limited. The question is why is there underutilization of the technology despite the abundant feedstock and the potential benefits. It is envisaged that promotion of the technology would provide checks and balances that would endorse quality assurance for biogas technology as an engineering project. Quality assurance is fundamental to ensuring that the technology delivers according to the design requirements. The harnessed gas would be used for power generation, cooking and heating as well as provide an income through the sale of bio-slurry. These benefits would go a long way in improving the sustainable economic transformation at community level. In terms of the methodology, the study undertook a comprehensive in-depth desk review of documents and other related literature to the subject of the study. The paper recommends the need for appropriate management of the biogas plant to ensure effective production of the gas for electricity and bio-slurry. Further, the paper also proposes a number of other recommendations that can be deployed to promote the effective promotion and adoption of the technology.

Keywords: Technology, biogas, bio-slurry, sustainable, engineering

1.0 Introduction

This study seeks to evaluate Zambia's sustainable economic transformation through quality assured engineering projects: A Case study of biogas technology deployment by Verde Technology in Zambia. The following sections will introduce the study.

1.1 What is biogas technology?

According to Mandelli *et al* (2016) biogas is defined as a renewable, as well as a clean source of energy and the gas generated through bio digestion is renewable, as well as a clean source of

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energy. The technology provides hygienic treatment of solid waste and wastewater and generation of clean energy for power and heat production which also contributes to nutrient-rich fertilizer (digestate) for agricultural usage (Lamolinara *et al*., 2022)

The production of biogas can reduce the need to import fossil fuels and substitute for inorganic fertilizer, which requires large amounts of energy to produce which in turn could enhance national energy security. It can also provide clean energy to rural and isolated communities, contribute to the reduction of greenhouse gas emissions and create new job opportunities in rural communities (International Labour Organisation, 2021).

The technology used to produce biogas is cheap and easy to set up and requires little investment when used on a small scale. Small biodigesters can be used right at home, utilizing kitchen waste and animal manure. The gas produced can be used directly for cooking and generation of electricity and this allows the cost of biogas production to be relatively low (International Larbour Organisation, 2014). Thus, customers such as farmers can make use of biogas plants and waste products produced by livestock and poultry.

Shackleton *et al* (2015) states that biogas technology promotes sustainable economic development which could help a nation to grow in ways that adapt to the challenges posed by climate change which in turn will help protect important natural resources for the present and future generations. According to (*Ibid*), the concept has the following main features:

- Improving the quality of human life.
- Minimizing the depletion of natural resources.
- Minimizing pollution levels.

In order to enhance sustainable economic transformation in biogas technology, quality assurance has to be adhered to. This will therefore help to ensure that the technology meets quality standards before deployment (Verde Technology, 2021).

Bearing in mind the pillars of sustainable economic transformation and quality assurance, there are number of benefits to be harnessed from the biogas technology (Akbas, 2015). However, despite the numerous benefits there are a number of factors that affect the effective deployment of the technology. Consequently, in order to navigate through the challenges, lessons have been learnt by the players in the sector on how to deploy the technology.

2.0 Literature Review

This section of the report reviews the literature on the Sustainable economic transformation through quality assured engineering projects: A Case study of biogas technology deployment by Verde Technology in Zambia. The literature was reviewed in order to bring together strands of knowledge on the subject that has been developed in isolation. The following sections provide information on the study based on the literature reviewed.

2.1 What is Verde Technology?

Verde Technology Ltd offers renewable solutions and energy products. The company has been in operation for the last two years. The firm is committed to the delivery of environmentally friendly energy solutions throughout Zambia and Sub-Saharan Africa. In order to promote sustainability and cost savings, the company offers renewable energy, waste management and supply chain services (Verde Technology, 2020). The firm recognizes the need to move towards renewable, circular economy technology that utilizes the natural resources available. The company's aim is to reduce the volume of waste produced and add value to waste streams, stimulating the economy, minimizing environmental degradation, and reducing the amount of waste directed to landfill sites (Verde Technology, 2020).

2.2 EPC Projects

As an Engineering Procurement and Construction Contract (EPC) company in the solar industry, Verde Technology offers services in engineering, procurement, and construction. The company provides end-to-end solar energy services, including designing, procurement equipment and installation. Further, after installation, the firm provides after services such as undertaking regular checks and continuous maintenance to ensure the system works at optimum efficiency (Verde Technology, 2020).

2.3 Renewable Energy & Waste Management Projects

The company specializes in a range of renewable energy and waste management products and services, ranging from biogas digesters to plastic recycling machines (Verde Technology, 2020). The firm provides circular economy solutions which add value to waste streams that lead to dumping and the subsequent environmental, social and economic impacts. Another product offered by the firm is the zero-waste toilet. The toilets ensure the safe management of human waste by breaking down faecal waste through micro-organisms and bacteria converting the waste into water, fertilizer and a harmless, odourless gas (Verde Technology, 2020).

2.4 Cold Storage and Blast Freezing

The firm manages all aspects of cold chain management, including blast freezing, cold storage and transit/distribution. Utilizing expert technology and logistics, the company is able to meet consumer demands for ice and refrigeration at decentralized locations across Lusaka to optimize distribution and capacity.

2.5 Digester and zero waste toilets

The biodigester and zero waste toilets are further explained as follows:

2.5.1 Biogas Digesters

Digester can be constructed at domestic and commercial sites and the sizes can range from $6m^3$ to $50m^{3.}$ These systems convert any organic waste items such as kitchen/food waste or animal manure and into valuable waste products. Based on the 9m cubed system, it can produce 2,000 - 3,000L of biogas per day at full capacity.This produce cooking gas for between 2-6 homes or between 10-20 individuals eating three meals per day. This would offset up to 426kg of charcoal every month. Based on the flagship M50, the system can offset 7100kg of charcoal a month and when offsetting LPG gas, the system can reduce the need to purchase up to 45kg of LPG per month if run optimally. This is the equivalent of approximately K1, 900.00 or $106.12 monthly. The system can also produce 120-180L of liquid fertilizer per day. This equates to the same volume of nitrogen in 0.24 – 0.32 bag of 50kg chemical fertilizer. This could be capable of generating $2,500.00 - $3,670.00 in one year if sold at only 1 kwacha per litre (Verde Technology, 2020). Figures 1a and 1b show C25 medium commercial biogas digester and D9 digester for domestic use while Table 1 shows digester designs and system dimensions characteristics

The technology has been rigorously designed to ensure sustainability within the African market. They are constructed locally and made from readily available materials which ensure the product, and its supply chain can be flexible and affordable. The material use is highly durable and suited to the African environment and they can all be assembled and maintained by local technicians (Verde Technology, 2021).

2.5.2 Zero waste toilets

The systems are designed primarily as hygienic toilet that also captures all the gas potential in human waste. With a retention time of no less than 90 days, the overflowing bio-slurry is fully broken down. Anaerobic digestion deactivates pathogens and parasites; thus, it's also quite effective in reducing the incidence of waterborne diseases. Similarly, waste collection and management significantly improve in areas with biogas plants. This in turn, leads to improvements in the environment, sanitation, and hygiene. Biogas which is Eco-Friendly is unlike other types of renewable energies which can create energy for power generation and heating. The raw materials used in the production of biogas are renewable and can be used as a fertilizer which is a highly sustainable option. The enriched organic digestate (fertilizer) is a perfect supplement to, or substitute for, chemical fertilizers. The fertilizer discharge from the digester can accelerate plant growth and resilience to diseases, whereas commercial fertilizers contain chemicals that have toxic effects and can cause food poisoning, among other things.

The Zero waste toilets ensure complete digestion of the waste in an anaerobic environment which means the waste does not build up. The system never has to be emptied, negating the need for expensive maintenance or the use of a vacuum truck (Verde Technology, 2020).

2.5.3 Benefits of biodigesters

Based on the products that are offered by the company, the paper focuses on biogas digesters. It is designed to provide gas for cooking purposes from animal manure, food waste and other organic material. The gas can also be used for powering lights, heat and even stand-by electricity by running a small biogas fuelled generator, thus eliminating the need to burn fossil fuels, namely charcoal or LPG. Further, a digester also generates organic fertilizer that enhance soil quality and the nitrogen, phosphorus and potassium in the soil, improving growing vegetables and other food crops while contributing to carbon mitigation through the displacement of environmentally hazardous methane gasses from entering the atmosphere.

(a) (b)

Figure 1: a and b: C25 Medium (Medium commercial biogas digester) and D9 Digester (Domestic biogas digester): Source – Verde Technology 2019 Annual Report.

Table 1: Digester designs and system dimensions characteristics: Source – Verde Technology 2019 Annual Report.

Option	D9 System	C15 System	C25 System	C50 System
Area	13.2m^2	22.5m^2	37.5m^2	77.7m^2
Max feed rate (per day)	20-60kg	250-280kg	400kg	800kg
Max gas output (day)	2,000L-3000L	15,000L	25,000L	50,000L
Charcoal offset (month)	150-426kg	1,065-2,130kg	1,775-3,550kg	3,550-7,100kg
Rural Catering	15-30 People	105-150 People	180-250 People	355-500 People
Urban Catering	10-15 People	75 People	125 People	250 People
LPG Offset per month	45kg	225kg	375kg	750kg
Liquid Fertiliser per day	120-180L	500-750L	800-1,200L	1,600-2,400L

The domestic biogas system is capable of digesting approximately 50kg of waste per day and providing gas for ten to twenty people eating three meals per day. The highly efficient and durable biogas systems take any organic waste items such as kitchen/food waste, animal manure or crop residues and convert them into valuable biogas and liquid organic fertilizer. The microorganisms in the container break down these organic items producing a clean and efficient fuel that can provide gas directly to cooking equipment. This provides an alternative to the use of charcoal and other energy intensive and polluting fuels. The biogas systems have an unmatched efficiency of waste-to-gas, which means they are not just a clean cooking solution but can be used as a substitute for conventional fuels fit for any purpose (Holm-Nielsen et al., 2009). The next section outlines the lessons learnt during the deployment of biogas technology by the company.

3.0 Methodology

This section of the report highlights the research methodology that was used in understanding how biogas technology deployment by Verde Technology in Zambia is contributing to sustainable economic transformation through quality assured engineering projects.

The research design adopted for this study was descriptive, which is a fact finding investigation with adequate interpretation (Kothari, 2004). The motivation for choosing this type of research design was that it was more specific than an exploratory and correlational study, as it focused on the particular aspect of the problem of the study.

The type of data collected for this study was qualitative in nature and based on the objective of the study. The qualitative data was obtained through the utilisation of secondary data to satisfy the objective of the study. The secondary data collection involved a comprehensive literature review on the research topic from published materials such as books, journals, internet and other relevant sources concerning this study. The reason was simply because these materials have a rich base of information and the fact that they were written by different individuals with different views. This gave the researcher a wide base of information to choose from and gain a broader understanding of the topic

4.0 Lessons learnt during the deployment of biogas technology

During the two years operation, a number of lessons have been learnt during the deployment of biogas technology over the two (2) years of operation. These lessons learnt have helped to make improvements and adjustments to the deployment of the technology. Some of the lessons learnt include high biodigester installation costs, lack or limited access to credit, inadequate numbers of skilled biodigester technicians, lack of awareness or limited information on biogas technology to mention a few. These challenges are discussed as follows:

4.1 High upfront cost of installing biodigester

Over a period of two years, the company has been monitoring the installation process and feedback from customer based on the assessments, approximately 80% of the customers are of the view that the biodigester technology tend to have a high upfront cost of installation and this was considered to be one of the major barriers that had hindered adoption among potential customers. According to Kalinda (1995), high investment costs in installing biogas units were blamed for the low adoption rates in many developing countries. Based on the study by (*Ibid*), it was observed that both the perceived cost and actual costs acted as barriers to the adoption of the biodigester technology. However, some farmers especially the ones involved in poultry and piggery were appreciative of the technology considering that it reduced the operational costs.

4.2 Limited access to credit facilities

Bearing in mind the high initial cost and coupled with the lack of credit financing arrangements have also contributed to the slow uptake of biogas technology among the potential customers. Financial credit facilities rarely give out loans for the sole purpose of agricultural or energy investments such as meeting the costs of constructing a biodigester. The terms and conditions demanded by lending institutions are unattainable to most customers. However, based on the study conducted by Kalinda, (2019), the study reviewed that it was not easy to obtain loans and this was mainly attributed to high interest rates charged and the reluctance by credit institutions to lend money to customers who lack collateral in form of title for the land they own.

In view of the above, it may be perceived that if lending institutions provided loans with low interest rates for the construction of biogas, many customers especially poultry and piggery farmers including a number of households could adopt the technology.

4.3 Insufficient numbers of skilled biodigester experts

The limited availability of well trained and skilled biogas experts such as masons or technicians has been observed to be another barrier attributing to low uptake of the technology. The few skilled biogas masons or technicians involved in construction and maintenance of the biodigesters may be operating in particular areas and this may increase transaction costs for new customers who may be located in non-operational areas. Over time, most customers have perceived that the lack of locally trained biogas technicians to have contributed to the slow adoption of biogas technology in their communities. Consequently, in order to increase adoption of biogas technology, there is need to have adequate numbers of trained masons or technicians at community level. The experts can therefore construct and provide quality services for any interested clients at a reasonable cost. Thus, in order to achieve this level of satisfaction, there is need to train a number of masons or technicians at community level in biogas installation, operation and maintenance (Gomez, 2013).

4.4 Absence of awareness and limited information on biogas technology

Lack of awareness and limited information on the benefits of biogas technology among communities is another major obstacle. However, from experience, the lack of awareness varies from one type of customers to another. As earlier mentioned most farmers especially the ones involved in poultry and piggery have adopted the technologies with open arms and as mentioned earlier, these types of customers can be used as ambassadors of the technologies.

In areas where biogas has been introduced and demo plants installed, the community around would acknowledge and appreciate the technology and also appreciate the details on the cost, availability of the equipment, materials required and general technical guidance needed for one to get started. Customers housing demo plants appear to be well versed and able to promote the benefits of the biodigester technology. According to Bhat *et al*. (2001), lack of awareness of the value of biogas has been attributed as an inhibiting factor in the uptake of this technology in India.

4.5 Negative attitude towards biogas technology

Most of the potential customers who have not gained access to biogas technology have a perception that biogas is a dirty thing since it is produced from animal waste. However, after witnessing a functional biodigester, most of these customers are normally motivated to adopt the technology. Demonstration plants help to lower uncertainty and also stimulate peer discussion among customers on the merits of the technology. In addition, negative publicity of biogas technology is as a result of poorly functioning biodigesters and this can also be a major difficulty faced by the biogas technology technicians (masons) in promoting the technology. One key barrier in the development and dissemination of biogas technology in many developing countries is wrong operation and poor maintenance by the users creating a bad image of the technology to non-users (Kalinda, 2019).

4.6 Regulatory and institutional barriers

Establishing biogas plants would require organizational capability and initiative. According to (Okello *et al*. (2013), countries that have strong institutional support to biogas, energies programmes have registered significant success in promoting the technology. In countries where renewable energy policies are in place, there is often a general lack of coherent strategy in place to promote commercial biogas technology (Parawira, 2009). For example, a 300-kW biogas energy plant in Dar es Salaam, Tanzania underwent vigorous planning and was supposed to generate 7.08 MWh/d of electricity from 2368 m^3 of methane per day (Mbuligwe *et al*., 2004). The plant failed to take off due to what was described as 'bureaucracy'. The institutional structures failed to come to a consensus on the actual direction for the project, whose main aim was to produce biogas and serve as a model for other urban areas (Parawira, 2009).

4.7 Research and Development

Research and Development (R&D) should be at the heart of biogas programmes and countries that what to see progress in the technology should embarrass R&D. For example, in India, a *"Biogas development and training centre"* had been instituted under the National Biogas and Manure Management Program to implement monitoring of biogas installations. Further in China, the Biogas Institute of the Ministry of Agriculture (BIOMA), is part of the Chinese Academy of Agricultural Sciences (CAAS), focusing on issues like fundamental research on anaerobic microbiology and design of biogas projects (Langeveld *et al*., 2018). Furthermore, countries like Germany and the Netherlands have emphasized the vital role that research and development has played in shaping their biogas sector.

Research support is much less intense in most African countries, as governments fail to fund research activities to support the technology (Mengistu *et al*., 2016). However, where there is research in Africa, there is a lack of coordination. For example, a study in Ethiopia, for instance, found that *"despite the existence of various research trials, both at private and institutional levels, they were fragmented and lacked continuity"* (*Ibid*). Consequently, ongoing research must identify, prioritize, and coordinate relevant research activities so that the limited resource available is optimized (Mshandete *et al*., 2009).

In view of the above, the Ministries in charge of agriculture, energy, environment, innovation, science and technology, must allocate funding from their respective budgetary allocations to boost research into biogas systems and help scale up biogas production which has the potential to provide power generation and job creation.

4.8 Other support systems

One of the factors that could spear and fast track the development of the biogas technology is for Government to deliberately come up with suitable long-term objectives with appropriate planning and strategies in order to nurture biogas development (Mukisa et al.,2022); Brunner *et al*., 2015). As observed by Parawira, (2009), *"new technologies often need to be nurtured for over decades, before sufficient socio-technical momentum emerges, and alignment between the technical, economic, regulatory and social context can provide the basis for building up momentum until the biogas technology can survive on its own"*. Therefore, Government should take the lead to provide suitable long-term objectives with appropriate planning and strategies.

5.0 Conclusion

Organic resources such as crop and animal waste, municipal and industrial wastewater, and municipal solid waste can be harnessed in commercial biogas plants to supplement power supply for internal consumption and excess fed to the grid. If properly managed, the biodigester plant could produce biogas that can supplement solar, wind, hydro and other renewable energy resources towards achieving energy security in the country and could serve as base loads in areas where the grid has yet to reach. Further, Biogas technology can also be used as an income generating activity through the sale of bio-slurry by some farmers. However, despite the advantages or benefits associated with utilization of biogas, over the years, very few potential customers have adopted the technology. Nevertheless, the lessons learnt over the years would provide a podium for the effective development and management of the technology and this would therefore require not only technical expertise but also serious attention to economic, energy and environmental policies.

6.0 Recommendations

In view of the lessons learnt over the years, the following are some of the recommendations that could be adopted to promote the promotion and adoption of biogas technology.

(i) There is need to consider enhancing sensitisation for potential customers on the benefits of biogas technology. This could be done through the combined efforts of the government through the line ministry extension services, private sector and NGOs such as SNV.

(ii) Lack of access to credit facilities is a major bottleneck to adoption of biogas digesters among potential users. The households could be encouraged to form or join cooperatives that could be used to solicit for financial support. Alternatively, based on member contributions, these institutions could offer credit facilities to its members. Further, the cooperatives could also be used as focal points for training members on biogas technology and this could go a long way in providing the needed skills for designing, developing and maintaining the biogas plants. This could help create a pool of qualified personnel at local level and the presence of trained biogas technicians would help reduce construction cost.

(iii) As part of R&D, various learning institutions especially universities could intensify and focus on research and development. Further, Government could focus on promoting training and capacity building programmes that could create links between research institutions and potential beneficiary industries. The strategy could benefit the private sector through capacity building and could also stimulate public-private partnerships where private companies and government agencies can tap into each other's strengths and complement their weaknesses. The strategy could also help address the challenge of limited number of skilled biodigester personnel

(iv) As mention above one of the factors that could spear and fast track the development of the biogas technology is for Government to deliberately come up with appropriate long-term objectives with appropriate planning and strategies to nurture biogas development. New technologies need to be nurtured over a period of time, before sufficient socio-technical momentum emerges and alignment between the technical, economic, regulatory and social context can provide the basis for building up momentum until the biogas technology can survive on its own. Further, Government partnerships with the private sector are crucial for successful development of the technology. Further, governments should take necessary steps to uplift biogas utilization through existing programs and facilities, and improve harmonization and communication between public and the private sectors. This approach could also help address the lack of awareness or limited information on biogas technology and lack of interest in biogas technology.

(v) Government could consider subsidizing the initial cost of installing biodigester installation costs by working with credit facility institutions. Consequently, in order to promote sustainability, potential customers could be encouraged to make contributions towards the installation costs.

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Subtleties of the off-grid standalone solar power supply system

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Abstract

Standalone solar-photovoltaic (PV) system comprise of PV panels, charge controller, battery bank, and inverter with electric power generated by the PV panels when exposed to the sunlight giving rise to voltage and current in a process called photoelectric effect. The PV modules arranged in series increase voltage and paralleled series strings increase current to achieve the required output power. In operation, the power generated by the panels during sun hours period must meet the load demand and battery storage in such a way the whole system operates as a well balanced system without excess generation or excess demand at all times. When not well balanced the system is inefficient and when demand exceeds supply the system eventually fails to meet the load requirement during times of low irradiation and at night and when panels produce more than the load demand and storage, power is lost and the system may be unnecessarily expensive. This problem is often experienced when designs and sizing is only based on manufacturer's specifications of batteries and panels. For the design of a well balanced PV system, careful consideration of metrological factors of temperature and insolation variations of the location of installation must be included in the sizing algorithms of the batteries and panels in proportion to the load demand. This situation has been observed when evaluating some installation operation problems in Zambia where systems operate irractically. The paper alludes to the observed and evaluated system perfomances that did not meet the desired operation and proposes the design of well balanced PV systems that takes into consideration in addition to the manufacture's specifications of batteries and panels, the effects of temperature and insolation of the installation location. . Inclusion of the equations that takes into account these parameters in the system design will enable the system to automatically adjust to variations of these parameters thereby making the system operation reliable.

Keywords: Standalone solar-photovoltaic, temperature and insolation, PV array , battery-bank, photo-electric effect, loading effect.

1. Introduction

It is without doubt that energy is a necessity for life at all levels (fauna & flora) though usage varies. On the modern human scale, energy is utilised primarily for economic sectors of domestic, commercial and industrial efforts that impact on national development. However, when looked at basic level of utilization, energy is used for preparation of food, keeping warm and lighting. On a broader scale, this statement can be categorised to make reference to developed and developing

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countries and when viewed from this standpoint it can be inferred to the fact that there is a correlation between the level of energy consumption and the level of national development when comparing energy usage of developed countries to developing countries. Conversely the contrasts are equally glaring when comparing developing countries urban and rural disparities in distribution and access to energy. (Cabraal 2005).

In general however, in the last decade global population access to electricity has increased but the number of people in the sub-Saharan Africa without access has actually increased threatening to miss the target of ensuring access to affordable, reliable, sustainable and modern energy by 2030 (Namukolo & Zulu 2017) the objective of the UN SDG7. The tone set out by the SDG7, objective is mainly in the increased use of renewable energy forms of solar, wind and biomass. (cabraal(2005)

While it remains a challenge to provide electric power to rural population in most African countries, the emergency of renewable technology has brought about renewed hope of increased rural electrification when compared to the costly utility electrification. From this renewable mix, solar systems is gaining increased acceptance as the preferred source, as cost of components that make up the systems have been continually reducing and system have proven reliable and efficient.(Cabraal 2005)

From the point of view of most African countries, the challenge of efficient, reliable and sustainability is brought about by lack, of technical skill and good understanding of the design, sizing, installation and protection of the systems. (https://trackingsdg7.esmap.org). These challenges of lack of fine tuned skills have resulted in poor installations that do not operate reliably. After evaluation of several of the installed systems, the most likely cause of unreliable operation arrived at is the omission of the inclusion of temperature and insolation variation in the design and sizing of the systems. To redress this problem of unbalanced solar system, this paper paper highlight the need of careful inclusion in the design, the effects of temperature and insolation at the location site of installation. It highlights the equations and how they are used in the design. When taken into account the system will be balanced, self regulating and operate reliably.

2. Standalone off-grid PV system

Mini-Grid PV system are either categorised in three types, standalone, grid connected and hybrid of which the standalone is mostly used for rural area applications. It consists mainly of four parts, the PV panels, charge controller, battery bank and the inverter (SIE,2004) as shown in figure 1.

2.1 PV Modulus

The main components of a solar system are the solar PV modules aso called panels. When exposed to sunlight, photons from the sun spectrum dislodge electrons from the p-n material of the solar cell which in turn create voltage that appear as open voltage (V_{oc}) across the cell and the electrons flow in shorted terminals as short circuit current (I_{sc}.) Solar cell exhibits ideal diode behaviour in dark and solar cell current source when exposed to sunlight. Three main types of solar cell are monocrystalline silicon, amorphous silicon and polycrystalline silicon.

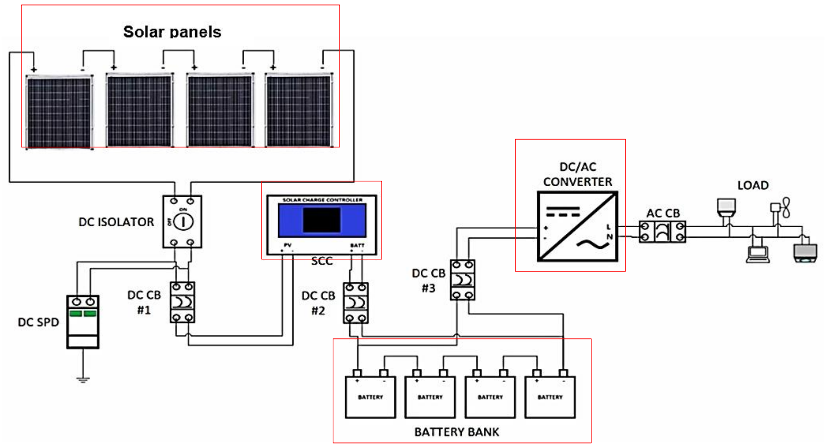

Figure1. four components of solar system

2.2 Charge controller

Solar system charge controller is an interface between PV panels and the battery- bank. It mainly works as a step down converter to convert the high panel's voltage to steady changing battery bank terminal voltage and makes sure that the battery is not undercharged or overcharged. Recent designs incorporate an Maximum Power Point Tracking (MPPT) algorithm a mechanism that tracks the maximum output from the PV array for maximum efficient operation at the particular irradiation level. Other functions of the MPPT charge controller include monitoring battery bank temperature.

2.3 Battery- bank

PV modules are only functional during the day when the sun is shining and they generate current at a specific voltage from the cell mechanism of photoelectric effect. At night or during the times when the sun is not shining no current is generated. This variability of power fluctuation is not acceptable by the load. To guarantee steady operation of the system at all times, energy is stored in the battery bank that is seamlessly accessed during the times of overcast conditions and at night. It is an interface between the energy sources of the PV panels and also serves to stabilise the output voltage that is supplied to the inverter and the DC load.

2.4 Inverter

The inverter converts incoming DC power to AC power for the utilization by the load. It is well noted that most appliances use AC power and when applied to solar systems new energy efficient appliances are being manufactured that are optimised for utilization by solar systems. The common output voltages from the inverters are 240VAC, 50HZ for single phase and 400VAC, 50HZ for three phase inverters. The internal mechanism of conversion is DC to AC conversion utilizing full bridge conversion and producing a pure sinusoidal output waveform.

2.5 Other requirements

Other important requirements for a stand-alone solar systems, are those additions that would make it sustainable, resilient and reliable in operation. From the point of view of installations, protection is of paramount importance. For systems that are installed in tropical regions where lightning is high, carefully designed lightning protection systems (LPS) is mandatory, and carefully coordinated with good earthing, bonding and surge protection.

3. A closer look at PV modules and batteries

PV modules are constructed from doped silicon base materials to form a solar cell. In the doped state the p-n material rearrange itself to form a depletion region with a voltage set across the region. In the dark, the cell is equivalent to diode displaying exact diode characteristics of forward and reverse biasing, whose current voltage relationship are also dependent on temperature. It is the temperature dependence that has an effect on PV module performance as will be discussed. It is also prudent to evaluate the effect of the insolation especially as it relates to the particular site of installation.

Batteries as has been alluded to above are utilized for electric power storage. In storing this energy, the battery is charged at a specified charging voltage at some given current for some specified time implying conversion of current to coulomb that is stored in the battery as understood by the specification of Amp hour (Ahr). In the main the battery operation is chemical in nature. Conversely, during periods of drawing power from the battery, current is drawn from the battery, thereby reducing on the number of stored coulombic charges. In both charging and discharging phases, chemical reactions take place. In the ensuing sections allusion to good practices that will guarantee the wellbeing of the operation of batteries thereby prolonging their life cycle will be highlighted. Since lead acid are still predominant batteries used and whose history is fairly well understood our discourse will be cantered on them.

3.1 Lead-acid batteries

Deep discharge lead acid batteries utilized in solar systems are fabricated with big plates housed in bigger containers to reduce the effects of plate contamination. These batteries can be cycled at 80% Depth of Discharge (DOD) but with lower life. When cycled at 25% DOD of its rated capacity, life cycle can be considerably increased up to 10 years. However, if DOD of 50% is used the life time can be reduced by half. It is clear therefore that if battery banks are sized to hold 4 to 5 days of daily energy demand this will reduce cycling and prolong battery life. Sulfation is the main cause of the shorted battery life, which occurs during each charge and discharge cycles. Keeping batteries as fully charged as possible mitigates against this problem.(Masters, 2013)

3.2 Battery capacity storage

Energy storage for batteries is specified in ampere-hour (Ahr) which alludes to the amount of coulombs of charge stored in the battery container at specified terminal voltage. From the manufacturers specification this includes discharge rate factor. The discharge rate is a figure given in terms of time required to drain the battery at 25^0C stated as (C/T) where; C is the battery capacity in Ahr, and T is time in hours required to drain the battery completely. Table 1 Shows an example of selected batteries showing the C/20 rates terminal voltage and weight.

Table 1: Deep- Cycle Lead-Acid Batteries Characteristics

Battery	Electrolyte	Voltage	Nominal Ah	Rate (h)	Weight (lbs)
Rolls Surette 4CS-17P	Flooded	4	546	20	128
Trojan T10S-RE	Flooded	6	225	20	67
Concorde PVX 3050T	AGM	6	305	24	91
Fullriver DC260-12	AGM	12	260	20	172
Trojan 5SHP-GEL	Gel	12	125	20	85

(Masters, 2013)

Batteries capacity (Ahr.) depends on both time rate of discharge and temperature as shown in figure 2 where capacity under varying temperature and discharge rates with reference to C/20 at 25^0C. From the figure C/20 reference capacity is 100% at 25^0C but its capacity would have reduced to almost 50% at temperature of -30^0C. Interestingly, at higher temperatures the capacity increases. However this is detrimental to the battery as by estimates every 10^0C increase beyond 25^0C optimum temperature, life of the battery is shorted by 50%. From the foregoing discourse, it is important therefore when sizing the battery bank to adjust the capacity taking into account the operating temperature and discharge rates.

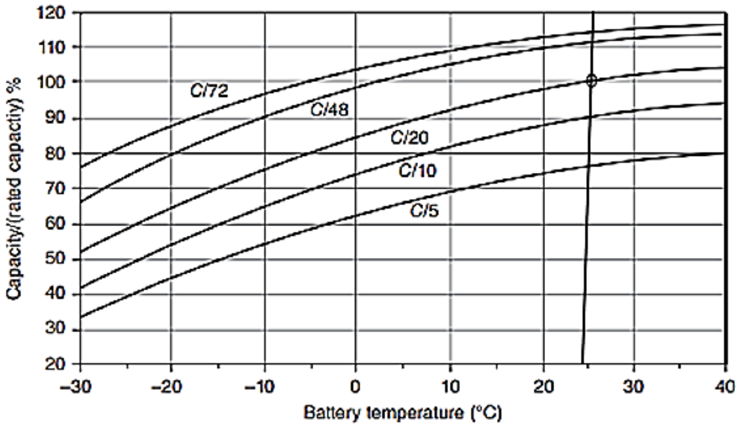

Figure 2. Lead–acid battery capacity depends on discharge rate and temperature. The capacity at C/20 and 25◦C.(Masters, 2013)

Another important point to observe when configuring batteries is the arrangement of the bank. To achieve the required total capacity of a battery-bank at a given terminal voltage, batteries are wired in series that increases their string voltage, but with the capacity of a single battery and to increase the capacity the strings are wired in parallel.

3.3 Solar cell model

Tigure 3. is a simplified model of a solar cell showing a current source (I_{SC}) that is proportional to the solar irradiation. Two important parameters are, the open circuit voltage (**V_{OC}**) seen across the open terminals, and since the circuit is open no current flows, and the short circuit current

(**I_{SC}**) flowing when terminals are shorted in which case the voltage across the terminals is zero. **V_{OC}** and I_{SC} are the main parameters that are affected by insolation and temperature variations.

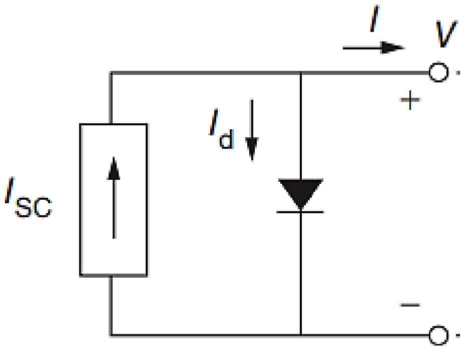

Figure 3. Simplified Solar cell model consisting of a current source and diode.(Masters ,2013)

Figure 4 shows graphical IV curves giving summary of the important solar cell characteristics listed as open circuit voltage, short circuit current, maximum power, maximum current at maximum power and fill factor.

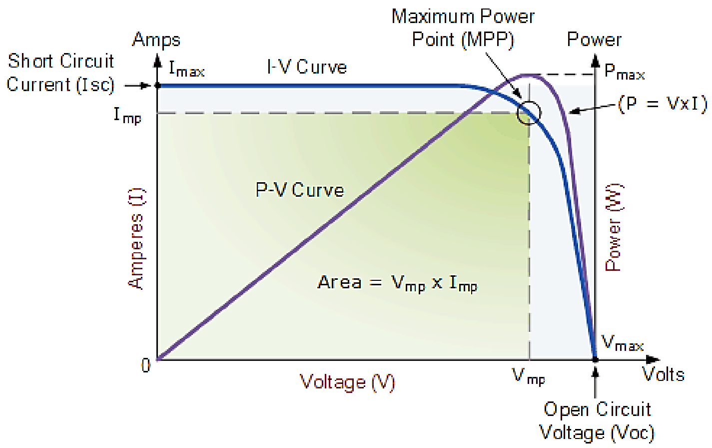

Figure 4. Solar cell IV curves and power output graph with maximum power point. (MPPT) (Martens2019)

Current voltage relationship can be derived from the model of figure3 as follows

$$I = I_{SC} - I_d \tag{1}$$

And substituting for the diode current expression

$$I = I_{SC} - (e^{\frac{qV}{kT}} - 1) \tag{2}$$

From the above equation for I = 0, open circuit voltage is

$$V_{OC} = \frac{kT}{q} \ln(\frac{I_{SC}}{I_0} + 1) \tag{3}$$

Thus deriving the important parameters of the solar cell model of the short-circuit current I_{SC} and the open circuit voltage V_{OC}.

3.4 Temperature and radiation effects on IV curves

The IV curves as given in Figure 5.show that short circuit current I_{SC} is directly proportional to irradiation intensity with very small change in the open circuit voltage. On the other hand I_{SC} increases very little with temperature while the V_{OC} decrease is significant. Table 2. shows the effects of temperature on some PV modules from various manufacturers.

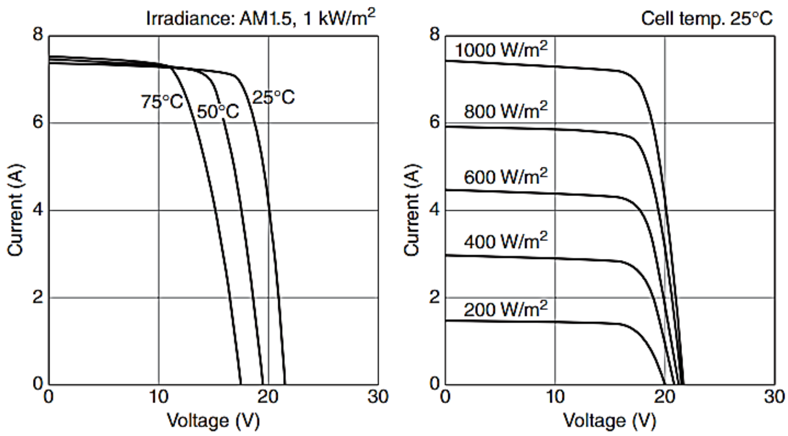

Figure 5: Current–voltage characteristic curves under various cell temperatures and irradiance levels for a Kyocera KC120-1 PV module.(Masters, 2013)

TABLE 2. Examples of PV Module Performance Data under Standard Test Conditions (1 kW/m2, AM1.5, 25◦C Cell Temperature) (Masters, 2013)

Manufacturer	SunPower	Yingli	First Solar	NanoSolar	Sharp
Model	E20/435	YGE 245	FS Series 3	Utility 230	NS-F135G5
Material	c-Si	mc-Si	CdTe	CIGS	a-Si
Panel efficiency	20.1%	15.6%	12.2%	11.6%	9.6%
Rated power P_{MPP} (W_p)	435	245	87.5	230	135
Rated voltage V_{MPP} (V)	72.9	30.2	49.2	40.2	47
Rated current I_{MPP} (A)	5.97	8.11	1.78	6	2.88
Open-circuit voltage V_{OC} (V)	85.6	37.8	61	50.7	61.3
Short-circuit current I_{SC} (A)	6.43	8.63	1.98	6.7	3.41
NOCT (°C)	45	46	45	47	45
Temp. Coeff. of P_{max} (%/K)	−0.38	−0.45	−0.25	−0.39	−0.24
Temp. Coeff. V_{OC} (%/K)	−0.27	−0.33	−0.27	−0.30	−0.30
Temp. Coeff. I_{SC}(%/K)	0.05	0.06	0.04	0.00	0.07
Dimensions (m)	2.07 × 1.05	1.65 × 0.99	1.20 × 0.60	1.93 × 1.03	1.40 × 1.00
Weight (kg)	25.4	26.8	15	34.7	26

Irradiation falling on cells is not all utilised for electricity conversion, significant amounts of irradiation end up converted to heat in the cell. To account for effects temperature and

irradiation on the performance of PV modules manufacturers provide a factor called nominal operating cell temperature (NOCT) described as the expected temperature in module, when ambient is 20^0C, solar irradiation is 0.8kWhr./m^2 with a wind speed of 1m/s. The final expression used to account for these effects being

$$T_{CELL} = T_{amb} + (\frac{NOCT - 20}{0.8}).S \quad (4)$$

Where T_{CELL} is cell temperature

T_{amb} is ambient temperature in (^{0}C) and

S is solar irradiation (kW.hr./m^2)

4. Conclusion

The work as presented in this paper projects stand-alone solar system as a preferred choice of cost effective means of rural electrification, given the continued improvements of system components, reliability of the systems and falling costs of the components. The technology is also touted to be clean when viewed from the perspective of climate change effects. It is also seen as a technology that can help achieve the United Nations (UN) goal of achieving affordable and clean energy access in the areas of the rural sub Saharan Africa. However, design and sizing and installations still pose challenges in operation. The paper has intentified and elaborated the causes as being brought about by not considering the hidden effects of temperature and irradiation at solar cell level when sizing the solar system. Equation 4. gives an equation that affects the open circuit voltage V_{oc} while the short cicuit I_{sc} is directly proportional to the location insolation. Other important points alluded to are the effects of temperature and charge and discharge rates of battery bank. To extend the life of battery bank it should be sized to store four times the daily load demand energy and be operated at 25^{0}C. Taking these factors in consideration as explained in the paper will ensure reliable operation of solar systems with reduced down time.

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Voltage dips/sags and their effects on process applications in industry

Kedrick Mulemwa[1]

Abstract

Voltage dips are one of the most common power quality events besides swells and transients on an electrical power system in present day and they pose a serious power quality issue for the process industry who are mostly supplied at distribution level. With advancement in power electronics, process industry has process applications that extract, transport and process raw materials to manufacture semi-finished or high-quality finished end products using sensitive equipment such as Variable Speed Drive (VSDs) controls, Programmable Logic Controllers (PLCs), Data Centres and motor contactors/relays. Therefore, this paper describes the causes of voltage dips, their impacts on these sensitive equipment's operation and the available possible solutions. The focus is on system faults and lightning as the major causes of voltage dips. Furthermore, the paper looks at the tools available such as SEMI F47 curve, ITIC curve and UNIPEDE graphs to help to determine if a measured voltage dip is causing equipment to malfunction. Finally, the paper suggests the available and possible remedial measures with related costs to mitigating the dips effects in the process industry.

Keywords: Power quality, Voltage sags/dips, short circuits, sensitive process, SEMI F47 curve, power electronics.

1. Introduction

A voltage dip is a sudden decrease of between 90% and 10% of the nominal voltage followed by a quick recovery to the normal level and usually caused by some remote fault somewhere on the power system. Voltage dips are the most important power quality problem facing many process industrial customers. Figure 1. shows how frequent dips occur on the power system compared to other power quality parameters. Equipment used in modern industrial plants (process controllers, Programmable Logic Controllers, Variable Speed Drives, robotics) is usually becoming more sensitive to voltage dips as the complexity of the equipment increases and the equipment is interconnected in sophisticated processes. Even relays and contactors in motor starters can be sensitive to voltage dips, resulting in shut down of a process when they drop out (McGranagham and Mueller, 2013).

It is important to understand the difference between an interruption (complete loss of voltage) and a voltage dip. Interruptions occur when a protective device actually interrupts the circuit serving a particular customer. This normally occurs if there is a fault on that circuit. Voltage dips occur

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during the period of a fault for faults over a wide part of the power system. Faults on parallel feeder circuits or on the transmission system will cause voltage dips but will not result in actual interruptions. Therefore, voltage dips are much more frequent than interruptions. If equipment is sensitive to these voltage dips, the frequency of problems will be much greater than if the equipment was only sensitive to interruptions (McGranagham and Mueller, 2013).

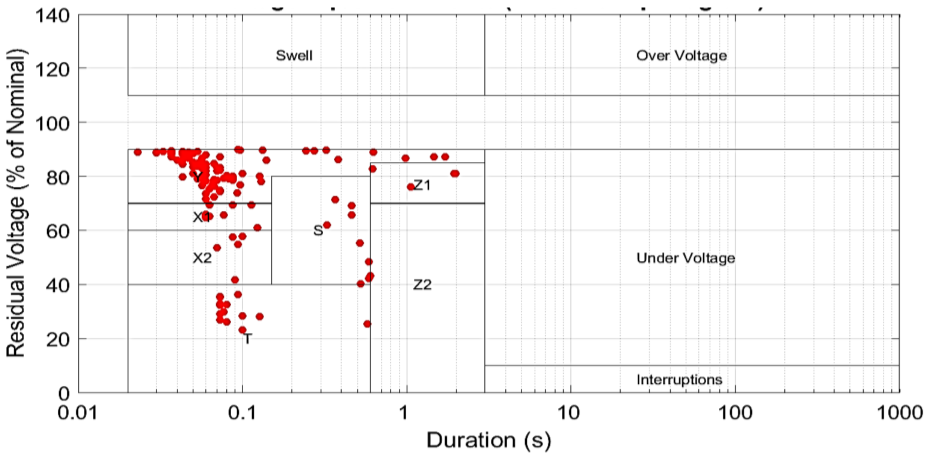


Figure 1: South African NRS 048 dip diagram showing dips according to duration and depth (Source: Rens, 2022).

This paper describes the voltage dip characteristics, effects on process applications in industry, causes, sensitivity of equipment and possible mitigation measures.

2. Sources and Causes of Dips

Voltages dips are power quality disturbances or events arising when the voltage decrease mostly because of high currents. The decrease is between 90% and 10% of the nominal voltage. Voltage dips are typically caused by fault conditions. Motor starting can also result in undervoltage but these are normally longer in duration than 60 cycles and the associated voltage magnitudes are not that low. Faults resulting in voltage dips can occur within the plant or on the system. Hence, in summary the causes are mainly due to:

1) Short circuits in High Voltage (HV) grid, Medium Voltage (MV) grid or Low Voltage (LV) grid. This is highlighted in Figures 2, 3 and 4 where lightning and birds are causing the dips.

2) High inrush currents of transformers and motors when connecting heavy loads.

Faults on the transmission system can affect even more customers as shown in Figure 5. Customers that are hundreds of kilometers from the fault location can still experience the dip resulting in equipment maloperation when the fault is on the transmission system (McGranagham and Mueller, 2013).

Figure 2: Lightning as one of the causes of dips on the transmission network (Source: Rens, 2022).

Figure 3: Birds as one of the causes of dips on the transmission network (Source: Rens, 2022).

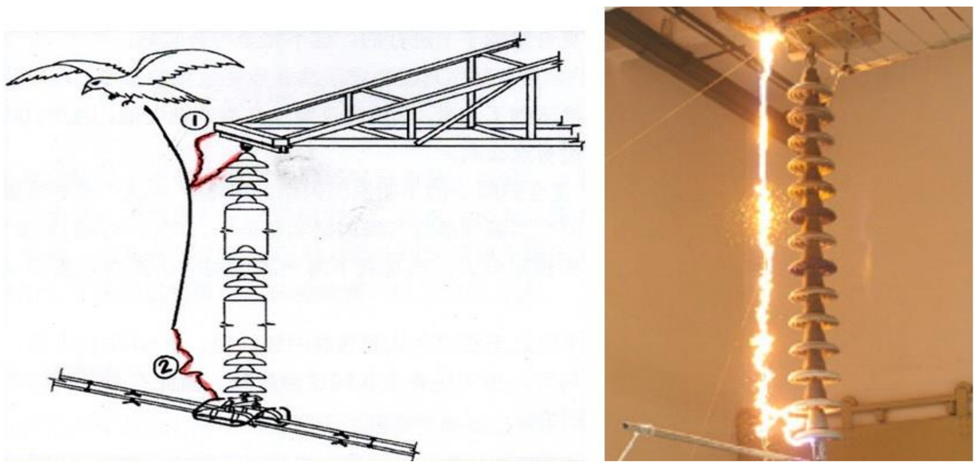


Figure 4: Birds droppings creating a short circuit on the transmission network (Source: Rens, 2022).

The majority of the faults on the utility system are single line to ground faults (SLGFs). Three phase faults are more severe but less common. SLGFs often result from weather conditions such as lightning, bird droppings (Figures 2, 3 and 4), wind, contamination of insulators, trees falling on overhead lines and animal contacts. Although utilities go to greater lengths to prevent faults on the system, they cannot be eliminated completely. Usually, these faults are temporary which means that they will not reinitiate after they have been cleared and the line is reclosed. Since faults (and therefore, voltage dips) are inevitable, it is important for the customer to make sure that critical equipment sensitive to dips is/are adequately protected (McGranagham and Mueller, 2013).

The faults in the LV grid do not affect the number of dips or points of connection connected to another MV transformer as shown in Figure 5. When a fault in the LV grid occurs, the voltage at the MV side of the transformer will still be near or even above 90% of the nominal voltage (Cobben, 2022).

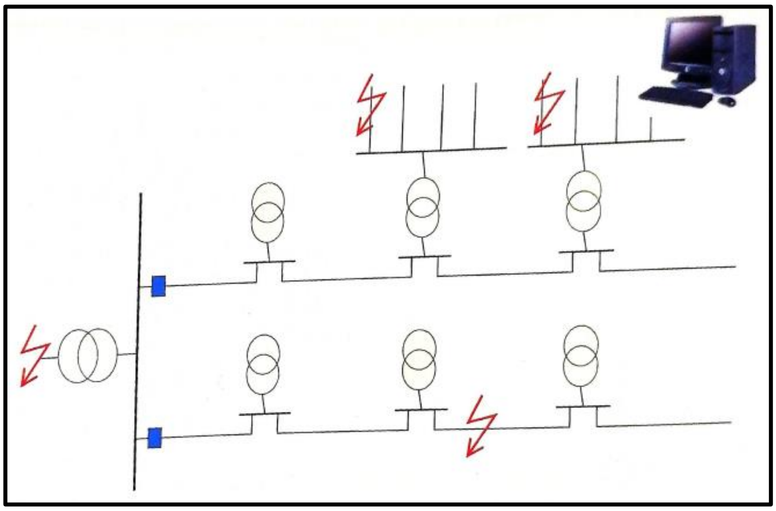


Figure 5: Distribution grid with short circuits on several locations. (Source: Cobben, 2022).

3. Sensitivity of Equipment to Voltage Dips

Process industry equipment can be particularly susceptible to problems with voltage dips because the equipment is interconnected and a trip of any component in the process can cause the whole plant to shut down. Important loads that can be impacted include the following:

- Motors, heating elements and other 3 phase loads that can be connected to LV bus.
- Adjustable Speed Drives (ASDs) and other power electronics devices that use 3-phase power will be connected directly to the LV bus, or, through an isolation transformer.
- Control devices such as computers, contactors and Programmable Logic Controllers (PLCs) are often supplied through a single-phase control transformer (McGranagham and Mueller, 2013).

The voltages experienced during a voltage dip condition will depend on the equipment connection. Figure 6 highlights that the individual phase voltages and phase to phase voltages are quite different during a SLGF condition on the transformer primary. Some single-phase loads will be unaffected and other single-phase loads may drop out, even though their sensitivities to voltage dips may be identical (Cobben, 2022).

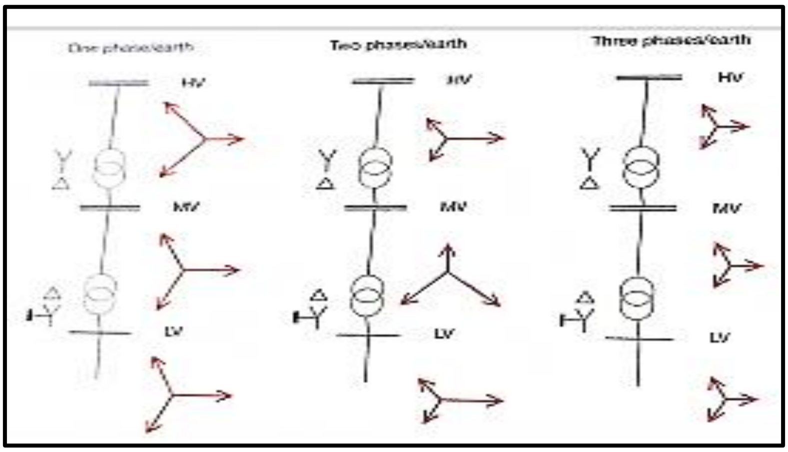


Figure 6: Transfer of dips from High Voltage (HV) to Low Voltage (LV). (Source: Cobben, 2022).

Voltage percentage unbalance is also a concern for motor heating. However, the durations of the unbalanced voltages during fault conditions are so short that motor heating is not a significant concern. Adjustable speed drives, however, may have controls that trip very quickly during unbalanced conditions.

Different categories of equipment and even different brands of equipment within a category (e.g two different models of adjustable speed drives) have significantly different sensitivities to voltage dips. This makes it difficult to develop a single standard that defines the sensitivity of industrial process equipment.

There are many power quality analyzers available on the market today such as Metrum AB Sweden that allow Operators to program various limits and perform high resolution recording to capture these types of voltage variations. The challenge is how to determine if the recorded voltage variation is causing the condition that the customer is reporting and how to locate the root cause.

The tools available today to help to determine if a measured voltage dip is causing equipment to malfunction are Information Technology Industry Council (ITIC) formerly known as Computer & Business Equipment Manufacturer Association (CBEMA), Semiconductor Equipment & Materials International (SEMI F47) curve and UNIPEDE in Figure 9. This is an American power quality tool to categorize dips. These tools are shown in Figures 7, 8 and 9.

The ITIC curve describes an acceptable AC voltage window that can be tolerated by most Information Technology Equipment (ITE). It basically describes the several voltage ranges for voltage variation events. The magnitude of the event as referenced to the nominal voltage is X coordinate and the duration of the event is either cycles or seconds is the Y COORDINATE as shown in Figure 7. Once the point is plotted, it is easy to see if the event could be the cause of information technology equipment malfunction (computers, routers, modems, internet, etc.) (Metrum AB, 2021)

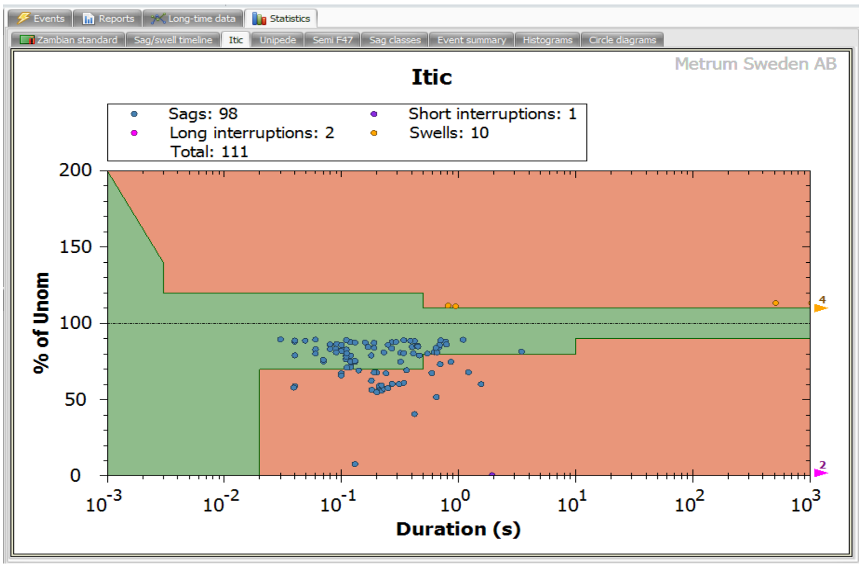


Figure 7: ITIC curve showing dips with durations and depths. (Source: Metrum AB, 2021)

The SEMI F47 curve was developed to place standards on semiconductor processing, metrology and automated test equipment. The SEMIF47 curve in Figure 8 defines a region of acceptable voltage variations on the AC power line of semiconductor processing equipment. The equipment should be able to tolerate voltage variations within this region. They must be able to tolerate dips up to 50% of equipment nominal voltage for durations of up to 200 milliseconds as well as dips of 70% for up to 0.5 seconds and dips of up to 80% for up to 1 second.

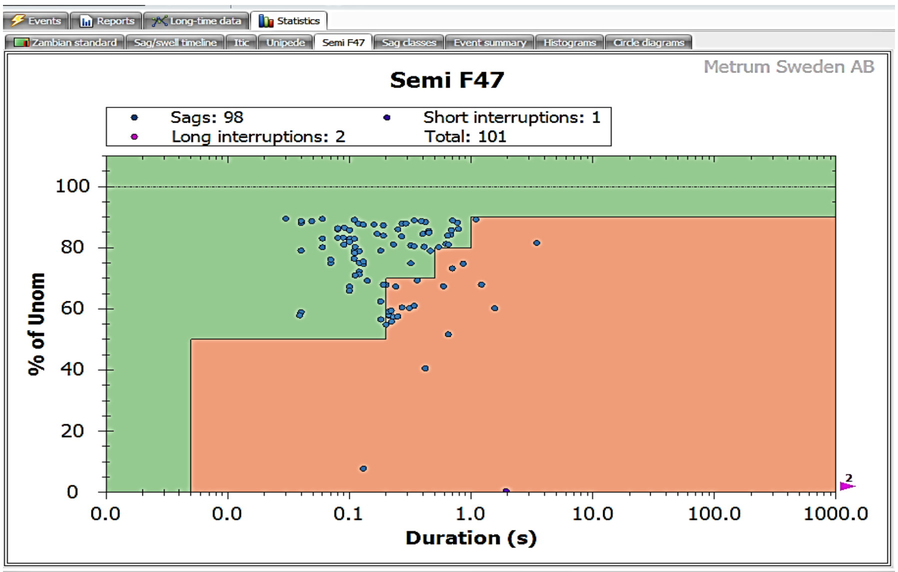
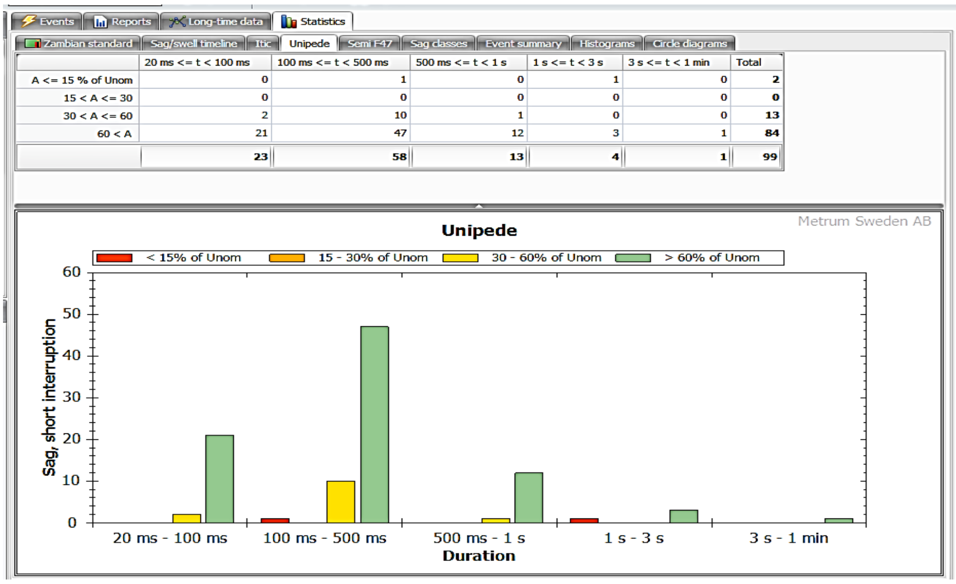


Figure 8: SEMI F47 curve showing dips with durations and depths. (Source: Metrum AB, 2021)



	20 ms <= t < 100 ms	100 ms <= t < 500 ms	500 ms <= t < 1 s	1 s <= t < 3 s	3 s <= t < 1 min	Total
A <= 15 % of Unom	0	1	0	1	0	2
15 < A <= 30	0	0	0	0	0	0
30 < A <= 60	2	10	1	0	0	13
60 < A	21	47	12	3	1	84
	23	58	13	4	1	99

Figure 9: UNIPEDE graph showing dips with durations and depths. (Source: Metrum AB, 2021)

4. Cost Due to Dips

Due to the sensitivity of the equipment in the process applications in industry, the cost associated with dips are twofold; Direct cost and Indirect costs

1.1 Direct costs

I. Damage to equipment or machines – Such as buying very critical equipment which is unbudgeted for after failure.

II. Loss of material - The abrupt stoppage of processes causes poor quality finished products which sometimes have to be recycled or thrown away as waste.

III. Unproductive staff hours – When there is damage to equipment or machine the Operators (staff) will have no work but spend hours waiting for restoration or resumption of the processes but are paid for those unproductive hours.

IV. Hours required for process restarting – Some processes are interlinked and they take long to restart, hence the losses are huge

1.2 Indirect costs

I. Damage to company reputation due to poor finished or semi-finished products.

II. Unable to deliver products on time and failure to meet firm contractual obligations to customers.

It is important to have some insight on the number, duration and depth of dips occurring at the point of connection. This makes it possible to estimate the costs and to choose the adequate mitigation methods. There are several ways to make the dips profile. Measuring during a longer period is one of them and another possibility is to model the HV and MV grid in a software package and with some assumptions about the failure rate of components calculating the dip profile (Cobben, 2022).

5. Responsibilities

Power quality and proper functioning of all devices, processes and installations is a shared responsibility of at least three parties: the manufacturer, the network operator and the user of the device, process or installation. It is the responsibility of the manufacturer to make the device in such a way that they will work within the given normal voltage characteristics. The network operator on the other hand is responsible for the quality of supply voltage. The strength of the network (LV grid) impedance or high short circuit power) should be their responsibility as well. The customer on the other hand has to use the devices according to the guidelines of the manufacturer (McGranagham, 2013).

6. Possible Solutions

There are several ways to prevent dips to interfere with installations and processes within the industry. Some solutions can be cheap while others can be very expensive. The costs have a strong relation with the amount of power (or energy) which has to be placed to mitigate a voltage dip.

Some of the solutions are as follows:

1. **Change motor starter contactors from AC to DC to extend ride through**. DC contactors and relays are readily available. A DC contactor or relay is stronger because the flux is constant. Relays are much faster to open than motor contactors because they are smaller, less mass, act quicker. They will open in 5 to 15 milliseconds; this is less than one cycle. There are very important application considerations when considering extending the ride through of motor contactors. The cost is about $100 (https://www.pge.com, 2018).

2. **Off-line UPS, uninterruptible power supply, on a PC, PLC or controls to switch to battery on a sag below 105 volts or an interruption**. The cost is $150 for a 150VA unit. An advantage is that the UPS will ride through not only dips, but also momentary and extended interruptions up to the limit of the battery capacity, maybe 5 to 10 minutes (https://www.pge.com, 2018).

3. **Ferro resonant (constant voltage) transformer on PC, PLC or controls to provide sag ride through**. They also provide filtering of transients. They will not ride through a momentary or sustained interruption. They have no moving parts, no battery and are very reliable. The cost for a 250-voltamp size is $250 and a 500VA size is $400.Oversizing will extend ride through. This is probably the most common mitigation measure used at present for this problem (https://www.pge.com, 2018).

4. **Precise Power Corporation's written pole Roesel motor generator technology.** This solution will ride through 99% of all dips, surges and momentary interruptions up to 15 seconds. What makes this product different from typical mgs is that they use power electronic switching to change the number of electrical poles to maintain the 50hz frequency and voltage output even as the input voltage degrades. It does not use a flywheel. The mechanical connection between the motor and generator prevents any electrical disturbance to transfer. A single-phase 15kVA unit costs approximately $22,000 and a three-phase 35kVA unit costs approximately $35,000. Typical motor generator sets have no flywheel to provide ride through for sags. With optional flywheels, it is possible to get 100 to 400 milliseconds of ride through (https://www.pge.com, 2018).

5. **Dip Proofing Inverter on PC, PLC, controls or motor starter contactors.** This is a technology developed for the utility industry initially. It is expensive but adjustable and durable. This device is essentially an off-line UPS but replaces the battery with an energy storage capacitor. This device will switch to backup capacitors in 600 microseconds. With this device, the trip magnitude is adjustable between 50 and 80% of nominal. The maximum time duration is 2.56 seconds and is adjustable to shorter durations in increments of 10 milliseconds. Minimum resynchronization time is 65 milliseconds. The cost for a 250 VA unit is approximately $1,000, which makes it a very expensive solution. Its advantages are that they are off line, highly efficient and require no maintenance. It is also more durable than a UPS and has better voltage support time duration limit than the ferro resonant transformer (https://www.pge.com, 2018).

7. Conclusion

The source and cause of dips should be measured and profiled as they pose a serious power quality problem in the process industry; this will ensure appropriate mitigation measures are applied to alleviate their effects on sensitive equipment such VSDs, PLCs, process controllers, contactors, data centres and robotics. Since dips can never be avoid on a power system, due to faults, lightning and other networks disturbances, solutions to mitigate dips are available to reduce on the downtime associated with dips on distribution network. The costs depend on where on the network the solution is applied. The vary from hundreds to thousands of dollars. Therefore, the economic aspects are to be taken into consideration before making a choice of the suitable mitigating device.

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Maximizing the potential of hard-tech development centers to enhance value addition, GDP, and manufacturing in Zambia

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Abstract

The high cost of developing hardware-based products (hard-tech) is a significant barrier to entry for engineers, entrepreneurs, and inventors worldwide (Chen et al., 2019; Hsu & Jhang, 2018; Shafiq et al., 2017). This is particularly true in developing countries like Zambia, where the lack of financial capacity to procure specialized yet expensive tools and equipment necessary for hard-tech development is a major challenge (Chaponda et al., 2020; Ngoma & Musukwa, 2018). The deficiency in the hard-tech development space has negatively impacted Zambia's ability to grow its manufacturing and value addition industries, which has a ripple effect on the country's GDP and its efforts to reduce reliance on raw material exports and imports of finished goods (Musukwa & Ngoma, 2020). To support the growth of the hard-tech sector and encourage inventiveness, the Engineering Institution of Zambia (EIZ), the largest engineering body in the country, should introduce and manage an inventor's fund. This fund would finance the development and operation of hard-tech fabrication facilities, where engineers and inventors can access the latest technology and equipment for creating prototypes and developing new products (Musukwa & Ngoma, 2020). By making these resources more affordable and accessible, the inventor's fund can help drive the growth of the hard-tech sector and support the development of new inventions and patent applications in Zambia.

Keywords: Invention, manufacturing, value addition, patents, hard-tech, patent, prototype

1. Introduction

Modern technological products are generally divided into two categories: software/service-based (soft-tech) and hardware-based (hard-tech). Soft-tech innovations are fast and easier to create, fast to launch, and can quickly gain popularity through social media platforms. Examples of soft-tech products include software and mobile applications. These products leverage existing infrastructure to scale up and expand quickly, making them easily accessible to a larger demographic far much faster. Their high scalability and ease of manufacture make them a popular choice for entrepreneurs looking to use technology to solve problems (Kautz & Shiraki, 2017).

In contrast, hard-tech products are new inventions that take longer to manufacture and launch to the public. Examples of hard-tech products include electric vehicles, screwdrivers, and rockets. These types of products require significant investment, they carry a lot of risk, and are often

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subject to tougher regulation (Danneels & Spender, 2015). These differences and many others are what make hard-tech product development far costlier than soft-tech product development.

2. The Differences Between Soft-Tech and Hard-Tech Product Design

Soft-tech and hard-tech products have distinct development processes that are influenced by their unique nature and components. A comparative analysis of the product development processes of these two categories of products reveals significant differences between them.

2.1 Soft-tech product development

The development of soft-tech products is often structured around the software development life cycle (SDLC) (Mantel, Meredith, Shafer, & Sutton, 2017) *(figure 1)*, which provides a framework for the development of software and information systems. Various software development models, which are based on the standard SDLC, are used during the software development process (Bajwa, Singh, & Mann, 2016). These models include the Agile model, the Spiral model, and the V model, among others (Boehm & Turner, 2004, p. 10). The SDLC model is a well-established and commonly used approach to software development, which is designed to ensure that software development projects are delivered on time, within budget, and to the required quality (Pressman & Maxim, 2014, p. 20).

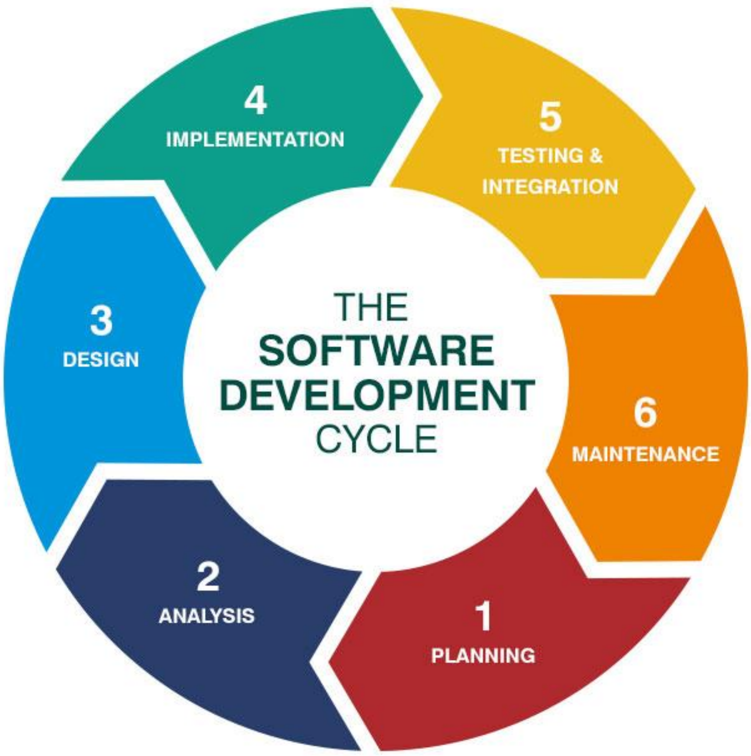

Figure 1 Software Development Cycle (BigWater Consulting, 2019)

1. Planning and Requirement gathering and analysis: In this phase, the software development team identifies the requirements for the software or information system by gathering information from stakeholders and end-users.

2. Design: In this phase, the software development team designs the software or information system based on the requirements identified in the first phase. This includes creating a software architecture, designing the user interface, and identifying data structures.
3. Implementation or coding: In this phase, the software development team starts coding the software or information system based on the design specifications created in the previous phase.
4. Testing: In this phase, the software development team tests the software or information system to ensure that it meets the requirements identified in the first phase. This includes unit testing, integration testing, and system testing.
5. Deployment: In this phase, the software or information system is deployed or released to the end-users.
6. Maintenance: In this phase, the software development team provides ongoing support and maintenance for the software or information system, including bug fixes and software updates.

2.2 Hard-tech product development

Hard-tech product development lacks a standardized or predefined method for execution, but there are four high-level steps that describe hardware development: Ideation, Design, Engineering, Validation, and Final Manufacturing (Karlsson, 2013). These steps may be iterative and overlapping, and the specific processes involved may vary depending on the product being developed as shown in Figure 2.

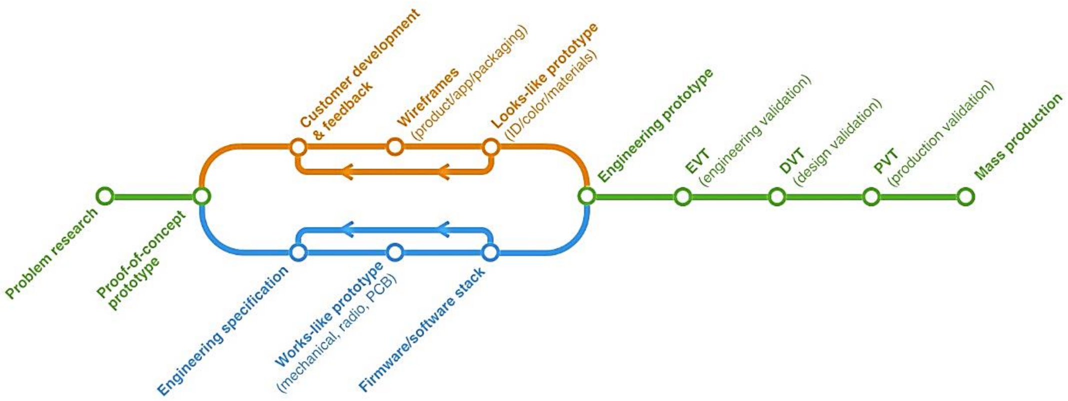

Figure 2 Hard-tech product development process (Einstein, 2015)

1. Ideation: This step involves generating and refining ideas for the new product. This could involve brainstorming sessions, market research, and discussions with potential users or customers. The focus is on identifying a need or problem that the product will solve.
2. Design: Once the idea has been refined, the design process begins. This step involves creating a detailed plan for the product, including its physical form, materials, and components. The design may involve the creation of prototypes or models to test and refine the product concept.
3. Engineering: In this step, the design is turned into a working product. Engineers work on the technical aspects of the product, such as selecting the appropriate components, building and testing the circuitry, and developing the software that will control the

product.

4. Validation: Once the product has been engineered, it needs to be validated to ensure that it meets the necessary requirements and standards. This may involve testing the product in a laboratory or real-world environment, or conducting user trials to gather feedback on the product.
5. Final Manufacturing: The final step in hard-tech product development is the manufacturing process. This involves producing the product at scale, often using specialized equipment and manufacturing processes. Quality control and testing are critical in this step to ensure that the final product meets the necessary standards and specifications.

3. The Challenges and Complexities of Developing Hard-Tech Products

Developing hard-tech products is a challenging process compared to soft-tech products due to several reasons (Eisenmann et al., 2011). Unlike soft-tech products, hard-tech products cannot be launched in a half-baked form with the strategy of adding features until the product-market fit is found. This is because many of the features and solutions in hard-tech require a physical component to be manufactured before the product launch. While for certain hard-tech products some minor features and performance improvements can be made with over-the-air updates, the majority of the functionality and capabilities must be established during the development phase (Eisenmann et al., 2011).

Therefore, it is essential to test and refine the product during the development cycle to ensure that the technology feature sets solve the customer's problem and drive the customer to pay for the solution (Ulrich & Eppinger, 2015). Developing hard-tech products requires full-stack teams with vast knowledge in science and engineering that spans across several disciplines (Eisenmann et al., 2011). The development process is lengthy and involves the use of expensive 3D CAD/CAM software, embedded system design software, and possibly even circuit board design software for creating a prototype (Ulrich & Eppinger, 2015).

As a product moves along in development, design and engineering teams need tools that produce prototypes consistent with the look, feel, and functionality of the final product. Advanced prototyping tools create custom parts from the same or similar materials and with surface finish and mechanical properties comparable to the final products. Examples of advanced prototyping tools are 3D printers, CNC machines, plasma cutters, and waterjet cutters (Eisenmann et al., 2011).

4. The Impact of Hard-Tech Development on Zambia’s Economy

The lack of a robust hard-tech development platform in Zambia has had negative implications for the growth of product design and manufacturing. Studies have shown that a thriving product development industry can have positive effects on a country's economy (Department of Trade and Industry, 2014). One way to gauge a nation's level of innovation is by examining the number of industrial design and patent applications it receives. In 2021, for instance, Zambia only received 29 patent applications, in contrast to China's 1.59 million (World Intellectual Property Organization, 2021a), (World Intellectual Property Organization, 2021b).

Furthermore, a recent study has revealed a significant relationship between key technology patents and a country's GDP per capita income. The study found that an average increase of 1% in key technology patents leads to an average increase of 0.108% in GDP per capita income. Key technologies include fields such as mobility, energy, nutrition, health, industry, digitization, materials, infrastructure, security, and the environment. These types of patents are among the top 10% of all patents, and are distinguished by their high economic value (Lan, Chen, & Lai, 2018).

These findings highlight the importance of investing in hard-tech development in order to drive economic growth and innovation. By improving access to the necessary tools, software, and equipment, as well as fostering a conducive environment for product design and manufacturing, Zambia can tap into the potential of its hard-tech industry and reap the associated economic benefits (Zulu, 2021).

5. Supporting Inventiveness through an Inventor’s Fund

The inventiveness of a country can be measured by the number of patent applications it produces, and this growth is largely driven by the engineering fraternity (Burk et al., 2022). This is because the development of hard-tech products requires specific skillsets, such as electrical engineering, embedded systems development, mechanical engineering, industrial design, and material or chemical science. In order to support and encourage the growth of inventiveness, the largest engineering body in the country, EIZ, should take a leading role in financing the development and operation of hard-tech fabrication facilities.

There are various examples of professional engineering organizations financing the development of hard-tech fabrication facilities in order to support innovation and economic growth. For instance, the Institution of Engineering and Technology (IET) in the United Kingdom has established a Technology Innovation Centre that provides prototyping facilities, engineering workshops, and access to specialist equipment for inventors and entrepreneurs (IET, 2022).

In addition, some countries have established national innovation funds that provide financial support for research and development, including the development of hard-tech fabrication facilities. For example, Singapore has established a National Research Foundation that supports research in a range of areas, including advanced manufacturing and engineering (National Research Foundation, 2022). Similarly, South Korea has established a Technology Innovation Program that provides funding and support for the development of key technologies, including advanced manufacturing (Korea Institute of S&T Evaluation and Planning, 2022).

These examples demonstrate the potential for professional engineering organizations and national innovation funds to support the growth of inventiveness by financing the development and operation of hard-tech fabrication facilities. By taking a leading role in such initiatives, the Engineering Institution of Zambia (EIZ) can play a significant role in promoting innovation and economic growth in the country.

There are several methods that the EIZ can use to raise funds for its innovation fund, including:

- Membership fees: EIZ can increase its membership fees and encourage more engineers to join the organization to generate additional revenue. EIZ members would enjoy a clear advantage by gaining access to the hard-tech innovation facilities. This benefit alone could warrant an increase in membership fees.
- Corporate partnerships: EIZ can form partnerships with corporate organizations to secure funding for its innovation fund.
- Grants and donations: EIZ can apply for grants from local and international organizations or solicit donations from individuals and organizations interested in supporting the development of engineering and technology in the country.
- Events and conferences: EIZ can organize events and conferences related to engineering and technology and charge admission fees or seek sponsorship from companies to raise funds.

The hard-tech innovation facilities must meet certain minimum technical requirements to effectively support product design and manufacturing. They should have the latest equipment and machinery, including 3D printers, CNC machines, and other specialized tools, to enable engineers to produce high-quality prototypes and products. The facilities should also be equipped with design software and tools, such as CAD/CAM software, simulation tools, and other similar programs, to allow for efficient and accurate product design. The facilities should have a robust internet connection to enable engineers to access online resources and collaborate with other innovators from around the world. Additionally, the facilities should have adequate space and ventilation to accommodate the equipment and machinery, as well as provide a comfortable and safe working environment for engineers. Overall, meeting these minimum technical requirements will help ensure that the hard-tech innovation facilities can effectively support the development of innovative and high-quality products.

6. Conclusion

Engineers and inventors in Zambia face a significant barrier when it comes to designing and developing hard-tech products. This barrier is primarily due to the high cost of producing these products, which can be prohibitively expensive for many individuals and organizations. As a result, there is low participation on the hard-tech development scene, leading to a low number of patent applications and a negative impact on GDP growth rate and productivity in the manufacturing and value addition sectors.

To overcome this barrier and support the growth of the hard-tech sector, the largest engineering body in the country, EIZ, should take a leading role in developing and managing an inventor's fund. This fund would be used to finance the development and operation of a hard-tech development center, where engineers and inventors can access the latest software and equipment for creating hard-tech products.

The hard-tech innovation facilities should have two main objectives. Firstly, to provide engineers with affordable access to the latest technology, equipment, and software needed for creating work-like prototypes. Secondly, to ensure that these resources are accessible to all engineers in the country, so that anyone with the necessary skills can contribute to the development of inventions and patent & industrial design applications. To support these objectives, the engineering body should establish an inventor's fund to provide financing for the fabrication facilities and other necessary resources. By making these resources widely available, the engineering body can help drive the growth of inventiveness and support the development of hard-tech products in the country.

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Developing of composite nanofibers from *Moringa oleifera* biomass for removal of lead ions from polluted water: A case study of Kabwe Town

Ronald Ngulube[1], Musango Lungu[2]

Abstract

The electrospun multi-composite fibers synthesized from extracts of *Moringa oleifera* (*M. oleifera*) seed biomass blended with polyacrylonitrile (PAN) was investigated as potential adsorbent. Batch adsorption experiments were carried out to evaluate the performance of PAN/*M. oleifera* nanofiber for Pb(II) removal from aqueous solution. The adsorption capacity was determined as a function of process parameters such as solution pH, initial Pb(II) concentration, and contact time. Experimental results showed that the PAN/*M. oleifera* adsorbent possessed a considerably high equilibrium adsorption capacity of 97.7 mg/g which was achieved after 90 min. The adsorption of Pb(II) onto PAN/*M. oleifera* fiber adsorbents better fitted the pseudo-second-order kinetics and the Langmuir isotherm models. Based on the Langmuir isotherm, the maximum adsorption capacity of 172.4 mg/g was obtained which is relatively high compared to most of the values from other previously reported adsorbents. These results demonstrate that PAN/*M. oleifera* nanofiber can be considered as an effective sorbent for Pb(II) ions remediation of polluted waters in the Kabwe Toawn of Zambia..

Keywords: Electrospinning, Nanofiber, *Moringa oleifera,* Adsorption, Kabwe town.

1. Introduction

Kabwe was one of African's major producers of lead and zinc for almost a century, with cadmium (Cd) and silver (Ag) being produced as by-products (GRZ 1983). However, the government owned corporation, Zambia Consolidated Copper Mines (ZCCM), operated the mine without proper environmental pollution controls for most of its life (ECZ 2008). This was because the operations were being undertaken during a period when statutory environmental controls in the mining sector were non-existent. In June 1994, the mine operations were shut down due to low resource prices and the exhaustion of the high-grade Pb and Zn mineral ore reserves (CSO Report 2011; Nachiyunde *et al*., 2013). Following this closure, several of Kabwe's ore beneficiation and waste storage installations were sold for waste re-processing to private investors with overall responsibility for the rehabilitation of the site retained by ZCCM, and its successor Zambia Consolidated Copper Mines Investments Holdings (ZCCM-IH). The Environmental Council of Zambia (2008) reported several environmental challenges arising from mining activities in Kabwe, the notable ones being dereliction of land through erosion, failure to restore mined and quarried land, air pollution by blowing dust, water pollution due to unmanaged waste water and

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sediment discharge and their subsequent wash-down into the water table and flowing water systems.

Recently, there has been an urgent need to develop and implement innovative technologies for the remediation of heavy metal ions contaminated soils and from wastewater in Kabwe. Most of research studies that have been conducted focus on investigating the extent of heavy metal contamination and examining the state of awareness by residents affected by the pollution. In order to mitigate negative effects of heavy metal ions on the environment and human beings in the city of Kabwe, Zambia Mining Environment Remediation and Improvement Project (ZMERIP) was launched in 2017 following the approval of US$16 million International Development Aid (IDA) credit by the World Bank. This credit is meant for a five-year period for environment remediation projects targeted at critically polluted mining areas of Kabwe. This has made soil remediation and water purification the most-sought technology. In this regard, water samples collected from five operating boreholes around the mining area showed Pb concentrations of about 5 mg/L which is above WHO safety limits of 15 μg/L (Tembo *et al*., 2006).Therefore, this research focus on developing a green, cost effective and efficient method that can be employed for the removal of Pb ions from wastewater samples of Kabwe Town.

In the last decade, there has been a remarkable potential for the remediation of Pb(II) ions as a result of nanotechnology developments in adsorption technology. A unique aspect of nanotechnology is the enormously increased ratio of surface area to volume presented in many nanoscale materials offering an alteration of physio-chemical properties of the corresponding bulk material properties. In the present study, *M. oleifera* seed extract was explored for its adsorption capacities. *M. oleifera* seed biomass has shown to be polycationic in nature serving as binding sites for heavy metal ions (Araújo *et al*., 2010; Kebede *et al*., 2018). In addition, *M. oleifera* is readily available, non-toxic, biodegradable and renewable. However, there are few nano based substrate which can be used to effectively deliver *M. oleifera* biomass for adsorption of heavy metal ions. Polymeric templates in the form of electrospun composite nanofibers could be an excellent substrate for such biosorbent in order to achieve effective adsorption. The main objectives of this study were to synthesize and characterize PAN/*M. oleifera* composite fibers and investigate the adsorption behaviour of nanofiber using laboratory prepared water containing Pb(II) ions. To the best of our knowledge, this is the first report on the synthesis of these materials for application as adsorbents.

2. Materials and methods

2.1 Chemicals

Polyacrylonitrile (PAN) average MW 150000, N, N dimethylformamide (DMF), sodium chloride (NaCl), lead nitrate ($Pb(NO_3)_2$) and ethanol were of analytical grade and used as purchased from Sigma-Aldrich. *M. oleifera* seeds were purchased from Umoyo Natural Health store, Zambia.

2.2 Characterization

The blended polymer solutions were electrospun using an electrospinning unit. This experiment was conducted at Council of Scientific & Industrial Research (CSIR), South Africa. The surface morphology of the materials was examined using a Zeiss Crossbeam 540 Field Emission-Scanning Electron Microscope (FE-SEM) coupled with energy-dispersive X-ray spectroscopy (University of Pretoria, South Africa). ImageJ software was used to estimate the average fiber diameters.

2.3 Synthesis details

2.3.1 *M. oleifera* saline solution preparation

Finely ground *M. oleifera* seed powder was added to a 95% ethanol aqueous solution and stirred for 30 min to remove fat from the seed powder. The powder was separated by centrifugation and dried at room temperature. This is in accordance with the previously reported method by Wahab (2019). The *M. oleifera* extract was obtained by adding 1.0 g of powder to 100 ml of 1 M NaCl salt. The solution was stirred for 1 h, followed by separation of the extract using filtration. The filtrate was frozen at −4 °C for 24 h and then freeze-dried. The obtained white powder was stored at room temperature pror to its use.

2.3.2 Synthesis of PAN/M. oleifera mats

The PAN/*M. oleifera* mats were synthsised via the electrospinning technique. Briefly, 8% w/v PAN solution was prepared by dissolving 0.8 g of PAN polymer powder in 10 mL DMF solution. The mixture was stirred for 8 h to form a homogeneous solution. Then 3.0 g *M. oleifera* powder was added to the above solution, and stirring was continued for another 5 h to ensure complete dissolution. The blended suspension was electrospun under optimal conditions (flow rate of 0.8 mL/h, applied voltage of 10 kV, and tip-to-collector distance of 15 cm). The nanofibrous mats obtained were placed in a vacuum oven (160 °C, 60 min) to increase their stability in water. The mats were detached from the aluminum foil and cut into 2 cm by 2 cm sections..

2.4 Stability study of nanofiber mats in water

Samples were submerged in deionized water for 7 days. They were then oven-dried (50 °C for 24 h) before reweighing. Stability was expressed as percentage solubility and was measured by comparing the weight of the mats before and after water immersion, using Eq. (1).

$$\% \, solubility = \frac{w_1 - w_2}{w_2} \, x \, 100 \qquad (1)$$

where w_1 is the weight of the nanofiber mat before suspension and w_2 is the weight of the nanofiber mat after suspension and drying.

2.5 Adsorption experiments

Batch adsorption experiments were conducted to investigate the adsorption behaviour of composite nanofiber synthesized at different parameters such as; solution pH, contact time and initial Pb(II) concentration. In order to achieve this, the composite nanofiber mat was immersed in 20 mL of water sample and agitated at 100 rpm. To optimize adsorption parameters, several parameters such as solution pH, contact time and initial Pb(II) concentration were varied. The concentrations of the metal ions were determined using an inductively coupled plasma mass spectrometry (ICP-MS). The equilibrium adsorption capacity (q_e) was determined using Eq. (2) (Sahoo and Hota, 2019). Blank experiments were conducted to validate the adsorption experiments (Chang *et al*., 2016).

$$q_e = \frac{(C_i - C_e)\ x\ V}{m} \tag{2}$$

where C_i and C_e are the initial and equilibrium concentration (mg/L), V is the volume of the solution (L), and m is the mass of fiber mat used (g).

2.6 Adsorption isotherms

Adsorption isotherms are essential in understanding the adsorption process and represent the interaction between the amount of the adsorbate adsorbed on the surface of the adsorbent at equilibrium concentration. The Langmuir and Freundlich isotherms were used in this study. These isotherms give information regarding the maximum adsorption capacity and binding mechanisms that can be obtained. The Langmuir isotherm assumes that the adsorbent has a homogenous surface and can only allow monolayer adsorption while the Freundlich isotherm assumes multi-layer and heterogeneous adsorption of solute on an adsorbent surface. These isotherms can be expressed by Eqs (6) (Sahoo and Hota, 2019)

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{K_L q_m} \tag{3}$$

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \tag{4}$$

where q_m is the maximum amount of adsorption (mg/g), K_L is the Langmuir constant related to binding energy between the adsorbate and adsorbent (L/mg), K_F is the Freundlich constant and is related to the binding capacity between absorbent and adsorbate and n represents the empirical constant that indicates heterogeneity factor and is related to the sorption intensity.

K_L can be used to determine the separation factor, R_L. The R_L value give information on the strength of adsorption and is defined by Eq. (5)

$$R_L = \frac{1}{1 + K_L C_i} \tag{5}$$

2.7 Adsorption kinetics

The adsorption kinetics were investigated using pseudo-first-order and pseudo-second-order kinetic studies. The pseudo-first-order model assumes physical adsorption as the dominant mechanism. On the other hand, the pseudo-second-order model indicates chemisorption as the rate-limiting step. These models can be represented according to Eq. (6) and (7) (Ge *et al*., 2017).

$$Iog\ (q_e - q_t) = Iog\ (q_e) - k_1 t \tag{6}$$

$$\frac{t}{q_t} = \left(\frac{1}{q_e}\right) t + \left(\frac{1}{k_2 \, q_e^2}\right) \tag{7}$$

where k_1 is the pseudo-first-order rate constant (min^{-1}), where k_2 is the pseudo-second-order rate constant (g/mg.min)

3. Results and Discussion

3.1 SEM micrographs of the nanofiber

SEM images of PAN/*M. oleifera* fibers have a characteristic interwoven network structure as shown in Fig. 1(a). These characteristics are caused by thermal crosslinking that increases the fibers stability in water. The fibers are continuous and bead-free indicating adequate optimization of electrospinning parameters (Kebede *et al*., 2018). The PAN/*M. oleifera* fibers shown in Fig. 1(a) exhibited a relatively smooth outer surface with an average diameter of 218 ± 22 nm (Fig. 1(b)).

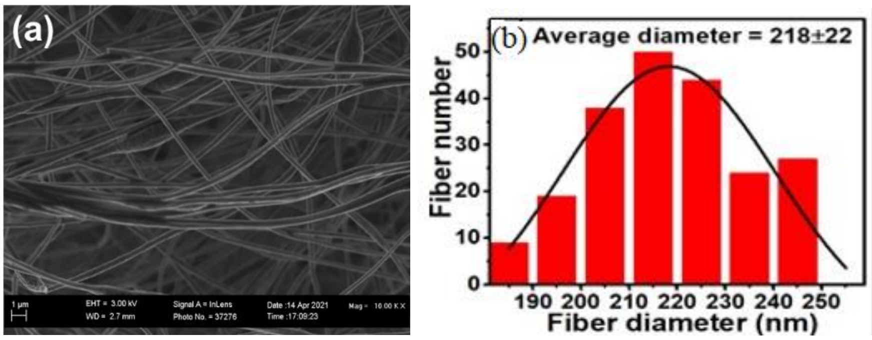

Figure 1: SEM images of (a) PAN/M. oleifera and (b) diameter distribution of PAN/M. oleifera nanofiber

3.2 FT-IR analysis

FT-IR spectroscopy was used to identify functional groups on the synthesized nanofibers. This is essential in order to gain insight into the adsorption mechanism. Functional groups identified in the obtained nanofibers (Fig. 2(c)) include N-H stretching (2931 cm^{-1}) ascribed attributed to the amine, C=O stretching (1650 and 1070 cm^{-1}) as a result of the presence of alcohol, carboxylic acid, phenol and amide groups predominant in the protein and fatty acid structures of the *M. oleifera* seed (Fig. 1(a)). These functional groups are also attributed to the polymer PAN powder as can be seen in Fig. 2(b). Other functional groups observed were the −C≡N stretching (2240 cm^{-1}) in the polymer chain and C-N stretching amine (1233 cm^{-1}) associated with the polymer PAN powder and *M. oleifera* seed respectively (Araújo *et al*., 2010; Bhutada *et al*., 2016). Thus, the presence of the amine, hydroxyl, nitrile, carbonyl and amide functional groups onto the surface of the fiber could be explored for adsorption of Pb(II) ions.

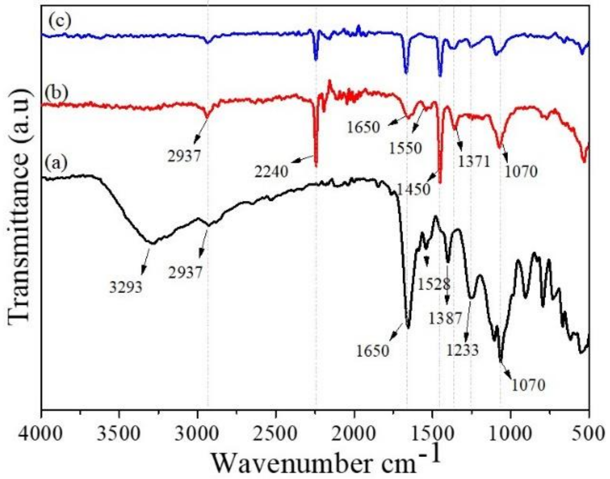

Figure 2: FTIR spectra of (a) M. oleifera powder, (b) PAN powder and (c) PAN/M. oleifera nanofibers.

3.3 Mechanical integrity of the fiber mats

To understand the mechanical integrity of the synthesized fiber mats, a water stability test (section 2.6) was carried out. PAN/*M. oleifera* fiber mats immersed in water for 7 days showed a 0.3% reduction in weight. The results suggest that the synthesized fiber mat is stable for use in water purification applications.

3.4 Effect of solution pH

The effect of solution pH on the removal of Pb(II) ions from water samples was investigated in the range of 3 – 10. The graphs in Fig. 3 shows that the adsorption capacity of the PAN/*M. oleifera* fiber are almost constant at lower solution pH values (3− 6), and at higher pH above 6, the adsorption capacity started increasing until the highest values of (70.1 mg/g) adsorption capacity was obtained at optimal solution pH of 9 Thereafter, at solution pH of 10 there was a decrease in adsorption capacity. When the solution pH is low (below 6), the surface of the composite fibers becomes positively charged. As a result of this, adsorption of positively charged Pb(II) ions is least favoured due to electrostatic repulsion. This explains the trend observed. The results implies that the optimum adsorption capacity occur at higher solution pH when the adsorbents surface become negatively charged. This is because the main mechanism of the adsorption process is the electrostatic attraction.

3.5 Effect of contact time

The influence of contact time on adsorption was examined between 30−150 min, while keeping the Pb(II) ion concentration at constant (5 mg/L), and at optimal solution pH of 9. The results obtained are presented in Fig. 4. The figure shows that as the time is increased from 30 min, the adsorption capacity of the fiber mats increased until equilibrium was reached at 90 min. The observed trend could be attributed to the availability of more active sites for adsorption on the fiber surface in the initial stages of adsorption, then adsorption declined because most of the active sites present were beginning to be occupied until the sites were saturated (Pradhan *et al*., 2017).

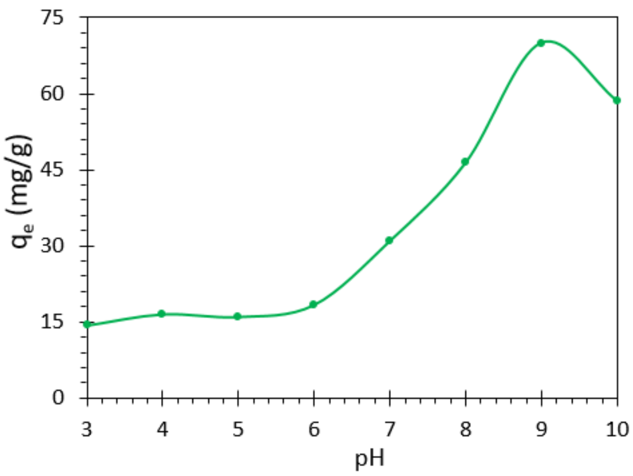

Figure 3: Plots of effect of pH on Pb(II) adsorption

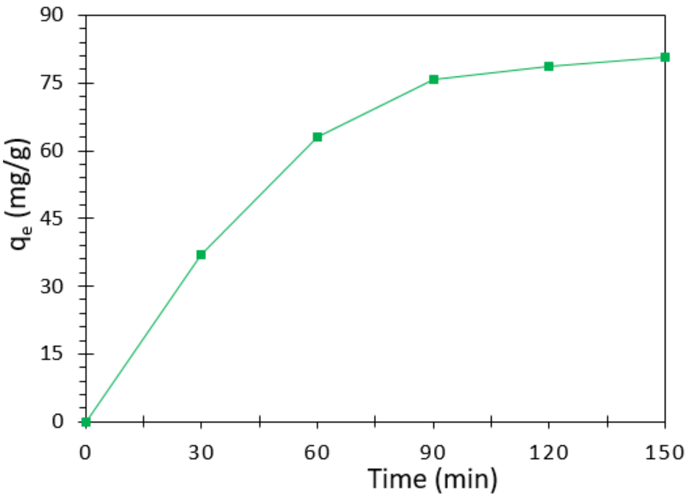

Figure 4: Effect of contact time on Pb(II) adsorption

3.6 Effect of initial Pb(II) concentration

The influence of initial Pb(II) ion concentration on the adsorption capacity of the fiber-matrix surface was studied between the range of 1 – 30 mg/L and under optimum pH and contact time. Fig. 5 shows that as initial concentration of Pb(II) ions increased, the adsorption capacity increased until saturation was approached at 20 mg/L. The increase in adsorption capacities of the fiber mats is due to the numbers of vacant active sites available for adsorption during the initial stage. As the adsorption process proceeded, the remaining vacant surface sites decreased resulting in slowing down of the adsorption capacity until reaching the saturation point (Lakhdhar *et al*., 2016). In order to further understand the adsorption behaviour, the data obtained was fitted to the isotherm models.

3.7 Adsorption isotherms

The adsorption equilibria were best expressed using the Langmuir and Freundlich isotherm model isotherm equations described in section 2.6. The linear fitting plots of C_e /q_e versus C_e and log q_e versus log C_e for the Langmuir and Freundlich isotherm models respectively are shown in Fig. 6(a,b). The isotherms corresponding parameters were determined as shown in Table 1. The best isotherm fit was determined by the correlation coefficients (R^2). The R^2 value which is close to 1 describes the best model fit for the experimental data.

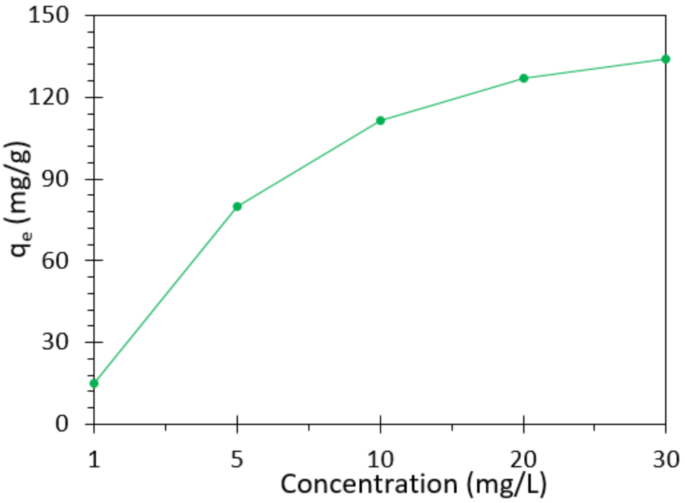

Figure 5: Effect of initial Pb(II) concentration on Pb(II) adsorption

By comparing the correlation coefficients (R^2) from Table 1, the Langmuir model fits well with the isotherms data. This implies that the equilibrium data for Pb(II) adsorption on the composite mats can be suitably represented by the Langmuir isotherm. The Langmuir isotherm indicates that the adsorption sites are homogenously distributed on composite fibers and the adsorption process could be considered monolayer adsorption. Based on the Langmuir fitting, the PAN/*M. oleifera* fiber recorded the maximum adsorption capacity (q_m) of 172.4 mg/g. The q_m value is a useful parameter to ascertain the maximum possible amount of an adsorbate that can be loadable on an adsorbent. The Langmuir constant (K_L) obtained by the PAN/*M. oleifera* fiber mat was estimated to be 0.134 L/mg. The Langmuir constant is an essential factor that predicts the affinity between the adsorbent and the solute. According to the Freundlich model, if the heterogeneity factor (n) values are between 0 and 1, the adsorption reaction is difficult to carry out. If n values range between 2 and 10, the adsorption reaction is favorable. Herein, since n is calculated between 1 and 2 as shown in Table 1, confirms the inapplicability of the model to better represent the adsorption data. The larger K_F implies a stronger binding capacity between the composite fibers and Pb(II) ion.

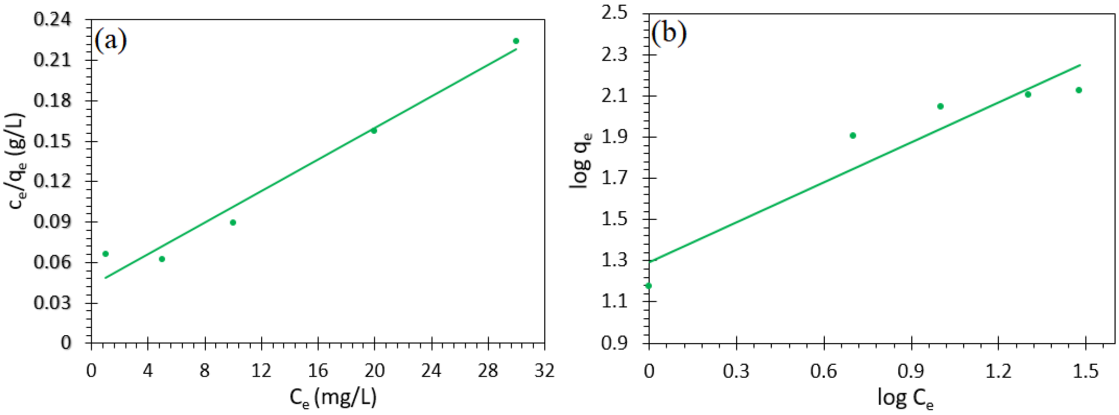

Figure 6: The fitted lines of (a) the Langmuir and (b) Freundlich isotherms

Table 1: Fitting parameters of Langmuir and Freundlich isotherm models

Adsorbent	Langmuir model			Freundlich model		
	R^2	K_L (L/mg)	q_m (mg/g)	R^2	K_F (mg/g)	n
PAN/*M. Oleifera*	0.97	0.134	172.4	0.90	23.43	1.557

The R_L values for the adsorbents were determined to range between 0.11 and 0.88. The R_L values specify if the adsorption is favourable ($0 < R_L < 1$), unfavourable ($R_L > 1$), irreversible ($R_L = 0$) or linear ($R_L = 1$). In this case, the fibers demonstrate a favourable Pb(II) adsorption process.

3.8 Adsorption kinetics

In order to understand the adsorption kinetics of Pb(II) ions by the fibers, the pseudo-first-order and pseudo-second-order kinetic models were used to test the experimental data. The linear fitting plots of $log\ (q_e\text{-}q_t)$ versus t and t/q_t versus t for the pseudo-first-order and pseudo-second-order models respectively are depicted in Fig. 7(a,b). According to R^2 values, the kinetic model that best fitted the data was the pseudo-second-order model. The model is based on the assumption that chemisorption is the rate-determining step. Table 2 summarizes the calculated parameters from the fitted models.

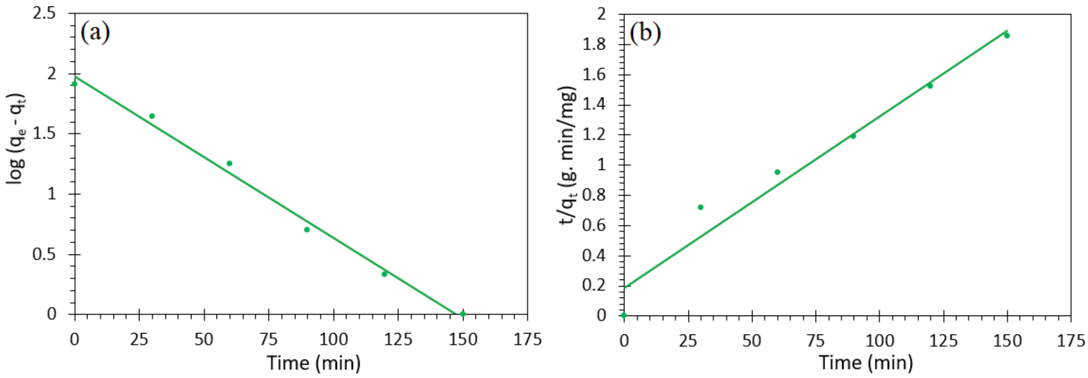

Figure 7: The fitted lines of (a) pseudo-first-order and (b) pseudo-second-order models

Table 2: Fitting parameters of pseudo-first-order and pseudo-second-order models

Adsorbent	Pseudo-first-order model			Pseudo-second-order model		
	R^2	q_e (mg/g)	k_1 (h^{-1})	R^2	q_e (mg/g)	k_2 (g/mg h)
PAN/*M. Oleifera*	0.92	94.24	1.206	0.97	87.71	0.015

Based on the pseudo-second-order model, it can be seen that q_e value of 87.71 mg/g was obtained by the PAN/*M. oleifera* fiber. Additionally, the experimentally determined values of q_e (Fig. 5) was very close to the calculated values in the pseudo-second-order model. This supports the applicability of the pseudo-second-order model.

4. Conclusion

With the need to synthesize an efficient adsorbent for the removal of potently toxic trace metals, electrospinning of composite mats from material with unique properties was attempted. In this study, we explored the adsorption capabilities of the synthesized material for adsorption of Pb(II) ion from aqueous solution. The adsorption of Pb(II) onto PAN/M. oleifera fiber adsorbents better fitted the pseudo-second-order kinetics and the Langmuir isotherm models. Based on the Langmuir isotherm, the highest maximum adsorption capacity of 172.4 mg/g was obtained by the synthesized fiber which is relatively high compared to most of the values reported in literature. Based on the obtained results, the PAN/*M. oleifera* composite fiber could be applied as an alternative adsorbent for wastewater treatment containing Pb(II) ions. Further studies to be undertaken with the synthesized material will involve investigating the adsorption performance for Pb(II) ions removal from real water samples of Kabwe town of Zambia. In addition, the adsorption behaviour will be investigated in temrs of the materials reusability and adsorption interference from competing cations and anions present in real water samples.

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Job creation through engineering MSMEs

Francis Mwale[1]

Abstract

In Zambia, Small and Medium Enterprises (SMEs) are officially classified into Micro, Small and Medium Enterprises (MSMEs). Further, the Eighth National Development Plan recognizes the need to develop MSMEs across all sectors in view of their high income and job creation potential. To appreciate existing opportunities for the development of engineering MSMEs, leading to higher job creation, a primary online survey was conducted for one month to observe supportive practices to core businesses of Zambian engineering MSMEs as well as establish challenges and expectations of engineering MSMEs from the Government of the republic of Zambia (GRZ) and the Engineering Institution of Zambia (EIZ). Literature review was also conducted to appreciate empirical findings of ways of supporting SMEs in job creation. Outcomes from the survey and from the literature review inform that predominant challenges among engineering MSMEs include lack of affordable capital, inadequate access to opportunities to participate in public and private tenders and contracts, and high incidence of corruption in tendering processes. Engineering MSMEs expect GRZ to increase the proportion of local MSME participation in contracts awarded to foreign contractors from 20% to 40%, provide a lower cost of doing business through reduced statutory obligations, and minimize corruption in tendering processes. The MSMEs expect EIZ to lobby for business opportunities for its members, encourage synergies among new and experienced MSMEs, reduce subscription and practicing fees, encouraging joint ventures between foreign contractors and local MSMEs and lobby for grants from GRZ for its members, among other measures. Access to affordable capital in form of loans for MSMEs is recommended as a catalyst for multiplication of jobs.

Keywords: Micro, Small and Medium Enterprises, supportive practices, expectations, engineering.

1. Introduction

In her Eighth National Development Plan (8NDP), the republic of Zambia aspires to attain a "prosperous Middle-income nation by 2030". This ambition coincides with the 2030 Agenda for Sustainable Development which aims to end poverty, fight inequality and injustice and tackle climate change through the pursuance of Sustainable Development Goals – SDGs (MFNP, 2022). Figure 1 illustrates that the key strategic outcome of the 8NDP is economic transformation and job creation.

The objective of this paper is to demonstrate current supportive practices to core businesses of

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engineering MSMEs while being involved in job creation. Further, the paper seeks to highlight the challenges and expectations of engineering MSMEs from the Zambian government (GRZ) and the Engineering Institution of Zambia (EIZ) in their quest to grow their companies and employ more people.

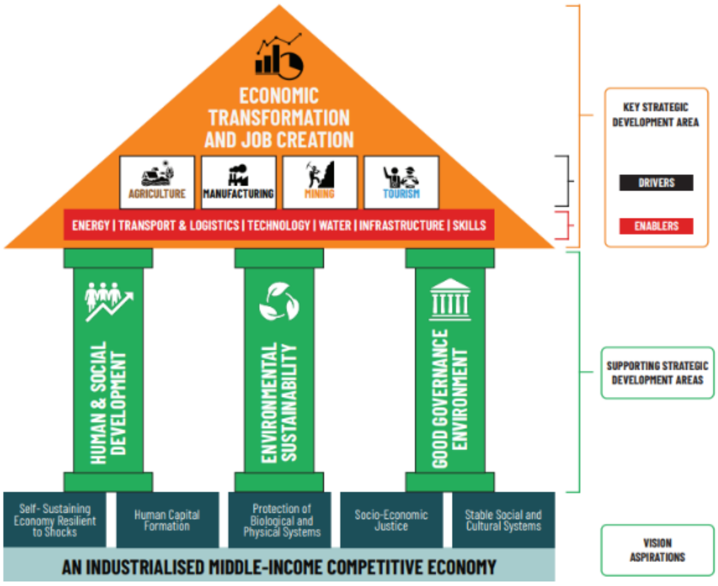

Figure 1: Overview of Vision 2030. Source: MFNP, 8NDP

2. Materials and Methods

A primary online descriptive survey targeting engineering MSMEs was conducted among Engineering Institution of Zambia (EIZ) members social media sites and via email from 8th December 2022 until 8th January 2023, inviting registered engineering Micro, Small and Medium Enterprises (MSMEs) to participate through their authorized representatives. Convenient sampling based on ease of access was used, though no particular MSMEs were targeted nor was any effort made to ensure a balance of respondents in terms of types of industries surveyed, in order to avoid research bias. The survey was designed to obtain quantitative information in order to establish whether recommended engineering and business practices such as internship, mentorship and strategic planning were taking place in MSMEs, as well as qualitative information to allow the MSMEs to express themselves freely and fully. Literature review was also conducted to ensure that the survey findings aligned to the Zambian MSME policy of 2008, at national level, and also compare observed key engineering MSME challenges to those on a global level among SMEs in order to recommend how best to grow engineering MSMEs. Contact was made with the Zambia Development Agency (ZDA) to establish if the new policy for actualizing the newly formed SME Ministry had been released. It was established that the SME policy was currently being drafted. As such the survey was aligned to the MSME policy of 2008. The Secretariat of the EIZ was also contacted to advise the current engineering organization MSME membership population, as well as to authorize access to prospective respondents through EIZ social media sites and emails to MSMEs. Total populations of the corporate memberships comprising C3, C2 and C1 corporate classes, which constitute the engineering MSMEs were estimated at 3,710, as of 30th January 2023.

3. Results

This section gives an outline of the online Survey findings

3.1 Activities of the eighteen MSME respondents

Figure 2 shows the number of survey respondents participating in a particular industry.

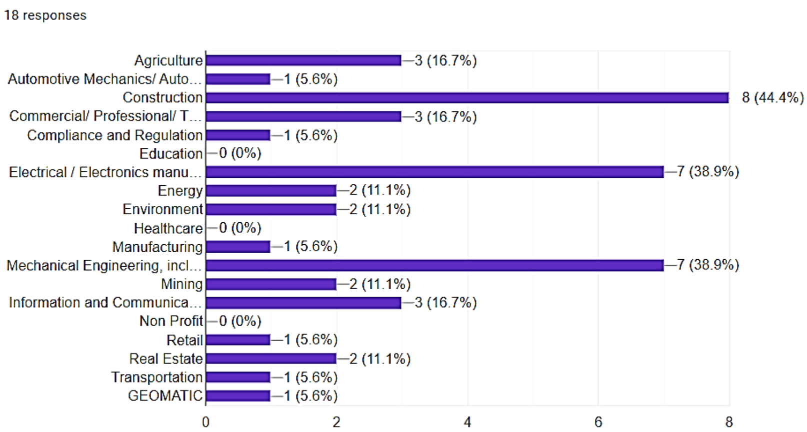

Figure 2: Bar graph showing industry spread of respondents

3.2 How long the MSME respondents have existed

Figure 3 shows the length of existence of the respondents in 5-yearly proportions as a percentage of the total number of respondents.

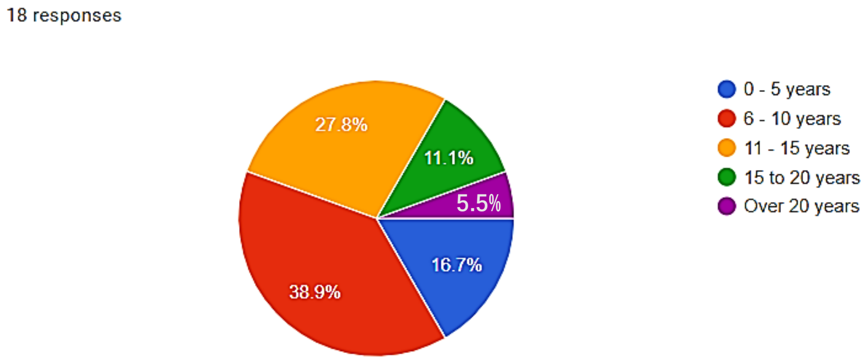

Figure 3: Showing length of existence of Respondent MSMEs in 5-yearly proportions.

3.3 Self-classification of respondent MSMEs, based on 2008 MSME Policy

Figure 4 shows the summary of the recommendation from the Zambian 2008 Policy on MSMEs for classification of MSMEs.

Category	Micro Enterprise	Small Enterprise	Medium Enterprise
Total Investment (equipment)	K1-K80,000	K80,001-K200,000	K200,001-K500,000
Annual Sales Turnover	K1-K150,000	K150,001-K300,000	K300,001-K800,000
Workers	1 to 10 employees	11-15 employees	51-100 employees

Figure 4 - Classification of MSMEs based on 2008 MSME Policy (Source: MSME Policy, 2008)

Figure 5 shows the percentage proportion of Micro, Small and Medium Enterprises out of the total population of respondents.

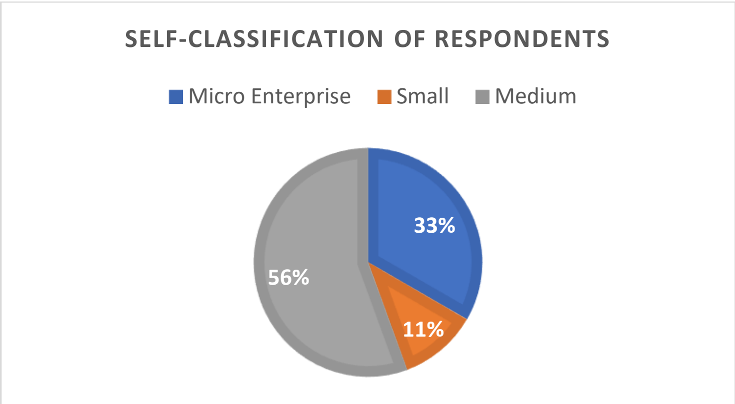

Figure 5: Self-classification of Respondent MSMEs

3.4 Average number of employees per annum

Figure 6 shows the respondent employee levels per annum.

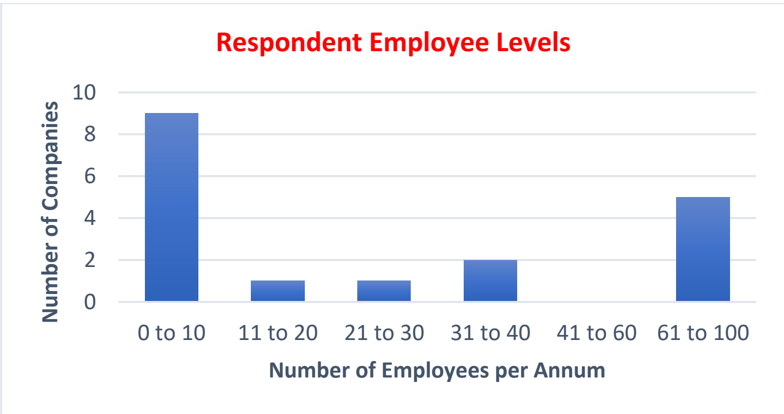

Figure 6: Respondent Employee Levels per annum

3.5 Engineering Classes Required by MSMEs to meet market expectations

Figure 7 shows the number of respondents who would need to employ a particular engineering class to meet market expectations.

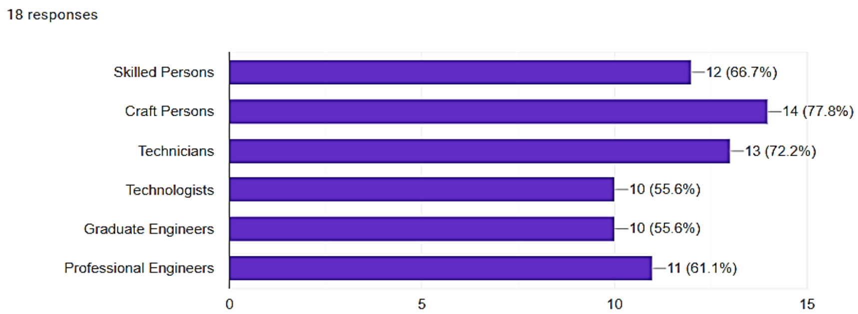

Figure 7: Market driven Engineering Classes Requirement

3.6 Challenges Faced in Growing employment of Qualified Engineering Personnel

Figure 8 gives the number of respondents who acknowledged a particular challenge that they faced in employing qualified engineering personnel.

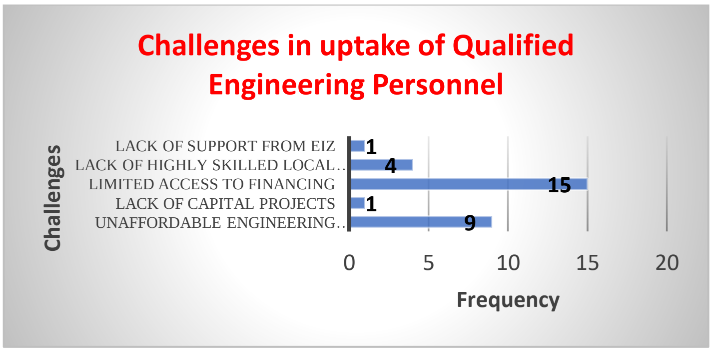

Figure 8: Challenges in Growing Employment of Qualified Engineering Personnel

3.7 Level of Involvement of Respondents in Industrial attachments and Internships

Figure 9 gives the levels of involvement of respondents in industrial attachments and internships for tertiary school students.

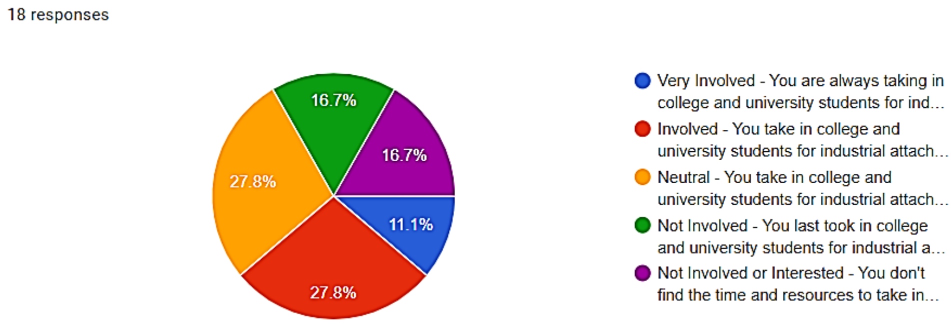

Figure 9: Respondent Level of Involvement in Attachments and Internships

3.8 Level of Involvement of Respondents in Mentorship Programs at Workplace

Figure 10 gives the levels of involvement of respondents in mentorship of their recruits.

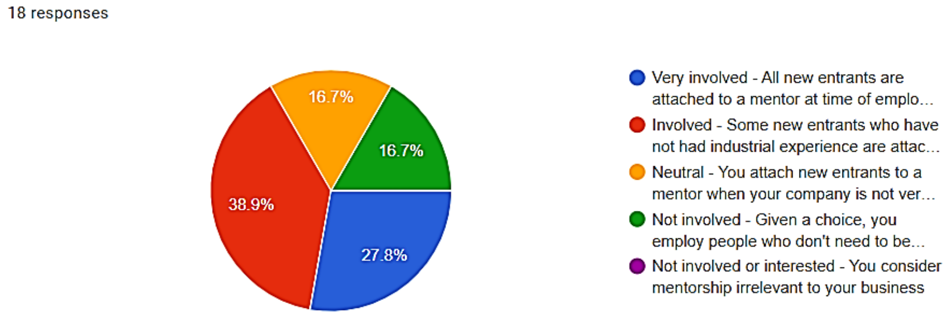

Figure 10: Respondent level of Involvement in Mentorship

3.9 Level of involvement of Respondents in Monitoring Local and Global Trends and Research and Development

Figure 11 gives the extent of use of knowledge (monitoring of trends and Research and Development in informing company strategy) by respondents.

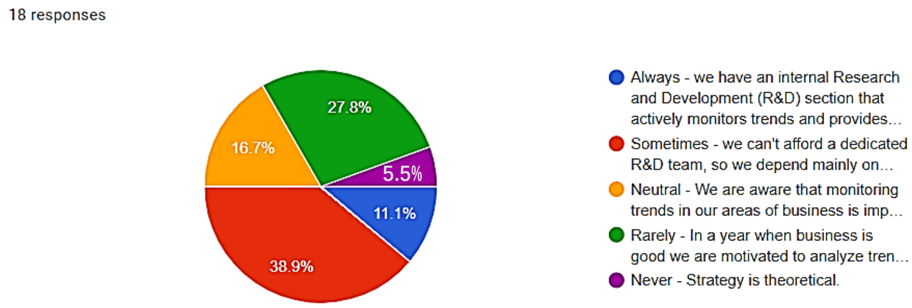

Figure 11: Respondents' extent of use of Knowledge

3.10 Respondents' Expectations of the Zambian Government

Table 1 captures the emerging thematic trends in respondents' expectations from GRZ towards growing their businesses in order that they would employ more of all required skills.

Table 1: Emerging Trends in Respondents' Expectations of GRZ to enable engineering MSMEs to grow their businesses and be able to employ more of all required skills.

Respondent's Expectation of GRZ	Frequency
Access to affordable capital, such as low interest loans	12
Increased access to opportunities for participation in tenders – including increasing local participation in contracts awarded to foreign firms from 20% to 40%, entrenching preference for local contractors and making it difficult for foreign contractors to import semi-skilled labour.	8
Reducing cost of doing business, including having fewer regulatory requirements.	4
Reducing corruption in tender processes, including by automating procurement processes using artificial intelligence to eliminate human vices.	4
Encouraging Joint Ventures and joint ownerships of Zambian businesses with foreign firms that invest in Zambia	3
Introducing flexible taxation	2
Government to equip colleges and universities to ensure production of competent graduates.	2
Government to rethink the curriculum from kindergarten to tertiary education.	1
Legislate charge-out rates, equal pay for equal work policy and implement living wages and reasonable conditions of service to help retain qualified employees.	1
Devise strategies to support and protect the local manufacturing companies.	1
All jobs valued at One Million Kwacha and below to be locally procured.	1
Make skill development levy usage more transparent and accountable	1

3.11 Respondents' Expectations of the Engineering Institution of Zambia

Table 2 captures the emerging thematic trends in respondents' expectations of EIZ to facilitate growth of MSME engineering businesses, ultimately leading to more direct jobs and creation of value chains which result in more jobs.

Table 2: Emerging Trends in Respondents' Expectations of EIZ to facilitate growth of MSME engineering businesses, ultimately leading to more direct jobs, creation of value chains which result in more jobs, etc.

Respondent's Expectation of EIZ	Frequency
Lobby for projects and business opportunities for its members.	6
Encourage synergies among engineering MSMEs, where older and matured MSMEs (and engineering personnel) subcontract startup engineering MSMEs, for capacity building and mentorship.	5
Reduce EIZ subscription and Engineering Registration Board practicing fees.	3
Advocate for foreign companies that are awarded projects in Zambia to form legally binding relationships with local engineering MSMEs, such as Joint Ventures.	3
Lobby GRZ for grants for MSMEs	3
Change the 20% local subcontracting policy for contracts awarded to foreign companies in Zambia, as some foreign contractors buy out local contractors and end up executing the whole contract.	2
Introduce a venture capital fund to be awarded to the most innovative startup MSME by category on an annual or biennial basis.	2
Work with GRZ to ensure registered engineering MSMEs have equal access to tendering opportunities.	2
Lobby for timeous payment of debts owed to engineering MSMEs for GRZ executed projects.	2
Take up active advertising of registered engineering MSMEs on its website and in its various publications at cost effective rates. The income so generated can grow the institution's non-traditional income.	2
Promote entrepreneurship in engineering courses in tertiary education.	2
Protect its members from unscrupulous and fraudulent individuals and organizations.	2
Visit worksites to familiarize with challenges engineering MSMEs encounter.	2
Regulate and standardize charge-out rates for engineering services.	1
Create a database of locally available specialized skills, so that foreign firms don't have to import locally available expertise.	1
Punish unprofessional or poor performance by its members and affiliate companies.	1

4 Discussion

4.1 Size Class definition of MSMEs and its effect on classification of MSMEs in Zambia

Many official definitions of the Small and Medium Enterprise (SME) size class are based on a combination of multiple indicators, dealing with the size of the workforce, sales volume and/ or amount of capital invested (de Kok *et al*., 2013). As Figure 4 demonstrates, classification of MSMEs in Zambia's 2008 Policy is based on the legal status (registration with Patents and

Companies Registration Agency – PACRA) and capitalization of equipment as the key basis, together with one other criterion (MSME Policy, 2008). The self-classification exercise could have wrongly classified businesses such as the Information and Communication Technologies (ICT) industry, which usually have a higher human capital investment than equipment. Construction business, on the other hand, requires high capital investment in machinery. Zambia Development Agency (ZDA) advised that the 2008 MSME Policy had focused on construction industry at the time of being implemented. They expected the new policy being developed for the new Ministry of Small and Medium Enterprises to address the bias towards investment in machinery.

4.2 Survey Observations

4.2.1 Sample Size versus Industry Coverage

With 18 respondents out of a population of 3,710 engineering MSMEs (0.5% of engineering MSME population), it is hoped that the views expressed by respondents represent a realistic insight into the MSME environment obtaining in Zambia. Figure 2 shows that 18 out of 21 pre-defined industries were represented, with Geomatic being the additional respondent-generated 19th industry that took part in the survey. As such, while the sample size was small (0.5%), the industry coverage was wider, with 19 out of 22 industries represented (86% of pre-defined and respondent-generated industries).

4.2.2 Predominant Supportive Practices observed

Figure 7 demonstrates that respondents required a wide spectrum of engineering classes to effectively meet market expectations. However, Figure 8 shows that cost implications limited the uptake of engineering personnel. In Figure 9, practices such as internship and industrial attachments showed a 39% occurrence of "involved and very involved" among the respondents, while in Figure 10, mentorship showed a 67% occurrence of "involved and very involved".

Figure 11 shows that 50% of the respondents indicated that they monitored local and international trends either sometimes or always. These respondents also indicated that they used strategy and research and development (R&D) to address business requirements, and, in particular, their human capital requirements to ensure adaptability, sustainability and survivability of their businesses. The collective use of information gathering and usage to enhance productivity nowadays constitutes a factor of production, additional to land, labour, capital and entrepreneurship. It would be desirable that all respondents effectively used knowledge as a factor of production, in itself (Mihaela, 2009).

4.2.3 Expectations raised by Respondents

4.2.3.1 Expectations from GRZ

Table 1 discusses expectations of engineering MSMEs respondents from GRZ. Consistent expectations concern GRZ enabling access to affordable capital in the form of low interest loans and even grants. Respondents also expect GRZ to provide a level playing field in accessing opportunities to tender for projects both in government and private sector by minimizing corruption in the procurement processes. They also request a policy shift from currently contractually requiring foreign contracted firms to subcontract 20% of the total contract, to 40%. Respondents also expect GRZ to reduce the cost of doing business, partly through reducing statutory obligations, and minimizing the incidence of corruption in the awarding of contracts. A suggestion was made to fully automate the government procurement system to eliminate bias in awarding contracts.

The rest of the expectations involve GRZ formulating policies to protect local MSMEs, make it favorable for foreign contractors to go into joint ventures with local MSMEs, and to rethink the educational curriculum and equip colleges and universities to ensure competent graduates; among other expectations.

4.2.3.2 Expectations from the EIZ

Table 2 discusses respondents' expectations from EIZ. Respondents' highest expectation is that EIZ lobbies for access to business prospects on behalf of its MSME members. They would also like the institution to encourage synergies among old and new MSMEs in the institution, to enable capacity building and mentorship.

The rest of the expectations involve capacity building, effective monitoring of registered engineering firms to ensure compliance, and joint efforts with GRZ to ensure timeous dismantling of debts owed by GRZ to MSMEs. The inculcation of entrepreneurship in tertiary education is also cited. Respondents also expect EIZ to ensure conducive welfare of MSMEs by protecting members from unscrupulous and fraudulent individuals and organizations and also minimizing importation of foreign skills when such skills exist locally through the creation of a skills database; among others.

4.3 Global view on financing of MSMEs to enhance employment creation

In a report entitled: Small Business, Big Growth – How investing in SMEs creates jobs (Khanna et al., 2021), two main conclusions are reached:

- Over two years, every million dollars loaned to SMEs in developing countries is associated with the creation of an average of 16.3 additional permanent jobs when compared to firms that did not have access to finance.

- Extrapolating this result to the SME loan portfolios of International Finance Corporation's (IFC's) client financial institutions suggests that in 2018, due to those client lending activities, the availability of financing was related to the estimated creation of between 4.7 million and 6.1 million additional permanent jobs.

4.4 Limitations

The survey and literature review focus on expectations and enablement of engineering MSMEs. However, jobs involve, employees, employers such as engineering MSMEs, GRZ, institutions like EIZ, among other stakeholders. There would be need to consider expectations of other stakeholders, in order to ensure alignment of stakeholder expectations in the same direction leading to stakeholder value creation rather than only shareholder value creation, resulting in sustainability of job creation (Freeman, 2013).

5 Conclusion and Recommendations.

Engineering MSMEs expect GRZ to increase the proportion of local MSME participation in contracts awarded to foreign contractors from 20% to 40%, provide a lower cost of doing business through reduced statutory obligations, and minimize corruption in tendering processes. The MSMEs expect EIZ to lobby for business opportunities for its members, encourage synergies among new and experienced MSMEs, reduce subscription and practicing fees, encouraging joint ventures between foreign contractors and local engineering MSMEs and lobby for grants from GRZ for its members, among other measures. As observed from engineering MSME submissions and the literature review, access to affordable capital in form of loans for MSMEs is recommended as a catalyst for multiplication of jobs. While other concerns, such as access to opportunities for tenders and contracts, are important, lack of financial capacity and capability is observably a major factor in limiting engineering MSMEs' ability to increase employment.

6 Acknowledgements and References

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- Appreciation goes to the eighteen respondents for providing useful feedback by responding to the survey.

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Push Factors to Zambia's Copper Royalty Fiscal Regime Changes

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Abstract

Zambia has been striving to economically develop from its copper mineral endowment through mineral royalty. Since the time of privatisation of the mines in 2000, some sections of the community feel copper royalty contribution by the mining companies is not enough. In response, successive Zambian Governments have tried to address citizen's concerns, but this has resulted in inconsistent policies and an unstable copper royalty regime. The main aim of the research, therefore, was to investigate the push factors that could have contributed significantly to the inconsistency changes to copper royalty fiscal regime in Zambia. Exploratory study and snowball sampling methods were used for data collection. The data collected was evaluated and subjected to comparative analysis.

The investigation results showed that the mineral royalty received by government on aggregated mineral commodities was less than the royalty calculated on copper for all the years from 2000 to 2021 except for 2011, 2015, 2016 and 2018. For example, in 2005, the government collected US$11,416,862 in mineral royalty from copper and other commodities while that calculated on copper was US$12,827,085. Emanating from the investigation results, it has been concluded that four push factors have been attributed to Zambia's Copper Royalty Fiscal Regime changes. The first is the conundrum that has existed between the Government of the Republic of Zambia and the Zambia Chamber of Mines where these two major stakeholders have their own definition of mineral royalty. The second is the "deserving desire" to benefit from the rising copper prices which has always resulted in pressure on government by the citizens, civil society organisations and opposition political parties to increase the royalty. Thirdly, the uncaptured mineral royalty on copper did not sit well with the citizens as it resulted in lack of transparency in the mining industry. The fourth push factor is transfer pricing.

Keywords: Mineral royalty, stakeholders, government, mining sector, push factor

1. Introduction

Mineral royalty in Zambia is a source of government revenue that is derived from the country's mineral resources. From the time of privatisation of Zambia Consolidated Copper Mines (ZCCM), the Government of the Republic of Zambia (GRZ) has been striving to harness the revenues from copper to provide for public infrastructure and services (see Figure 1). However, Zambia has been characterised by inconsistent mineral royalty fiscal regimes (Institute, 2015)

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changes. This is in its quest to maximise the benefits from the country's mineral resources. The motivation to the changes to copper royalty has been the focus of investigation in this article.

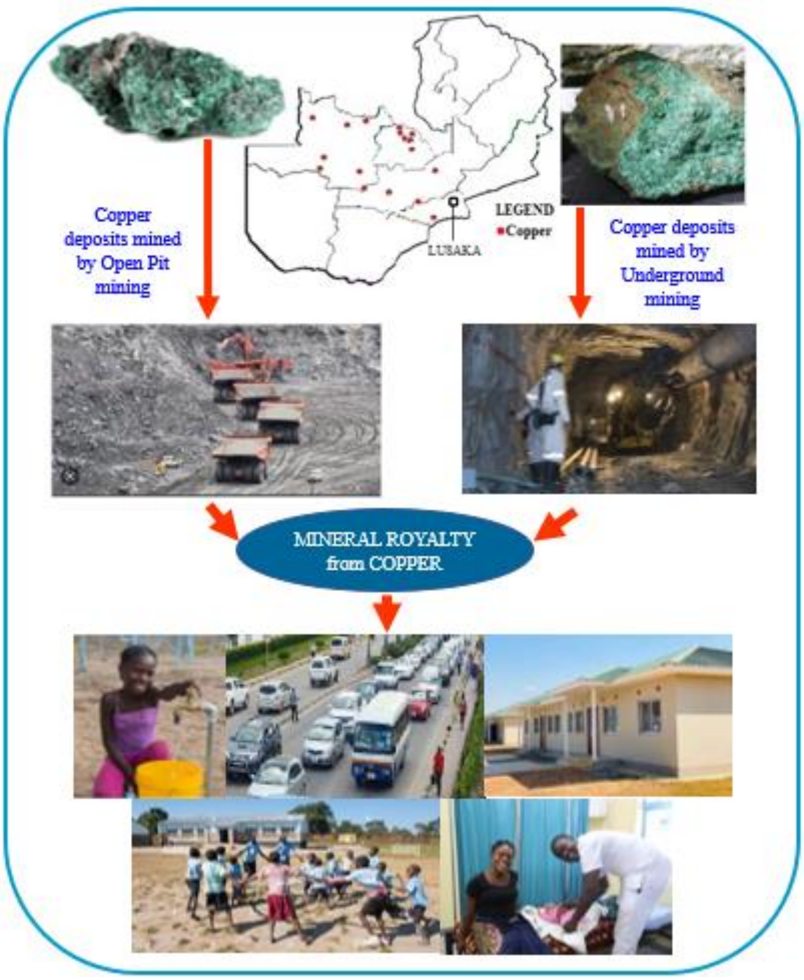

Fig. 1: Public infrastructure and services

2. Definition of Mineral Royalty

Wherever mineral royalty has been considered, the aspect of ownership of a mineral resource has stood out to be fundamental as to who should be paid the mineral royalty. Although the matter of the right of ownership of minerals in Zambia was dealt with at independence (O'Faircheallaigh, 1986) and restated in the Mines and Minerals Development Act No. 11 of 2015 (Government of the Republic of Zambia, 2015), it is confounding that GRZ and the Zambia Chamber of Mines (ZCM) have different definitions of mineral royalty (see Table 1). In 2016, Zambia Chamber of Mines published a booklet entitled *"A Guide to Understanding Mineral Royalty Tax"* (Zambia Chamber of Mines, 2016). In 2019, ZCM published another booklet entitled *"Taxing the Mining Sector: Report by the Zambia Chamber of Mines"* (Zambia Chamber of Mines, 2019).

Table 1: Definition of Mineral Royalty

Mineral Royalty Definition	Author (s)
Mineral Royalty means a payment received as consideration for the extraction of minerals.	Government of the Republic of Zambia (2008, 2015)
A *royalty* is defined as a payment made to the owner of an asset by those who wish to make use of it to generate revenue.	Zambia Chamber of Mines (2016, 2019)

In both publications, the ZCM has emphasised on *what mineral royalty is not and what it is.* This is evident that what is thought by the government and the citizens as mineral royalty is not what it is in as far as the Chamber is concerned. ZCM has further argued that mineral royalty is in essence not a tax, and this article shares the same point of view with the Chamber. According to the Collins English Dictionary, *"a tax is a compulsory financial contribution imposed by a government to raise revenue, levied or paid on the income or on property of persons or organisations, on production costs or sales prices of goods and services, etc"* (HarperCollins Publishers, 2023). In view of the above, a mineral resource is an asset for the inherent owner of the mineral asset, thus, the value of an asset derived from it as mineral royalty does not qualify to be referred to as a tax payment. Albeit pointing to the fact that *"Consensus among key stakeholders is a prerequisite for a sustainable tax framework"* (Fjeldstad, et al., 2016), the Chamber has not taken the initiative to have dialogue with government on the meaning of mineral royalty. Instead, it has relied on its two publications to send the message to government and the people of Zambia. This is a major push factor to mineral royalty changes as the conundrum is perpetuated. ZCM has been standing in the way of its own progress without realising it. Without a common understanding of their mutual relationship, there would always be a push by the owner of the mineral asset to want to get more or a push factor by the investor to want to pay less of the mineral royalty than the fair value of the mineral asset.

3. Price of Copper

Although about 8% of formal occupation, 30% of Government earnings, over 70% of foreign exchange earnings, and 10% of the country's Gross Domestic Product (GDP) is accounted for by mining of different minerals in Zambia (Kabuswe, 2021), a larger share to the country's GDP, foreign exchange earnings, government revenue, and formal employment could be attributed to copper if Zambia Revenue Authority (ZRA) in their annual reporting were to indicate royalty for each commodity. Copper mining has therefore, been the backbone of Zambia's economy from the time of its independence in 1964. Unlike pay as you earn (PAYE), corporate income tax etc., which are common to any other investments in Zambia, mineral royalty from copper and other minerals is unique only to the mining sector. Because mineral royalty entitles citizens to ownership of the mineral resources, Zambians have always looked forward to maximising on the royalty whenever the price of copper soared (see Figure 2). From Figure 2, the trend of the price of the commodity was evaluated to determine the effective net copper price for the mines that signed development concessions with government (see Table 2).

The mines that signed development agreements with the Zambian Government included Chibuluma Mine Plc, Konkola Copper Mines Plc (KCM), Mopani Copper Mines Plc (MCM), Chambishi Non-ferrous Company Africa Mining (NFCA), and China Non-ferrous Metals Company Luanshya Copper Mines Plc (CNMC Luanshya Copper Mines Mine Plc, formerly Roan Antelope Mining Corporation).

From Table 2, copper price rose by an effective net price increase of 255.6% in 2011 above the concessional price in 1997 for Chibuluma Mine. For NFCA and Chambishi Metals, the prices soared above the concessional copper price in 1998 by an effective net price increase of 427.2% in 2011. In the case of KCM and MCM, the effective net price increase of 361.8% in 2011 was observed above the concessional price in 2000. Albeit the effective net price increases by 255.6%, 427.2% and 361.8%, the mining investors still claimed losses. As a result, the government could not get the benefit for its citizens from the rising copper prices.

Fig. 2: Average Copper Price from 1995 to 2021 (source: https://www.lme.com/en/)

Table 2: Effective net copper price increase between 1995 and 2021

MINE	Chibuluma Mine (1997)	NFCA & Chambishi Metals (1998)	KCM & MCM (2000)
Concessional Copper Price (US$)	2,277	1,654	1,846
Lowest Copper Price in 2002 (US$/t)	1,557	1,557	1,557
Price Decrease (US$)	-720	-97	-290
Price Decrease	-31.6%	-5.9%	-15.7%
Highest Copper Price in 2011 (US$/t)	8,817	8,817	8,817
Price Increase (US$/t)	6,540	7,163	6,970
Price Increase	287.2%	433.1%	377.6%
Effective Net Price Increase	**255.6%**	**427.2%**	**361.8%**

After selling the mines cheaply and signing development agreements (Clifford Chance, 2016a; 2016b; 2016c; 2016d; 2016e) for low mineral royalty for a minimum of 15 years tenure at the backdrop of low copper prices that prevailed at the time, this was a great setback for Zambian citizens. In light of the above, the general citizens, civil society, and opposition political parties advocated for the Zambian Government to renegotiate the terms of the development agreements (Lungu, 2008) particularly on mineral royalty. The result of this was not a renegotiated concessions but a radical change of mining legislation in 2008. Later after 2008, the trend of frequent mineral royalty changes continued without empirical research studies to support the change. Copper being the country's main mineral asset, the urge to increase the royalty always becomes an emotive issue for the citizens, civil society, and opposition political parties. This "deserving desire" to benefit from increasing copper price is another push factor to the mineral royalty fiscal regime changes.

4. Zambia's Uncaptured Mineral Royalty on Copper

International organisations have time and again said that the concern that the country has not been benefiting much from its mineral wealth through mineral royalty by Zambians, civil society organisations, opposition political parties and the local media houses are totally unfounded but mere sentiments (Fjeldstad, et al., 2016). In addressing this matter, the study examined the actual mineral royalty collected by ZRA from copper and other mineral commodities and mineral royalty calculated on copper production from 2000 to 2021.

4.1 Aggregated Mineral Royalty earnings from copper and other commodities

Table 3 shows the actual mineral royalty received by government on all commodities.

Table 3: Actual mineral royalty from copper and other commodities (ZRA, 2008-2021; Moore Stephens, 2009; Manley, 2013)

Year	Mineral Royalty (US$)	Year	Mineral Royalty (US$)	YEAR	Mineral Royalty (US$)
2000	973,156	2008	48,770,995	2015	434,426,419
2001	1,832,302	2009	46,590,008	2016	296,129,971
2002	632,905	2010	86,210,504	2017	255,529,906
2003	1,747,583	2011	175,644,502	2018	374,923,810
2004	859,936	2012	280,771,593	2019	290,611,111
2005	11,416,862	2013	326,660,482	2020	292,251,366
2006	14,292,636	2014	287,300,813	2021	623,671,522
2007	16,109,927				

4.2 Mineral Royalty calculated from Copper Production and average Copper Price

When ZCCM was privatised, there was accelerated flow of foreign direct investment (FDI) into the Zambian mining industry, for example, from almost no investment during ZCCM to US$2.24 billion and US$2.9 billion during MCM and KCM, respectively (Sikamo, et al., 2016). The result was an accelerated copper production from as low as 321,285 tonnes in 1995 (George, 1999) to 226 845 tonnes in 2000 and 882,061 tonnes in 2020 before dropping to 803 747 tonne in 2021 (Ministry of Mines and Minerals Development, 2022). Copper production tonnages have been shown in Table 4 from 2000 to 2021 for the following mines: Chibuluma Mine Plc, KCM, MCM, Chambishi NFCA, CNMC Luanshya Copper Mines Mine Plc, FQM Kansanshi Mining Plc (KMP), Barrick Gold Lumwana Mine Plc, Lubambe Mine Plc and FQM Trident Minerals Ltd (formerly FQM Kalumbila Minerals Ltd). The details of the copper royalty rate specific to individual mines have also been provided in Table 5.

Given the LME average copper price in Figure 2, copper production in Table 4 and the copper royalty rate in Table 5, royalty on copper was calculated using Equation 1.

$$Mineral\ Royalty\ (US\$) = Finished\ Copper\ (t) \times Copper\ Price/t \times \%\ Mineral\ Royalty \qquad (1)$$

For example, in 2000, KCM produced 158,343t of copper sold at the LME average copper price of US1,846/t with 0.6% mineral royalty chargeable.

$$\therefore Mineral\ Royalty\ (US\$) = 158{,}343t \times \text{US\$1,846/t} \times 0.6\% = \boldsymbol{US\$1,753,807}$$

Table 4: Copper production from 2000 to 2021 (Ministry of Mines and Minerals Development, 2022; George, 1999)

Year	KCM (t)	MCM (t)	Chibuluma Mine (t)	Chambishi NFCA (t)	CNMC Luanshya (t)	FQM Kansanshi (t)	Barrick Lumwana (t)	Lubambe Mine (t)	FQM Trident (t)	Other (t)	TOTAL (t)
2000	158,343	50,645	7,832							10,025	226,845
2001	196,805	83,515	7,403							9,642	297,365
2002	222,010	103,149	7,548							11,877	344,584
2003	195,163	134,394	6,887	6,300						29,518	372,262
2004	191,685	160,613	5,248	19,432	5,172					41,544	423,694
2005	163,603	132,581	5,699	19,789	17,632	78,135				49,076	466,514
2006	141,777	135,126	9,718	22,603	22,793	127,179				19,232	478,428
2007	154,304	104,179	12,636	24,185	20,832	163,825				33,114	513,075
2008	128,016	113,382	15,504	26,001	22,098	215,315				14,022	534,338
2009	137,711	100,424	16,246	23,490	508	244,979	109,413			4,829	637,600
2010	138,726	102,380	17,821	22,030	10,017	231,124	146,690			17,304	686,092
2011	134,690	119,552	17,533	23,279	16,018	230,295	117,022			12,221	670,609
2012	159,877	117,804	17,932	26,272	24,289	261,351	81,144	3,221		13,847	705,737
2013	130,457	149,966	18,101	28,068	36,091	270,724	117,968	22,192		18,648	792,215
2014	120,409	109,870	15,825	28,601	44,422	262,706	97,058	25,725		3,643	708,259
2015	115,098	93,260	12,956	26,041	44,039	226,674	130,363	24,860	32,956	4,612	710,860
2016	111,529	43,020	10,831	26,870	34,286	253,274	122,872	19,033	143,659	8,916	774,290
2017	86,585	44,144	11,300	27,706	43,693	253,272	116,171	18,037	190,683	7,739	799,329
2018	97,946	62,191	10,349	27,603	50,363	167,675	101,474	22,081	223,656	98,607	861,946
2019	96,769	62,191	6,021	39,372	47,918	177,392	107,902	23,015	220,006	15,843	796,430
2020	61,943	30,079	2,218	48,883	54,047	221,482	124,970	21,062	251,175	66,201	882,061
2021	58,948	45,313	3,051	62,347	57,785	201,185	108,790	18,373	232,688	15,268	803,747

Table 5: Copper royalty rates from 2000 to 2021

Year	KCM	MCM	Chibuluma Mine	Chambishi NFCA	CNMC Luanshya	FQM Kansanshi	Barrick Lumwana	Lubambe Mine	FQM Trident
2000	0.6%	0.6%	2.0%						
2001	0.6%	0.6%	2.0%						
2002	0.6%	0.6%	2.0%						
2003	0.6%	0.6%	2.0%	3.0%					
2004	0.6%	0.6%	2.0%	3.0%	3.0%				
2005	0.6%	0.6%	2.0%	3.0%	3.0%	0.6%			
2006	0.6%	0.6%	2.0%	3.0%	3.0%	0.6%			
2007	0.6%	0.6%	2.0%	3.0%	3.0%	0.6%			
2008	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%			
2009	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%		
2010	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%		
2011	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%		
2012	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	
2013	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	
2014	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	
2015	8.0%	8.0%	8.0%	8.0%	8.0%	9.0%	9.0%	8.0%	9.0%
2016	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
2017	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
2018	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
2019	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
2020	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
2021	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%

The above calculation was performed for KCM for all the other years to 2021. In a similar manner, the copper royalty for each mine was determined. The results of the total copper royalty calculated for all the mines in each particular year have been shown in Table 6.

Table 6: Calculated Mineral Royalty on Copper

Year	Total Calculated Copper Royalty (US$)	Year	Total Calculated Copper Royalty (US$)	Year	Total Calculated Copper Royalty (US$)
2000	2,604,552	2008	108,319,899	2015	332,309,925
2001	2,888,134	2009	98,021,489	2016	186,548,326
2002	3,271,902	2010	151,345,032	2017	294,741,677
2003	4,101,418	2011	174,148,135	2018	299,760,591
2004	8,477,945	2012	329,745,377	2019	353,369,917
2005	12,827,085	2013	340,403,209	2020	380,141,674
2006	26,735,329	2014	288,651,441	2021	737,937,901
2007	29,676,735				

A comparative analysis of the actual mineral royalty receipted by ZRA (government) on all mineral commodities (copper inclusive) and the calculated mineral royalty on copper from 2000 to 2021 has been shown in Figure 3.

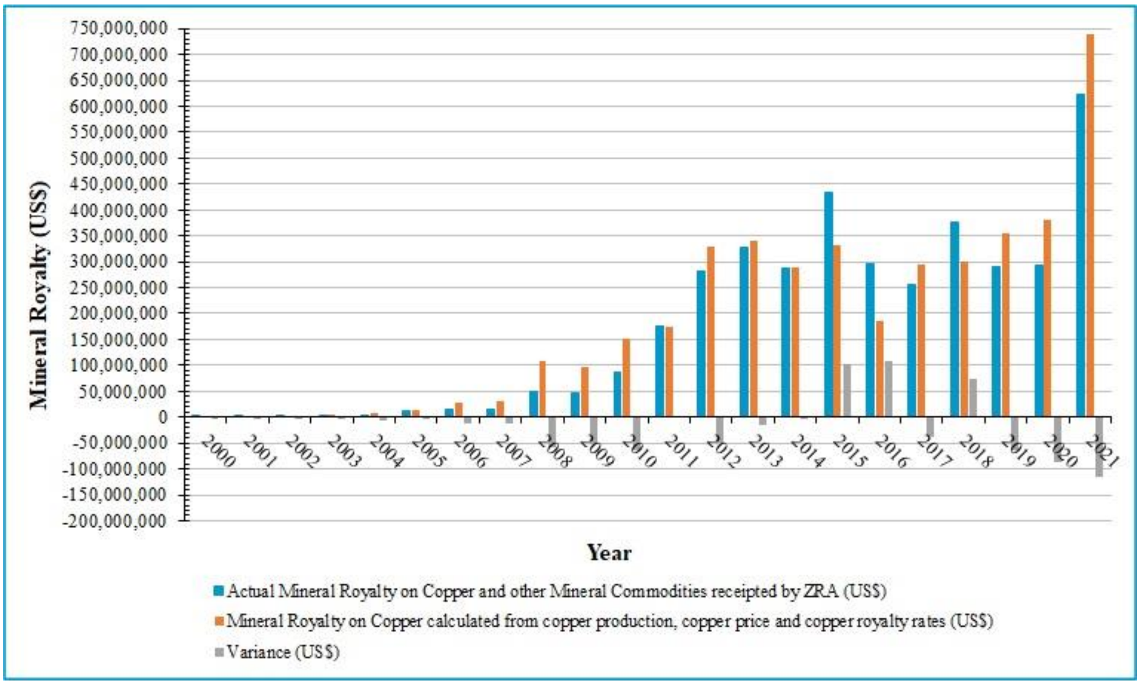

Fig. 3: Actual Mineral Royalty on all commodities and calculated Mineral Royalty on Copper

5. Discussion

Here now lies the conundrum when calculated mineral royalty on copper in Table 6 is compared with actual mineral royalty on all commodities in Table 3. The receivable royalty by ZRA as an aggregate on all mineral commodities inclusive of copper was lower than what would have been received on copper alone given copper production and the average copper price that prevailed at the time. As can be observed from Figure 3, Zambia captured less mineral royalty on the aggregated mineral commodities than on copper during all the years from 2000 to 2021 except for 2011, 2015, 2016 and 2018. For example, in 2000, actual royalty received on all commodities (copper inclusive) was US$973,156 while the royalty calculated for copper is US$2,604,552. In 2005, the actual royalty collected on all commodities was US$11,416,862 while that on copper is US$12,827,085. Thus, US$1,631,396, and US$1,410,223 of copper royalty was not captured in 2000 and 2005, respectively. The observation in Figure 3 also agrees with one case in point of the Supreme Court judgement in favour of Zambia against Glencore in 2020 where transfer pricing was cited (Supreme Court of Zambia, 2020). "Transfer pricing is an accounting procedure that involves companies charging higher price to divisions in high-tax countries (reducing profits) or charging a lower price (increasing profits) for division in low-tax countries when products or services are traded between a subsidiary company and a parent company" (Readhead, 2016). It cannot, therefore, be disputed that Zambians have not been receiving a fair share of their mineral wealth. Hence, the uncaptured mineral royalty and transfer pricing are also factors which motivated the need for copper royalty changes enabling Zambians to benefit from their country's mineral endowment.

6. Conclusion

From the findings, it is concluded that the push factors that have been leading to frequent mineral royalty fiscal regime changes are: (i) The conundrum that lies with the definition of mineral royalty, (ii) the "deserving desire" to benefit from the rising copper prices (iii) the uncaptured mineral royalty on copper, and (iv) transfer pricing. For stability of the mining sector, it is recommended that the Zambian Government and the Zambia Chamber of Mines should consider harmonisation of their understanding of mineral royalty without alienating the inherent ownership of the mineral asset from the Zambia citizens. In the absence of this common understanding of their mutual relationship, there will always be a push by the owner to want to get more or a push factor by the investor to want to pay less of the mineral royalty than the fair value of the mineral asset.

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