2024 ENGINEERING INSTITUTION OF ZAMBIA SYMPOSIUM

Effect of particle-wall friction on slugging fluidization dynamics

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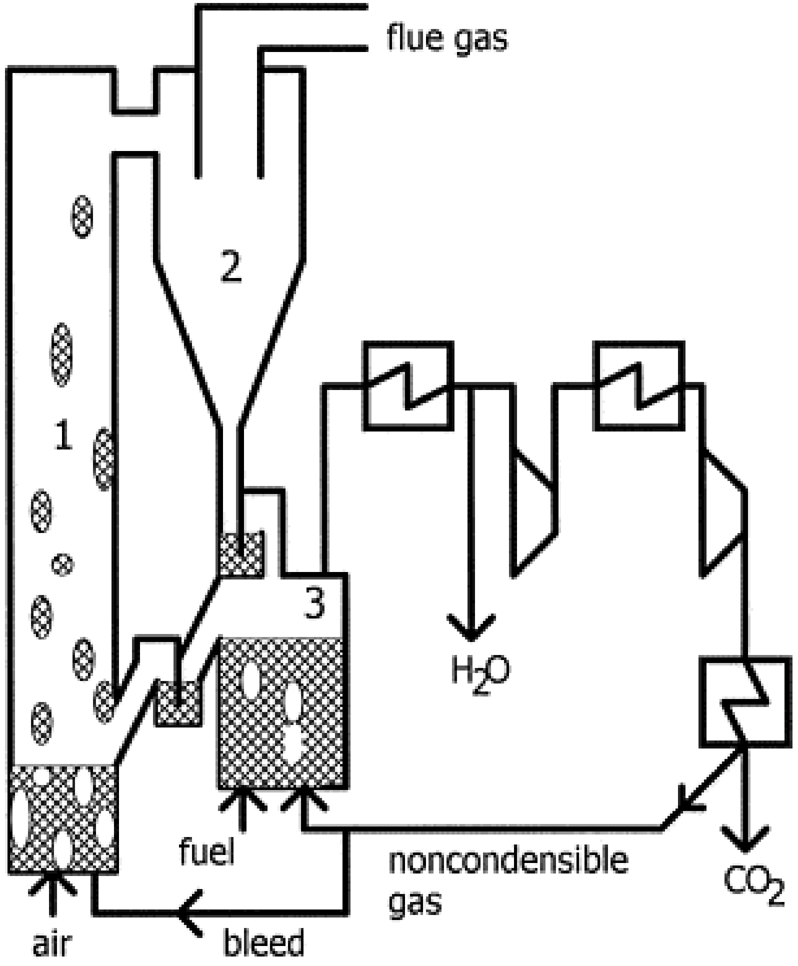
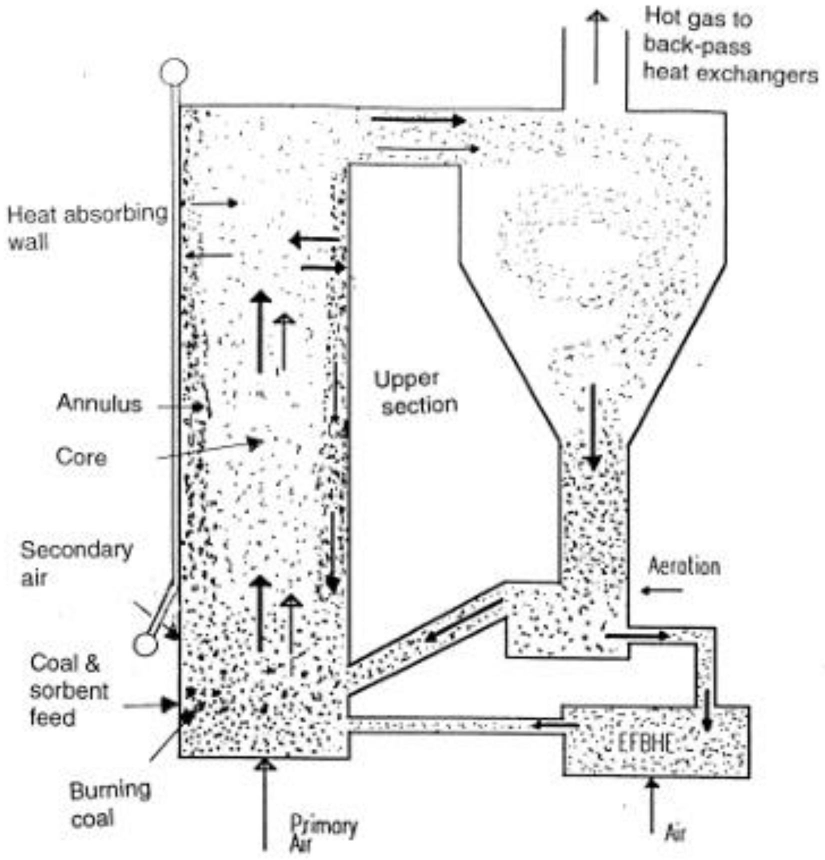
INTRODUCTION

- Fluidization technology is key in tackling sustainability challenges including energy and carbon capture to make mention.



chemical-looping combustion process (Lyngfelt et al., 2001)



CFB boiler furnace (P . Basu, 1999)

INTRODUCTION

- Despite inherent advantages of fluidization, designing, troubleshooting and scaling up is still rather difficult.
- Modeling tools such as Computational Fluid Dynamics (CFD) have become indispensable in design efforts complementing experimentation.
- Not only does CFD offer detailed insights limited by experimentation but also makes it possible for novel reactors to be designed and existing ones to be optimized.
- Of the various CFD models available, the Euler-Euler model also known as the Two-Fluid-Model (TFM) and the Euler-Lagrange model or discrete particle model (DPM) are the most widely used.
- In TFM, understanding of gas-solid interactions (drag), particle-particle interactions (collision forces) and particle-wall interactions is still quite poor (Deen, et al., 2007).

INTRODUCTION

- The Johnson and Jackson wall boundary condition (Johnson and Jackson, 1987) is often used to describe the particle-wall interaction.
- Incorporates a term called the specularity coefficient, ϕ which varies between zero and unity depending on the roughness of wall.
- Unfortunately the specularity coefficient cannot be physically measured.
- The objective of this work is to quantify the effects of ϕ on fluidized bed dynamics.
- Pressure and bed height fluctuations are used to characterize the time dependent behavior of the fluidized bed at different ϕ values and superficial gas velocities.

TFM MODEL

Table 1: Summary of TFM equations

Mass conservation of phase k

(k = g for gas and s for solid phase)

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \nabla \cdot (\alpha_k \rho_k \mathbf{u}_k) = 0$$

Momentum conservation for solid phase:

$$\frac{\partial}{\partial t}(\alpha_s \rho_s \mathbf{u}_s) + \nabla \cdot (\alpha_s \rho_s \mathbf{u}_s \mathbf{u}_s) = \nabla \cdot \overline{\overline{\tau}}_s - \alpha_s \nabla p \text{-} \nabla p_s + \beta_{gs} (\mathbf{u}_g - \mathbf{u}_s) + \alpha_s \rho_s \mathbf{g}$$

Momentum equation for gas phase:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g \mathbf{u}_g) + \nabla \cdot (\alpha_g \rho_g \mathbf{u}_g \mathbf{u}_g) = \nabla \cdot \overline{\overline{\tau}}_g - \alpha_g \nabla p - \beta_{gs} (\mathbf{u}_g - \mathbf{u}_s) + \alpha_g \rho_g \mathbf{g}$$

Granular Temperature equation

$$\frac{3}{2}\left[\frac{\partial}{\partial t}(\alpha_s \rho_s \Theta_s) + \nabla \cdot (\alpha_s \rho_s \mathbf{u}_s \Theta_s)\right] = \left(-p_s \overline{\overline{I}} + \overline{\overline{\tau}}_s\right) : \nabla \mathbf{u}_s + \nabla \cdot (\kappa_s \nabla \Theta_s) - \gamma_s - 3\beta_{gs} \Theta_s$$

TFM MODEL

gas-solid interaction

Gidaspow drag model

$$\beta_{gs} = \frac{3}{4}\frac{C_D \alpha_s \alpha_g \rho_g \left|\mathbf{u}_g - \mathbf{u}_s\right|}{d_s}\alpha_g^{-2.65} \quad ,\alpha_g > 0.8$$

$$C_D = \frac{24}{\alpha_g Re_s}\left[1 + 0.15\left(\alpha_g Re_s\right)^{0.687}\right], Re_s = \frac{\rho_g \left|\mathbf{u}_g - \mathbf{u}_s\right| d_s}{\mu_g}$$

$$\beta_{gs} = \frac{150\alpha_s\left(1-\alpha_g\right)\mu_g}{\alpha_s d_s^2} + 1.75\frac{\rho_g \alpha_s \left|\mathbf{u}_g - \mathbf{u}_s\right|}{d_s} \quad ,\alpha_g \le 0.8$$

wall boundary conditions

$$\vec{\tau}_s = -\frac{\pi}{6}\sqrt{3}\phi\frac{\alpha_s}{\alpha_{s,\max}}\rho_s g_0 \sqrt{\Theta_s}\vec{U}_{s,\|}$$

$$q_s = \frac{\pi}{6}\sqrt{3}\frac{\alpha_s}{\alpha_{s,\max}}\rho_s g_0 \sqrt{\Theta_s}\vec{U}_{s,\|}\cdot\vec{U}_{s,\|} - \frac{\pi}{4}\sqrt{3}\frac{\alpha_s}{\alpha_{s,\max}}\left(1-e_{sw}^2\right)\rho_s g_0 \Theta_s^{\frac{3}{2}}$$

SIMULATION SET-UP

- Modeled system is a transparent thin rectangular column with dimensions of 0.075 m depth, 0.23 m width and 1.22 m length (Gopalan, et al., 2016).

Table 2: particle properties

physical property	units	Nylon beads
minimum fluidization velocity	m/s	1.05
bed height at minimum fluidization	m	0.173
void fraction (fluffed)	-	0.42
particle density	kg/m^3	1131
particle size (Sauter mean diameter)	µm	3256
sphericity	-	0.94
particle-wall coefficient of restitution (normal)	-	0.92
particle-particle coefficient of restitution (normal)	-	0.84
terminal velocity	m/s	9.94
superficial gas velocities	m/s	2.19, 3.28, 4.38

SIMULATION SET-UP

- Velocity inlet and pressure outlet boundary conditions were specified at the bed inlet and outlet.
- Partial slip of the Johnson and Jackson boundary condition is imposed for the solid phase at the walls using ϕ values of 0.005, 0.05 and 0.5 at three different superficial gas velocities.
- The gas phase was modeled using the no-slip boundary condition.
- The 2ND order upwind scheme was used to discretize momentum and granular temperature equations and QUICK scheme for the spatial discretization of the volume fraction.
- The 1st order implicit scheme was used for the transient formulation and Phase Coupled SIMPLE for pressure–velocity coupling.
- Simulations are run for a total of 40 s on a Sugon I620r-G server consisting of 5 nodes each employing a maximum of 16 cores.

SIMULATION SET-UP

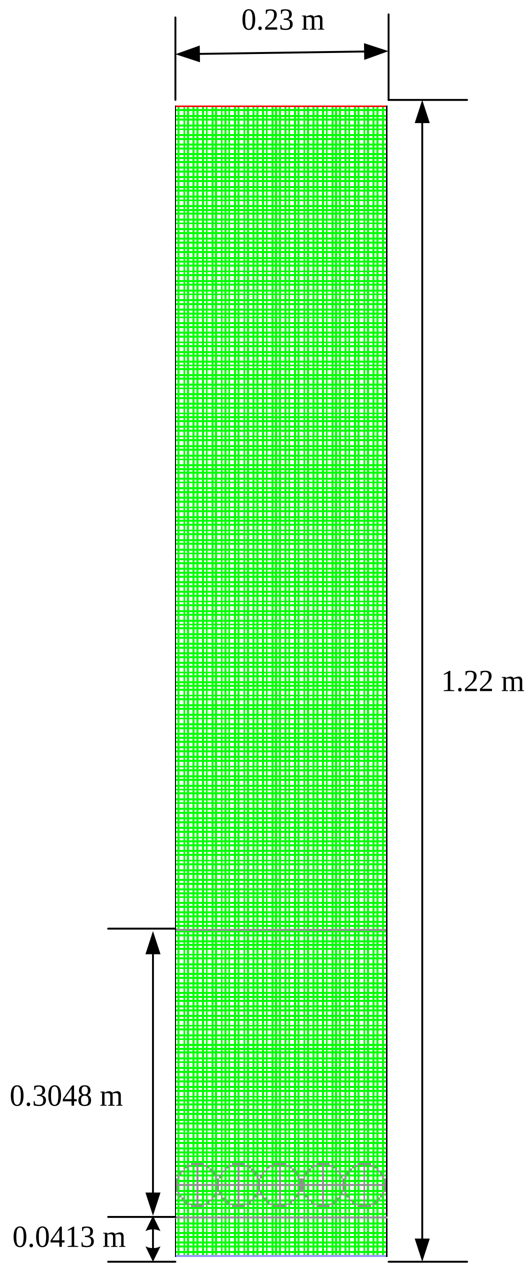


Fig.1: computational domain with measurement locations

- Data sampling for time statistics was activated after 15 s at which the flow field achieved pseudo steady state.
- Monitors were set-up within the computational domain at locations corresponding to the experimental set up measurement positions as shown in the figure to obtain time series data for pressure and solid particle velocity fluctuations sampled at a frequency of 200 Hz.
- Bed height fluctuations were also extracted at a frequency of 200 Hz during post processing.

RESULTS AND DISCUSSION

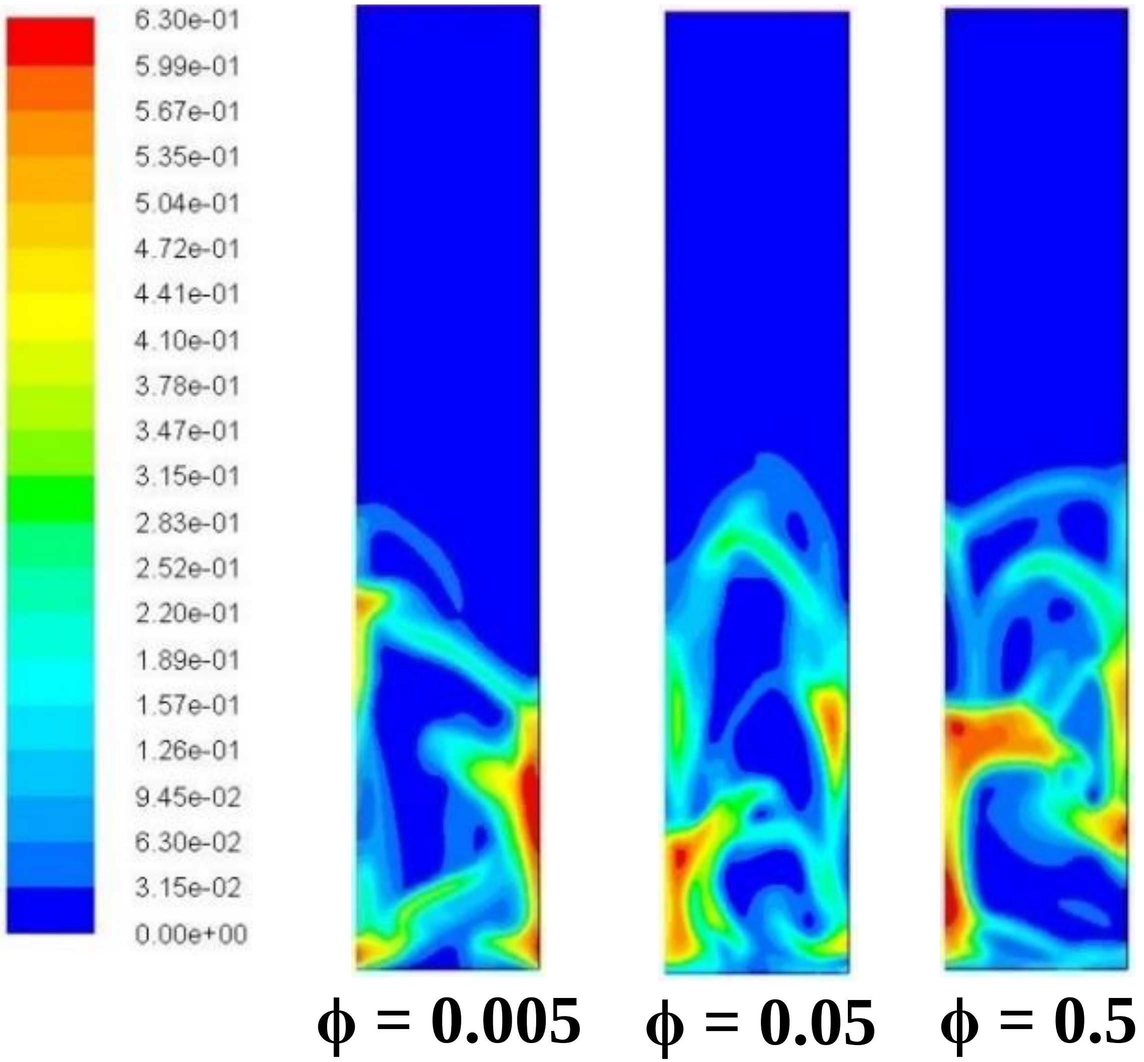


Fig.2 : Contour of solid volume fraction for different ϕ and U_g = 4.38 m/s.

- Contour plot shows the fluidization pattern for different ϕ values.
- An increase in the bubble size and bed height is observed for increasing ϕ.

RESULTS AND DISCUSSION

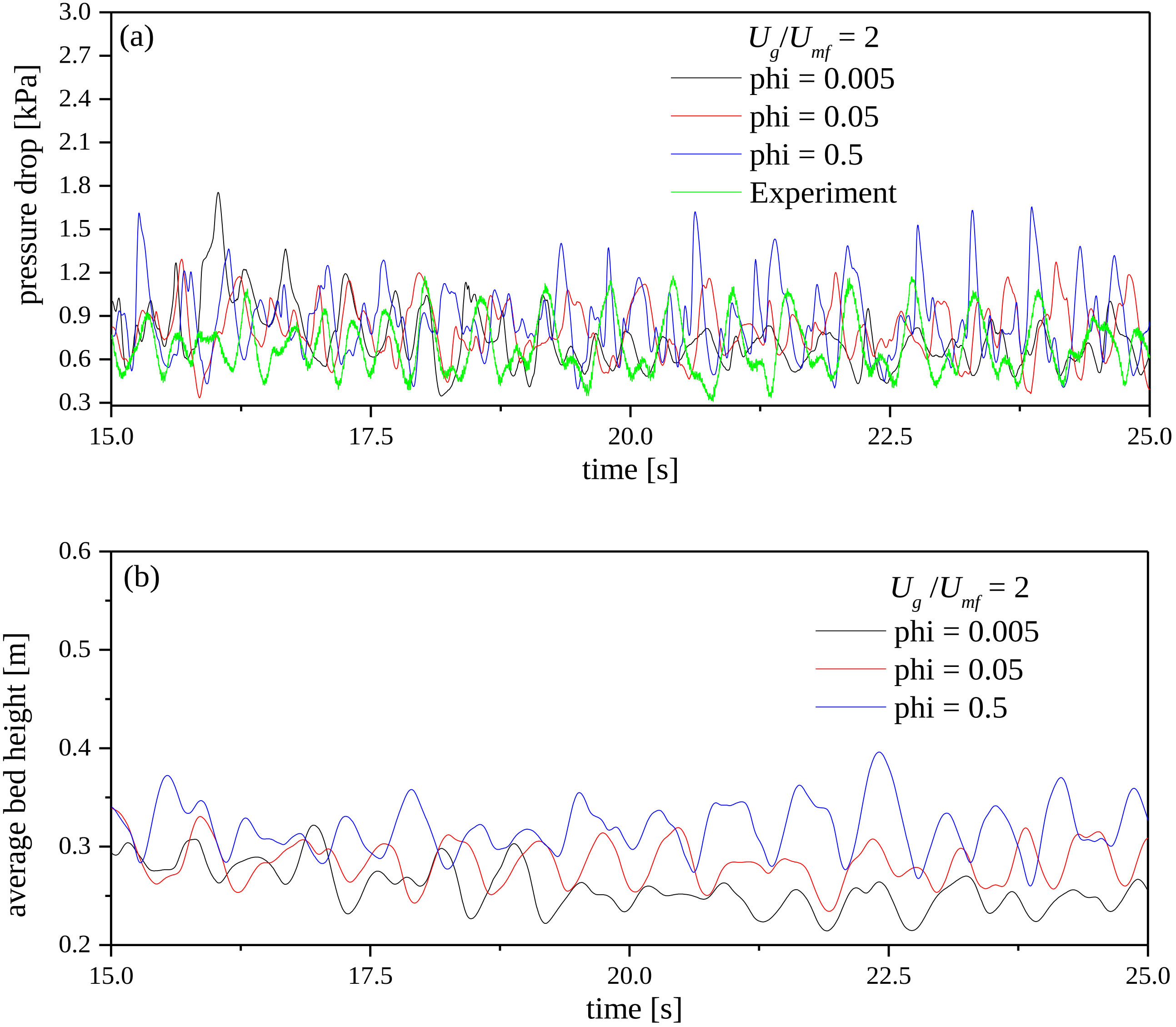


Fig. 3: Pressure drop and bed height fluctuation for U_g = 2.19 m/s

- In comparison to the bed height fluctuations, the amplitude and frequency of the pressure drop fluctuations are much larger as seen .
- The average bed height was calculated at each time step (Goldschmidt, et al., 2001) :
- Intensity of pressure fluctuations increases with increasing ϕ .
- Bed height increases with increasing particle-wall friction i.e. increasing ϕ .

$$\langle h \rangle = \left[\sum_{\#cells} \alpha_{s,cell} h_{cell} \right] / \sum_{\#cells} \alpha_{s,cell}$$

RESULTS AND DISCUSSION

Table 3: Summary of measured and predicted bed dynamics

	U_g / U_{mf}	$\langle h \rangle$	$\langle h \rangle_{rms}$	$\langle \Delta p \rangle$	$\langle \Delta p \rangle_{rms}$
measurement	2	-	-	0.69	0.1825
measurement	3	-	-	0.65	0.3182
measurement	4	-	-	0.50	0.2326
TFM prediction					
$\phi = 0.005$	2	0.250	0.0197	0.66	0.1272
$\phi = 0.005$	3	0.283	0.0214	0.57	0.2053
$\phi = 0.005$	4	0.316	0.0241	0.44	0.1672
$\phi = 0.05$	2	0.331	0.0355	0.78	0.1802
$\phi = 0.05$	3	0.414	0.0403	0.72	0.2676
$\phi = 0.05$	4	0.436	0.0439	0.65	0.2807
$\phi = 0.5$	2	0.415	0.0398	0.88	0.2298
$\phi = 0.5$	3	0.501	0.0514	0.84	0.3587
$\phi = 0.5$	4	0.545	0.0564	0.77	0.3786

RESULTS AND DISCUSSION

- For a given superficial gas velocity, the mean height and intensity of the fluctuations (characterized by the rms) increase with increasing particle-wall friction.
- Similar observations are made for a fixed specularity coefficient value and different superficial gas velocities.
- The mean pressure drop reduce with increasing superficial gas velocity.
- The rms pressure drop passes through a maximum which can be interpreted as a transition from slugging to turbulent fluidization (Bi, 2007).
- The transition from slugging to turbulent fluidization is captured by the simulations at $\phi = 0.005$.

RESULTS AND DISCUSSION

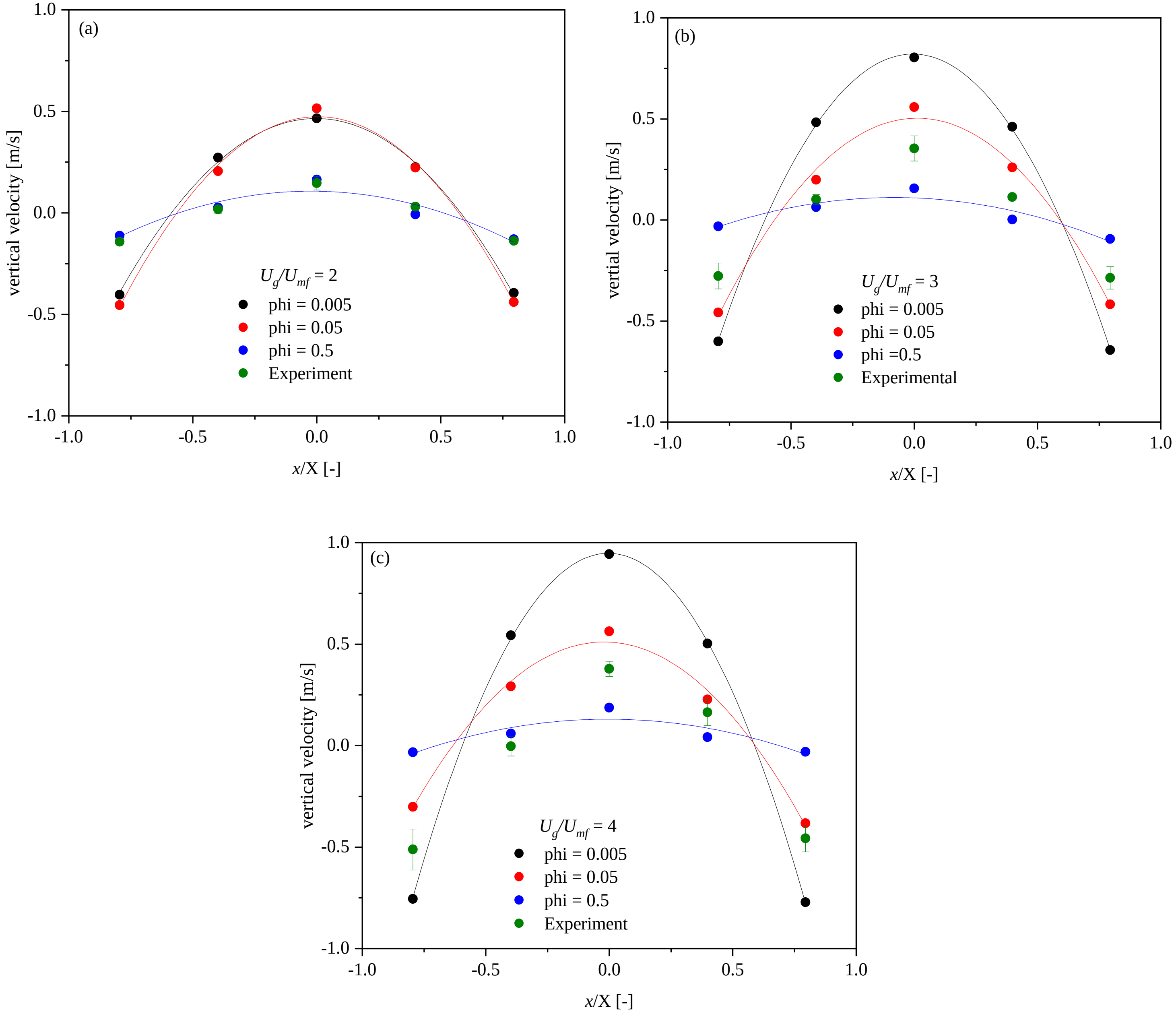


Fig.4 : Effect of ϕ on mean particle vertical velocities for different operating conditions

RESULTS AND DISCUSSION

- Downward negative solids particle velocity near the walls increases with a reduction in ϕ.
- Our result is consistent with the findings of (Li, et al., 2010) .
- Generally a smaller specularity coefficient is used with increasing superficial gas velocity.
- A single ϕ value for a given operating condition is not satisfactory for a complete validation of experimental data.
- Fluidization is a multi-scale phenomena and therefore it is likely that a multi-scale particle-wall friction modeling approach is warranted.

SUMMARY AND CONCLUSION

- The effect of the particle-wall friction on TFM predictions is investigated for different superficial gas velocities.
- For a fixed operating condition, the mean and rms values of the pressure and bed height fluctuations shows a tendency to increase with increasing particle-wall friction.
- Particle-wall friction is dependent on operating conditions which is consistent with previous findings.
- In tuning the time averaged axial velocity profiles to match the experimental profiles, lower values of ϕ were used with increasing superficial gas velocity.
- This study shows that it is not possible to specify a ϕ value at a given operating condition that will give satisfactory predictions of different parameters.

The End

THANK YOU FOR YOUR ATTENTION.