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NUMERICAL ESTIMATIATION OF PRESSURE DROP IN HORIZONTAL AND VERTICAL SLURRY PIPELINE

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Abstract

Transportation of solids with water as a carrier in the form of slurry through long length pipelines is widely used in many industries and power plants. In this perspective, numerical simulation of three-dimensional vertical slurry pipeline (VSPL) and horizontal slurry pipeline (HSPL) carrying glass beads solid particulate of spherical diameter 440 µm and density (ρ = 2470 kg/m^3) is carried out. The 3D computational model is developed for vertical and horizontal slurry pipeline of diameter 0.0549 m and analyzed in available commercial software Fluent using Eulerian two-phase model with RNG k-ε turbulence closure at different velocity range 1-2 ms^{-1}, and solid concentration range 10-20 % (by volume). It is found that the pressure drop increases for vertical and horizontal slurry pipeline with increase in flow velocity at all efflux concentration. The pressure drop in vertical slurry pipeline is found higher as compared to the pressure drop in horizontal slurry pipeline. The obtained results of predicted pressure drop in horizontal slurry pipeline are validated with the available experimental results in the literature. Finally, the results of solid concentration contour and pressure drop were also predicted in both the slurry pipelines.

Keywords: *3D Vertical and Horizontal slurry pipeline; Eulerian two-phase model; slurry concentration; velocity distribution; pressure drop*

1. Introduction

Transportation of solid in the form of slurry has been used by various industries and power plant since several decades. Slurry transport through long length pipelines is employed by many industries because it has several advantages such as no pollution, no traffic, less power consumption and continuous delivery etc. Solids like coal ash, iron ore, copper, zinc tailing, rock, and cement material transported with water in the form of slurry at the desired delivery location by many industries. The slurry transportation system consist of horizontal pipes, vertical pipes and various intermediate stage pumps for the continuous delivery of the solid at the desired location. The solid concentration cause the erosion wear, damage and deterioration in pipelines and pumps. Thus, the slurry transportation system require an attention to make it more efficient and economical. Therefore, it is essential to know the effect of slurry flow characteristics using available commercial software Fluent for the design of an efficient and economical pipeline system. Numerous research experiments are available in the literature to evaluate the various slurry flow parameters like pressure gradient, velocity and concentration measurement etc. However, in real time it is quite complex and difficult to design and fabricate the experimental set up as it require long time span and high cost. In recent times, many investigators/researchers have analyzed the solid-liquid flow problems based on Computational Fluid Dynamics (CFD), as it has the advantages to predict the slurry flow characteristic within a short span of time.

Colwell and Shook [1] performed experiment in a horizontal pipe of 50 mm diameter by using sand and polystyrene mixture, and found the optimal entry length, velocity distribution and concentration distribution. Turian et al. [2] in their experiment studied the effect of friction losses by using minute glass beads flow in a horizontal pipeline. They observed that inertial effects are more dominated in case of non-colloidal flow as compared to the colloidal flow. Matousek [3] in a laboratory experiment analysed sand flow pattern in a pipe of 105 mm diameter at three different inclinations viz. horizontal, vertical and −35° descending pipes. Krampa-Morlu et. al. [4] carried out the coarser particle numerical simulation in a vertical pipe using k-ε turbulence closure and studied the effect of particulate size, concentration and viscosities for different slurry range. Kraft [5] presented various processes in order to study the slurry flow characteristics in a slurry pipeline. Kaushal et al. [6] experimented the effect of near wall lift on solid particulates in a pipe of 0.0549 m diameter and observed that effect of slip velocity on pressure drop, and found that effect is more at higher velocity as compared to low velocity. Kumar et al. [7] used two layer and Karabelas model, and studied the effect of pressure drop and solid concentration on bimodal slurries. Singh et al. [8] carried out the experimental and numerical simulation of sand water flow and observed that the pressure drop increases non linearly with increase in velocity and solid concentrations.

2 Mathematical model

The present work simulation for both VSPL and HSPL is done by using Eulerian two phase model with RNG K-ε turbulence closure. The governing equations used for the turbulent flow of glass beads slurry flow are as given below.

2.1 Eulerian model

Eulerian model is used as it is the efficient model to solve the set of continuity and momentum equation for each phase and coupling between the phases is achieved through pressure and interexchange coefficients. In Eulerian model, the slurry mixture is supposed to be consist of solid (α_s) and liquid (α_f) phases i.e. $\alpha_s + \alpha_f = 1$. In the present model, granular flow properties are obtained from kinetic theory applications. The forces acting on the particulates in the slurry flow are:

1. Static/solid pressure gradients, ∇P/∇Ps.
2. Forces due to the difference in velocities of two phases, $K_{sf}\left(\vec{v}_s - \vec{v}_f\right)$
3. Viscous and body forces, $\nabla.\overline{\overline{\tau}}_f$ and $\rho\vec{g}$, where $\overline{\overline{\tau}}_f$ represents the stress fluid, ρ denotes the mass density and g is gravitational acceleration.
4. Lift/virtual mass forces. The coefficient of virtual mass/ lift forces, C_L/C_{vm} are assumed to be 0.5.
   The solid particulates in the fluid domains are assumed to be fluidic in nature.

2.2 Governing equations

The governing equations used for the turbulent flow of glass beads slurry flow are as given below. The continuity and momentum equation for each phase is defined as:

Continuity Equation

$$\nabla.(\alpha_t \rho_t \vec{v}_t) = 0 \tag{1}$$

Here, t can be considered as f or s.

Momentum Equations for fluid and solid phases

For Fluids:

$$\nabla.(\alpha_f \rho_f \vec{v}_f \vec{v}_f) = -\alpha_f \nabla P + \nabla.(\overline{\overline{\tau}}_f + \overline{\overline{\tau}}_{t,f}) + \alpha_f \rho_f \vec{g} + K_{sf}(\vec{v}_s - \vec{v}_f)$$
$$+ C_{vm} \alpha_s \rho_f (\vec{v}_s.\nabla\vec{v}_s - \vec{v}_f.\nabla\vec{v}_f) + C_L \alpha_s \rho_f (\vec{v}_f - \vec{v}_s) \times (\nabla \times \vec{v}_f) \tag{2}$$

For Solids:

$$\nabla.(\alpha_s \rho_s \vec{v}_s \vec{v}_s) = -\alpha_s \nabla P - \nabla P_s + \nabla.(\overline{\overline{\tau}}_s + \overline{\overline{\tau}}_{t,f}) + \alpha_s \rho_s \vec{g} + K_{fs}(\vec{v}_f - \vec{v}_s)$$
$$+ C_{vm} \alpha_s \rho_f (\vec{v}_f.\nabla\vec{v}_f - \vec{v}_s.\nabla\vec{v}_s) + C_L \alpha_s \rho_f (\vec{v}_s - \vec{v}_f) \times (\nabla \times \vec{v}_f)$$

2.3 Wall function

The present work employed with standard wall function proposed by Launder and Spalding (1974) has been employed for both pipe geometry. The chosen wall function provides more accurate and precise results for both solid and liquid phases using Eulerian two-phase model.

3 Computational domain

The computational mesh for both 3D slurry pipeline of length 3.8 m and diameter 0.0549 m is generated in ANSYS 16. The pipe length considered for the computational domain is sufficiently long fully developed flow as it satisfies the criteria of more than 50D. The computational geometry contains 4.62 lakhs hexahedral and quad type mesh elements. The grid independent test is carried out by using different mesh geometry containing 1.54 lakh, 2.43 lakh, 3.82 lakh, 4.62 lakh and 5.22 lakh hexahedral/quad elements at C_{vf} = 10 % and V_m = 5 ms^{-1}. It is seen that the results for solid concentration and solid velocity are not changing for the grid geometry containing 4.62 lakh and 5.22 lakh mesh elements. The results of solid phase velocity for different grid geometry is depicted in the figure (b). Hence, a grid geometry with 4.62 lakh elements is preferred for simulation of slurry flow as shown in the figure 1 (a).

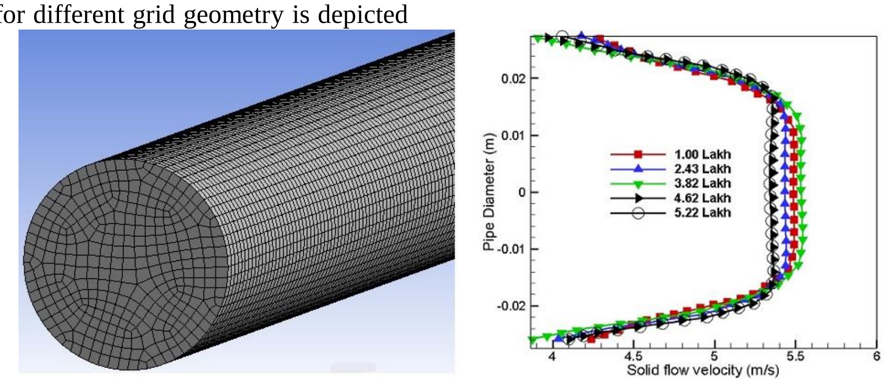

Fig.1 (a) Grid geometry and (b) Velocity profile of solid phase with respect to the diameter of pipe at C_{vf} =10 % and V_m = 5 m/s.

3.1 Boundary conditions

The 3D slurry pipeline geometry consist of three faces viz. inlet, outlet and wall boundaries to achieve the computational results. The 3D pipe geometry is employed with velocity inlet, pressure outlet and no slip conditions in the computational domain. The boundary conditions at inlet face of the pipe is applied at particular velocity and solid volume fraction whereas pressure outlet is applied at outlet face of the pipe. The no slip conditions has been considered at the wall boundaries. In addition, the roughness constant of the wall is assumed to be 0.5.

3.2 Solution strategies and convergence criteria

A second order upwind scheme is used to solve the fluid/solid phase continuity, momentum, turbulence kinetic energy equations. This arrangement offers high precision, reliability and converging of the solutions. The convergence criteria is set to 0.001times the initial residual values for every constraint viz. mass, turbulent kinetic, velocity, dissipation energy and volume fractions. SIMPLE algorithm is used to achieve the coupling between velocity and pressure linked equations. The other solution strategies and convergence factors values are: pressure - 0.3, momentum – 0.5, volume fraction – 0.5, turbulent viscosity – 0.8, turbulent kinetic/dissipation energies - 0.8.

4 Results and Discussions

4.1 Solid concentration contours in vertical slurry pipeline

Figures 2 depict the solid concentration contours in vertical slurry pipeline in xy plane and yz plane in the last one-meter length and outlet section of the pipeline respectively. It has been observed that the maximum solid concentration zone is located near the pipe wall and is minimum at the centre of the pipeline for chosen range of velocity and solid concentration. At low velocity, the solid concentration zone about the centre of the pipeline increases as depicted in the figure 2 (a-b) at V_m = 1 ms^{-1}, however as the velocity increases from 1 to 2 ms^{-1}, the solid concentration zone shifts towards the pipe wall as depicted in figure 2 (a-b) at V_m = 2 ms^{-1}.

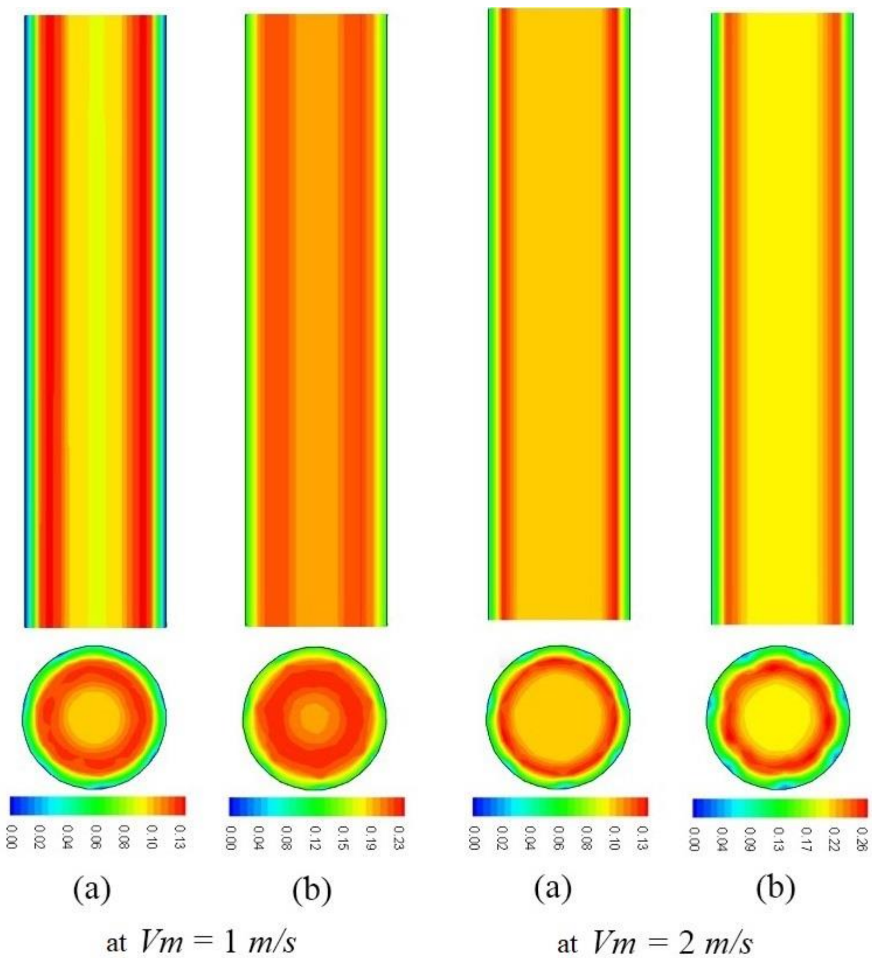

Fig. 2 Concentration contour for velocity range, $V_m = 1 – 2$ m/s at solid concentration (a) C_{vf} = 10 % and (b) C_{vf} = 20 %.

4.2 Solid concentration contours in horizontal slurry pipeline

Figures 3 depict the solid concentration distribution in horizontal slurry pipeline at different velocity (V_m = 1-4ms^{-1}) and solid concentration (C_{vf} = 10-20%). It has been found that at low velocity solids tends to settled down at pipe bottom as depicted in the figure 3 (a-b) at V_m = 1m/s, However as the velocity increases from 1-2 ms^{-1} the solids particles shifts away from the pipe bottom as depicted in the figure 3 (a-b) at V_m = 2 m/s.

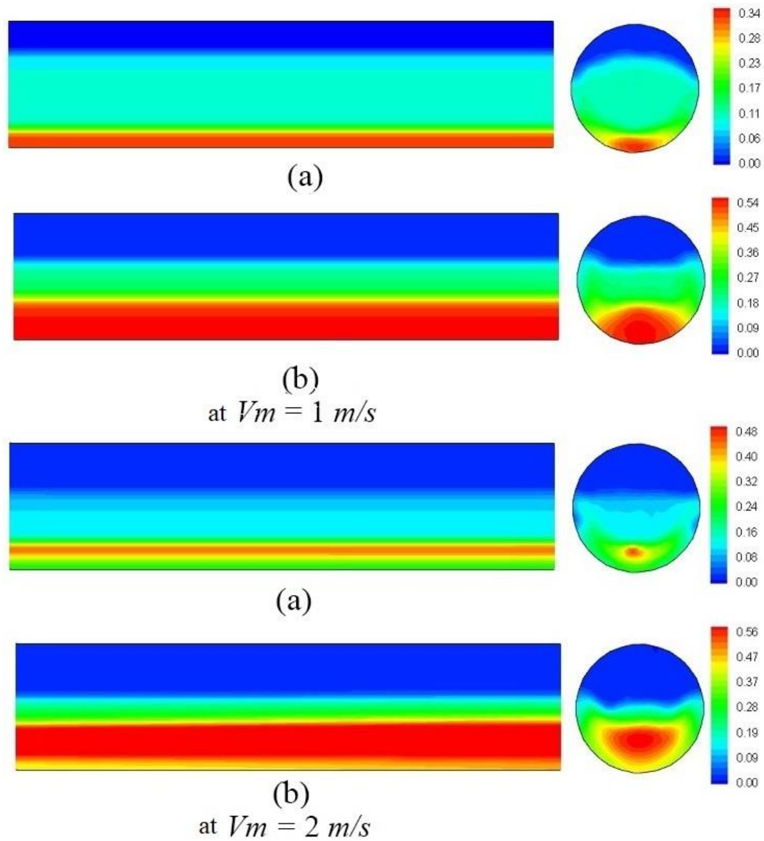

Fig. 3 Concentration contour for velocity range, V_m = 1 – 2 m/s at solid concentration (a) C_{vf} = 10 % and (b) C_{vf} = 20 %

4.3 Pressure drop in vertical and horizontal slurry pipeline

Figure 4 (a-b) depicts the pressure drop variation in vertical and horizontal slurry pipeline at different range of velocity and solid concentration. It has been found that the pressure drop increases at all velocity and solid concentration for both vertical and horizontal slurry pipeline. The pressure drop in the vertical slurry pipeline is found higher than the horizontal slurry pipeline for chosen solid concentration range 10 % and 20 % as depicted in the figure 4 (a) and (b) respectively. The computational pressure drop in vertical slurry pipeline for chosen velocity and solid concentration range is in trend and higher than the computational pressure drop in horizontal slurry pipeline.

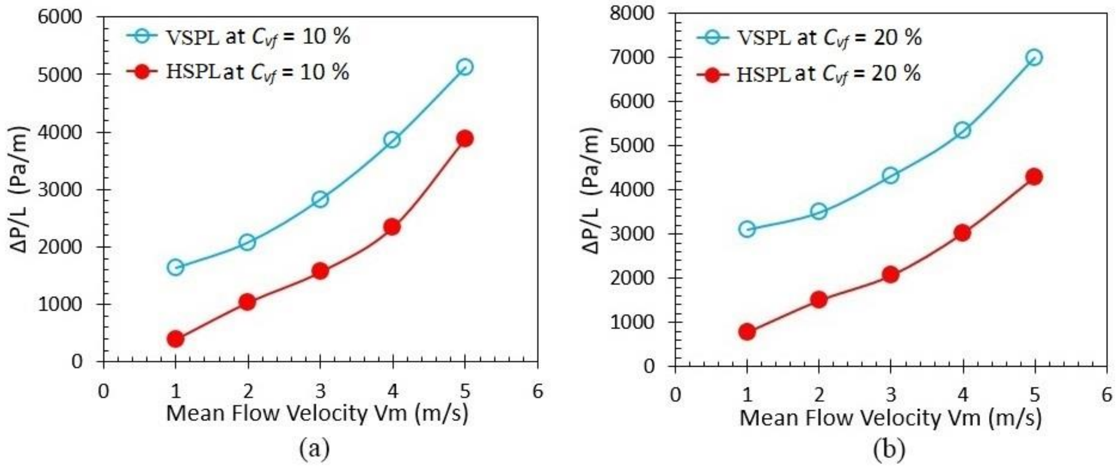

Fig. 4 Pressure drop variation with mean flow velocity for HSPL and VSPL at solid concentration (a) C_{vf} = 10 % and (b) C_{vf} = 20 %

5. Model validation

The present computational model developed for horizontal slurry pipeline is validated with the available experimental data of Kaushal et al. (2007) at C_{vf} = 10% and 20 % as depicted in the figure 5 (a) and (b) respectively. It has been found that the present computational model gives the satisfactory results with the available experimental data. The computational pressure drop results in vertical slurry pipeline for chosen velocity and solid concentration range are also found parallel with the pressure drop results of horizontal slurry pipeline.

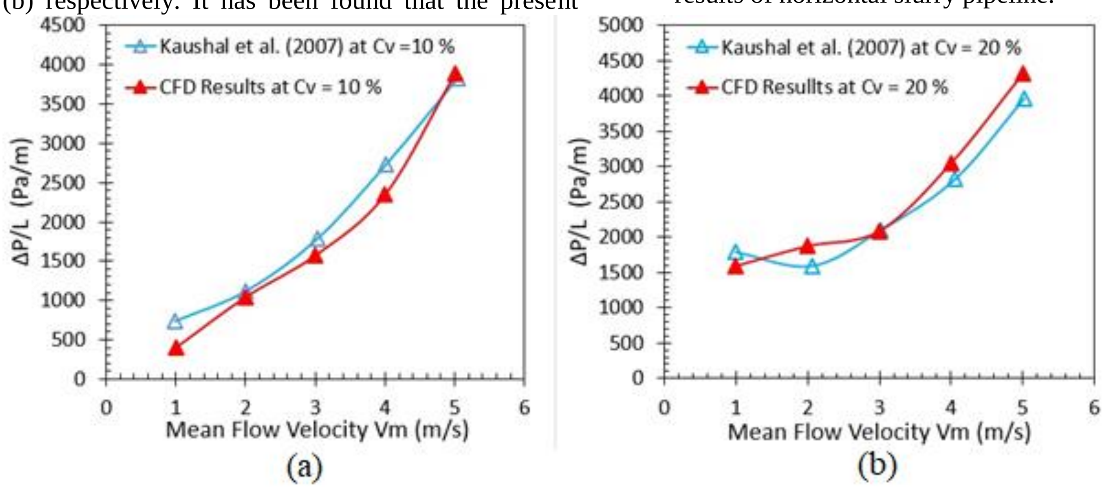

Fig. 5 Validation of computational results for HSPL at solid concentration (a) C_{vf} = 10 % and (b) C_{vf} = 20 %

6 Conclusion

Based on the developed computational model for 0.0549 m diameter glass -beads vertical and horizontal slurry pipeline for chosen velocity and solid concentrations, the following conclusions have been drawn:

- It is observed that Eulerian model using RNG k-ε turbulence closure gives the more appropriate and meticulous predictions of the pressure drop in vertical and horizontal slurry pipeline for chosen range of velocity and solid concentration.
- The high solid concentration zone is located near the pipe wall in vertical slurry pipeline and is minimum at the centre of the pipeline. However, the high concentration zone is located near the pipe bottom in horizontal slurry pipeline and solid

concentration decreases from bottom to top of the pipeline.

- Pressure drop increases for both vertical and horizontal slurry pipeline at all velocity and solid concentration range.
- Pressure drop in vertical slurry pipeline is found higher than the pressure drop in horizontal slurry pipeline.

The predicted pressure drop results for horizontal slurry pipeline are found to be in good agreement with the available experiment results in literature.

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