Modeling and Simulation of sand-water slurry flow

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ABSTRACT

This paper shows modeling and numerical simulation of slurry consist of water plus sand through a horizontal pipe. The size of the sand particulates in water having 125µm mean diameter was analyzed through 54.9 mm diameter pipe at concentrations ranging from (10-20%) by weight for the flow velocity of 3 m/s. Eulerian model with RNG k-ε turbulence closure was adopted to analyze the slurry flow. The flow characteristics of the slurry flow is analyzed using the FLUENT software. The results of the slurry flow in terms of concentration and velocity profiles were predicted in this paper.

Key Words: *sand –water slurry flow, Eulerian model, Fluent*

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1. INTRODUCTION

The settling behavior of the particles is influenced by the gravity. Slurry is a mixture of liquid and solids flowing through the pipeline. Slurry flow is described as homogeneous and heterogeneous flow (Abulnaga, 2002). In homogeneous flow the solids are uniformly distributed in the liquid carrier and the particle size is less than 100µm. For example, drilling mud, sewage sludge, fine limestone and copper concentrate after undergoing a process of grinding and thickening behave as homogeneous slurry. Transportation of solids and wastes with water or some other fluid as a carrier in the form of slurry through pipeline system are widely used in many applications such as petrochemical, pharmaceutical mines, chemical, energy, metallurgical, food, power generation, food, and biochemical industries. Wood et al. [1] carried out the study by applying swirl induction for reduction of damage due to erosion from slurry flow in pipeline bend. The results of the study by applying the swirl flow predict the reduction in the wear rate, low flow rates, improvement in particle distributions and particles impingement. Kaushal et al. [2] carried out the study for the multi-sized particulate slurry flowing through closed ducts and open channels. Multi-sized particulate iron ore slimes, copper tailings and zinc tailings slurries flowing through 105 and 55 mm diameter pipelines were considered. It was concluded that solid concentration at the pipe bottom reaches approximately 3.0 times the product of efflux concentration and static settled concentration by volume at deposition velocity. Based on extensive analysis of experimental data, the Karabelas [AIChE J. 23 (1977) 426] model for prediction of concentration profile was modified. Kaushal et al. (2002) modified the analytical model proposed by the karabelas (AIChE J. 23 (1977) 426] to predict the concentration profile and particle distribution for the flow of multisized particulate slurry across the cross section of the rectangular duct. The predicted results have been compared with the experimental data reported by kaushal [Prediction of particle distribution in the flow of multi-sized particulate slurries through closed ducts and open channels, 1995]. The modified model results were found to be in good agreement with the available experimental results in the literature. Kaushal et al.[3] evaluated the pressure drop and concentration profile for multi-sized particulate zinc tailing slurry flow through pipe and rectangular duct having hydraulic diameter of 80 mm, width of 200 mm and height of 50 mm. The experiments were conducted at different flow velocities ranging from 1 to 4 m/s using five efflux concentrations ranging from 4% to 26% by volume for each velocity. It was observed that solid concentration profiles were found to be a function of particle size, velocity of flow and efflux concentration of slurry. Solid concentration varied with the vertical position, except for particle size of 38 micrometer. Pressure drops and solid concentration profile data measured for the rectangular ducts were compared with previous data for 105 mm diameter pipe. Gillies et al.[4] evaluated the concentration profile and velocity profile at high velocities for heterogeneous sand slurries of median diameter 0.09 mm and 0.27 mm in a laboratory test pipeline of 0.103 m in diameter. Measurements show that the pipeline friction is lower than expected at high velocities. A correlation for the slurry friction at high velocities has been obtained. This correlation has been used to modify the model for predicting friction of heterogeneous slurries at velocities above the deposition condition. Kaushal et al. [5] evaluated the pressure drop and concentration profile for highly concentrated slurry in horizontal pipe of 54.9 mm diameter. The slurry consists of glass beads of size 440 µm & 1.2 µm and flow velocity was up to 5 m/s. It was observed that pressure drop is decreased for the mixture at high concentrations except 5 m/s. The particles size 440µm indicating a sliding bed regime, while the profiles in the horizontal plane remains almost constant irrespective of flow velocity, overall concentration and slurry type.

2. MESHED MODEL

The 3D model of pipe is shown in figure-1. The model with 485528 hexagonal structured elements was used for the simulation. The grid independency test has been carried out for the selected model.

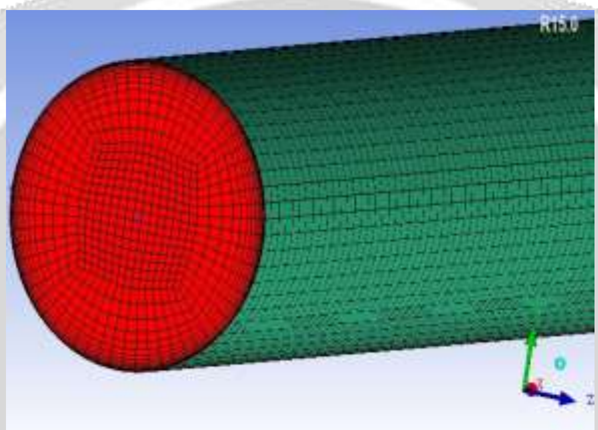


Fig – 1: Meshed model of pipe

2.1 CFD ANALYSIS

The computational fluid dynamics CFD has become most powerful tool for the numerical solutions of a wide range of problems. It has done by increasing the use latest technologies which are really helpful in getting the best solution of the both engineering and non-engineering. This involves three phases: Pre-processing, Solution phase, Post-processing. The preprocessing phase includes the material properties, boundary condition etc. Solution phase includes the results information in terms of variables like velocity, pressure, stress etc. Post processing includes the plots and graphs of the available results.

2.2 EULERIAN MODEL

In Eulerian model, slurry is assumed to be consists of solid “s” and fluid “f” phases which are separating, yet maintain interpenetrating continua such that $\alpha_s + \alpha_f = 1$. Here α_s and α_f are the concentrations of solid and fluid phases by volume respectively. The laws of conservation of mass (continuity equation) and momentum equation are satisfied by each phase individually which are coupled through pressure and inter-phasial exchange coefficients.
The forces acting on a single particle in the slurry are:

1. Static pressure gradient, ∇P.
2. Solid pressure gradient or the inertial force due to particle interactions, ∇Ps
3. Drag force caused by the velocity difference between two phases, $K_{sf}\left(\vec{v}_s - \vec{v}_f\right)$ where K_{sf} is the inter-phase drag coefficient and $\overrightarrow{v_s}$ & $\overrightarrow{v_f}$ are velocity of solid and fluid phase respectively.

4. Viscous forces, $\nabla.\overline{\overline{\tau}}_f$ where $\overline{\overline{\tau}}_f$ is the stress tensor for fluid.
5. Body forces, $\rho\vec{g}$, where, ρ is the density and g is acceleration due to gravity.
6. Virtual mass force, $C_{vm}\alpha_s\rho_f\left(\vec{v_f}.\nabla\vec{v_f}-\vec{v_s}.\nabla\vec{v_s}\right)$ where C_{vm} is the coefficient of virtual mass force and is taken as 0.5 in the present study.
7. Lift force, $C_L\alpha_s\rho_f\left(\vec{v_s}-\vec{v_f}\right)\times\left(\nabla\times\vec{v_f}\right)$ where C_L is the lift coefficient taken as 0.5.

2.3 GOVERNING EQUATIONS

2.3.1 Continuity Equation

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

where, t is either s or f.

2.3.2 Momentum Equations

For fluid phase:

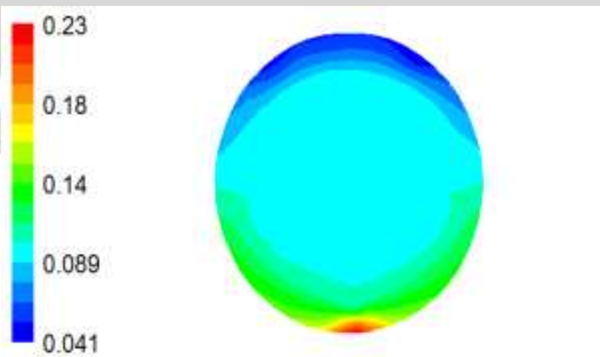
$$\nabla.(\alpha_f\rho_f\vec{v}_f\vec{v}_f)=-\alpha_f\nabla P+\nabla.(\overline{\overline{\tau}}_f+\overline{\overline{\tau}}_{t,f})+\alpha_f\rho_f\vec{g}+K_{sf}(\vec{v}_s-\vec{v}_f)+C_{vm}\alpha_s\rho_f(\vec{v}_s.\nabla\vec{v}_s-\vec{v}_f.\nabla\vec{v}_f)$$
$$+C_L\alpha_s\rho_f(\vec{v}_f-\vec{v}_s)\times(\nabla\times\vec{v}_f)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

For solid phase:

$$\nabla.(\alpha_s\rho_s\vec{v}_s\vec{v}_s)=-\alpha_s\nabla P-\nabla P_s+\nabla.(\overline{\overline{\tau}}_s+\overline{\overline{\tau}}_{t,f})+\alpha_s\rho_s\vec{g}+K_{fs}(\vec{v}_f-\vec{v}_s)+C_{vm}\alpha_s\rho_f(\vec{v}_f.\nabla\vec{v}_f-\vec{v}_s.\nabla\vec{v}_s)$$
$$+C_L\alpha_s\rho_f(\vec{v}_s-\vec{v}_f)\times(\nabla\times\vec{v}_f) \qquad \text{Eq. 3}$$

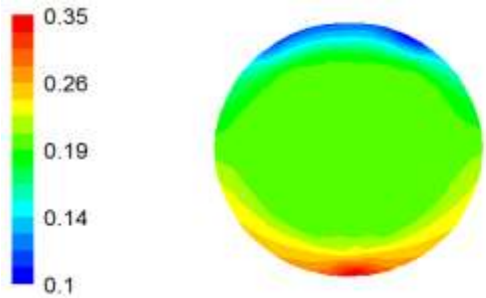
3. RESULTS AND DISCUSSIONS

The solid concentration profile at mean flow velocity 3 m/sec and concentration ranging from (10-20%) is shown in the figure. 2 and 3. The velocity profile at 3 m/sec and concentration ranging from (10-20%) is shown in the figure 4 and 5.



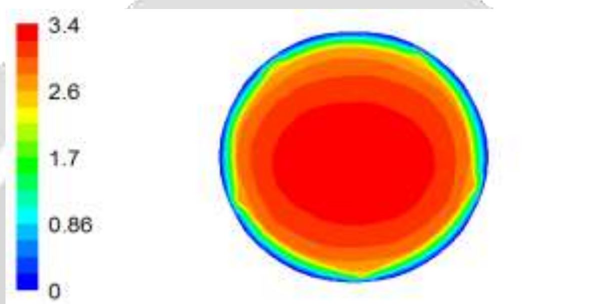
(a) Mean flow Velocity = 3 m/sec

Fig - 2: Solid concentration profile predicted by CFD at C_{vf} = 10%



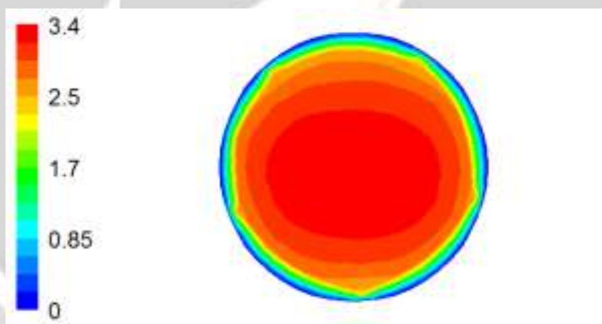
(b) Mean flow Velocity = 3 m/sec

Fig - 3: Solid concentration profile predicted by CFD at C_{vf} = 20%



(c) Mean flow velocity = 3 m/sec

Fig - 4: Velocity profile predicted by CFD at C_{vf} = 10%



(d) Mean flow velocity = 3 m/sec

Fig - 5: Velocity profile predicted by CFD at C_{vf} = 20%

4. CONCLUSION

Following conclusion has been drawn on the basis of present study

1. Solids concentration profiles were found to be a function of particle size, efflux concentration and velocity of flow.
2. The solids concentration varied with the vertical position.
3. For increasing the solid concentration at the same velocity the deposition of solid concentration found to be more near the bottom of the pipe.

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