Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

Pressure drop in vertical pneumatic conveying: Comparison between numerical predictions with existing correlations

Pandaba Patro[a,*], Debasis Mishra[b]
[a]*Mechanical Engineering,VSSUT, Burla 768018, Odisha, India*
[b]*Mechanical Engineering,VSSUT, Burla 768018, Odisha, India*

*Corresponding author Email: ppatro_me@vssut.ac.in

Numerical simulations using Euler-Euler model (also known as two fluid models) was used to predict pressure drop in pneumatic conveying (i.e. gas-solid flows) in vertical pipes. Standard $k-\varepsilon$ turbulence model has been used for gas phase and kinetic theory of granular flows (KTGF) was used to close solid phase stresses and solid pressure aroused due to inter-particle collisions. The model was validated by comparison with the available experimental data and good agreement was found for pressure drop prediction. The effect of important flow parameters like gas phase Reynolds number, solid loading ratio and particle density on pressure drop was investigated. It was observed that pressured drop increased with gas velocity and solid loading ratio. Finally, computed results for pressure drop are compared with the existing correlations. Present predictions showed good agreement with the correlations of Reddy and Pei (1969) and Capes and Nakamura (1973) data.

***Keywords*:** Pneumatic conveying, Pressure drop, Eulerian modeling, Solids loading ratio

1. Introduction

There are many industrial applications of pneumatic conveying of solid particles or gas-solid flow such as pneumatic transporters, fluidized beds, pulverized coal combustion, spray drying, spray cooling, jet impingement cooling etc. Presence of solids in gas flow gives rise to interaction terms between the two phases and makes the flow complicated for modeling of these interactions. There are two approaches for numerical modeling of such flows i.e. Lagrangian and Eulerian models. Lagrangian model imposes a restriction on the number of particles (i.e. solids loading ratio, which is defined as the ratio of mass flow rate of solid phase and mass flow rate of gas phase). So, this model is not suitable for many industrial-size problems, where solid loading ratio is relatively high. However, the Eulerian model can be used for any solid loading ratio. This model treats the solid-phase as continuum like gas phase and hence, mean equations are solved for both gas phase and solid phase. This model has been used by many researchers[1-3] to investigate the gas-solid flows.

For the design of piping layout in pneumatic conveying, it is very important to predict pressure drop to find the pumping power requirement for solids transportation. A number of researchers[4-7] predicted pressure drop in pneumatic conveying experimentally. It is very much complicated to get the pressure drop data under various operating conditions experimentally. With the development of high speed computers, researchers in industries have extensively been using commercial computer codes to solve two-phase flow problems. But, unfortunately, only very few research publications are available in open literature, which investigated the capabilities of commercially available CFD codes (like Ansys Fluent) as pressure drop prediction tools in relatively high solids loading (volume fraction in the range 0.01 to 0.1). Patro and Dash[8-9] investigated gas-solid flows in horizontal and vertical pipes and predicted pressure drop numerically using Ansys Fluent. It was clear that the commercial CFD computer code Ansys Fluent can be used successfully to predict pressure drop in gas-solid flow with acceptable level of accuracy.

In the present work, numerical simulations were performed using the Eulerian approach for gas-solid flow in vertical pipes. An extensive study was performed to see the effect of gas Reynolds number, solid loading ratio and particle density on pressure. The predicted data for pressure drop are also compared with the existing correlations developed from experimental data by many researchers.

2. Numerical Procedure

In Euler-Euler model, both gas and solid phases are treated as continuum. So, Navier-Stokes equations are solved for both the phases. The Reynolds stress (generated due to Reynolds Averaging of Navier-Stokes equations) for gas phase employs the Boussinesq hypothesis. It is used to write Reynolds stresses in terms of mean velocity gradients in turbulent flows. Standard $k-\varepsilon$ model was used for the gas phase turbulence. Particle-particle collisions give rise to solids pressure and stresses, which are closed by incorporating kinetic theory of granular flows (KTGF). Detail mathematical modeling and closure equations are described by Patro and Dash[8-9]. Space limitation did not permit us to explain these details in the present paper.

Finite volume method has been used to discretize the governing equations in terms of algebraic equations, which are solved along with the initial condition and boundary conditions. For pressure-velocity coupling, phase-coupled SIMPLE algorithm (PC-SIMPLE), which is an extension of SIMPLE algorithm in two-phase flows, has been used. Fig.1 shows the computational domain and the cross sectional meshing. The computational domain is 30 mm in diameter and 3 meter long. Three different grids of mesh sizes 21800, 32700 and 70600 cells are used for grid independence study. Grid independent solution was observed for the second mesh with 32700 cells by checking that an increase in no of cells had a negligible effect on the computed velocity profiles and pressure drop.

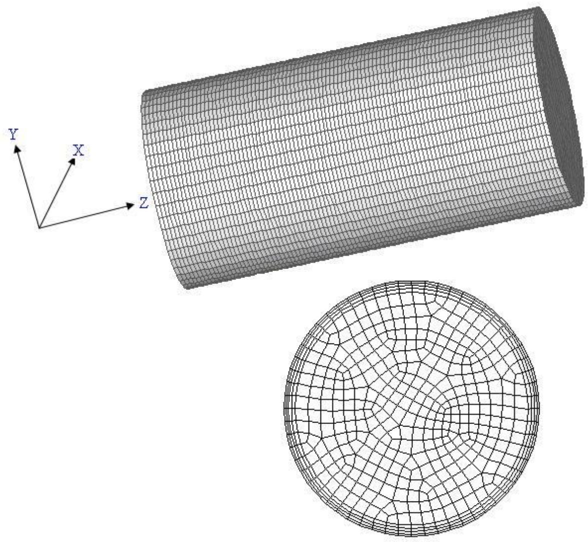

Fig.1. Computational domain

Velocity inlet boundary conditions are used at the inlet of the pipe. Fully developed velocity profiles are defined for both phases at inlet along with the volume fraction of the solid phase.

$$\frac{U}{U_c} = (1-\frac{r}{R})^{1/7}$$

Where U_c is the centre line velocity and R is the radius of the pipe.

The turbulence intensity (I_g) at the inlet boundary is specified as 2% based on previous research experience of authors in this field.

At the outlet, fully developed flow conditions are used for both phases. For gas phase, no-slip wall condition is valid even in two phase flows. For the solid phase, no-slip boundary condition is not valid. Solid particle get rebounded or slide along the wall after hitting it. A value of 0.9 is set for coefficient of restitution for particle-particle collision and particle-wall collisions.

4. Results and Discussion

Experimental findings for pressure drop of Tsuji et al.[10] are used for comparing our numerical results and validating the numerical model for the prediction of pressure drop. The experiments are carried out at particle diameter of 200 micron and density 1020 kg/m^3. Gas phase velocity was varied from 6 m/s to 20 m/s.

The numerical parameter known as specularity coefficient plays important role in pressure drop prediction while other parameters such as restitution coefficients and drag and lift coefficient are insensitive. When the numerical results are compared with experimental data, satisfactory agreements were reported for specularity coefficient equal to 0.1 for vertical flows (Fig.2). So, this value was used for the rest of the simulations.

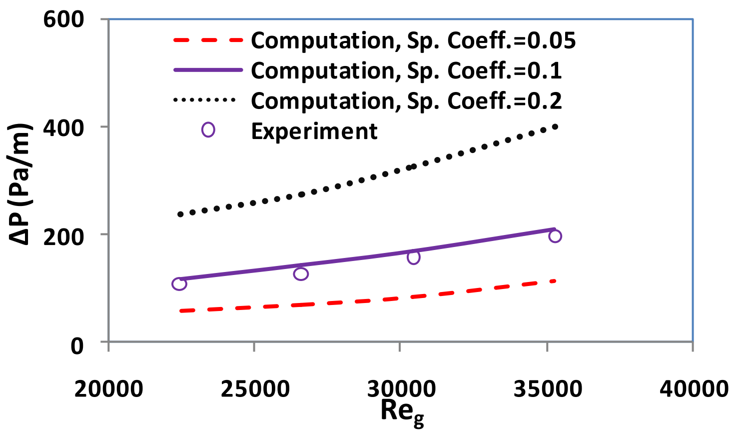

Fig.2. Comparison of pressure drop predictions in vertical flow with the experimental data at SLR=1, dp =200 micron

The main objective of the present research work is to predict pressure drop using available correlations in pneumatic conveying and make a quantitative comparison. Pressure drop form present predictions show good agreement at low loading. The most disadvantages of the existing correlations are the inability to predict the pressure drop in pneumatic conveying with relatively high solids loading. On the other hand, operating parameters of the present work are comparable to industrial applications. There are many correlations[11-15] available in literature for the pressure drop in pneumatic conveying in vertical flows. The present computations for two-phase pressure drop are compared with the existing correlations and also the effect of important flow parameters like solids loading ratio (SLR), Gas phase Reynolds number (Re$_g$) and solid phase density on pressure drop.

In gas-oslid flows, the overall pressure drop consists of static and frictional components.

$$\Delta P = \Delta P_{static} + \Delta P_{frictional}$$

$$\Delta P_{static} = \alpha \rho_s g L + (1-\alpha)\rho_g g L$$

$$\Delta P_{frictional} = \Delta P_{fg} + \Delta P_{fs}$$

$$\Delta p_{fg} = \frac{f_g \rho_g U_g{}^2 (1-\alpha) L}{2D}$$

The gas friction factor can be calculated using Blasius equation for dilute phase flows.
Blasius equation:

$$f_g = \frac{0.316}{\mathrm{Re}_g^{\;0.25}}$$

The solids contribution to the friction pressure loss is normally given as:

$$\Delta p_{fs} = \frac{f_p \rho_s U_s^{\;2} \alpha L}{2D}$$

For vertical flows, many researchers[11-15] like Pfeffer et al. (1966), Reddy and Pei (1969), Konno and Saito (1969), Capes and Nakamura (1973), Yang (1974) etc. developed correlations for solid friction factor (f_p). In the present work, predicted pressure drop was compared with the pressure drop calculated from different correlations (fig. 3-5).
We observed that solids loading ratio and gas velocity are the dominant factors for pressure drop in pneumatic conveying. Pressure drop increases sharply with increase in loading ratio and gas velocity. There is some disagreement in the pressure drop prediction between the existing correlations. The data from Pfeffer et al.[12] over predicts all the data. Our numerical predictions are in good agreement with the Reddy and Pei[12] and Capes and Nakamura[14] data.

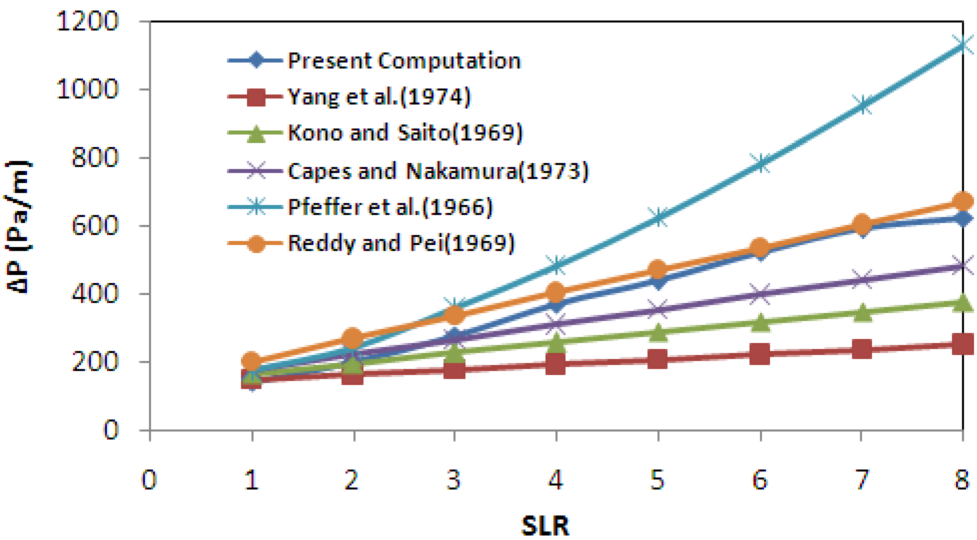

Fig.3. Pressure drop comparison at different loading ratios for D = 30 mm, dp=200 micron, Ug=15 m/s, particle density = 2500 kg/m^3

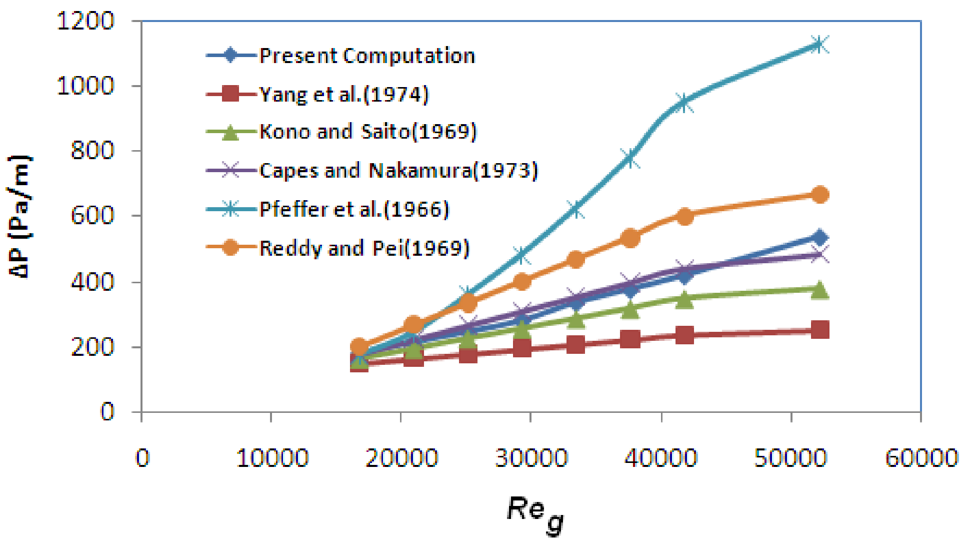

Fig.4. Pressure drop comparison at different gas Reynolds number for D = 30 mm, dp=100 micron, SLR=5, particle density = 1500 kg/m^3

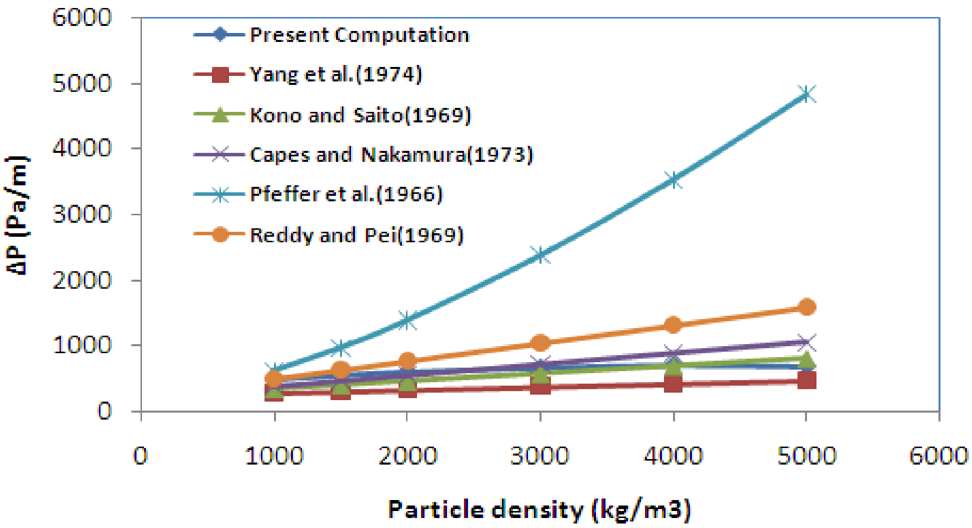

Fig.5. Pressure drop comparison at different particle densities for D = 30 mm, dp=150 micron, SLR=8, Ug=20 m/s

5. Conclusion

Computations using Euler-Euler approach for gas-solid flows were performed in vertical pipes to study the effect of gas inlet velocity (in the range 10 to 25 m/s), solids loading ratio (in the range 1 to 10) and particle density (in the range 1000 to 2500 kg/m^3) on pressure drop predictions. It was found that pressure drop increases with solids loading ratio (linearly) and gas phase Reynolds number. There is no significant rise of pressure drop with increase in particle density. Computed results for pressure drop are also compared with the existing correlations in vertical flow. The correlations by Reddy and Pei[12] and Capes and Nakamura[14] show better agreement with our numerical data.

References

1. C.K.K. Lun and H.S. Liu, Int. J. of Multiphase Flow. 23(3), 575–605 (1997).
2. C. Masson and B.R. Baliga, Int. J. Num. Methods in Fluids. 28, 1441 (1998).
3. R.I. Issa and P.J. Oliveira, Int. J. Num. Methods in Fluids. 43, 1177 (2003).
4. H.E. Rose and R.A. Duckworth, Engineer. 227, 478 (1969).
5. W.C. Yang, Journal of Powder and Bulk Solids Technology. 1, 89 (1977).
6. W.C. Yang, AIChE Journal. 20 (3), 605 (1974).
7. G.E. Klinzing, N.D. Rohatgi, A. Zaltash and C.A. Myler, Powder Technology. 51(2), 135 (1987).
8. P. Patro and S. K. Dash, Particulate Science and Technology. 32 (1), 94 (2014).
9. P. Patro and S. K. Dash, Powder Technology. 264, 320 (2014).
10. Y. Tsuji, Y. Morikawa, and H. Shiomi, J. Fluid Mech. 139, 417 (1984).
11. R. Pfeffer, S. Rosettti, and S. Licklein, Report NASA, TN-D 360 (1966).
12. K.V.S. Reddy, and D.C.T. Pei, Ind. Eng. Chem. Fundam. 8, 490 (1969).
13. H. Konno, and S. Saito, J. Chem. Eng. Jpn. 2(2), 211 (1969).
14. C.E. Capes, and K. Nakamura, Can. J. Chem. Eng. 51, 31 (1973).
15. W.C. Yang, *AICM J.* 24, 548 (1978).