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Pressure Drop Characteristics of Bi-Modal Slurry at Medium Concentration in Straight Horizontal Pipes

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Abstract: In the present study, pressure drop have been measured for narrow sized silica sand slurry and bi-modal slurry consisting of narrow sized silica sand and fly ash as fine particles in different proportions keeping the overall efflux concentration same using a pilot plant test loop. The pressure drop has been measured over a length of 4.0 m in 50 mm NB diameter pipe line for fully developed flow. Bi-model slurry pressure drop measurements at efflux concentration of 20.4% (by weight) shows that the pressure drop reduces considerably with addition of the fine particles. This reduction is in pressure drop is more at lower velocities. For bi-model slurry the deposition velocity reduces slightly with increase in percentage of fines.

Keywords: Sand slurry, bi-modal, fine particles addition, pressure drop, horizontal pipe.

Introduction

Slurry pipelines are used to transport solid materials using water or any other liquid as a carrier fluid for long distance haulage of bulk materials like minerals ore to processing plants, coal to thermal power plants. They are also used for disposal of waste materials like fly ash, tailing materials etc. to the disposal sites. Pipe line transportation of solids has been accepted by various industries as an extremely safe and attractive mode of transportation because of it low maintenance round year availability and being eco friendly. The design of transport pipelines depends on number of parameters, the most important are deposition velocity and pressure drop. Several methods have been suggested in the literature to reduce the values of these parameters. One of the methods suggested is the addition of fine particles in small quantities to the slurry being transported but very little data is available. Kazanskij et al. [1] has carried out experiments in 100 mm pipeline and found that pressure drop reduces at lower velocities with the reduction being 30% close to the deposition velocities due to addition of fine particles in coarse slurries. Boothroyde et al. [2] concluded that the coarse particles can be transported at a lesser velocity leading to reduction in specific energy consumption by mixing fine particles. Shook et al. [3] have shown that addition of small percentage of fine particles in a coarse slurry reduces the bend loss. Mishra et al [4] has modified the two-layer model of Gillis et al. [5] to predict the pressure drop for coarse slurry mixed with fine fly ash slurry. From the scanty literature available, it is seen that no systematic experiments have been carried out to throw some light on the mechanism responsible for reduction in pressure drop and deposition velocity. It is in this light, the present study has been undertaken to establish the effect of addition of fine particles of fly ash to a narrow-sized coarse slurry of silica sand on the flow characteristics like pressure and deposition velocity.

.Experimental Setup

The pilot plant used in the present study is schematically shown in Figure 1. It consists of a closed recirculating Mild steel pipe test loop of 30 m length with inside diameter of 53 mm. The slurry is prepared in the hopper shaped mixing tank having a suitable stirring arrangement for keeping the slurry well mixed. The slurry is drawn from the mixing tank into 53 mm diameter pipe loop slurry pump having Ni-hard impeller and casing, and driven by a pulley belt drive system. The capacity of pump is sufficient to cover entire range of head and discharge needed for simulating the condition in the prototype pipeline. The flow rate in the loop can be varied over a wide range by suitably operating the plug valves provided in the loop as well as in the bypass pipeline. For continuous monitoring of the flow rate, a pre-calibrated electromagnetic flow meter is installed in the vertical pipe section of the loop as shown in the Figure 1. The test loop is provided with an efflux sampling tube fitted with a plug valve in the vertical pipe section near the discharge end, for collection of the slurry sample to monitor the solid concentration. The deposition velocity is estimated without disturbing the flow by observing the particle movement in the transparent observation chamber provided in the pipe loop. The average efflux concentration is evaluated using standard correlation between the slurry specific gravity and the solid concentration.

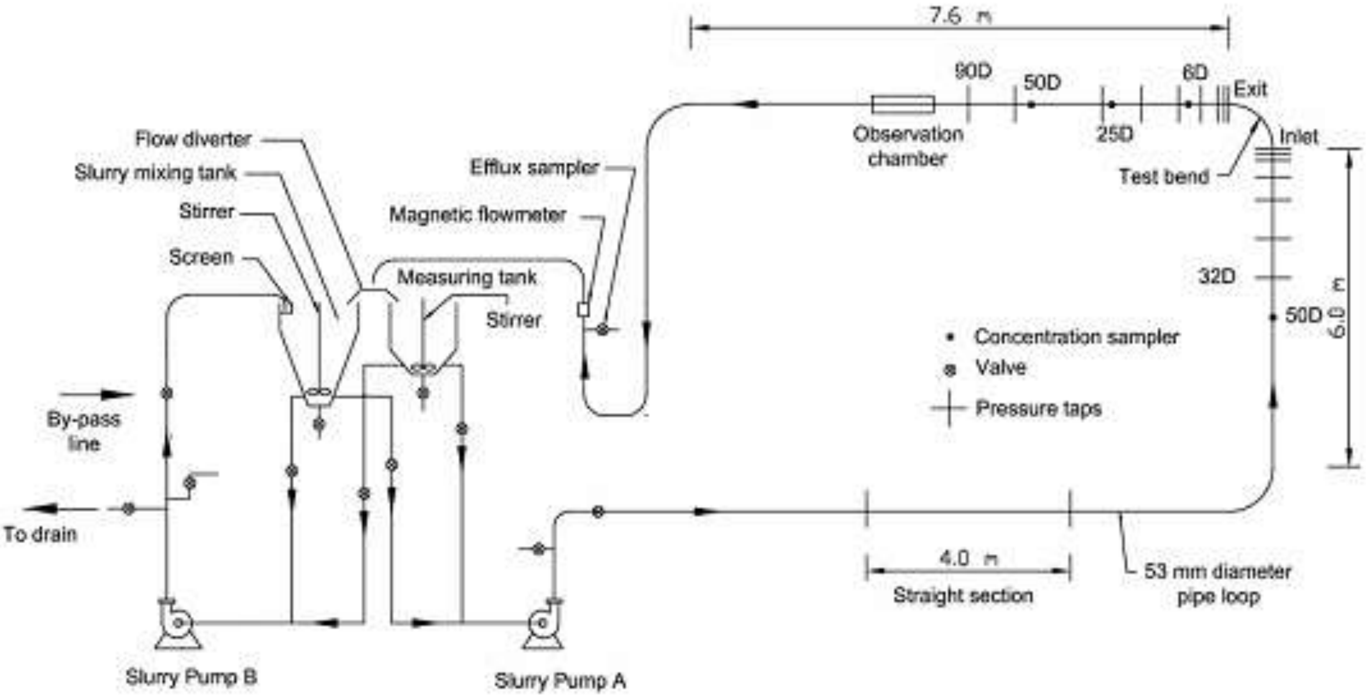

Fig. 1: Schematic Diagram of the pilot plant test loop

Physical Properties of Materials Used

The two solid materials used to prepare the bi-modal slurry are narrow-sized silica sand and fly ash obtained from thermal power plant as fine particles. The physical properties of these solid materials namely density, particle size distribution, static settled concentration etc. are evaluated using standard instruments/ procedures.

Properties of silica sand

The solid material used to prepare the slurry is narrow-sized silica sand sieved between two successive sieves to get the narrow-sized particles with a mean diameter of 448.5μm. The measured specific gravity of silica sand and the final static settled concentration is 2.65 and 69.44% (by weight) respectively. The settling characteristics of silica sand slurry indicates that it is fast settling slurry.

Properties of fly ash

The measured density of fly ash is 2170 kg/m^3. The particle size distribution for fly ash shows that 97.5% particles are finer than 75 μm with largest particle size being 150 μm. Based on the particle size distribution, fly ash particles are used as fine fraction for addition in coarse slurry of narrow-sized particles of silica sand to establish the effect of addition of fine particles on pressure drop in a straight pipe. The settling characteristics of fly ash slurry indicates that it is reasonably slow settling slurry and the final static settled concentration is 57.7% (by weight). The pH value of both narrow sized silica sand as well as bi-modal slurries in the concentration range of 0-50% (by weight) exhibit a non-reactive nature at all concentrations tested.

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Experimental Procedure and Range of Parameters

The pressure drop is measured in the straight pipe over a length of 4.0 m in a 50 mm NB diameter pipeline using the pilot plant test loop [Fig. 1]. For measurement of pressure drop as a function of flow velocity, the pressure taps provided with separation chambers are connected to U-tube differential manometer having a least count of ± 1 mm. Deposition velocity and efflux concentration in the pipe loop are determined using the transparent observation chamber and efflux sampler respectively.

Pressure drop characteristics for the pipe loop are first established with water and then with slurry. The slurry for narrow-sized silica sand is prepared in the hopper to achieve the desired efflux concentration. For preparing the bi-

modal slurry, depending on the efflux concentration of narrow-sized silica sand slurry in the test loop, the finer particles (<75 µm) of fly ash are mixed in the required proportion to achieve the desired ratios between narrow-sized silica sand and fine particles of 9:1, 8:2, 7:3 and 6:4 keeping the overall efflux solid concentration nearly constant. The pressure drop and deposition velocity in straight pipe are measured for each efflux concentration of narrow-sized silica sand or bi-modal slurry by varying the velocity between maximum achievable values and the deposition velocity.
The narrow sized silica sand slurry is tested for average efflux concentrations of 9.8, 20.4 & 33.9% (by weight). The average efflux concentration selected for the bi-modal slurry is 20.4% (by weight). The various weight ratios of fine particles added to the total solids are 9%, 17%, 27% and 38% for an efflux concentration of 20.4% (by weight) keeping the overall efflux concentration for the bi-modal slurry to be nearly equal to the initial efflux concentration.

Results and Discussion

The pressure drop vs flow velocity data are presented Figs. 2 to 3. The variation of deposition velocity as a function of average efflux concentration of solids is presented in Fig.4 to5 for both narrow-sized and bi-modal slurries.

Pressure drop characteristics

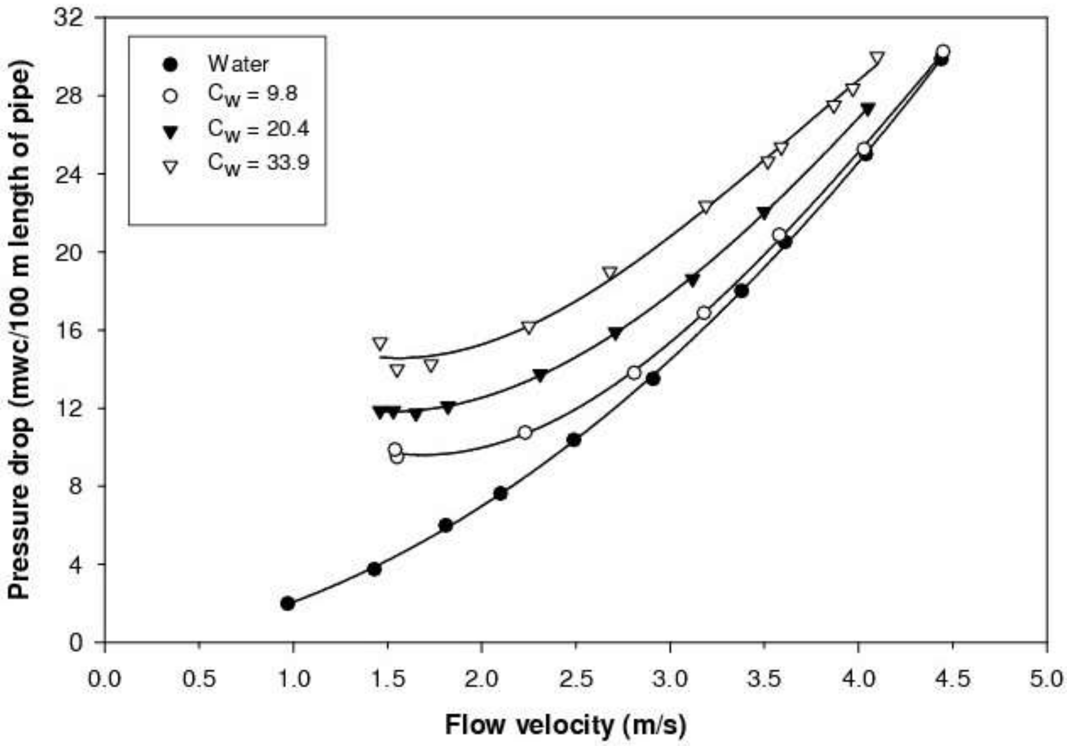

Fig. 2: Pressure drop variation for narrow-sized silica sand slurry at various efflux concentrations (% by weight).

The pressure drop as a function of velocity for narrow-sized silica sand slurry for average efflux concentrations of 9.8%, 20.4% and 33.9% (by weight) along with the water data is shown in Fig. 2 It is seen that for any given concentration, the pressure drop increases with increase in velocity. It is also seen that at higher flow velocities, the pressure drop for slurry has a tendency to get closer to the value of water and at 10% efflux concentration the pressure drop for water and slurry are same at a velocity of 4.5 m/s. This effect can be attributed to the uniform distribution of solids which is expected at higher velocities. Further, it is seen that at any given flow velocity, pressure drop increases with increase in the solid concentration, the rate of increase of pressure with concentration being higher at lower velocities. This phenomenon can be attributed to the settling behavior of solids at low velocities. At velocities close to deposition of solids, it is seen that pressure drop is significantly higher for slurries in comparison to water and further reduction in velocity also increases the pressure drop. This phenomenon can be attributed to the reduction in effective flow area due to settling of particles. The trends observed for pressure drop are in close agreement to the trends reported in literature for coarse slurries [6].

Fig. 3 presents the pressure drop characteristics for the bi-modal slurry having an average efflux concentration of 20.4% (by weight) with varying concentration of finer particles of 0, 9, 17, 27 and 38% of the total solids. It is seen that the pressure drop at any given velocity reduces with increase in concentration of fine particles, the drop being more pronounced at lower velocities. Close observations of the pressure drop characteristics of the bi-modal slurry highlights two velocity regions namely low velocity region and high velocity region (velocities higher than 2.5 m/s). In the low velocity region, addition of fine particles reduces the pressure drop considerably, which can be attributed to the comparatively more uniform distribution of coarse particles in this region. This can also be attributed to the increased interaction between particles and better suspension of coarse particles due to increased viscosity of the carrier fluid. For increase in the percentage of fines particles from 27% to 38% the reduction in pressure drop is only marginal. In the high velocity region, the pressure drop reduction is seen only up to 17% of fine particles and the reduction is nearly around 10% in this velocity region. Further increase in percentage of fine particles, results in increase in pressure drop in the high velocity region as a result of increased viscosity of the slurry mixture which leads to higher pressure drops at higher velocities.

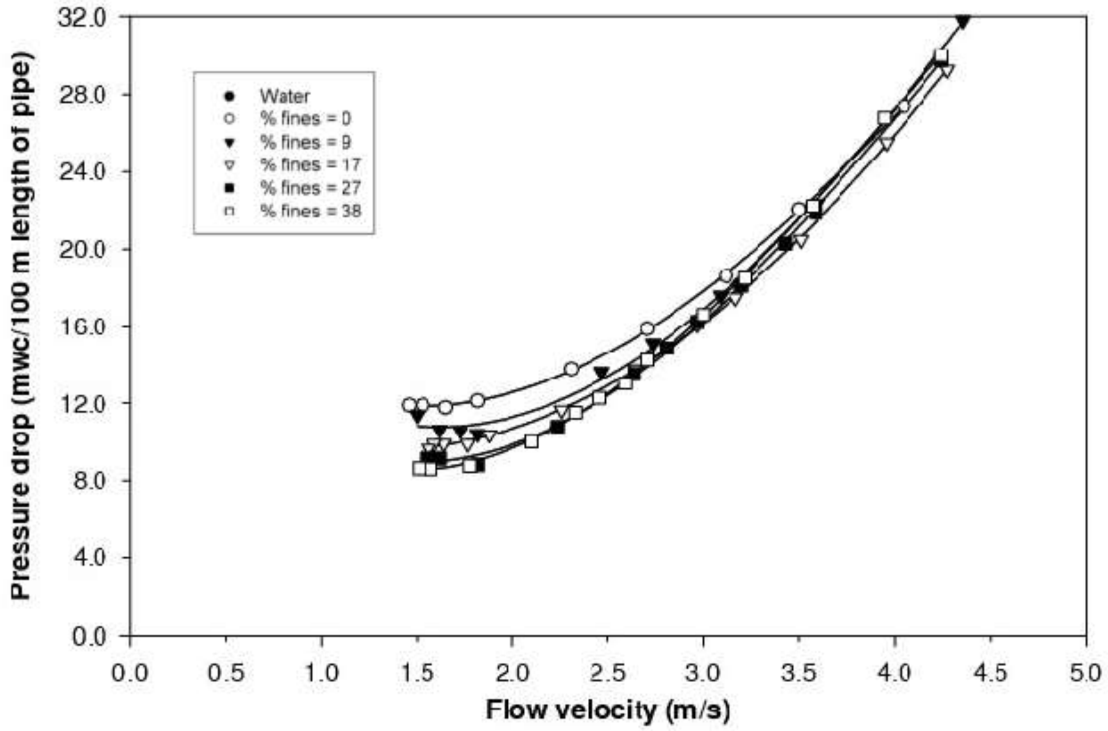

Fig.3: Pressure drop variation for bi-modal slurry of silica sand slurry and fly ash mixed in different proportions of fly ash having average efflux concentration20.4 (%by weight).

Deposition velocity

Deposition velocity data measured in the straight pipe for narrow-sized and bi-modal slurry with different proportions of coarse and fine particles is presented in Fig. 4 to 5. For the narrow-sized silica sand slurry, there is marginal drop in the deposition velocity with concentration [Fig. 4]. For the bi-modal slurry, the deposition velocity reduces with increase in percentage of fines, the reduction being more at the lower average efflux concentration than compared to higher average efflux concentration [Fig. 5]. From the data presented in the figures, it can be concluded that over the range tested, the addition of fines has only marginal effect on deposition velocity.

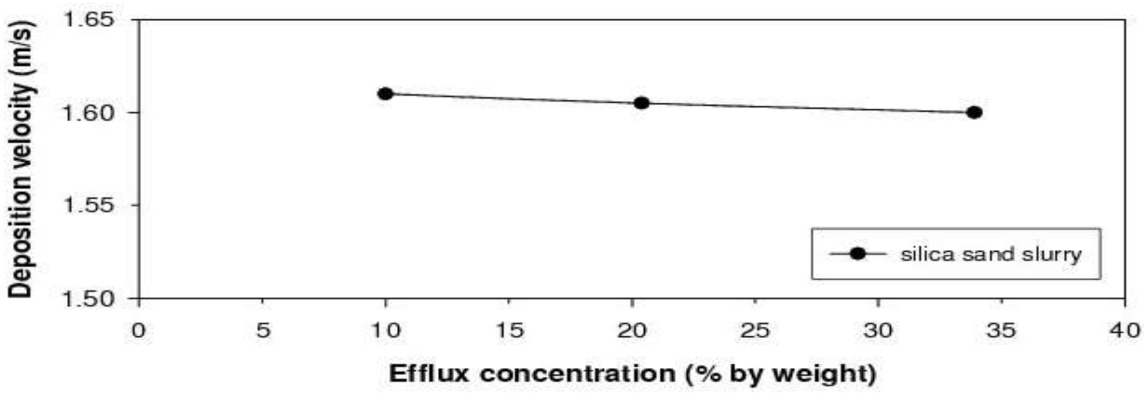

Fig 4: Deposition velocity for narrow-sized silica sand slurry

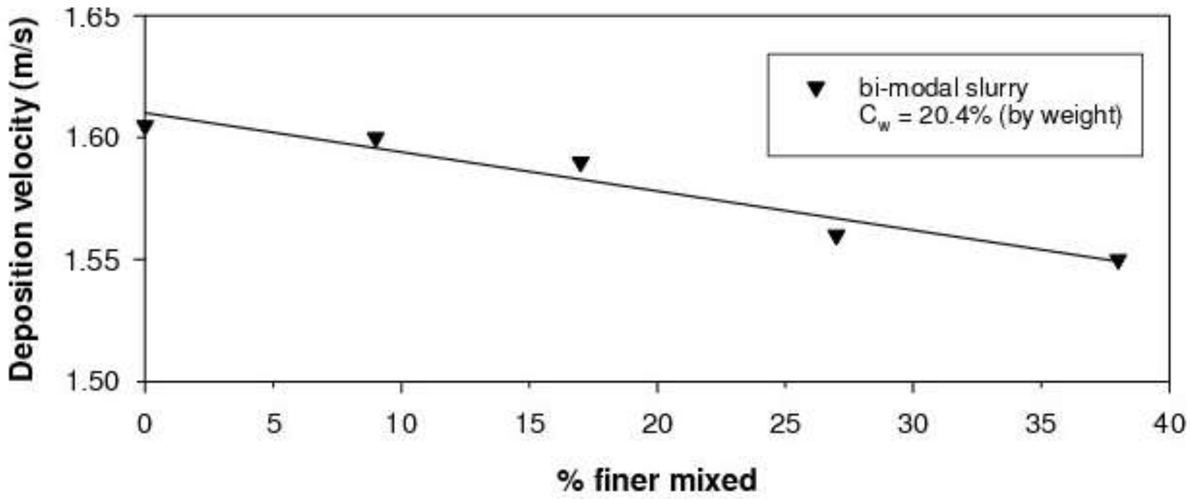

Fig. 5: Deposition velocity for bi-modal slurry having average efflux concentration 20.4 (%by weight).

Conclusions

Based on quantitative data given in the present study, which will be useful in verifying the assumptions made in flow models proposed by various researchers, the major conclusions which can in general be summarized as follows:

1. The pressure drop in the narrow sized coarse sand slurry at any given solid concentration increases with increase in velocity and at any given flow velocity, pressure drop increases with increase in solid concentration, the rate of increase of pressure with concentration being higher at lower velocities. The increase in pressure drop is much higher in the low velocity range compared to high velocity region for any efflux concentration.
2. The pressure drop for the bi-modal slurry at efflux concentration of 20.4% (by weight) shows that in the low velocity region addition of fine particles reduces the pressure drop considerably. In the high velocity region, the pressure drop reduction is seen only up to 27% of fine particles and further increase in percentage of fine particles, results in increase in pressure drop as a result of increased viscosity of the slurry mixture,
3. For the narrow-sized slurry, there is very marginal drop in the deposition velocity with increase in efflux concentration. Minor reduction in deposition velocity with increase in percentage of fines is observed for the bi-modal slurry over the range tested.

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