International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-4, April 2015

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

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***Abstract*— In the present paper, pressure drop and deposition velocity characteristics of 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 have been analyzed experimentally. The pressure drop measurements are done over a length of 4.0 m in 50 mm NB diameter pipe line under fully developed flow conditions using a pilot plant test loop. The pressure drop measurements for bi-model slurry at efflux concentration of 33.9% (by weight).shows that the pressure drop reduces at higher rate for low velocity region as compared to high velocity region with addition of the fine particles. The bi-model slurry shows slight reduction in deposition velocity with increase in percentage of fines**

***Index Terms*— Bi-modal slurry, deposition velocity, fine particles, pressure drop**

I. INTRODUCTION

Pipe line transportation of solids has been widely used by various industries as an extremely safe and attractive mode of transportation because of its low maintenance, round the year availability and being ecofriendly. They are also used for disposal of waste materials like fly ash, tailing materials etc. to the disposal sites in addition to transport solid materials using water or any other liquid as a carrier fluid for long distance haulage of bulk materials. Pressure drop and deposition velocity are the two most important parameters to design this type of pipelines. The importance of these parameters further increases with increase in need to transport solids at high concentrations. Several methods have been suggested in the literature [1,2] 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. Kazanskij et al. [3] based on the experiments carried out in 100 mm pipeline 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, They have identified this mechanism as a lubrication effect. Seshadri et al [4] found that the coarse particles require higher velocity for transportation thereby requiring more power whereas presence of excessive amount of fine particles gives the slurry a strong non-Newtonian character giving rise to higher pressure drops. The de-watering cost also increases with the increase in the proportion of fines. It is therefore possible to get a good suspension and transportation of mixed slurry, at moderate velocities by proper choice of particle size distribution. Boothroyde et al. [5] from their study of very coarse slurries mixed with fine particles have concluded that the coarse particles can be transported at a lesser velocity leading to reduction in specific energy consumption. Shook et al [6,7] experimentally investigated the effect of addition of fine particles in coarse particles slurry and observed that the distribution of the particles across the pipe cross-section becomes more uniform and concluded that it may be better to transport mixed size particulate slurry than an equi-sized particulate slurry. Mishra et al [8] has modified the two-layer model of Gillis et al. [9] 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. In the present study fly ash is used as fine solid particles and silica sand as narrow-sized coarse slurry. The aim of the present paper to highlight the effect of addition of fine particles to a narrow-sized coarse slurry on the two flow characteristics i.e. pressure and deposition velocity at high efflux concentration.

Manuscript received April 22, 2015.

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II. 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 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 448.5 μm. The particle size distribution for fly ash [Fig.1] 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 and deposition velocity at high efflux concentration in a straight pipe. The measured density of silica sand and fly ash is 2650 kg/m^3 and 2170 kg/m^3 respectively. The final static settled concentration of silica sand and fly ash is measured as 69.44% (by weight) and 57.7% (by weight) respectively using standard procedure. This shows that narrow-sized slurry of silica sand is fast settling slurry while the. fly ash slurry is reasonably slow settling slurry. 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.

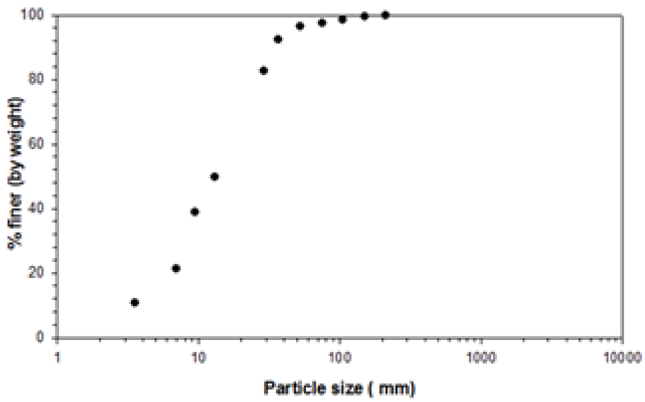

Fig. 1: particle size distribution curve for fly ash

III. Experimental Setup and Range of Parameters

The pilot plant used by Kumar et al [10] for the present study is schematically shown in Fig. 2. It consists of a closed recirculating Mild steel pipe test loop of 30 m length with inside diameter of 50 mm NB. The slurry is prepared in the hopper shaped mixing tank having a capacity of 2.73 m^3 with a suitable stirring arrangement for keeping the slurry well mixed. The slurry is drawn from the mixing tank into 50 mm NB diameter pipe loop by 50K “WILFLEY” (Manufacturer: M/s Hindustan Dorr Oliver Limited) model slurry pump having Ni-hard impeller and casing, and driven by a pulley belt drive system coupled to a 22 KW, 415 amp induction motor (Type: 2136 – 4, Make Siemens Limited). 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. The operation of the bypass line also helps in keeping the slurry well mixed in the mixing tank. For continuous monitoring of the flow rate, a pre-calibrated electromagnetic flowmeter 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 average efflux concentration is evaluated using standard correlation between the slurry specific gravity and the solid concentration [1,2]. Deposition velocity is estimated without disturbing the flow by observing the particle movement in the transparent observation chamber provided in the pipe loop.

The pressure drop is measured in the straight pipe over a length of 4.0 m in a 53 mm diameter pipeline using the pilot plant test loop [Fig. 2]. 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. Deposition velocity is determined using the transparent observation chamber and efflux concentration by efflux sampler provided in the test loop .Pressure drop characteristics for the test loop are first established with water and then with slurry. The slurry for narrow-sized silica sand is prepared in the hopper to get the desired efflux concentration. For preparing the bi-modal slurry, the finer particles 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, and 7:3 keeping the overall efflux solid concentration nearly constant, based on the efflux concentration of narrow-sized silica sand slurry in the test loop,. The desired data for narrow sized silica sand slurry is measured for average efflux concentrations of 9.8, 20.4 & 33.9% (by weight). The average efflux concentration selected for the bi-modal slurry is 33.9% (by weight). To achieve this, various weight ratios of fine particles added to the total solids are 8%, 18% and 27% keeping the overall efflux concentration for the bi-modal slurry to be nearly equal to the initial efflux concentration. The pressure drop and deposition velocity in straight pipe are measured by varying the velocity between maximum achievable values and the deposition velocity, for each efflux concentration of narrow-sized silica sand slurry or bi-modal slurry.

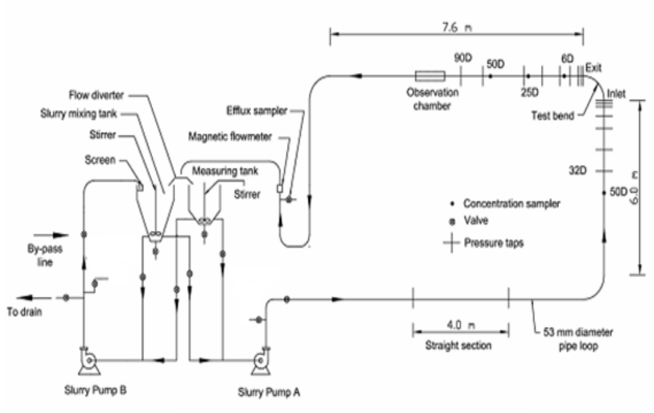

Fig. 2: Schematic Diagram of the pilot plant test loop

IV. Results and Discussion

The variation of pressure drop with flow velocity are presented Figs. 3 to 4. Figs. 5 and 6 shows the variation of deposition velocity as a function of average efflux concentration of solids is presented for both narrow-sized and bi-modal slurries.

Fig. 3 shows that for any given average efflux concentrations of 9.8%, 20.4% and 33.9% (by weight) for narrow-sized silica sand slurry, the pressure drop increases with increase in velocity. At higher flow velocities, the pressure drop for slurry has a tendency to get closer to the value of water which can be attributed to the uniform distribution of solids 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 may be due to the settling behaviour 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 which may be due to the reduction in effective flow area due to settling of particles.

Fig. 4 presents the pressure drop characteristics for the bi-modal slurry having a high average efflux concentration of 33.9% (by weight) with varying concentration of finer particles of 0, 8, 18 and 27% of the total solids. For 33.9% efflux concentration, the pressure drop reduction occurs up to

27% of fines over the complete velocity range tested. 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, the reduction in pressure drop being in the range of 15-20% in the low velocity region and being around 8 to 10% in the high velocity region. The higher reduction in pressure drop due to addition of fine particles in low velocity region compared to high velocity region can be attributed to the comparatively more uniform distribution of coarse particles in the low velocity region as well as the increased interaction between particles and better suspension of coarse particles due to increased viscosity of the carrier fluid.

For the coarse slurry [Fig.5], there is marginal drop in the deposition velocity with concentration. For the bi-modal slurry [Fig.6], the deposition velocity reduces with increase in percentage of fines, but over the range tested, the addition of fines has only marginal effect on deposition velocity.

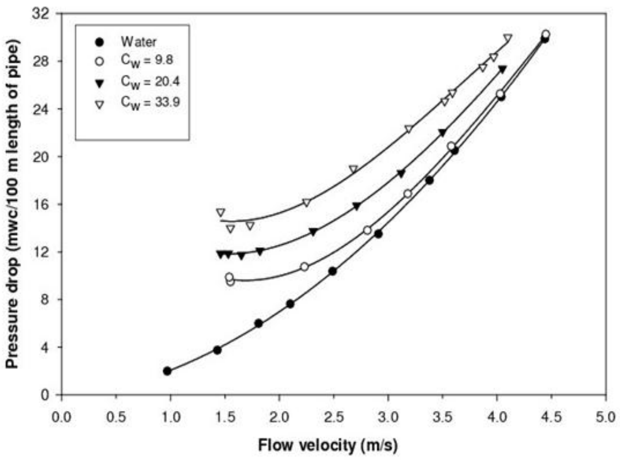

Fig.3: Pressure drop variation for narrow-sized silica sand slurry at various efflux concentrations (% by weight).

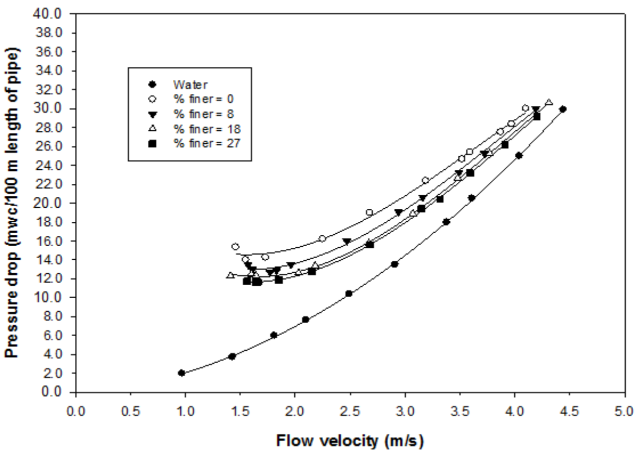

Fig.4: Pressure drop variation for bi-modal slurry of silica sand slurry and fly ash mixed in different proportions of fly ash having average efflux concentration 33.9 (%by weight).

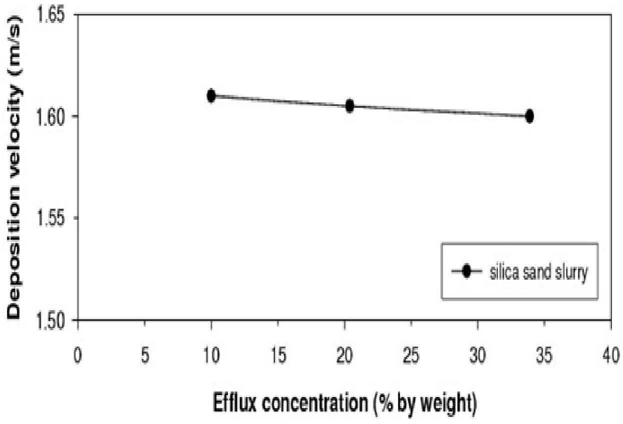

Fig.5: Deposition velocity for narrow-sized silica sand slurry

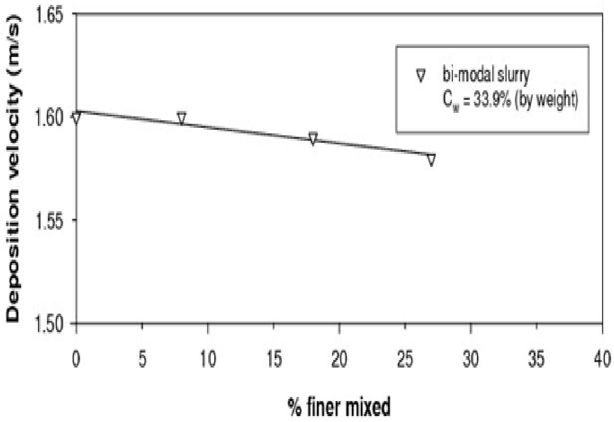

Fig.6: Deposition velocity for bi-modal slurry having average efflux concentration 33.9 (%by weight).

V. Conclusion

Based on the present study, it can be seen clearly that at any given solid concentration, pressure drop for the narrow sized sand slurry 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 whereas for the bi-modal slurry having a high average efflux concentration the pressure drop reduction occurs with addition of fines over the complete velocity range tested as well as the pressure drop at any given velocity reduces with increase in concentration of fine particles, the drop being more pronounced at lower velocities. It is also seen that the reduction in pressure drop is higher in the low velocity region compared to high velocity region. For bi-modal slurry over the range tested, the deposition velocity reduces with increase in percentage of fines, but the addition of fines has only marginal effect on deposition velocity.

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