Prediction of pressure drop for the flow of zinc ore-water suspension in horizontal pipeline

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Abstract. Present study was focused on the flow characteristics of zinc ore water suspension. The solid concentration was varied in the range of 30-60% (by weight). The rheometer is used to study the flow behaviour of slurry suspension. The slurry exhibits Non-Newtonian behaviour at solid concentration of 30%. Whereas at higher solid concentrations slurry shows Bingham flow characteristics. The increase in temperature shows significant effect reduction of apparent viscosity. Fanning equation was used to predict the pressure drop in horizontal pipe. From the results it was noticed the pressure drop was increased with solid concentration and flow velocity.

1. Introduction

Slurry pipelines are mostly used for transportation of bulk solid materials over long and short distances by using carrier fluids. Carrier fluids such as air, water, oil etc. are used to convey solid materials as per industrial application [1-2]. The maintenance of the pipelines is low as well as pipelines are beneficial in providing economic efficiency. Solid particles of different shapes and sizes are transported with the help of pipeline. The solid liquid flow behaviour depends on many factors such as such as particle size, solid concentration, flow velocity, slurry viscosity etc. [3-5]. Nowadays pipelines are widely used to convey mineral ore slurry, water is mainly used in slurry formation as it is cheaper and easily available.

The efficient transportation of slurry at high solid concentrations is a subject of keen interest for researchers. The study of rheological characteristics of slurry suspension helps to design the optimum slurry conveying system. Zinc is the most consumed metal in the world. It has anticorrosive nature and links well with various metals [6-7]. Thus around 50% of the zinc which is produced is used as part of zinc galvanizing, which is the process of adding layers of zinc to iron or steel to protect them from rusting. Marcos and Antonio [8] studied about the effect of rheological behaviour of ultrafine iron ore slurry. They found as the pH of slurry was increased the slurry dispersion degree increases. The appreciable decreases in yield stress and viscosity was observed with increase in pH. Kirk et al. [9] studied about the impact of binary mixtures of fly ash-limestone and ternary mixture of fly ash, limestone and metakaolin on the rheological properties of cement pastes. Bingham model for fluid suspensions was used to predict the metal behaviour. They found that yield stress and plastic viscosity were remain unchanged by replacing ordinary Portland cement by coarse limestone powder for both mixtures. Chen et al. [10] studied the effects on the water resistance of concrete. They found that addition of limestone as cement paste replacement would improve the strength, stability and substantially improve the water resistance of the concrete. Singh et al. [11] reported that it is possible to decrease the viscosity of fine coal water slurry suspension by addition sulfonic acid as an additive at higher solid concentrations. Kumar et al. [12] studied about to improve the rheological properties of bottom ash with the help of additives. They found that sodium sulfate, was much better than henko detergent. The flow characteristics of the bottom ash improved with the addition of 0.4% sodium sulfate.

Form the literature available it was revealed that the work reported on transportation of zinc slurry is minimum. In present study the attempt has been made to study the physical and rheological characteristics of zinc ore water slurry at solid concentration of 30-60% (by weight). The pressure drop characteristics of zinc ore water slurry was also investigated with the help of Fanning's equation. SEM and EDS analysis of zinc ore was also studied to analyse the surface and chemical characteristics.

2. Materials and Methods

The zinc ore was collected from RampuraAgucha mine, Rajasthan, India. The zinc particles were crushed with the help of crusher and then passed through sieves to obtain particle size distribution. The known mass of zinc ore was passed over the sieve shaker for 15 minutes. After 15 minutes the weight retained on each sieve was measured and analysed. The effect solid concentration on the pH of slurry was analysed with digital pH meter. The pH meter was calibrated with buffer solutions before experimentation. The physical and chemical morphology of zinc ore was studied with the help of scanning electron microscope and energy dispersive microscope. In order to obtain the SEM/EDS spectrum the powdered zinc ore was first coated with gold so that conductive medium can be obtained. A high energy beam of electrons was made to incident on the sample which was to be analysed. After interacting with the particles of zinc ore, these energetic electrons produce different signals that were detected by the sensors. During pipeline transportation of solid particles, the energy estimation needed for pumping always relies on the viscosity of slurry. The viscosity of carrier fluid changes by the presence of solid particulates in the carrier fluid depends upon the particle distribution size, Specific gravity, Settling, pH and concentration of the solids present. These rheological studies are exceptionally valuable for deciding the various characteristics of slurry w.r.t slurry concentration. The rheological data was produced by an Anton-PaarRheolab-QC rheometer. The slurry for rheological tests was prepared by mixing the required amount of ore in water. The slurry was stirred with the help of stirrer so as to ensure the uniform mixing and avoid settling. After stirring the slurry was poured into the rotating bod and cup attachment up to the engraved mark. The temperature during rheology test was kept constant i.e. 25°C. Experimentation was also extended to analyse the effect of temperature on rheological characteristics of zinc-ore water slurry at higher solid concentrations.

3. Results and Discussions

3.1 Physical and chemical characteristics of zinc ore

The particle size distribution of zinc ore sample was carried out with the help of mechanical sieve shaker. Figure 1 shows the variation in particle size of zinc ore sample. From the results it was seen that all the particles were finer than 710 µm. However, 73.99 and 31.68% particles were finer than 355 and 75 µm respectively. The acidic or basic nature of the slurry suspension was investigated by examining the pH. The pH was measured by the calibrated pH meter. It was observed that the zinc ore slurry was basic in nature. The pH of slurry was decreased as solid concentration was increased. At 30, 40, 50 and 60% solid concentration the pH was noticed as 8.85, 8.67, 8.35 and 7.95. The decrease in pH with solid concentration was observed because increase in solid particles leads to more leaching of trace elements in the slurry solution.

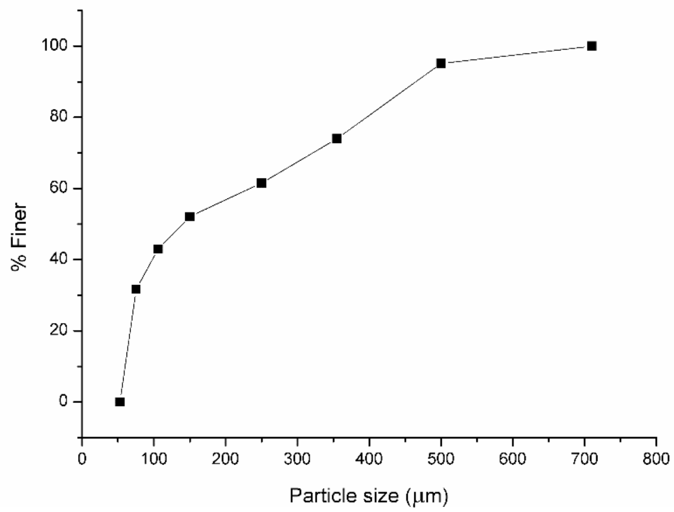

Figure 1. Particle size distribution of zinc ore sample

The surface morphology of the zinc ore was studied by using SEM analysis. Figure 2 shows the high resolution SEM image of the zinc ore sample. From the results it was observed that particles of the zinc ore were irregular in the shape. Also the particles were white bluish colour. The chemical composition of the zinc ore was studied by the EDS analysis. From the result data it was observed that the percentage of ZnO, CO_2, Sio_2, Al_2O_3, SO_3, FeO, K_2O was found as 75.54, 5.98, 4.96, 4.74, 4.15, 3.13 and 1.5% respectively.

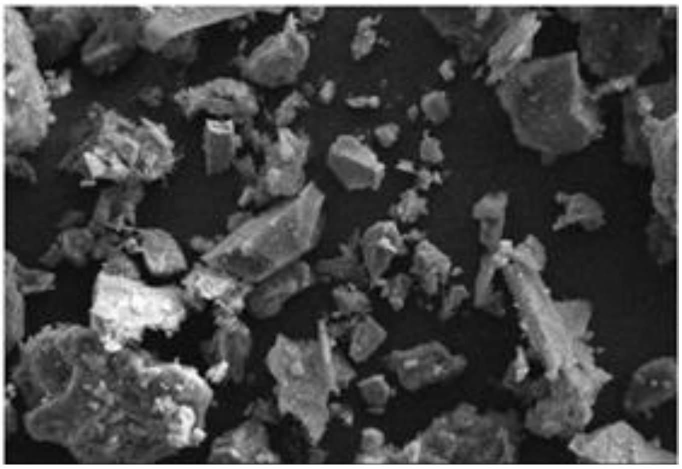

Figure 2. SEM micrograph of zinc ore

3.2 Effect of concentration on rheological behaviour of zinc ore-water suspension

The extensive experimentation was carried out to examine the rheological behaviour of zinc ore water suspension. The rheological experiments were performed for the solid concentration range of 30-60%. The slurry temperature was kept constant during experimentation i.e. 25°C. The shear rate was varied in the range of 40 to 600 s^{-1}. Figure 3 shows the variation in shear stress with shear rate at different solid concentrations. From the results it was seen that the flow behaviour of slurry suspension was severely changed as solid concentration was varied. As the solid concentration of slurry was increased appreciable increase in the apparent viscosity was observed. This increase in apparent viscosity was

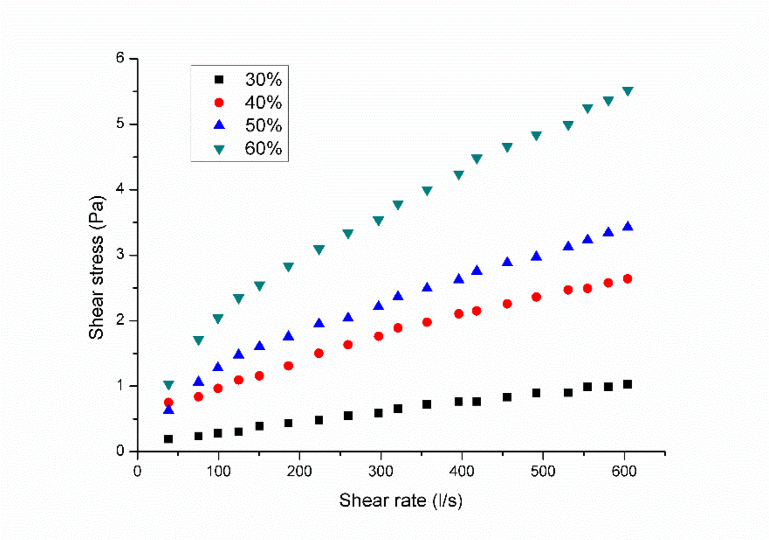

Figure 3. Variation of shear stress with shear rate at different solid concentration

occurred because of increase in number of solid particles in the slurry suspension. As the loading of solid in slurry increased the restriction to slurry flow increased. Hence the viscosity of slurry was increased. It was also observed that zinc ore water slurry shows the Newtonian flow characteristics for solid concentration of 30%. Whereas, as the solid concentration of slurry was increased from 40-60% the floe behaviour of slurry suspension was changed to Bingham flow. At the shear rate of 320 s^{-1} the shear stress was increased by 65.35, 20.08, and 37.43% as the solid concentration was increased from 30-40, 40-50 and 50-60% (by weight).

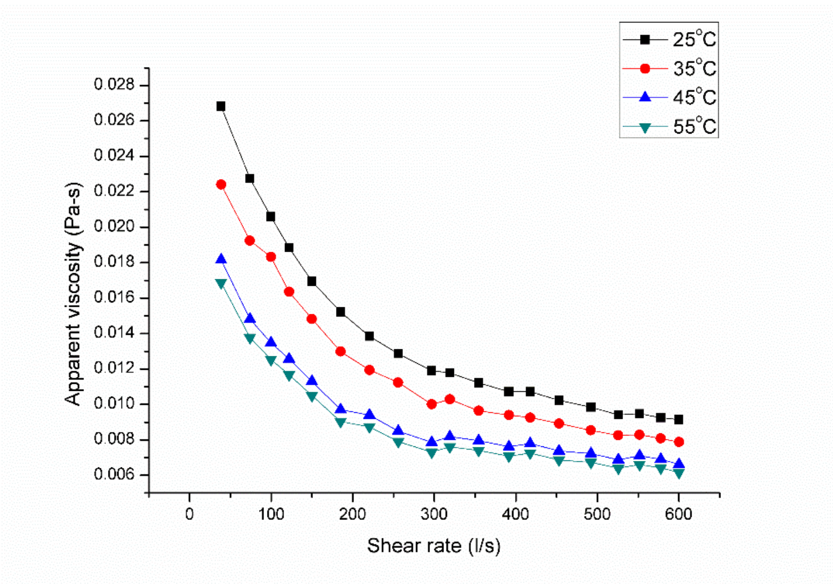

Figure 4. Variation of apparent viscosity with temperature at solid concentration of 60% (by weight)

3.3Effect of temperature of rheological behaviour of zinc ore-water suspension

The detailed experiments were carried out by varying the temperature to investigate the effect of temperature on slurry viscosity. The slurry temperature was varied in the range of 25-55°C. The solid concentration of the slurry was kept constant i.e. 60%. Figure 4 shows the variation in apparent viscosity with the temperature for solid concentration of 60%. From the results it was observed that the appreciable decrease in slurry viscosity was noticed as the slurry temperature was increased from 25 to 55°C. This decrease in apparent viscosity with temperature was seen because of increase in particle-particle interactions. With the increase in particle-particle interaction the relative movement among solid particles in slurry is increased. This leads to reduction in cohesive forces among solid particles. Hence results into reduction in slurry viscosity. However it was also observed that the percentage reduction in apparent viscosity was less as the slurry temperature was increased from 45-55°C. The apparent viscosity was decreased by 13.63, 15.78 and 5.43% as the temperature of slurry was increased from 25-35, 35-45 and 45-55°C. The optimum temperature was found as 45°C.

3.4 Prediction of pressure drop characteristics of zinc ore water slurry

The pressured drop was also predicted for the flow of zinc ore water slurry. The calculation for pressure drop was determined on the basis of Non-Newtonian model. The solid concentration was varied in the range of 30-60% (by weight). The density of the slurry at different solid concentrations was determined by the equation as given below.

$$\rho_m = 100 \Big/ \left(C_W / \rho_s\right) + \left[\left(100 - C_W / \rho_l\right)\right] \qquad (1)$$

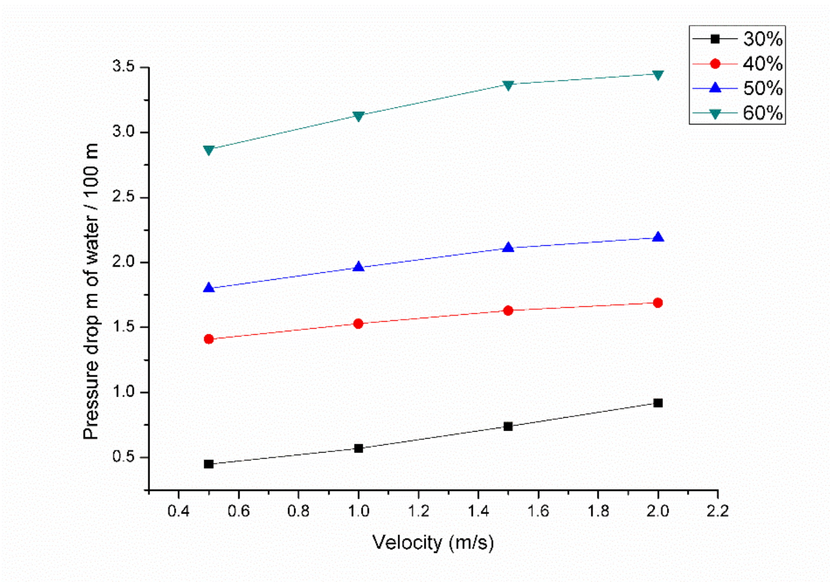

Figure 5. Variation of pressure drop with flow velocity at different solid concentrations

The power law was used to determine the consistency parameter (K) and flow behaviour index (n). Reynolds number was calculated by the following expression.

$$\mathrm{Re} = \frac{8D^nV^{2-n}\rho_m}{K}\left\{\frac{n}{2+6n}\right\}^n \quad (2)$$

The flow was assumed to be laminar and the friction factor was calculated as.

$$f = \frac{16}{\mathrm{Re}} \quad (3)$$

The flow velocity for the flow of slurry was varied in the range of 0.5-2 m/s. The pressure drop was calculated by Fanning equation as given below.

$$h = \frac{2fV^2\rho_m}{gD\rho_w} \quad (4)$$

The diameter of the horizontal pipe was taken as 100 mm. Figure 5 shows the variation in pressure drop with flow velocity at different solid concentrations. From the results it was seen that the values of head loss was increased as the flow velocity was increased. The pressure drop was also a function of solid concentration. As the solid concentration was increased from 30-40, 40-50 and 50-60% the pressure drop is increased by 83.69, 29.58 and 57.53% for flow velocity of 2 m/s.

4. Conclusions

Present study was carried out to investigate flow and rheological characteristics of zinc ore water slurry suspension. The pressure drop was also predicted from the fanning equation. The solid concentration was varied in the range of 30-60% (by weight). The pipe diameter and flow velocity range was taken as 100 mm and 0.5-2 m/s. the following conclusions were drawn from study are shown below.

- The pH of the slurry suspension was varied in the range of 8.85-7.95.
- The slurry suspension shows Newtonian behaviour only up to 30% solid concentration and after that it behaves like non-Newtonian in nature.
- Appreciable decrease in apparent viscosity was observed as the temperature was increased from 25-55°C.
- Pressure drop was increased with flow velocity and solid concentration. As the solid concentration was increased from 30-40, 40-50 and 50-60% the pressure drop is increased by 83.69, 29.58 and 57.53% for flow velocity of 2 m/s.

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