Abstract

The presence of wide distribution of fine and coarse particles in the slurries transporting through pipeline critically influence the slurry rheology and pressure drop. In the past decades, a number of techniques capable of reducing pressure drop either by altering the rheological properties or by reducing the impact of adverse flow properties of the slurries, have been investigated. Determining these complex flow behaviours through experiments become very difficult and expensive. Hence, numerous mathematical expressions of varying complexity and form have been proposed in the past. Many of these equations available in literature are developed based on limited data and their applicability is also limited. For these reasons, computational fluid dynamics (CFD) based simulations offer a relatively easy alternative and are becoming increasingly attractive due to recent advances in numerical models. Based on these notions, the following works have been carried out.

In the first stage of present work, the effects of non-chemical additives on the rheological properties of coal ash slurries have been studied using advanced computerized rotational rheometer. Solid bottom ash (BA) was added in the fly ash (FA) slurry and solid FA was used as additive in the BA slurry at various solid concentrations and mixing proportions. The investigation showed the FA slurries with and without the addition of BA behave as Bingham fluids and substantial reduction in yield stress was observed up 30% additive. On the other hand, the BA slurries with and without the addition of FA behave as Newtonian fluids at all concentrations and additive proportions. Furthermore, the viscosity increases with increasing the concentrations as well as the proportion of FA.

Likewise, the influence of chemical agents, namely quick lime (QL), hydrated lime (HL), Sodium hexametaphosphate (SHMP) and Acti-Gel, on the rheological behaviors of iron ore slurries at different solid concentrations and additives’ dosages have been
investigated. Moreover, based on the rheological data the impact of these chemical agents on the pressure drop along slurry pipeline were analyzed using numerical model. The investigation showed that minimum shear stress and viscosity were obtained at 2% dosage of QL for 18.8% and minimum flow behaviour index was obtained at 25.8% with 2% additive dosage. The addition of HL markedly increases all the rheological parameters. When SHMP is used, minimum shear stress and viscosity were obtained at dosage of 1.5%, 2% and 2% for 50%, 55% and 60% respectively. Acti-Gel resulted higher values of yield stress and flow behaviour indices at all solid concentrations. QL was more effective in reducing the friction factor than HL, SHMP and Acti-Gel. At high flow velocities and low dosages, SHMP yielded minimum friction factors. But, the addition of Acti-Gel yielded larger results than the rest.

In the second stage of present work, a new empirical model has been developed for the viscosity of multi-sized Bingham fluids as a function of solid volume fraction, maximum solid volume fraction, intrinsic viscosity, median particle diameter, and coefficient of uniformity using optimization and nonlinear least square curve fitting techniques. A bench scale test was carried out to obtain the rheological properties of the slurries at high solid concentrations. Additional data have also been collected from open literature. The predicted viscosity based on the proposed model were compared with these data and found to be much better than the previously developed models over the entire range of volume fraction.

Similarly, a new approach for predicting the pressure drop multi-sized slurry flow along slurry pipeline have been proposed. Prior to this, the accuracy and applicability of the existing explicit friction factor correlations developed for smooth pipes have been examined. Nine models developed for different flow regimes were chosen and the comparisons of the selected equations with the experimental data were expressed through MARE, RMSE, $\Theta$, S, AIC and MSC. The analyses showed that the Wilson-Thomas
(1985) and Morrison (2013) models are best fit models for the Reynolds number up to 40000 but beyond this value the Morrison model showed better predictions. Hence, this model can be used as an alternative to the Moody chart and other implicit formulae developed for smooth pipes. Furthermore, new simplified approaches were adopted to improve the Wasp model for predicting the pressure drops of multi-sized slurry flowing through pipeline. The two implemented approaches are the physics-rheological approach that takes into account the particle size distribution as well as slurry viscosity and the multiphase flow modelling approach that considers the different flow regimes. Extensive experiments were carried out to measure the physical properties, rheological behaviours and pressure drops at various solid concentrations. Moreover, additional data were collected from open literature. The predicted pressure drops obtained by the proposed approach were compared with model of Williamson and Kaushal & Tomita. It is concluded that the current approach provides an improved results over previously available models in wider range of solid concentrations.

In the last stage of present work, the performance of Eulerian multiphase model coupled with k-ε turbulence closures along with its model alternatives based on the types of secondary phase, near wall treatment and pipe roughness were evaluated using ANSYS FLUENT 14.0. The simulated results were compared with the experimental data and with numerical equations chosen from open literature. If CPU memory storage and computational time are not an issue, granular realizable model with standard wall function is capable of accurately simulating the slurry flow through pipeline. Finally, based on the above findings, the CFD simulation of iron ore slurry flowing through horizontal pipeline at various concentrations and flow velocities have been carried out. The CFD predicted pressure drops were compared with own measured data and showed maximum RMSE of 17.36% at all concentrations and flow velocities. Hence, it is be concluded that the CFD predicted results were in good agreement with measured data.