

Abstract

Pipeline transportation of mineral and industrial waste slurries has emerged as a sustainable and energy-efficient alternative to conventional bulk transport systems. However, the highly concentrated nature of such slurries introduces complex rheological and flow behaviors that significantly cause pipeline pressure losses, flow instability, and huge energy consumption. Despite extensive research, a comprehensive understanding of the influence of particle characteristics, solids concentration, and chemical additives on flow behavior remains limited, particularly for dense-phase slurries such as iron ore and fly ash. Motivated by the increasing industrial need for optimizing slurry transport efficiency and reducing energy costs, this thesis undertakes experimental and computational investigations of the flow behavior of highly concentrated iron ore and fly ash slurries, while developing improved prediction models for pressure drop estimation.

This thesis focuses on the combined experimental and numerical analysis of slurry flow behavior under varying physical, chemical, and hydraulic conditions. Furthermore, the thesis systematically examines the effects of chemical additives on rheological properties, pressure drop, and flow regime transitions. This thesis proposes a modified Slatter's method and validates a 3D CFD-based model to enhance the accuracy of pressure drop predictions in pipeline transport systems.

The experimental investigation was carried out using a 2-inch diameter pilot-scale pipeline loop for both iron ore and fly ash slurries. The iron ore slurry in the thesis had a mean particle diameter of 55 μm and a maximum static settled concentration of 75.20% (w/w). Experiments were conducted over a velocity range of 1-3.5 m/s and a solids concentration range of 60-72% (w/w), (C_{vf} = 22.02-32.70%), both with and without the addition of Sodium Hexametaphosphate (SHMP) as a chemical additive in dosages ranging from 0.1-1.5% w/w of solids. The results demonstrated that SHMP effectively reduced the yield stress and apparent viscosity, resulting in a significant decrease in pressure drop. The optimum dosage for zero yield stress and maximum pressure drop reduction was observed to increase from 0.8% to 1.2% w/w of solids as the efflux concentration increased. The critical deposition velocity was also found to increase with both additive dosage and solids content, ranging from 1.0 to 1.95 m/s.

The fly ash slurry, with a mean particle diameter of 85 μm , was studied across a concentration range of 20-60% w/w (C_{vf} = 9.59-38.9%) and a flow velocity range of 1-4 m/s. Experiments were conducted both with and without the addition of Sodium Silicate and Sodium Sulfate as

chemical additives in dosages ranging from 0.1-1.5% w/w of solids. Results showed that both additives significantly improved the slurry's flowability by reducing yield stress, viscosity, and consequently pressure drop, with the additives reducing the pressure drop up to 25% at 60% w/w efflux concentration. The optimum additive range for minimizing pressure drop was identified as 0.4-0.8% w/w of solids.

A modified Slatter's method, incorporating an optimum particle diameter (in place of the conventional d_{85}), was proposed using experimental data from rheological tests and pipe loop measurements. The modified method predicted the pressure drop within an error margin of $\pm 15\%$ for both iron ore and fly ash slurry, showing higher accuracy than existing models. To complement the experiments, a 3D CFD-based model employing the Eulerian multiphase framework was developed using the $k-\epsilon$ turbulence model for the iron ore slurry and the $k-\omega$ turbulence model for the fly ash slurry. The predicted pressure drop using the 3D CFD-based model was validated against the experimental results. The CFD simulations predicted pressure drop with an accuracy of $\pm 15-30\%$, demonstrating significantly improved prediction in the 2-3 m/s velocity range, where deviations remained under 5% compared to experimental results. Additionally, the simulations provided detailed insights into velocity distribution, slip velocity, and solid concentration profiles.

Overall, this thesis establishes a comprehensive framework integrating experimental, empirical, and computational approaches for predicting the hydraulic behavior of iron ore and fly ash slurry. The findings contribute significantly to the optimization of slurry pipeline design and operation, offering practical insights into the energy-efficient and reliable transport of mineral and industrial waste slurries.