Conveying of Coarse-Grained Particles in Pipes

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ABSTRACT

The effect of slurry velocity and concentration on the coarse-grained particle–water mixtures flow behavior and pressure drops was studied in horizontal and inclined pipes of inner diameter 100 mm. The study revealed that the coarse-grained particle-water mixtures were significantly stratified, the particles moved principally in a layer close to the pipe invert, for higher flow velocities particle saltation becomes dominant mode of conveying. Frictional pressure drops in vertical pipe were less than in horizontal pipe, the frictional pressure drops in ascending pipe increases with inclination angle up to about 30 degrees.

KEY WORDS: Hydraulic conveying; coarse-grained slurry; concentration distribution; pressure drops; pipe inclination.

INTRODUCTION

Pipeline transport of coarse-grained material is not very frequently used due to the problems of wear, material degradation, high operational velocities and energy requirement. However, pipeline transport of coarse particles is of potential importance e.g. in mining industry. The hydraulic pipelining is the preferable way of poly-metallic nodules transport from the ocean bottom to the surface (Vlasak and Chara, 2007; Vlasak, Chara, Kysela and Sobota, 2011).

The understanding of the slurry flow behavior makes it possible to optimize transport parameters and energy requirements, to improve quality, safety, economy and reliability of transport. Information on the slurry flow behavior, operational velocities and pressure drops are essential to safe and effective operation of a slurry piping. A progress in the theoretical description of heterogeneous slurry flow is limited due to the lack of experimental data on the flow behavior and an inner structure of slurry flow. The study of the inner structure of such flow is very difficult, since many well-known techniques suitable to determine the inner structure of fluid flow (e.g. LDV, PIV, UVP) cannot be used in solid-liquid mixtures. Description of the slurry flow behavior and the inner structure are much more complex than measurements of overall flow parameters, e.g. the flow rate, pressure drop, mean concentration.

Flow of heterogeneous slurries in horizontal pipe may be defined by asymmetrical velocity and concentration distribution, where a Coulomb type friction contributes significantly to the friction losses. A flow pattern with a bed layer and a skew concentration distribution generally exist for these slurries (Wilson, Brown and Streat, 1979). The flow behavior of coarse-grained slurry depends on particle size, shape, density and concentration of solids, the diameter and roughness of the pipe, and on the density and rheological properties of the carrier liquid. A slurry flow mechanism can be theoretically described by so called microscopic model (Shook and Roco, 1991). Unfortunately, the experimental technique is not able to provide enough information of the slurry flow mechanism at a microscopic level, and the model remains only theoretical. A compromise between the microscopic and empirical approaches is a macroscopic modeling.

The first mechanistic approach for coarse-grained particle slurry flow was probably that of Newitt, Richardson, Abbott and Turtle (1955), who distinguished between velocity dependent fluid friction and velocity independent particle-wall friction of the Coulomb type, and defined coarse particle conveying as flow with sliding bed and particle saltation. Wilson (1976) interpreted the high concentration experimental results with glass spheres in smooth pipes and proposed a two-layer model for settling slurries. Based on experimental data from the large test pipelines of the Saskatchewan Research Council the two-layer model was extended even for finer particles (Newitt, Richardson, Abbott and Turtle, 1955). The so called RSC two-layer model is based upon force balance for the upper and lower horizontal layers. All the above mentioned quantities, including the Reynolds number, friction factor and Coulomb type friction are defined for each layer as well as the interfacial friction factor and the flow parameters could be determined (Matousek and Krupicka, 2009).

The two-layer model may be used for the description of the fully or partially stratified flow patterns and prediction of the deposition velocity limit, pressure drops due to friction, thickness and translational velocity of the sliding-bed, and also the value of the mean slip between the solid and liquid phases.