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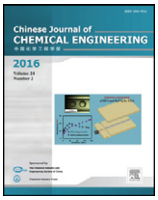

Fluid Dynamics and Transport Phenomena

Experimental study on the effects of big particles physical characteristics on the hydraulic transport inside a horizontal pipe

Salah Zouaoui [1],*, Hassane Djebouri [1], Kamal Mohammedi [2], Sofiane Khelladi [3], Aomar Ait Aider [1]

[1] LMSE Laboratory, Mouloud Mammeri University of Tizi-Ouzou, P.O. Box 17 RP15000, Algeria
[2] LEMI Laboratory MESO, M'Hamed Bougara University of Boumerdes, 35000, Algeria
[3] DynFluid Laboratory, Arts et Metiers ParisTech, 151 boulevard de l'Hôpital, 75013 Paris, France

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ABSTRACT

This paper presents an experimental study of the physical characteristic effects of large particles on hydraulic transport in a horizontal pipe. The particles are spherical and are large with respect to the diameter of the pipe (8%, 10%, 16% and 25%). Experiments were done to test the important parameters in solid transport (pressure, velocity, *etc.*). As a result, the relationship between the pressure gradient forces and the mixture velocity was substantially different from the pure liquid flow. However, in a single-phase flow a monotonous behavior of the pressure drop curve is observed, and the curve of the solid particle flow attains its minimum at the critical velocity. The regimes are characterized with differential pressure measurements and visualizations.

1. Introduction

During these last decades, the demand of mineral materials from emerging countries strongly increased, causing the exploitation of new deposits. For this reason, several firms have recently launched a subsea mining project study, and the main task was to estimate the pressure drop of solid–liquid mixture in the flow line for various flow regimes. In this case, the circuit would have various and complex shapes, including vertical, horizontal ones, potentially bends, and S-shapes.

In general, solid transport is divided into three major flow patterns [1]:

(1) Pseudo-homogeneous or homogeneous flow and heterogeneous flow.
(2) Heterogeneous and sliding bed flow (or moving bed flow).
(3) Saltation and stationary bed flow.

In a pseudo-homogeneous flow case, the particles are distributed almost uniformly over the pipe cross-section and moved at a very high velocity. When the flow velocity of the particles decreases, the heterogeneous flow pattern occurs if there is a concentration gradient in the direction perpendicular to the pipe axis. Most of particles are carried out in the lower part of the pipe cross-section.

Transporting solid particles in a fluid flow is very complex. Many researchers have tried to create a mathematical model in order to predict the head losses in slurry transport. Such as the models of Zandi [2], Turian and Yuan [3], Doron *et al.* [4], Doron and Barnea [5], Wilson and Pugh [6], Matousek [7], Bratland [8], and references therein. Lahiri and Ghanta [9] proposed a hybrid support vector regression-genetic algorithm approach to predicting the pressure drop of solid–liquid slurry flow. Recently, Edelin *et al.* [10] reported an experimental investigation of the transport of fluids composed of water and small size polypropylene particles, in order to study the transport of floating particles, also to determine the conditions that minimize the energy consumed by installations designed to this type of flow. These models enabled a fast and a global approach of the transported solid quantity in fluid flows, but they are generally approximate [11]. A predictive model for transporting large particles in vertical pipes was proposed and ratified on a set of experimental data, based on the work of Newitt *et al.* [12], Richardson and Zaki [13], Xia *et al.* [14], and Yoon *et al.* [15]. In horizontal pipes, the prediction of the flow patterns and pressure gradient known as a complex problem is treated *via* experimental correlations. Some of them are restricted to one or two flow patterns [16–18]. However, different authors [12,19–21] claim to apply these correlations for all flow patterns of liquid–solid systems. Miedema [22,23] proposed a new head loss model for slurry transport in the heterogeneous regime. This model shows resemblance with the Durand and Condolios [24] model. However the influence of the pipe diameter is much less matching the experimental results in larger pipes.

Many parameters are needed to describe the solid transport, such as water flow rate and solid particles, particle density and diameter, and

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* Corresponding author.
E-mail addresses: zouaouisalah@ummto.dz, zouaoui_salah2003@yahoo.fr (S. Zouaoui).

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the pressure drop along the pipe. This last is considered to be the mainly important parameter in solid–liquid flow. Most investigations carried out concerns only the very small ratio of particle to pipe diameter and low solid concentration. In this present study, an experimental investigation is conducted in a small scale to identify the effects of physical characteristics of big particles on the hydraulic transport in horizontal pipe. Moreover, influence of concentration, size and density of particles on the pressure drop, and mixture velocity above which the bed starts to move (critical velocity) are highlighted. Also, this work allows one to understand the blocking problem of the pipelines transporting water-solid mixture.

2. Experimental Device

2.1. Test loop

We performed a series of tests with the experimental loop shown in Fig. 1, and the different materials used are described below. We focused on the liquid–solid flow in a horizontal rigid pipe of length $L = 2 \times 2$ m and diameter $D = 60$ mm. This tube carries a 180° horizontal curve with 30 cm of diameter curvature. The test loop composed with a pump to supply the circuit with clear water and an injection system for solid particles. The particles fall down by gravity through a flexible tube connecting the bottom of particle tank to the main duct *via* a buffer zone. The last one, situated between the two valves is divided into three compartments of known capacity, allows us to determine the mean solid flow rate. The flow rate of injected particles into the pipe is adjusted by the lower valve (Fig. 1). Globally the particles flow is relatively stable and uniform, since we are dealing with a mean particles flow rate through measurement of time elapsed between opening and closure of the lower valve. The mixture arrives finally in a system to separate the solid from the liquid. This system consists of a first tank with a filter to recover the solid particles and allows only water to pass to the second tank. In order to realize a closed circuit for water, the second tank is connected to a pump which delivers the water into the circuit (Fig. 1).

2.2. Particles and pipe

The circuit is constructed with Plexiglas tube to allow the visualization of the flow. The calibrated beads of alumina (Umicore, Alumina Degussit 92%, with a relative size dispersion of 10%), and glass (SiLi, SiLibeads type M, with a relative dispersion of size of 4%) are used [11]. The particles are relatively large, with size up to 25% of the pipe diameter. Their physical and geometrical characteristics are summarized in Fig. 2.

2.3. Control parameters

To masseur the flow parameters, we need some necessary measuring instruments. The water flow rate is measured using an electromagnetic flow meter (KROHNE Optiflux 2000), and adjusted using a pump's variator. The flow rate of solids is controlled by a device designed and realized in the laboratory. Optical measurements are also performed with a high-speed camera (Optronis CamRecord600). Typically 1000 images are recorded with a resolution of 1280 × 1024 pixels at a frame rate of 500 Hz. The flow is illuminated backwards with a LED plate from Phlox, and the pressure drop is measured using two differential pressure sensors (VEGADIF65, VEGA, Germany).

The aim of the present work is to measure the pressure drops in different parts of the test loop as a function of solid concentration and mixture velocity. The parameters that are adjusted with experimental means are the volumetric flow rates of liquid (Q_l) and of solids (Q_s). To present the results we define the mixture velocity (U_m) and the delivered concentration (C) as follows:

$$U_{\mathrm{m}} = \frac{Q_l + Q_{\mathrm{s}}}{S} \tag{1}$$

$$C = \frac{Q_{\mathrm{s}}}{Q_{\mathrm{s}} + Q_l} \tag{2}$$

where S is the cross-section area of the pipe, and the mixture velocity (U_{m}) presents a volumetric average of the velocities of each phase.

The pressure drops (G) are expressed in terms of hydraulic gradients (meters of water column per meter of pipe):

$$G = \frac{\Delta P}{\rho_{\mathrm{e}} g L} \tag{3}$$

where ρ_{e} is the water density equal 1000 $\mathrm{kg \cdot m^{-3}}$ and L the distance between the pressure taps equal to 1.4 m.

3. Results and Discussion

The thick black line in all figures stands for the measured hydraulic gradient with pure water flowing ($C = 0\%$). The Reynolds number is 10^5 and the flow is fully turbulent and the estimated rugosity is 20 μm. We observe inside the pipe that the pressure drop and the

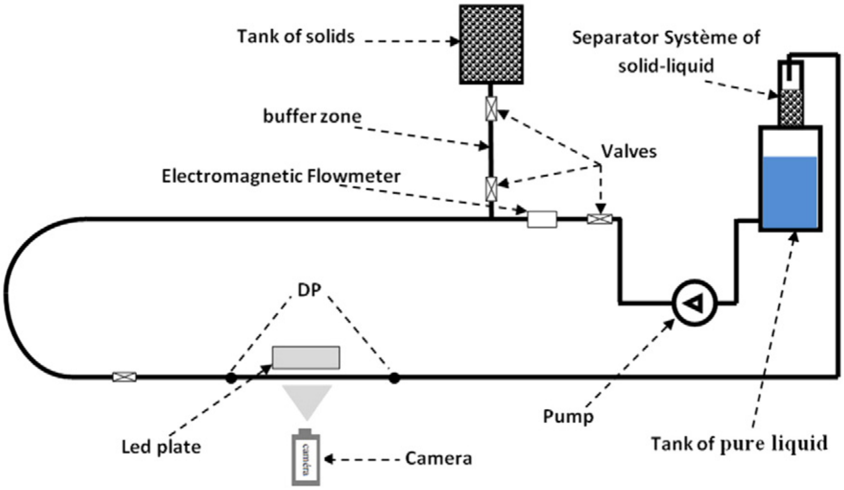

Fig. 1. Sketch of test loop.