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Movement of Solid Particles in Vertical Pipe

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ABSTRACT

The paper presents results of experimental measurements devoted to movement of single spherical particles in suspensions of different concentrations. Obtained results have been compared with estimations based on equations for calculation of fall velocities of spherical particles in liquids. In second investigation presented in this paper relations between parameters of falling particles and flowing medium in vertical pipeline have been presented. Between others, drag coefficients have been determined in function of particles diameter and flow velocity in a vertical pipeline. Foamed polystyrene particles have been used successfully as a model for air bubbles in laboratory measurements.

KEY WORDS: fall velocity in suspension, velocity of single particle

INTRODUCTION

Development of the civilization requires increasing consumption of rare elements instead of previously used metal elements. Resources of rare elements available for traditional mining technologies are limited and become more and more often depleted. Therefore resources located on the oceanic floors entered in the range of interest of mining companies. Technologies of deep sea mining, regardless of the way, in which the nodules are collected, use pipeline transport to haul the minerals onto the surface. The material to be transported in the pipeline system consists of nodules, particles of sand an other substances from the sea floor, and sea water. In certain technologies compressed air can be used for transportation of nodules, in such a case a three phase mixture of solids, water, and air flows in the pipeline.

Description of transportation technologies with use of two phase mixture can be found in works of Sobota (2005), Aleksandrov (2005) and with use of three phase mixture in work of Bournaski (2001).

In case of two phase mixtures, drop velocity of coarse grains in lifting mixture is an important factor for operation of the transport system. This velocity limit the flow velocity of mixture in pipeline, which must ensure lifting of all grains onto the surface. In other case all solid particles fall down in pipe and the system stops. The fall velocity of the largest particles is also important in description of the phenomena of mixture flow in vertical pipe.

The physical mechanism of falling of single spherical particle in a liquid describes well known equation, which is derived from balance of forces acting by the falling, and which could be presented in following form:

$$W_o = \sqrt{\frac{4dg(\rho_s - \rho_w)}{3c_w\rho_w}} \tag{1}$$

where:
W_0 – fall velocity, m/s,
g – acceleration of gravity, m/s^2,
ρ_s – density of solids, kg/m^3,
ρ_w – density of water (liquid), kg/m^3,
c_w – drag coefficient, -

To determine the value of fall velocity from Eq. 1, drag coefficient c_w for falling particle must be known. In case of spherical particle value of this coefficient can be derived from equation, in which $c_w = f\,(Re_d)$. However, to calculate the Reynolds number, fall velocity must be known. This inconvenience removes relation between Archimedes number and Reynolds number, because to determine the Archimedes number knowledge of physical properties of liquid and the falling particle is required:

$$\mathrm{Re}_d = \frac{Ar}{18 + 0{,}61\sqrt{Ar}} \tag{2}$$

Archimedes number and Reynolds number are defined as follows:

$$Ar = \frac{d^3 g(\rho_s - \rho_w)\rho_w}{\mu_w^2} \tag{3}$$

$$\mathrm{Re}_d = \frac{W_o d\rho_w}{\mu_w} \tag{4}$$

where:
μ_w – viscosity of water (liquid), Pa·s.

In the range of turbulent fall, drag coefficient takes constant value of $c_w = 0{,}4 \pm 0{,}04$.

In case of three phase mixture flow a significant factor for operation of transport system is velocity of air bubbles in flowing mixture.