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Solid-liquid Flow Experiment with Real and Artificial Manganese Nodules in Flexible Hoses

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ABSTRACT

Experiments have been performed to study the differences of the flow characteristics between real and artificial manganese nodules-water mixture and synthetic nodules-water. The results show that the hydraulic gradients of the mixtures were almost identical in the case of both the real and synthetic nodules. However, when the solid volume fraction is high, the hydraulic gradients of the flow of the real manganese nodules were a little lower than those of the artificial ones, because the drag effect is not so apparent.

KEY WORDS: Manganese nodules; flexible hose, mixture, hydraulic gradient

INTRODUCTION

Hydraulic pumping system is two-phase lifting technology, by which manganese nodules are conveyed from the seafloor to the mining ship. Most of the system is located under the sea level, which demands its stability and durability more than anything else because of the difficulty in repairing. Also, economical recovery of the manganese nodules requires stable operating conditions and optimum power prediction of the lifting pump.

Hydraulic pumping system is two phase lifting technology of solid and liquid. There are considerable studies on the hydraulic transportation of two-phase mixture. Newitt et al. (1961) carried out an experiment to predict the hydraulic gradients and flow rates of water and solid particles in the pipe of 1 inch in diameter. Noda et al. (1986) derived the settling velocity and drag coefficient of the particle group related to in-situ volume of solid using coal sample. Kitaha et al. (1985) dealt with the hydraulic behavior of simulated nodules and other kinds of solid with grain size up to 42 mm in the vertical pipe. Chung et al (1998) and Sumardi and Chung (1996) presented a two-phase (solid-water) vertically upward flow system with 1 inch diameter clear PVC pipe to test flow characteristics. Xia et al. (1997) studied the basic characteristics of solid-liquid two phase flow transport, the prediction and optimization of hydraulic pumping parameter for commercial mining system. There also have been the studies on the flow behaviors of solid particles in a pipe, which are based on the hydrodynamic models (Yoon et al., 1998). Sobota et al. (2001) investigated the slip velocity between solid and liquid in a vertical pipe by experiments.

We the authors have tried to develop a lifting system for 5,000 m deep sea-bed manganese nodules. In 1999 (Yoon et al., 1999), the 4.3 meter-scale hydraulic pumping experiments were conducted and the 30 meter scale on-land hydraulic pumping system, which enabled us to analyze the two-phase flow was designed and constructed. On the system we performed the experiments up to 20% volume fraction (Yoon et al., 2005). In this study, flow experiments were performed to compare flow characteristics between the real and artificial manganese nodules in the flexible pipe in similar ways as above.

HYDRAULIC GRADIENT OF SOLID-LIQUID TWO-PHASE FLOW

The experiments aimed to analyze and understand the flow parameters such as each phase velocity, in-situ and discharged volume fraction, pressure gradient, and hydraulic gradient of the solid-liquid two-phase mixture in a small vertical tube by measuring the discharged mass flow rate of solid and liquid and the pressure drop as a function of the diameters and volumetric flow rate of solid particles. Followings are the basics for the analysis of two-phase mixture flow.

By measuring discharged solid mass flow rate (W_{SS}) and discharged liquid mass flow rate (W_{SL}) from two-phase mixture, superficial volumetric flow rate of solid particles (Q_{SS}) and superficial volumetric flow rate of liquid (Q_{SL}) can be obtained from Eqs. (1) and (2).

$$Q_{SS} = \frac{W_{SS}}{\rho_S} \tag{1}$$

$$Q_{SL} = \frac{W_{SL}}{\rho_L} \tag{2}$$

where ρ_S and ρ_L are the density of solid particle and liquid respectively. Therefore, the discharged solid volume fraction (C_S) can be expressed as follows:

$$C_S = \frac{Q_{SS}}{Q_{SS} + Q_{SL}} \tag{3}$$

The superficial solid velocity (V_{SS}) and the superficial liquid velocity