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Fine particle classification by a vertical type electrical water-sieve with various particle dispersion methods

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1. Introduction

Recently many studies for the production of high value products using nano-particles have been carried out using various powder processes. In order to increase high product performance, which is related to particle materials, particle classification technology with the cut size in the nano-size or sub-micron range is strongly required. Particle classification using a liquid medium is more suitable compared to the dry classification method, because particle dispersion control is easy to operate in a liquid state.

The hydro-cyclone is one method used to classify particles in a liquid state, but a cut size of less than approximately 1 μm is difficult and requires a high pressure drop [1]. On the other hand, a rotating cylindrical centrifugal separator is used in sub-micron particle classification, but classification accuracy is not always good, and it requires careful maintenance of the high speed rotating part [2].

The water-sieve is the conventional particle classification apparatus used for a liquid state, but it requires a very long time to classify sub-micron particles. On this problem, Yoshida et al. [3] and Matsuzawa et al. [4] developed a new type of electrical water-sieve, and sub-micron particle classification is realized using electrical potential applied to flow direction.

In order to increase classification performance, particle dispersion control is an important point for the electro-potential separation method. However, this problem is not clearly investigated in the previous report.

This paper examines the effect of particle dispersion state on classification performance using an electrical water-sieve. Regarding the particle dispersion method, the ultra-sonic probe dispersion and beads mill dispersion methods were used. The new data of particle charge level was obtained using the special effective zeta-potential measurement method proposed by Yoshida et al. [5,6]. The interesting new data is obtained with the two particle dispersion methods, and the cut size data agrees with the theoretical model.

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2. Experimental apparatus

The experimental apparatus of the vertical type electrical water-sieve is shown in Fig. 1. The apparatus consists of a feed slurry tank [2], feed liquid pump [4], flow meter [6], particle separation tank [7] and over-flow and under-flow part, respectively. The feed slurry is supplied to the central downward pipe and changes its direction to the upper direction, passing through the lower perforated metal plate. The fine particles are collected to the upper over-flow part and the coarse particles are collected to the lower under-flow part. The cut size of particle classification can be easily controlled with the value of electrical potential applied to both perforated metal plates. Because of the electrical potential applied to the vertical direction, the cut size can be easily changed to the sub-micron range. The electrical potential was changed from zero to 30 V and spherical silica particles were used in the experiment. The feed slurry concentration was set to 0.5wt%, and the slurry temperature was set to 293 K using a temperature controller. The feed slurry flow rate Q_0, over-flow rate Q_f, and under-flow rate Qc was 45, 15 and 30 ml/min, respectively. Fig. 2 shows the details near the lower perforated metal plate. In order to create uniform upward flow distribution in the apparatus, the central feed pipe is divided into 6 pipes. For the upper and lower perforated plate, the hole diameter and plate thickness was set to 3 mm and 2 mm, respectively.

The effective particle sedimentation velocity is shown in the following equation.

$$v = v_g + v_e \tag{1}$$

where V_g is gravitational sedimentation velocity and V_e is electrophoretic velocity of the particle.

The downward particle sedimentation velocity can be easily increased by the electrical migration velocity.

Fig. 3 shows the state of feed slurry motion for the two elapsed time cases. In the photographs, the interface between water and slurry layers is indicated as dotted lines. It is found that the interface line is nearly a horizontal state, then the flow velocity distribution inside the water-sieve is considered as a uniform state. The formation of this uniform velocity distribution is due to the use of the lower perforated metal plate and 6 divided central feed pipes, which is shown in Fig. 2.

Nomenclature

a, b, c	parameter defined by Eq. (6) (–)
C	particle mass concentration (wt%)
D_p	particle diameter (μm)
D	inside diameter of water sieve (m)
D_{p100}, D_{p50}	particle diameter corresponding to partial separation efficiency of 100% and 50%, respectively (μm)
$D_{p,min}$, $D_{p,max}$	minimum and maximum particle diameter(μm)
E, E_f	particle collection efficiency of coarse and fine side (–)
E	strength of electro-potential (V/m)
e	logarithmic constant (=2.718) (–)
$f(D_p)$	particle size distribution of mass base (–/m)
$f_c(D_p)$, $f_s(D_p)$	particle size distributions of classified coarse and fine particles, respectively (–/m)
$g(t_i, D_p)$	kernel function defined by Eq. (3-2) (–)
g	gravity acceleration (m/s^2)
G_0, $G(t_i)$	total sedimentation mass and sedimentation mass at time t_i, respectively (kg)
$G(t_i)_{exp}$, $G(t_i)_{cal}$	experimental and calculated sedimentation mass at time ti(kg)
h	sedimentation distance (m)
h_3	distance between upper and lower electrical plate (m)
$J(a, b, c)$	criteria function defined by Eq. (7) (–)
$m_c \cdot m_s$	particle mass flow rate in coarse and fine side (kg/s)
Q_0, Q_C, Q_f	liquid flow rate of feed, coarse side and fine side, respectively(m^3/s)
t_i	time elapsed from start of experiment (s)
u_f	average upward liquid velocity in over-flow side (m/s)
$v(D_p)$	particle sedimentation velocity (m/s)
v_g v_e	particle sedimentation velocity by gravity and electro migration effect (m/s)
ΔV	electro-potential difference (V)

Greek

$\Delta\eta$	partial separation efficiency (–)
μ	fluid viscosity (Pa·s)
μ_e	electrical particle mobility ((m/s)/(V/m))
ρ_p, ρ_f	particle and fluid density, respectively (kg/m^3)
$\zeta_e(D_p)$	effective zeta-potential (mV)
ε	dielectric constant (F/m)
σ	surface charge density (C/m^2)

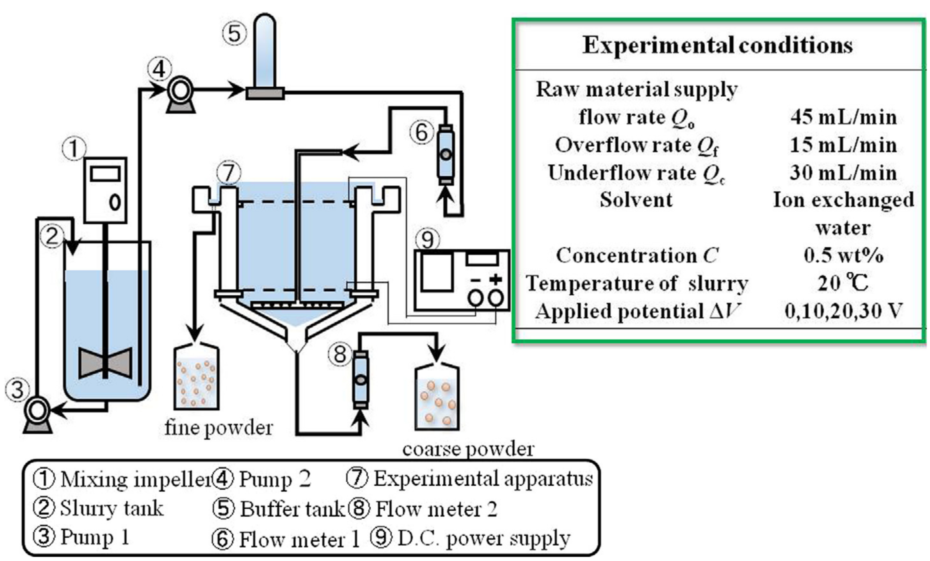

Fig. 1. Experimental apparatus of electrical water-sieve.

Fig. 4 shows the particle size distribution of the test particles. The test particles were spherical pure silica particles with size range from 0.5 to 5 μm. The two types of dispersion methods were used in the pre-treatment of feed particle dispersion.

In order to realize accurate particle classification in this water-sieve, feed particles should be dispersed completely and each particle charge level should be a high value. The first method of particle dispersion was by use of ultra-sonic probe dispersion. The experimental conditions selected were as follows.

Power of ultra-sonic probe	125 W
Time of dispersion	10 min
Slurry volume	300 ml

The other method used in particle dispersion was by beads mill (UAM-015 by Kotobuki Industries Co., Ltd.). The dispersion conditions were selected as follows.

Rotational speed	1250 rpm
Dispersion time	45 min
Beads medium	Silica particle of 100 μm

After the particle dispersion process, the feed slurry of 0.5 wt% was supplied to the water-sieve. In order to separate fine silica particles by electrical force, ion exchanged pure water with low electrical conductivity was used as a solvent.

Classification performance was evaluated by use of collection efficiency E and partial separation efficiency $\Delta\eta$, as calculated by the following equation.