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Original Research Paper

The effect of particle size distribution on effective zeta-potential by use of the sedimentation method

Yuta Nakatuka [a], Hideto Yoshida [a,*], Kunihiro Fukui [a], Mitsuharu Matuzawa [b]

[a] Department of Chemical Engineering, Hiroshima University, 1-4-1, Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8527, Japan
[b] Hitachi Chemical Co. Ltd., Shimodate works, 1150 Goshomiya, Chikusei-shi, Ibaragi 306-8524, Japan

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ABSTRACT

A new method of effective zeta-potential measurement by use of the liquid sedimentation balance method is developed. The test samples used were spherical silica particles, and an ultrasonic probe was used to enhance particle dispersion.

In order to obtain reliable data, rapid change in sedimentation mass due to a small air bubble detachment from the detection tray is corrected in the data analysis process. The new method can be used to estimate the effective zeta-potential of each particle size range. The absolute value of negative zeta-potential of small particles is greater than that of large particles. The absolute values of negative zeta-potential increased with the increase of the ultrasonic probe power. The absolute value of negative zeta-potential shows a maximum value at the initial stage after the dispersion process, however it decreases over an elapsed time period. After an elapsed time greater than approximately 200 h, the zeta-potential shows a constant value. The data obtained by the new method qualitatively agreed with the conventional method.

1. Introduction

Particle size distribution is measured by various methods, including laser diffraction-scattering, the electrical sensing zone method, sieving, the dynamic light-scattering method, and the sedimentation method. While the laser diffraction-scattering method, the electrical sensing zone method, and the dynamic light-scattering method have the advantage of a shorter measuring time and good reappearance, they require complicated calculations and the results are not always reliable for agglomerated particles.

On the other hand, the sedimentation method can measure the Stokes diameter of particles, and therefore clearly defines the physical properties. This method has been widely used, and the Japanese Industrial Standard (JIS) adopts this method [1]. The sedimentation balance method is used to measure the size distribution of JIS powders in Japan. A revised sedimentation balance method was developed by Yoshida et al. [2,3]. By using a deeper detection tray, we showed that the measuring results agree with the microscopic method when the sample size is greater than about 10,000. Due to a deeper detection tray, the radial movement of fluid flow in the upper part of the detection tray is reduced and the measured sedimentation mass agrees with the theoretical value. It is considered that the sedimentation balance method can measure not only particle size distribution, but also other physical properties of particles. In previous research, the authors carried out the experiment of sub-micron particle classification in a wet process by using an electrical potential field [4,5]. In order to increase the accuracy of particle size classification, detailed measurement of zeta-potential in each particle size range is required. However, there is limited availability of zeta-potential measurement apparatus, and it is difficult to obtain the individual zeta-potential of the sample slurry. Therefore, a new apparatus to measure the effective zeta-potential of each size range should be developed by use of the sedimentation method.

The proposed new method can measure the zeta-potential of each particle size using poly-disperse suspensions. The conventional zeta-potential measurement apparatus has difficulty obtaining the zeta-potential of each size range, because the conventional method assumes zeta-potential is independent of particle size. By use of the sedimentation balance method, particle size distribution is obtained from the particle sedimentation data. In the data reduction process of the sedimentation method, particles of different diameter indicate different sedimentation velocity. Using the above data reduction process, the zeta-potential of each particle

* Corresponding author. Tel.: +81 82 424 7853; fax: +81 82 424 5494.
E-mail address: r736619@hiroshima-u.ac.jp (H. Yoshida).

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Nomenclature

a, b, c	parameters defined by Eq. (4) (–)
D_p	particle diameter (μm)
$D_e(t)$	critical particle diameter (μm)
$D_{p\ max}$, $D_{p\ min}$	maximum and minimum particle diameter (μm)
e	logalismic constant (=2.718) (–)
$f(D_p)$	particle size distribution of mass base (–/μm)
g	gravity acceleration (m/s^2)
$g(t, D_p)$	kernel function defined by Eq. (2) (–)
G_0, G_t	total sedimentation mass and sedimentation mass at time t, respectively (kg)
G_{th}, G_n	theoretical sedimentation mass and sedimentation mass at time t_n, respectively (kg)
$G(t_i)_{exp}$, $G(t_i)_{cal}$	experimental and calculated sedimentation mass at time t_i (kg)
G_{th}	theoretical sedimentation mass calculated by Eq. (7) (kg)
h	sedimentation distance (m)
h_3	distance between two electrodes (m)
$J(a, b, c)$	criteria function defined by Eq. (5) (–)
m	number of data sampling (–)
n	sample number of size measurement (–)
t	time (s)
t_m	operating time of particle dispersion by ultrasonic probe (s)
t_w	elapsed time after particle dispersion (s)
$v(D_p)$	particle sedimentation velocity (m/s)
V	volume of feed slurry (m^3)
v	upper volume inside the detection tray (m^3)
w	mass of feed powder (kg)
ΔV	electrical potential (V)
μ	fluid viscosity (Pa s)
ρ_p, ρ_f	particle and fluid density (kg/m^3)
ε	permittivity (F/m)
$\zeta(D_p)$	zeta potential of particle diameter D_p (mV)

size range can be measured by the proposed new sedimentation method.

This report presents a new method of effective zeta-potential measurement by use of the revised sedimentation balance method as discussed in our previous papers [4,5]. The newly developed method has the advantage of measuring effective zeta-potential for each size range. In our previous report, beads mill was used in the particle dispersion process [8], however ultrasonic probe dispersion is widely used to disperse particles in a wet process. This report then examines the change of zeta-potential of each size range under various ultrasonic probe dispersion conditions.

Conventional zeta-potential measuring apparatus causes difficulty in measuring the dependency of zeta-potential on each particle size range. By using the new measuring method, the effect of particle size on zeta-potential is clearly measured for spherical silica particles. New data for the effective zeta-potential change under various ultrasonic dispersion conditions was also derived and some interesting conclusions are obtained.

2. Experimental apparatus

2.1. Particle size distribution of test particles

In order to measure the zeta-potential of the test particles, particle size distribution was examined by use of the microscopic method. The test particle was spherical silica, with Fig. 1 showing a photograph of particles measured by a scanning microscope (SEM, S-4800, Hitachi, Co., Ltd.). The magnification and acceleration voltage were 20,000 and 2 KV, respectively. Each unidirectional particle diameter was measured manually on the particle. In order to eliminate counting errors near the screen frames, size measurement was only carried out on the particles having the center positions inside the test screen region.

Fig. 2 shows particle size distribution with a sample size equal to 93,535. It is found that silica particles nearly follow the log-normal distribution and the error bar shows the uncertainty region of 95% confidence level as calculated in our previous paper [9].

2.2. Effective zeta-potential measurement

Fig. 3 shows the schematic diagram of the improved sedimentation method [6,7]. The feed slurry in the dispersion bath ③ is poured into the sedimentation bath ⑨ through the main inlet pipe ⑦ and the bypass ⑧. The detection tray ⑩ is hung below the precision electronic balance ⑤. The computer ⑪ records the sedimentation mass on the detection tray with a sampling interval of one second. The measuring accuracy of mass change is 0.1 mg. The mixing tank ③ and sedimentation tank ⑨ are connected by

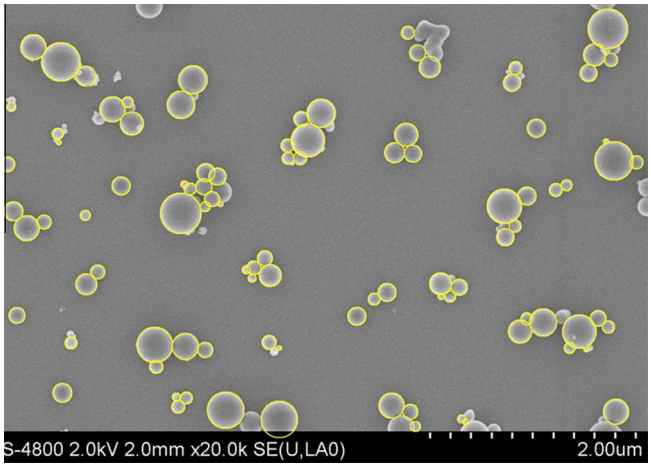

Fig. 1. Photograph of silica particles by SEM.

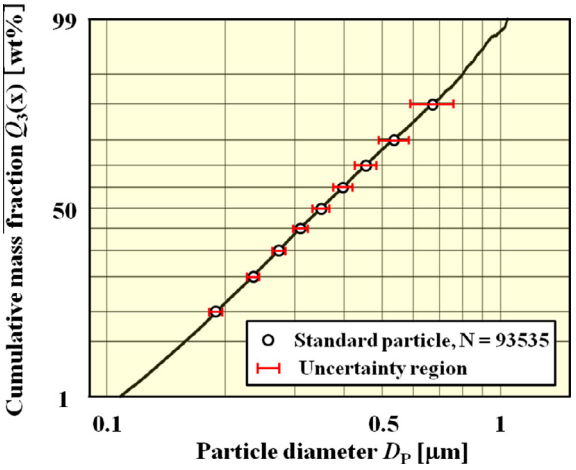

Fig. 2. Particle size distribution with uncertainty region.