



“Estimation of particle size distribution using the sedimentation method enhanced by electrical-potential”



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ABSTRACT

The reliability of particle size measurement by the sedimentation balance method has been examined by numerical experiment and simulation. In order to shorten the measurement time for sub-micron particles, the effect of electrical-potential applied in a sedimentation bath on particle size measurement is examined. The reliability is evaluated by comparing the true original distribution and estimated results. The reliability of the converged solution by the Twomey iteration method increases as the iteration number increases. Reliability of the converged solution is confirmed to nearly mono-dispersed particles. The original size distribution that follows a log-normal distribution with a geometric standard deviation of 1.1 is estimated with the iteration number of 3000. The reliability of the picket-fence size distribution composed of three kinds of nearly mono-dispersed particles is also confirmed. In order to measure sub-micron particle size distribution, it is effective to apply electrical-potential in the particle sedimentation bath. The simulation result by use of both electrical-potential and gravity provides a better estimated results compared to that of only the gravitational sedimentation method.

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1. Introduction

Particle size distribution is measured by various methods such as microscopy, laser diffraction scattering, the electrical sensing zone method, and the liquid sedimentation method. The microscopic method requires a long measuring time because of the increased sample size for widely distributed particles. Although the laser diffraction scattering method and electrical sensing zone method have the advantage of shorter measurement time and good repeatability, they need complicated calibration by the direct method. For the laser diffraction scattering method, the data reduction procedures still include the problems for non-spherical particles or for samples with an unknown refractive index.

On the other hand, the liquid sedimentation method can measure the Stokes diameter of particles, which is clearly physically defined. The liquid sedimentation balance method has been widely used as the standard method, and the Japanese Industrial Standard (JIS) adopts this method [1]. However, the conventional sedimentation balance method is not automated. To solve this problem, Yoshida et. al. [2,3] improved the detection tray and the slurry sup-

ply section, and automated the sedimentation balance method. Furthermore it was clarified that Twomey's non-linear iteration method is applied to the sedimentation balance method and the estimated particle size distribution agrees well with true size distribution [4]. However, the particle size measurement with relatively wide distribution was mainly measured by the sedimentation balance method. This report examines the reliability of particle size measurement by the sedimentation balance method using nearly mono-dispersed particle and picket fence distribution composed of several kinds of nearly mono-dispersed particles. These points are not clearly investigated in previous studies. On the other hand, it requires a long measurement time for sub-micron particles by use of the sedimentation balance method. The reliability of particle size measurement using picket-fence distribution composed of several kinds of nearly mono-dispersed particles is also investigated. Nakatuka et.al. [5] propose a new method to measure effective zeta-potential by use of the sedimentation balance method.

In this report, a new method using electrical-potential applied to the conventional sedimentation balance method is proposed and interesting results are obtained. A reliable particle size distribution under a short measurement time is obtained to measure sub-micron particles by use of the improved sedimentation balance method.

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Nomenclature

D_p	particle diameter [μm]	MM	division number of particle size [–]
$D_e(t)$	particle diameter calculated by Eq. (3) [μm]	NN	total data point [–]
D_{p50}	mass median particle diameter [μm]	Q_3	cumulative distribution of mass base [–]
$D_{p, \min}, D_{p, \max}$	minimum and maximum particle diameter [μm]	t	time elapsed from start of size measurement [s]
d_1, d_2	inside diameter of tray and sedimentation bath, respectively [m]	$v(D_p)$	particle sedimentation velocity [m/s]
E	strength of electrical-potential [V/m]	x_1, x_2	mass fraction of particles 1 and 2, respectively [–]
$f(D_p)$	size frequency distribution of mass base [–/ μm]	h_3	distance between upper and lower electrical plate [m]
$g(t_i, D_p)$	kernel function defined by Eq. (5) [–]		
g	gravity acceleration [m/s^2]	<i>Greek</i>	
G_0, G_t	total sedimentation mass and sedimentation mass at time t , respectively [kg]	ΔV	electrical-potential difference [V]
h	sedimentation distance [m]	μ	fluid viscosity [Pa·s]
KMA	iteration number [–]	ρ_p	ρ_f : particle and fluid density, respectively [kg/m^3]
		ζ	zeta-potential [mV]
		ε	dielectric constant [F/m]

2. Improved sedimentation balance method

2.1. Measurement apparatus

Fig. 1 shows the schematic diagram of the improved sedimentation balance method [2,3]. The detection tray^⑩ is hung below the precision electronic balance^⑤. The test slurry in the dispersion bath^③ is poured into the sedimentation bath^⑨ through the main inlet pipe^⑦ and the bypass^⑧. A personal computer^⑪ records the sedimentation mass on the detection tray every one second. The accurate mass change is always recorded by use of the electronic balance. The dispersion bath and the sedimentation bath are connected by the electronic valve^④. From the measurements of the improved apparatus, after supplying 3.0 g of particles into the dispersion bath, all necessary procedures are automated and, therefore, human errors decrease significantly.

In order to measure particle size distribution within a relatively short measurement time for sub-micron particles, an electrical-potential is applied in the vertical direction in the sedimentation

bath. Fig. 2 shows the sedimentation bath using electrical-potential in the vertical direction. The upper and lower part consists of a perforated metal plate with hole diameter of 2 mm. Before the measurement, zeta-potential of the original test particles should be measured by a conventional zeta-potential measurement device.

2.2. Theory of measurement

In the measurement of the particles of size distribution $f(D_p)$, the sedimentation mass G_t at time t is given by Eq. (1).

$$\int_{D_{e(t)}}^{D_{p, \max}} f(D_p) dD_p + \int_{D_{p, \min}}^{D_{e(t)}} \frac{v(D_p)t}{h} f(D_p) dD_p = \frac{G_t}{G_0} \quad (1)$$

where G_0 is the theoretical total sedimentation mass, $v(D_p)$ is the particle terminal settling velocity and h is the sedimentation distance indicated in Fig. 1.

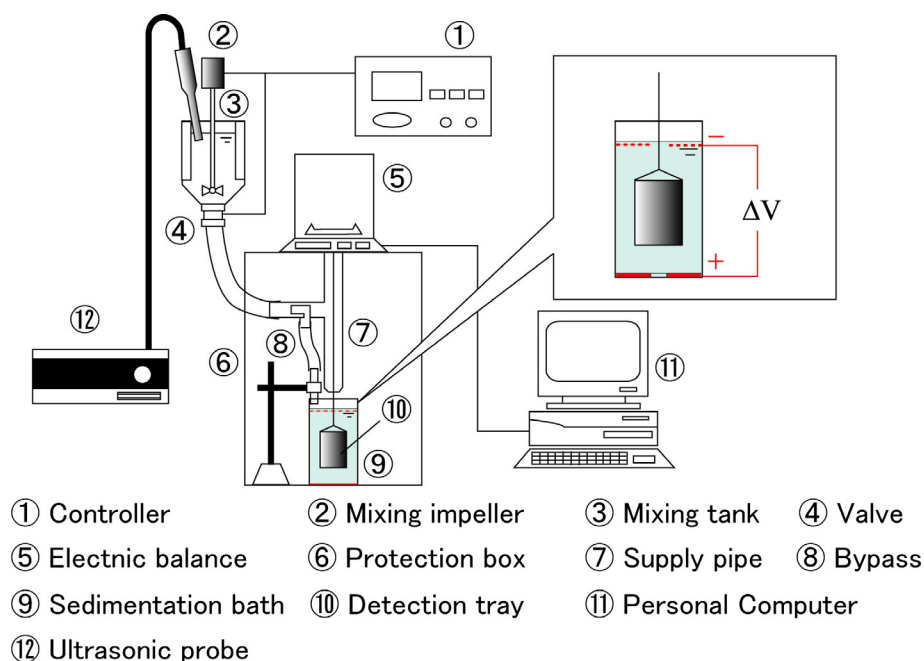


Fig. 1. Improved sedimentation balance method.

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