Comment on “Investigation of a Sequential Filtration Technique for Particle Fractionation”

SIR: Droppo et al. (1) describe the difficulties in obtaining accurate size fractions of bottom sediments from Lake Erie by sequential filtration of samples through a series of nylon screens (pore sizes of 60, 41, 20, and 10 μm) and a polycarbonate filter (pore size 8 μm). Instead of achieving a sharp size separation based on particle size, they observed that the size distributions retained on the filters were quite broad, with many particles retained by the screen that were smaller than the filter pore. Such observations are not new however and have been previously studied by aquatic scientists. Using a Coulter Counter to monitor suspended particle size spectra before and after filtration through a series of filters, Sheldon (2) also observed that it was impossible to obtain discrete size separations using filters. Other studies (3, 4) have provided similar data.

The reasons given by Droppo et al. (1) for broad particle sizes from separations include “sediment and pore geometry, pore clogging, the flocculation and disaggregation process, and instrumental assumptions of spherical particles.” While all of these aspects are important, the main factor affecting the accuracy of size separations is that particle filtration does not occur only by straining. Particles smaller than the pore diameter collide with screen fibers during particle separations. If the particles are sticky, those colliding with the screen mesh will remain attached to the screen while those with a low adhesion for the surface will pass through the mesh pores. Thus, the size and stickiness of the particles are critical factors affecting measured size distributions.

The retention of particles smaller than the screen pores is predictable from filtration theory. Spurney et al. (5) modeled particle removal of aerosols in polycarbonate filters by considering the filter to be a series of tubes. The overall filter efficiency was the sum of removal by individual mechanisms minus the removal that occurs by mechanism overlap or

\[ E_T = \alpha (\eta_{DC} + \eta_{RC} + \eta_{IC} - \eta_{DC}\eta_{IC} - \eta_{DC}\eta_{RC} - \eta_{IC}\eta_{RC}) \]  

(1)

where \( \eta_{DC}, \eta_{RC}, \) and \( \eta_{IC} \) are the individual removal mechanisms for diffusion, interception, and impaction, and \( \alpha \) is a sticking coefficient defined as the ratio of the rate particles stick to the filter to the rate they strike the filter. Since particle removal by impaction into the filter surface is unimportant for particle removal in aqueous solutions where particle and fluid densities are similar, eq. 1 can be simplified to

\[ E_T = \alpha (\eta_{DC} + \eta_{RC} - \eta_{DC}\eta_{RC}) \]  

(2)

For diffusion, removal is calculated using (6)

\[ \eta_{DC} = 2.56D_5^{2/3} - 1.2D_5 - 0.177D_5^{1/3} \]  

(3)

where \( D_5 \) is a dimensionless number defined as

\[ D_5 = \frac{4\lambda Dp}{a_3^3 U_b} \]  

(4)

\( L \) is the screen thickness (filter depth), \( p \) is the filter porosity, \( a_3 \) is the filter pore diameter, \( U_b \) is the approach or superficial velocity, and \( D \) is the particle diffusivity calculated using

\[ D = \frac{kT}{3\pi \mu a_3} \]  

(5)

where \( k \) is Boltzman’s constant (1.38 x 10^{-23} \text{ J K}^{-1}), \( T \) is the absolute temperature, \( \mu \) is the fluid dynamic viscosity, and \( a_3 \) is the particle diameter. Equation 3 is only valid for \( D_5 < 0.001 \), which is within the range of values used here.

Particles are removed by interception when the fluid stream lines bring a particle sufficiently close to the filter surface. Removal by interception is calculated using (7)

\[ \eta_{RC} = (2R_h - R_h^{3/2}) \]  

(6)

where \( R_h = d_p/d_a \) is the interception number. Equation 6 has been shown to provide good agreement with experimental data on aerosol removal in Nucleopore filters (6). Equations 2–6 also have been tested using fluorescent microspheres (0.49–4.12 μm in diameter) suspended in a phosphate buffer and nylon screens with pore diameters of 10, 20, and 30 μm (6). There was reasonable agreement between the model and experiments for sticking coefficients calculated to be in the range of 0.33–0.52.

In order to show that this model accounts for the results given by Droppo et al. (1), I used data in their Figure 1 to reconstruct the particle size distribution (Figure 1). This size spectrum consisted of particles separated into 41 evenly spaced size classes (based on log \( d_p \)) over the range of 1–100 μm. Based on these data, the “actual” discrete size spectrum shown in Figure 2 should be produced by filter sizes of 60, 41, 20, 10, and 8 μm if particles were separated only by straining. This distribution is compared to the distributions measured by Droppo et al. (1) (their sample 3 as given in their Table 3) and predicted using the filtration equations with \( \alpha = 0.2 \) for the nylon screens and \( \alpha = 0.6 \) for the polycarbonate filter. The measured and predicted size distributions can be very similar without needing to consider pore clogging or particle coagulation.

Discrete distributions produced by serial or parallel size separations are sensitive to particle sticking coefficients (8). Two particles of similar size, but with sticking coefficients differing by an order of magnitude or more, can be separated quite differently by a screen. For example, the retention of three species of phytoplankton (Thalassiosira weissflogii, Nitzschia angularis, and Chaetoceros gracilis) on a 230-μm pore diameter polycarbonate screen produced sticking coefficients of 0.05, 0.26, and 0.73, respectively (9).
FIGURE 1. Volume distribution (percent finer by volume) assumed here for all calculations: figure is redrawn from the size spectrum reported by Droppo et al. ref 1, (Figure 1).

FIGURE 2. Percent of particles (by volume) in size classes defined by nominal pore diameters of screens (60, 41, 20, and 10 µm) and a polycarbonate filter (8 µm). Actual distribution is based on the size distribution given in Figure 1; sample 3 is the distribution measured by Droppo et al. (ref 1, sample 3 in Table 2); model distribution is calculated using equations presented here assuming the following: $T = 293 K$, $\mu = 1.02 g \text{ cm}^{-1} \text{ s}^{-1}$, $U_k = 0.01 \text{ cm s}^{-1}$, $\alpha = 0.2$ for nylon screens, $\alpha = 0.5$ for polycarbonate filter, and values given in Table 1 of Droppo et al. (1) for filter information with $d_k$ = nominal pore size, $p = 0.01 \times \%$ open area, and $L$ = fabric/filter thickness.

Highly heterogeneous samples may therefore produce separations based more on particle types and screen materials than by size.

Although the filtration equations given here are useful for evaluating potential errors in size distributions produced by screens and filters, they may have some limitations in their application to aquasols. First, the models were developed for aerosols and may imperfectly predict aquasol removals. Second, these equations were developed for Nuclepore filters with round tubes, but they have been applied here to screens containing square holes. Third, particle removal by gravitational separation is usually included in most fibrous filter models (10, 11) but has not been included in eq 1 here. Fourth, when efficiencies are multiplied by a sticking coefficient, it is possible to calculate that a particle larger than the pore will pass through the pore even though the particle could be removed by straining. However, many particles are not perfectly spherical, and this situation does allow for particles larger than the pore diameter to pass through the filter.

Despite these limitations of the filtration equations, this analysis makes it clear that filtration theory can account for the inaccurate size distributions observed by Droppo et al. (1) and others (2-4). The differential adherence and nonspherical nature of similar sized particles are important factors in the outcome of discrete particle size distributions prepared using screens and filters. Such factors should be carefully considered when choosing screen sizes to prepare samples and when analyzing data obtained from such separations.

**Literature Cited**


**Bruce E. Logan**

Department of Chemical and Environmental Engineering
University of Arizona
Tucson, Arizona 85721

ES950168Y