Investigation on effects of aggregate structure in water and wastewater treatment

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Abstract The fractal structure and particle size of flocs are generally recognized as the two most crucial physical properties having impact on the efficiency of operation of several unit processes in water and wastewater treatment. In this study, an experimental investigation is undertaken on the effect of aggregate structure in water and wastewater treatment in Hong Kong. The fractal dimension of the resulting aggregate is employed as a measure of the aggregate structure. Small angle light scattering technique is used here. Different amounts of polymers are mixed to bacterial suspensions and the resulting structures are examined. The addition of polymer may foster aggregate formation by neutralization of the bacterial surface charge and enhance inter-particle bridging. The aggregation behavior may affect the efficiency of certain water and wastewater treatment processes such as dewatering and coagulation. The impacts of aggregate structure on two representative processes, namely, ultra-filtration membrane fouling and pressure filter dewatering efficiency, are studied. It is found that the looser flocs yield a more porous cake and less tendency to foul whilst more porous filter cakes yield more ready biosolids dewatering.

Keywords Aggregate structure; biosolids; fractal structure; Hong Kong; wastewater treatment; water treatment

Water Science and Technology **Vol 50 No 12 pp 119–124** © IWA Publishing 2004

Introduction

It is generally recognized that the fractal structure and particle size of flocs are the two most crucial physical properties having impact on the efficiency of operation of several unit processes in water and wastewater treatment including flotation, dewatering, membrane filtration, and so on. Whilst sufficient research efforts have been devoted to studying aggregate size, attention on the aggregate structure has been comparatively less. It has been reported that particle assemblages often exhibit mass fractal properties (Ganczarczyk, 1994). The mass of fractal aggregates may be related to their radius of gyration by an exponential relationship with the exponent termed fractal dimension ranging typically from 1.7 to 2.5. Among other factors, the rate of aggregation of colloidal particles has been found to have the most significant effect on the fractal dimension of the resulting aggregate (Lin *et al*., 1990).

Conventional methods to determine the fractal dimensions of colloidal aggregates such as large angle static light scattering techniques (Avnir, 1989), settling velocity measurement (Namer and Ganczarczyk, 1993), X-ray scattering (Amal *et al*., 1994), etc. are too complicated and not convenient. Jung *et al*. (1995) demonstrated that small angle static light scattering techniques might be employed for larger aggregates.

In this study, with the use of static light scattering, experimental investigation is undertaken on the effect of aggregate structure in water and wastewater treatment in Hong Kong. The fractal dimension of the resulting aggregate is employed as a measure of the aggregate structure. The small angle light scattering technique is used here to gain insight into the structure of colloidal aggregates, in view of its capability to furnish fast and non-intrusive determination of structural information on particulate aggregates. Since the rate of aggregation of colloidal particles may exert an impact on the aggregate structure, a variety of rates are performed. Different amounts of polymers are mixed to bacterial suspensions and the resulting structures are examined. The addition of polymer may foster aggregate formation by neutralization of the bacterial surface charge and enhance inter-particle bridging. The aggregation behavior may affect the efficiency of certain water and wastewater treatment processes such as dewatering and coagulation. The impacts of aggregate structure on two representative processes, namely, ultra-filtration membrane fouling and pressure filter dewatering efficiency, are studied.

Light scattering technique

The underlying theory of the light scattering technique is based on the fact that if a beam of light strikes a suspension of particles comprising polarizable electrons, part of it will be scattered. The intensity of the scattered light will depend on: the shape of the particles; the size of the particles; the wavelength of the incident light; and, the angle of observation.

The following represents the equation for the scattered intensity from a randomly oriented aggregate of identical, rigid, spherically symmetric elements (Sorensen *et al.*, 1992)

$$I(k) = nI_0(k_a)\Omega(k)(1)$$

where k = the magnitude of the wave vector; $I(k)$ = the scattered intensity from the aggregate; n = the total number of elements in the aggregate; $I_0(k_a)$ = the scattered intensity from the individual element; $\Omega(k)$ = the structure factor which has the following form

$$\Omega(k) = D_f \Gamma(D_f - 1) x \frac{\sin[(D_f - 1)\tan^{-1}(k\xi)]}{(ka)^{D_f}\{1 + (k\xi)^{-2}\}^{(D_f - 1)/2}} \quad (2)$$

where D_f = the fractal dimension of the colloidal assemblage; a = the radius of the primary element; and ξ = a cut-off value for fractal behavior with the following equation

$$\xi^2 = \frac{2}{D_f(D_f + 1)} R_g^2 \quad (3)$$

where R_g is the radius of gyration of the fractal aggregate.

Under the condition of $ka<1$ and $k\xi>>1$, $\Omega(k)$ is proportional to k^{-D_f} and hence

$$I(k) \propto k^{-D_f} \quad (4)$$

Hence this power law scattering can be illustrated by plotting the logarithm of $I(k)$ against the logarithm of k, with the fractal dimension represented by the slope of the resulting line.

Method

Biosolids from wastewater treatment plant

Samples of biosolids were obtained from the wastewater treatment plants in Hong Kong. They were, as far as possible, analyzed on the day of collection. In addition to the characterization of unconditioned biosolids, studies were undertaken on adding cationic polymer [Zetag, Allied Colloids Pty Ltd] in order to induce significant change in biosolids structure. The polymer, being of high molecular weight, is a copolymer of acrylamide and quarternized dimethyl amino ethylacrylate. The samples were prepared by first adding a given amount of polymer. They are mixed rapidly at 400 rpm using flat blade paddle for 30 seconds and then at 150 rpm for another minute.

Determination of aggregate size and structure

The particle size information for biosolids aggregates, in the 500 μm range, was acquired employing a Malvern Mastersizer/E. The aggregate structure was determined on the basis of the theory on static light scattering techniques. The light intensity at small angles of scattering (less than 7°) was determined.

Separation processes in wastewater treatment

Membrane filtration

Investigation was undertaken on the effect of aggregate structure on permeate flux through ultra-filtration membranes. The volume of the suspension permeating a Millipore UF membrane was measured as a function of time.

Biosolids dewatering

In the dewatering processes, a pressure of 300 kPa was applied to a cylindrical cell 50 mm in diameter and 135 mm in height through a pneumatically operated piston. Over both the base plate and the end of the plunger, porous sintered steel plates of 10 μm nominal pore size were fitted. In order to facilitate removal of filtrate from the cell, vacuum lines were attached to both of them. The mass of water removed was then measured as a function of time.

Results and discussions

Measurement of aggregate size and structure

Figure 1 shows the particle size distribution of the wastewater biosolids suspension. Figure 2 shows the plot of log *I* against log *k* for the biosolids in the absence and presence of added polymer. It can be observed that a very typical scattering plot is acquired with noticeable power law scattering over a large range of wave vector ($10^{-4} - 10^{-2.5}$ nm^{-1}).

Table 1 shows the fitted relationships of log *I* against log *k* for different polymer doses for samples from wastewater treatment plants in Hong Kong. These fitted equations approximate the data well as reflected from the regression coefficients. It can be observed that the fractal dimension from these logarithm plots generally decreases on increasing polymer dose. In other words, a more open or loose structure will result from the addition of the types of high molecular weight cationic polymers employed in this experiment. The phenomenon can be explained by the effect of the polymer-induced bridging between the bacterial assemblages and the bacteria.

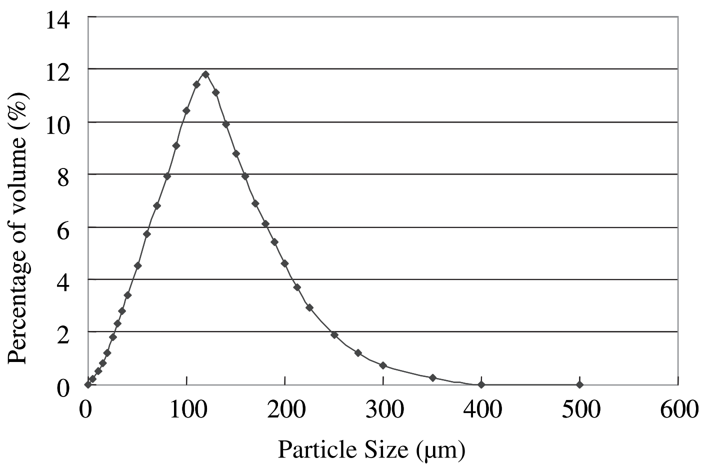

Figure 1 Particle size distribution of the wastewater biosolids suspension

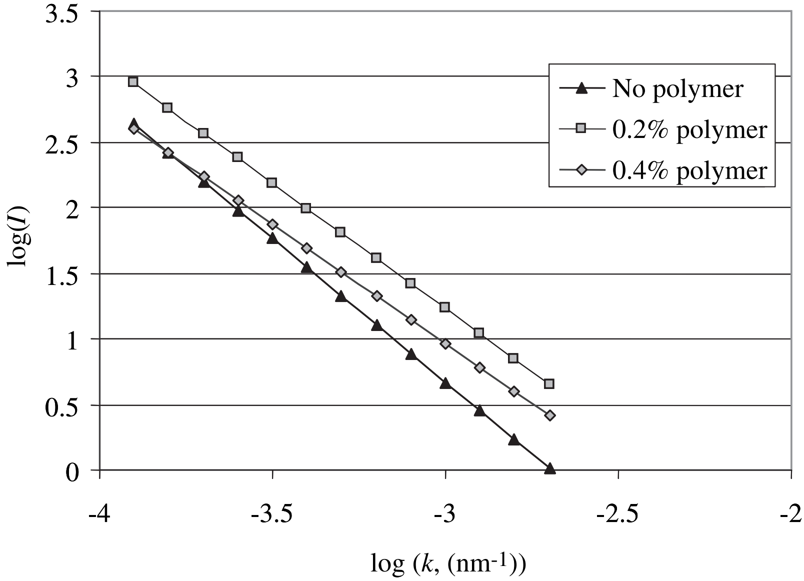

Figure 2 Plot of log *I* against log *k* for the biosolids in the absence and presence of added polymer

Table 1 Fitted relationships of log *I* against log *k* for different polymer doses for samples from wastewater treatment plants in Hong Kong

Polymer dose (%)	Fitted linear equation ($y = \log I$; $x = \log K$)	Regression coefficient
0.0	$y = -2.19x - 5.9$	0.998
0.2	$y = -1.91x - 4.5$	0.996
0.4	$y = -1.82x - 4.5$	0.999

Implications to unit processes

The generation of aggregates in both natural aquatic environments and treatment processes will form a fractal structure. The aggregate size and structure will have significant impacts on several unit processes in water and wastewater treatment plants: filtration; sedimentation; dewatering; and, flotation (Gregory, 1997). The significance of the relationship between addition of polymer and sludge structure in wastewater treatment lies mainly in the effect on the dewaterability and the settling rate in sludge thickening.

Table 2 displays the results showing correlation between aggregate structure and ultrafiltration of colloids. Under conditions of reaction limited aggregation in which compact flocs exist, a high cake resistance at *ca*. 125×10^{-10} m^{-1} is found with quite a rapid flux decline over time. However, under conditions of diffusion limited aggregation in which loose flocs exist, a relatively low cake resistance at *ca*. 10×10^{-10} m^{-1} is found with quite a slow flux decline over time. It can be observed that the looser flocs will generally yield a more porous cake and less tendency to foul. Hence it may be deduced that the aggregate structure in suspension has a far-reaching effect on cake porosity as well as on the extent of fouling with respect to time.

Table 2 Results showing correlation between aggregate structure and ultra-filtration of colloids

Condition	Salt concentration (mmol l^{-1} KCl)	Cake resistance ($\times 10^{-10}$ m^{-1})
Reaction limited aggregation	0–60	125 ± 25
Diffusion limited aggregation	65	10 ± 3

Table 3 Relationships between polymer dose, fractal dimension, and biosolids dewatering by pressure filtration for samples from wastewater treatment plants in Hong Kong

Polymer dose (%)	Fractal dimension	Attained cake solid content (%)
0.0	2.19 ± 0.02	2.7 ± 0.5
0.1	1.99 ± 0.03	9.6 ± 1.2
0.2	1.91 ± 0.01	17.9 ± 1.8
0.3	1.84 ± 0.02	19.5 ± 2.1
0.4	1.82 ± 0.01	21.3 ± 1.7

Table 3 shows the relationships between polymer dose, fractal dimension, and biosolids dewatering by pressure filtration for samples from wastewater treatment plants in Hong Kong. It can be noticed that the increase of the polymer dose will lead to increasing cake solid contents with dewatering by pressure filtration for these samples. Moreover, the increment amount of solid contents decreases with the increase of the polymer dose. High molecular weight cationic polymer will have the effect to enhance the formation of a less compact aggregate by augmenting inter-particle bridging and neutralization of the bacterial surface charge. It is apparent that the fractal dimension can be employed as a measure of degree of compactness of floc structure in water and wastewater treatment processes. It is also found that, in general, looser aggregates can lead to enhanced process performance.

Conclusions

In this paper, experimental investigation has been undertaken on the effect of aggregate structure in water and wastewater treatment of Hong Kong. The impacts of aggregate structure on two representative processes, namely, ultra-filtration membrane fouling and pressure filter dewatering efficiency, are studied. Such bacterial assemblages are shown to exhibit mass fractal properties with the determination of fractal dimension available from relatively straightforward analysis of their power law light scattering behavior. It is demonstrated in the membrane filtration process that the aggregate structure in suspension has a far-reaching effect on cake porosity as well as on the extent of fouling with respect to time. The addition of different high molecular weight cationic polymer in the biosolids dewatering process has been shown to have significant effects on the fractal dimension. It can be observed that the looser flocs will generally yield a more porous cake and less tendency to foul. Moreover, high molecular weight cationic polymer will have the effect to enhance the formation of a less compact aggregate by augmenting inter-particle bridging and neutralization of the bacterial surface charge. Since the structure of particle aggregates has apparent implications for many unit processes in water and wastewater treatment, it may be concluded that the fractal dimension can be employed as a measure of degree of compactness of floc structure in water and wastewater treatment processes.

References

Amal, R., Gazeau, D. and Waite, T.D. (1994). Small-angle X-ray scattering of hematite aggregates. *Particle & Particle Systems Characterization*, **11**(4), 315–319.

Avnir, D. (1989). *The Fractal Approach to Heterogeneous Chemistry: Surfaces, Colloids, Polymers*, Wiley, New York.

Ganczarczyk, J.J. (1994). Microbial aggregates in waste-water treatment. *Wat. Sci. Tech.*, **30**(8), 87–95.

Gregory, J. (1997). The density of particle aggregates. *Wat. Sci. Tech.*, **36**(4), 1–13.

Jung, S.J., Amal, R. and Raper, J.A. (1995). The use of small angle light scattering to study structure of flocs. *Particle & Particle Systems Characterization*, **12**(6), 274–278.

Lin, M.Y., Klein, R., Lindsay, H.M., Weitz, D.A., Ball, R.C. and Meakin, P. (1990). The structure of fractal colloidal aggregates of finite extent. *Journal of Colloid and Interface Science*, **137**(1), 263–280.

Namer, J. and Ganczarczyk, J.J. (1993). Settling properties of digested-sludge particle aggregates. *Wat. Res.*, **27**(8), 1285–1294.
Sorensen, C.M., Cai, J. and Lu, N. (1992). Test of static structure factors for describing light-scattering from fractal soot aggregates. *Langmuir*, **8**(8), 2064–2069.