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The filtration characteristics of hollow fiber microfiltration – Effect of various kinds of solids in the excess activated sludge

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ABSTRACT

The submerged membrane separation activated sludge process has some benefits such as small installation area and good quality of treated water (effluent) *etc*. We made constant pressure filtration of the excess activated sludge using the microfiltration hollow fiber (pore diameter size: 0.1 μm). Solids in the activated sludge are consisted of two elements, suspended solids (SS) and dissolved solids (DS), and we define DS as the solids contained in the filtrate from glass fiber filter (pore diameter size: 0.6 μm), in this paper. Three sludge samples were used in this work; ''Activated sludge,'' ''Supernatant by 1600 g centrifugal settling,'' and ''Filtrate with glass fiber filter.'' Thereby, we could widely examine the effect of various kinds of solids in the activated sludge on the filtration characteristics of this hollow fiber microfiltration. As a result, the followings were obtained. The filtration characteristics of the three samples are very different from each other, affected differently by various kinds of solids, and the total filtration resistance for the filtrate with glass fiber filter is much larger than the filtration resistance of membrane only. Filtrate with glass fiber filter, which contained only DS, made the cake that produces the filtration resistance. Therefore, it is guessed that the cake filtration resistance is greatly affected by not only SS but also DS. The discussion of the contribution of the various solids to cake filtration resistance leads to the fact that the SS and DS remaining after centrifugal settling had a considerable effect to the cake filtration resistance of this microfiltration.

Keywords: Filtration characteristics; Hollow fiber membrane; Activated sludge

1. Introduction

The wastewater treatment system used membrane separation method can highly separate suspended solids (SS) such as fine particles and bacteria included in stabilized wastewater, and the energy cost for the separation is not so large. Owing to these advantages the system will spread more [1–3].

The submerged membrane bioreactor process (SMBR) is one of the promising technologies, where the solid–liquid separation is done using the membrane immersed directly in the aeration tank (bioreactor). In this process, the quality of the effluent is very good regardless of settling characteristics of the sludge and then this can be operated under very high SS (microorganism) concentration condition. The final clarifier is unnecessary and the settleability of microorganisms has no problem to the solid–liquid separation. Consequently we can reduce the bioreactor volume and the plant area. As a result, this SMBR will be expected as the hopeful treatment system for reuse of water.

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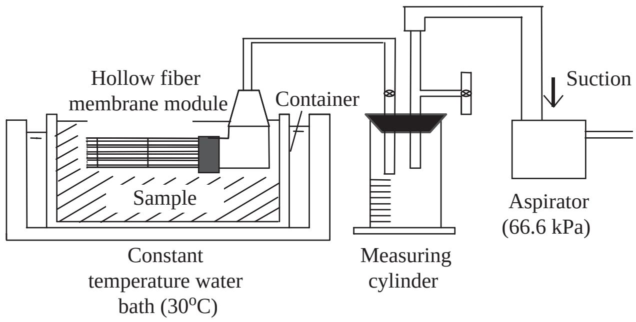

Fig. 1. Experimental apparatus.

This SMBR, however, has some disadvantages that the filtration rate of membrane decreases in progress of wastewater treatment *etc*. The disadvantages (filtration resistance) are caused by the adhering of sludge solids onto the membrane surface and the clogging of membrane pore [1–3]. The activated sludge has various solids, like as a lot of kinds of microorganisms and clay. The range of these solids diameter is very wide. These solids might be a cause of the filtration resistance [4,5], but the effect of these solids has not quantitatively been clarified yet.

We have reported some papers about SMBR with hollow fiber membrane module [6,7]. In this paper, in order to examine the change of the filtration resistance at wider range of SS concentration in SMBR, we prepared three experimental samples removed SS by three levels, and carried out the microfiltration experiment with the hollow fiber used actually in the SMBR. From these experimental results, we considered quantitatively the influence of various kinds of solids in the activated sludge on the filtration characteristic of the hollow fiber microfiltration membrane.

2. Experimental

2.1. Experimental apparatus

The experimental apparatus is consisted of a container having capacity 3.2 L (L 80 × D 200 × H 200 mm) set at 30°C and a hollow fiber membrane module, as shown in Fig. 1. The membrane was made of polyethylene with pore size 0.1 μm and the inner/outer diameter is 270/410 μm. The hollow fiber membrane module was consisted of five strings of length 200 mm bent to U-shaped, and fixed both ends to the connected part of the suction pipe. The module was made by ourselves and immersed horizontally in the container. Filtrate might flow out through the whole surface of five strings, and the effective surface area of the module was 1.29×10^{-3} m^2. The suction pressures ΔP of these experiments were set at 34.7 kPa.

2.2. Materials

The solid in the activated sludge can be roughly divided into two groups: SS and dissolved solids (DS) are classified according to the size of the particle. In the Gesui Siken Houhou [8], there are two classification methods; (A) the centrifugal settling method and (B) the glass fiber filtration method.

(A) The centrifugal settling method: measuring the mass of residue dehydrated by 110°C drying, where the sediment is centrifugally settled for 10 min at 3,000 rpm (1,600 g).
(B) The glass fiber filtration method: measuring the mass of the solid captured by the filtration of the sample with the glass fiber filter (Advantech: GS-25, nominal pore size = 0.6 μm).

In this paper, SS is defined by (B) glass fiber filtration method because (B) can measure more mass of solids than (A). Consequently SS is what does not pass through the glass fiber while DS is what passes through it.

We used three samples as described below.

(1) ''Activated sludge'' (AS), which is the excess activated sludge from the municipal wastewater treatment plant in Matsuyama, Japan settled for 18 h in the refrigerator (5°C).
(2) ''Centrifugal settling supernatant'' (CSS), which is the supernatant of AS by the centrifugal settling (3,000 rpm, 1,600 g, 10 min).
(3) ''Glass fiber filtrate'' (GFF), which is the filtrate of CSS with glass fiber filter (nominal pore size: 0.6 μm).

The average values of SS and DS for three samples are listed in Table 1. The order of SS is AS > CSS > GFF. SS of GFF is 0 and we can understand that glass fiber filtration method can remove all SS in the sample. Moreover, the values of DS are also listed, and almost equal.

Table 1
The average values of SS and DS for three samples

Sample	AS	CSS	GFF
SS [mg/L]	8,190	50	0
DS [mg/L]	590	550	570

AS: activated sludge, CSS: centrifugal settling supernatant, GFF: glass fiber filtrate.

2.3. Experimental method

We carried out the experiment as following procedures.

1. Pure water flux (J_v) of a new module was measured at the temperature (30°C) and at the suction pressure ($\Delta P = 34.7$ kPa).
2. Immersing the module into the sample sludge (30°C), constant pressure filtration was conducted for 100 min under $\Delta P = 34.7$ kPa, and a change of the filtrate volume with time was measured.
3. After 100 min filtration, the module was taken out from the sample sludge and washed by pure water to strip the adhering cake on the module.
4. Water flux of the washed module was measured.

2.4. Calculation method of filtration resistances

When pure water is permeated through the membrane, the flux is proportional to the pressure difference. Using Darcy's law, a relationship between the flux J_v and pressure difference (= suction pressure) ΔP can be represented by the following equation,

$$J_v = \Delta P/(\mu R), \tag{1}$$

where μ: viscosity of filtrate [Pa s], R is the filtration resistance [1/m].

We can obtain the various filtration resistances by Eq. (1), using the following manners. The values of J_v under various conditions are obtained from the experimental methods mentioned above. Therefore we can get the various filtration resistances by substituting the J_v values into Eq. (1), based on the following procedure.

(a) R_m (R of membrane) is obtained from the pure water flux (J_v) according to the method 1).
(b) R_t (total R) is obtained from the filtrate flux (J_v) according to the method 2).
(c) R_{mc} (R of washed membrane) is obtained from the flux (J_v) of the method 4), where the membrane is clogged at the end of filtration. Accordingly, R_{cl} (R of clogging) is calculated from ($R_{mc} - R_c$).
(d) R_t obtained from (b) corresponds to the sum of R_{mc} and R_c (R of the cake formed on the membrane surface during filtration). Consequently the following equation can be written.

$$R_t = R_{mc} + R_c = R_m + \mathrm{R}_{cl} + R_c. \tag{2}$$

Therefore, R_c is calculated by the following equation:

$$R_c = R_t - R_m - R_{cl}. \tag{3}$$

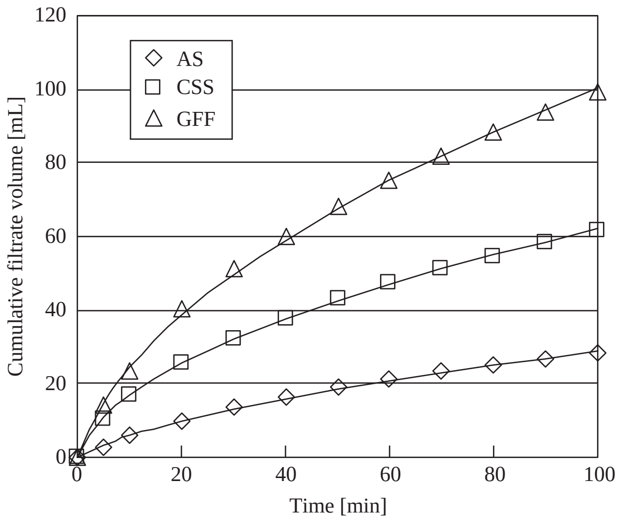

Fig. 2. Change of cumulative filtrate volume with time.

3. Results and discussion

3.1. Change of cumulative filtrate volume with time

Fig. 2 shows one example of the change of the cumulative filtrate volume with time. Decreasing SS concentration increases the amount of cumulative filtrate volume. For GFF which does not include SS, the cumulative volume is especially much larger than the other two samples. The lower SS decreases the mass of the cake produced on the membrane by filtration, and increases the filterability. Moreover, the filtration resistance for GFF is increasing with the filtration time, because the experimental results draw a convex curve not a straight line, and this result (a convex curve) is like as for AS. Therefore, the cause of the filtration resistance may be DS and the gel materials (particle size: 0.1–0.6 μm), which can pass through the glass fiber filter but cannot through the hollow fiber membrane.

The approximated curves, correlating the experimental results with Ruth's filtration equation, are shown in Fig. 2, also. Since almost all experimental data are on the curves, we can understand that the experimental results can be represented by Ruth's filtration equation. Therefore, one can calculate J_v from this Ruth's filtration equation and can obtain the change of R_t with time.

3.2. Comparison of four filtration resistances

Fig. 3 shows the values (at 100 min) of the four filtration resistances for three samples (AS, CSS and GFF). The total filtration resistance R_t for the filtrate with GFF

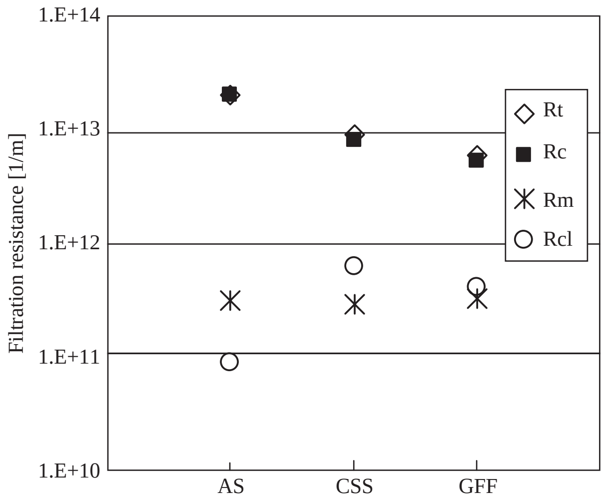

Fig. 3. Various filtration resistances of three samples.

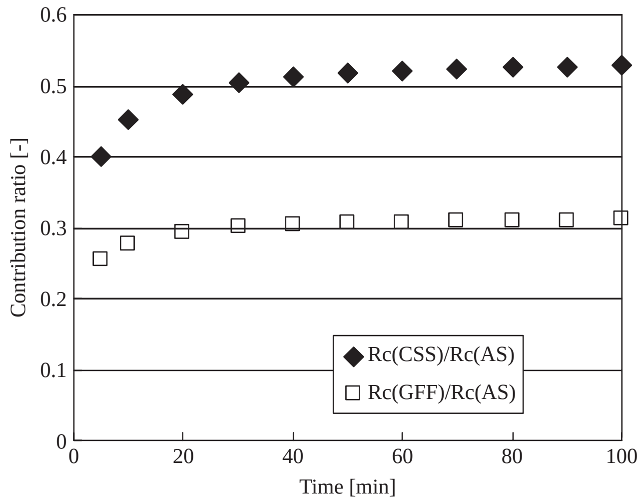

Fig. 4. Change of contribution ratio of filtration resistance with time.

is much larger than the filtration resistance of membrane R_m only.

Filtrate with GFF, which contained only DS, formed the cake that corresponds to the filtration resistance of cake R_c. Therefore, it is guessed that R_c is greatly affected by not only SS but also DS.

The value of R_{cl} for AS is much smaller than that for the other two samples (CSS and GFF). The cause of these results is considered that smaller filtrate volume of AS reduces the clogging of membrane (see Fig. 2). The value of R_c is almost equal to R_t (from Eq. (3)), because R_{cl} is smaller than 1/10 of R_t and R_m is as small as R_{cl}.

3.3. Contribution of various solids to cake filtration resistance

R_c is produced by the cake formed on the membrane that consists of various solids in samples. Therefore, one would be able to calculate the contribution of individual solids to R_c by measuring the value of R_c of each sludge sample.

Fig. 4 shows the change of R_c(CSS)/R_c(AS) and R_c(GFF)/ R_c(AS) with time. In this case, the values are calculated using the R_t values because R_c is almost equal to R_t, as shown in Section 3.2. The values of both ratios are almost constant after 20 min. Therefore, the value at 50 min constant pressure filtration is regarded as the representative value in Fig. 4, and hereafter the influence of the various solids in the activated sludge on the filtration characteristics is considered as follows.

The solids in the activated sludge can be divided into SS and DS as mentioned above, and SS can be divided into two groups, such as SSa, which can be removed by a centrifugal settling, and SSb, which remains in the supernatant and can be caught by the glass fiber filter. Therefore, the composition of solids included in each sample can be shown as follows; AS includes SSa+SSb+DS, CSS includes SSb+DS and GFF includes DS only. The cake generated in Section 2.3 (method 2) is composed of a combination of these three solids.

R_c is produced by the cake that consists of various solids in the samples. Therefore, we can consider that the difference between R_c(AS) and R_c(CSS) corresponds to the filtration resistance of SSa: R_c(SSa), the difference between R_c(CSS) and R_c(GFF) corresponds to the filtration resistance of SSb: R_c(SSb), and R_c of GFF corresponds to the filtration resistance of DS: R_c(DS).

Fig. 5 shows the ratio of R_c(SSa), R_c(SSb), and R_c(DS) to R_c(AS) calculated for eight experiments. The ratios of

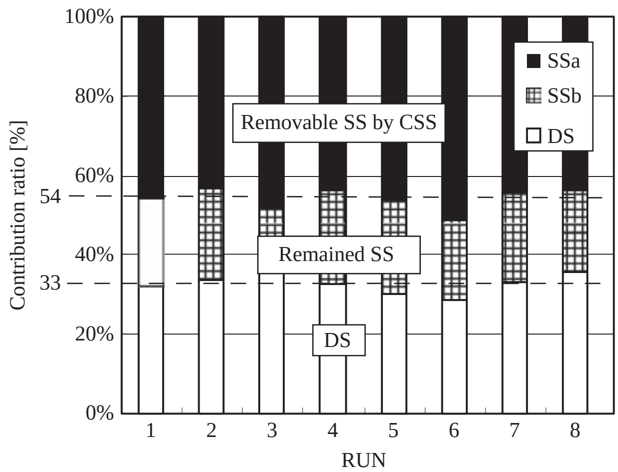

Fig. 5. Contribution of each sample solids to R_c.

Table 2
Mass ratio and R_c ratio of each solid

Solid	SSa	SSb	DS
Mass ratio [%]	93	0.6	6.4
R_c ratio [%]	46	21	33
R_c ratio /mass ratio [–]	0.5	35	5.2

all experiments are almost equal in Fig. 5. The average values are as follows: R_c(SSa): R_c(SSb): R_c(DS) = 46 : 21 : 33. We can understand that not only SS but also DS influence largely the cake filtration resistance R_c.

Moreover, Table 2 shows the mass ratio of each solid to the total solids from Table 1, and the average ratio of cake filtration resistance R_c for each solid to the R_c(AS) from Fig. 5. Also, we calculate the value of (R_c ratio/mass ratio), which shows the value of R_c per the unit mass of each solid and means the degree of R_c of the each kind of solids.

In practice, SSa occupies 93 mass% in total solid, but the ratio of cake resistance R_c(SSa) is not so large (46%). On the contrary, SSb is only 0.6% of a total quantity of solids in sludge, but this R_c ratio accounts for 21%. Comparing the value of (R_c ratio/mass ratio) in Table 2, the value and the influence for SSb is about 70 times larger than those for SSa, and DS influence to the cake filtration resistance is about 10 times larger than SSa. Therefore it has been quantitatively found that the very small diameter solid, like as SSb and DS, plays a major role in the cake filtration resistance. Since these solids (SSb and DS) are very small, it is considered that these might be measured as an origin of the organic carbon concentration of the supernatant in the aeration tank of the activated sludge process. We reported that the value of R_c was very large in the higher organic carbon concentration condition [9] and this corresponds well to the results of this paper.

4. Conclusions

By constant pressure filtration with the hollow fiber microfiltration membrane of three samples; the activated sludge (AS), the supernatant by 1,600 g centrifugal settling (CSS) and the filtrate with gas fiber filter (GFF), the filtration characteristics of each sample were examined. We widely investigated the influence of the SS concentration in the activated sludge.

1. The filtration characteristics are affected greatly by the SS concentration, and the cake filtration resistance is largely affected by not only SS but also DS.
2. The SS and DS remained after centrifugal settling had a considerable effect to the cake filtration resistance of the microfiltration.
3. The filtration resistance of clogging of AS is smaller than that of GFF because of decreasing filtrate volume.

Symbols

J_v	flux [m/s]
R	filtration resistance [1/m]
R_c	filtration resistance of cake [1/m]
R_{cl}	filtration resistance of clogging [1/m]
R_m	filtration resistance of membrane [1/m]
R_{mc}	filtration resistance of washed membrane [1/m]
R_t	total filtration resistance [1/m]
ΔP	pressure difference (= suction pressure) [Pa]
μ	viscosity of filtrate [Pa s]

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