Sludge thickening performance of mesh filtration process

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Abstract Small-scale wastewater treatment facilities play an important role in improving the aquatic environment in many countries. Although sludge treatment is essential for overall wastewater treatment, it is difficult for small-scale facilities to use mechanical equipment or other facilities. As the first step of the sludge treatment, it is important to develop a convenient sludge thickening process for small-scale facilities. In this work, we examined the sludge thickening performance of a mesh filtration system: the mesh opening sizes of 100–500 μm, and the sludge (3,000–9,000 mg-SS/L) was obtained from a domestic wastewater treatment facility. The filtration was carried out only under the hydraulic pressure between the water level and the effluent port connected to the mesh filter module. The sludge reduction rates were in the range of 85–95% for 6–7 h; the initial filtration rate was very high, but the rate decreased with a decrease in hydraulic pressure due to the reduction of the water level in the vessel. In addition, the effluents (passed through the mesh) contained very low SS and could be directly discharged into the environment.

Keywords Mesh filtration; sludge thickening; sludge volume reduction rate; small-scale wastewater facility

Introduction

Sludge processing and disposal is an essential and important subject in wastewater treatment, because of the following: (1) biological wastewater treatment produces excess sludge and (2) inappropriate sludge treatment will cause other environmental pollution. Sludge thickening and dewatering are common processes for sludge treatment; sludge is reduced or disposed directly or after insulation, etc. Considering the overall cost of wastewater treatment including biosolids treatment, the efficiency of the solid-liquid separation process is a key factor in wastewater treatment (Dentel, 2001). For example, the cost of the dewatering step in municipal treatment plants, including conditioning agents, typically accounts for 30–50% of the annual operating costs (Mikkelsen and Keiding, 2001). Sludge dewatering was also pointed out as one of the most expensive processes (Burris, 1979; Bruus *et al*., 1992). Therefore, many researchers (Krofta and Wang, 1986; Tokunaga *et al*., 1986; Vesilind, 1995) focused on improving the efficiency of the dewatering and thickening systems.

For small-scale wastewater treatment facilities, however, it is difficult to carry out sludge treatment on site, and therefore, in many cases, the excess sludge is transported to other sludge processing facilities. Even in this situation, sludge volume reduction is also an important subject in view of transport costs and energy saving. However, we can find little evidence concerning the development of a sludge thickening and dewatering system for small-scale wastewater treatment facilities.

For sludge thickening, some processes have been applied: gravimetric thickening, dissolved air flotation and centrifugation, etc. Gravimetric thickening is commonly used in wastewater and water treatment facilities because of the simple structure of the apparatus and low energy requirements. On the other hand, the gravimetric thickening process

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requires a large volume thickening tank and a long operational period. In addition, the supernatant from the gravimetric thickening tank contains a high level of SS and returning to water treatment is a necessary process for small-scale facilities. Some other mechanical thickening processes may not be applicable for small-scale facilities due to expensive costs and a low working rate. Considering these points, for small-scale wastewater treatment facilities to develop an alternative sludge thickening process, it must be of high performance and be easy to operate.

In our previous work (Kiso *et al.*, 2000), it was indicated that a mesh filter can reject effectively activated sludge, where the wastewater treatment performance was examined with a mesh filtration bioreactor. The mesh filtration bioreactor was a mesh filter instead of a MF membrane for a membrane bioreactor, and it was an efficient system as an alternative advanced wastewater treatment system. Other researchers reported the performance of similar systems (Moghaddam *et al.*, 2001; Daido *et al.*, 2000). In this work, we focused on the performance of mesh filtration for sludge thickening in small-scale wastewater treatment facilities. We examined the performance of the mesh filtration process with a bench scale apparatus taking into account the following: mesh opening size, filter area, operational pressure, sludge concentration, quality of the filtrate, and the effects of the coagulant addition.

Materials and methods

Sludge thickening apparatus and filter module

The sludge thickening apparatus was composed of a cylindrical tank (19 cm i.d. × 75 cm height: working volume: 15 L) equipped with a mesh filter module. The schematic diagrams of the apparatus and the mesh module are shown in Figure 1. The filtrate is withdrawn from the effluent port equipped at the lowest point of the cylinder. The filtration was carried out only by hydraulic pressure between the effluent port and the water level in the cylinder. The dead volume in the apparatus is dependent upon the position of the lower end of the mesh filter module and was ca. 0.45 L for this apparatus, corresponding to 3% of the working volume. The mesh filter module was composed of a stainless steel frame, a spacer, and a mesh. The following three kinds of meshes were used in this work: 100, 200, and 500 μm opening size. In general, the effective mesh area was 1,078 cm^2 (38.5 × 14 cm); the mesh area ratio against the fed sludge volume was 6.67 m^2/m^3.

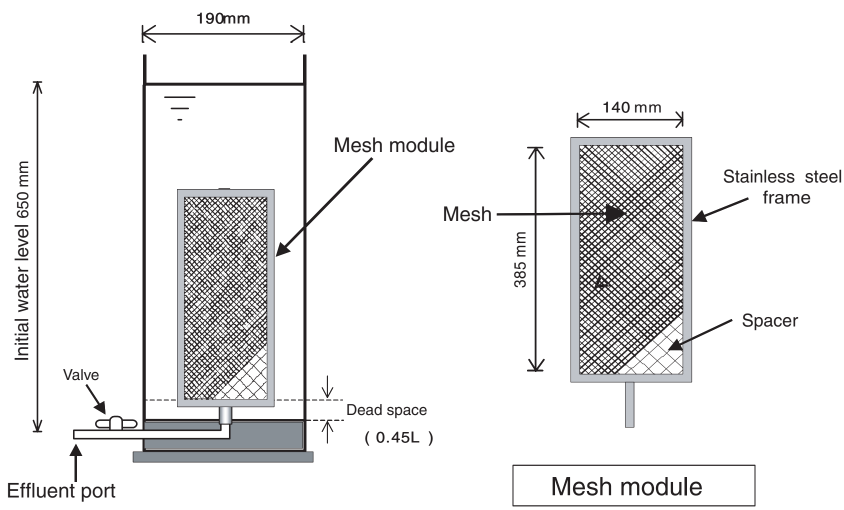

Figure 1 Sludge thickening apparatus and filter module

Sludge filtration procedure

The sludge (the return activated sludge (ca. 9,000 mg/L) and its diluted sludge (ca. 3,000 and 6,000 mg/L) was obtained from a domestic wastewater treatment facility (extended aeration process) in our institution. Fifteen L of sludge was fed into the thickening vessel and the valve of the effluent port was opened immediately. The filtrate from the effluent port was corrected, and its quality and the filtration rate were monitored periodically. The filtration was continued for 6 or 7 h. In this method, the hydraulic pressure decreased due to the progress of the filtration, and the effective filter area also decreased after a time when the water level in the vessel was reduced to the top end of the mesh module. Moreover, it is pointed out that the sludge settled during the filtration period because it was not circulated.

The experimental conditions are summarized in Table 1. In Run 1, Run 2, and Run 3, the mesh opening size and the effects of the initial SS concentration were examined for each. The effects of the sludge settling in the vessel were examined in Run 4, where the sludge settled 1 hour prior to the filtration. Since the effective mesh area varies in the operational period as mentioned above, the effects of the filter area were examined in Run 5, where the height of the mesh module was one-half of the module mentioned above: 539 cm^2 of the mesh area.

Effects of coagulant addition on the mesh filtration performance

A coagulant was added in order to examine the effects on the mesh filtration performance such as the filtration rate and the effluent quality (Run 6). Alum was added into the vessel and aerated for a few minutes for mixing. The coagulant dosage was 10% as $Al_2(SO_4)_3$ based on dry sludge. In this case, the filtration was carried out after 1 h of settling in the same way as Run 4.

Results and discussion

Direct sludge filtration

In this mesh filtration process, the sludge passed through the mesh just after the start of the filtration; however, the sludge accumulated at the mesh surface within a few minutes and formed a cake layer, which effectively rejected the sludge. The filtration rate decreased with the progress of the filtration, due to a decrease of the hydraulic pressure and an increase of the thickness of the accumulated sludge layer. In preliminary experiments whereby the filtration was conducted for 12 h, we found that the filtration rate was very low in the latter half of the period. Based on the results, the filtration experiments were carried out for 6 or 7 hours for this work.

In the case of 9,000 mg/L of the fed sludge, the relationship between the sludge volume reduction rate and the operational period are shown in Figure 2, where the filter area decreasing point is also indicated: when the sludge volume is lower than this point, the upper part of the mesh is not used for the filtration. One-half of the fed sludge passed through the mesh in ca. 20 min; afterwards the filtration rates decreased rapidly. However,

Table 1 Summary of the operating conditions

Run No.	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Mesh opening size (μm)			100/200/500			
Initial SS (mg/L)	3,000	6,000	9,000	6,000	9,000	9,000
Settling time (hr)	–	–	–	1	–	1
Effective mesh area (cm^2)	1,078	1,078	1,078	1,078	539	1,078
Coagulant dosage (%)[a]	–	–	–	–	–	10

[a]: The rate based on dry sludge

ca. 90% of the fed sludge was filtrated within 7 h. From the results of Figure 2, it was pointed out that the mesh opening size had little influence on the filtration rate.

On the other hand, the SS of the filtrate was influenced by the mesh opening size as shown in Figure 3. Although the initial filtrate contained high SS, the SS decreased rapidly. In the case of 100 μm mesh, SS of the filtrate decreased to less than 10 mg/L after 2 min. In the case of 200 and 500 μm meshes, the filtrate contained more than 100 mg/L of SS after one minute; however, the effluent SS decreased to lower than 10 mg/L within several minutes. In addition, the SS of the filtrates was less than 1 mg/L for all mesh modules after 10 min, and similar results were obtained for other fed sludge (3,000 mg/L and 6,000 mg/L).

When the initial filtrate (5–10 min) is returned into the reactor, the effluent from this system contains very low SS and can be discharged directly into the environment. This is one of the advantages of this system.

The performance of the system, such as the volume of reduction rates, and the sludge recovery, etc., is summarized in Table 2. The volume reduction ratios were 86.7–95.3%, and the lower SS of the fed sludge containing a lower SS indicated a higher volume reduction ratio. Considering the effluent SS at the 5–6 min after the start of the filtration, the effluent from the mesh of 100 μm opening size was the lowest. When the initial filtrate is returned to the filtration vessel within a few minutes, low SS effluent may be withdrawn stably and the effluent may be discharged directly into the environment. The recovery rate of the SS was calculated taking into account both the SS in the residual sludge and the

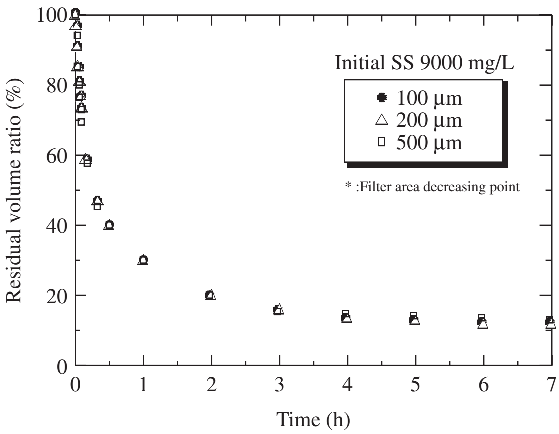

Figure 2 Relationship between residual volume ratio and filtration period

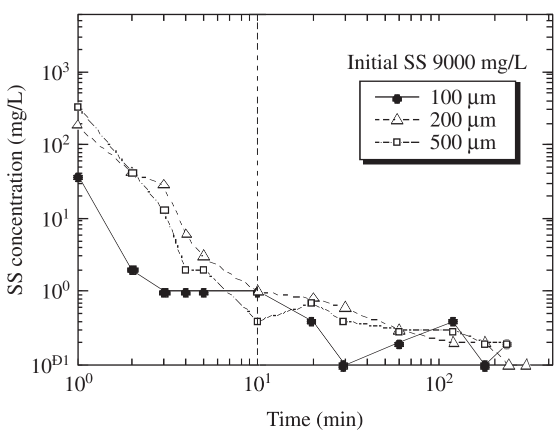

Figure 3 Relationship between effluent SS and filtration period

Table 2 Sludge separation properties of the filter modules

Run No.	Run 1-1	Run 1-2	Run 1-3	Run 2-1	Run 2-2	Run 2-3	Run 3-1	Run 3-2	Run 3-3
Mesh opening size (μm)	100	200	500	100	200	500	100	200	500
Initial SS (mg/L)	2,670	2,940	3,370	6,200	6,000	5,940	9,010	9,380	9,100
Final SS (mg/L) [a]	20,600	19,000	33,800	27,800	36,000	48,800	58,100	64,100	45,600
Volume reduction ratio (%) [6 h]	93.3	94.8	95.3	88.7	92	94	88	88.7	86.7
Filtration period (h)	6	6	6	6	6	6	7	7	7
Effluent SS (mg/L) [b]	6.8	15	84	4.1	13	45	1	3	2
Effluent turbidity [b]	5.9	7.5	30.5	0.2	6.8	17.5	0.7	0.6	0.35
SS recovery (%) [c]	88.2	77.3	71.7	91.2	83.4	77.2	97.8	90.7	88.4

[a] : Without attached SS on the mesh filter
[b] : The effluent obtained at 5–6 min
[c] : Including the attached SS on the mesh filter

SS attached on the mesh surface, and was in the range of 71.3–97.8%. The low recovery rate may be affected by some sampling errors and the effects of SS in the initial filtrate. It is obvious, however, that the mesh filtration system enables the separation of sludge effectively.

Effects of sludge settling before filtration

The filtration process includes the effects not only of filtration but also of sludge settling as mentioned above. In order to examine the effects of sludge settling, the experiments were conducted under the following conditions: the sludge was settled for 1 h after the sludge feeding, and then filtration was started. In the case of Run 4-1, the relationship between the volume reduction ratio and the experimental period is shown as a sample in Figure 4, where the results of Run 2-1 are plotted for comparison. The filtration rates were improved greatly in the initial period as expected. However, the filtration rates decreased rapidly after that, and the volume reduction ratios within 6 h were similar to those in cases without settling. The sludge recovery improved a little in comparison with those cases without settling as shown in Figure 5.

The results of the series of Run 4 are summarized in Table 3. As a result, it is concluded that the sludge settling before filtration had little effect on the effluent water quality, although the effluent SS was slightly higher than that in the cases without settling. From another viewpoint, the results indicate that this system can enable flexible operation with or without settling.

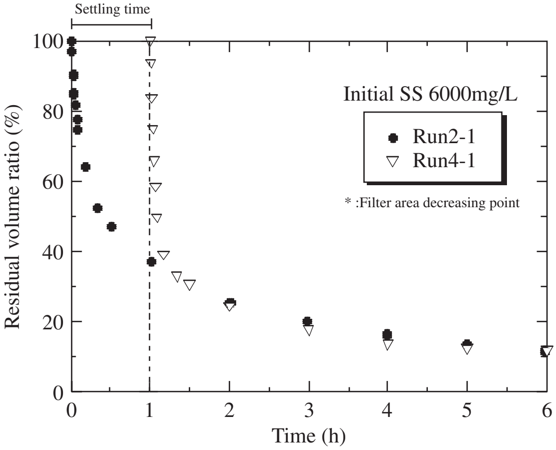

Figure 4 Residual volume ratio vs. time

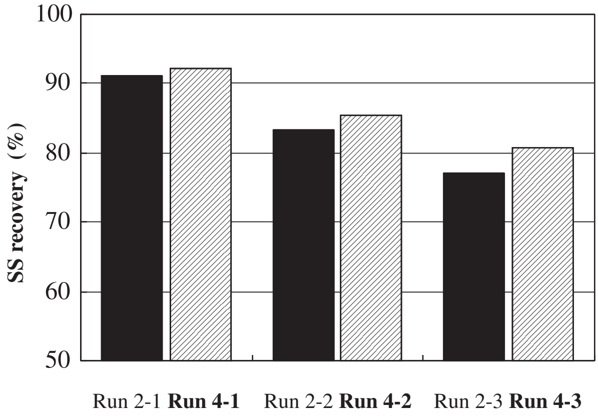

Figure 5 SS recovery

Table 3 Effects of sludge settling before filtration

Run No.	Run 4-1	Run 4-2	Run 4-3
Mesh opening size (μm)	100	200	500
Initial SS (mg/L)	6,200	6,000	6,080
Final SS (mg/L)[a]	36,400	36,500	76,700
Volume reduction ratio (%)	88.7	88.7	94.7
Filtration period (h)	6	6	6
Effluent SS (mg/L[b]	14.4	3	36.1
SS recovery (%)[c]	92.2	85.4	80.8

[a]: Without attached SS on the mesh filter
[b]: The effluent obtained at 5–6 min
[c]: Including the attached SS on the mesh filter

Effects of filter area

It was revealed that the mesh filtration system is potentially useful for sludge thickening. In this system, however, the effective mesh area decreases with progress of the filtration as mentioned previously. Therefore, it is important to examine the effects of the mesh area. A smaller mesh module was used for this purpose: a half area of the mesh module as used in the above experiments.

Figure 6 shows the volume reduction rate for the case of Run 5-1 in comparison with the results of Run 3-1. In the case of Run 5-1, the volume reduction rates within 4 h were

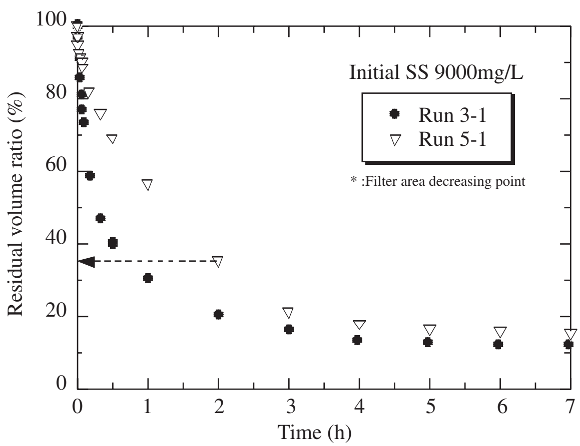

Figure 6 Residual volume ratio vs. time

significantly lower than the case of Run 3-1; however, the residual volumes after 4 h were similar to those of Run 3-1. The SS recovery improved little as shown in Figure 7.

The results of Run 5-1, 5-2, and 5-3 are summarized in Table 4. It is obvious that almost all properties of the cases with the smaller module were similar to those shown in Table 2. As a result, when the thickening operation is continued for more than 4 h, the smaller mesh modules may also be applicable; the mesh area ratio against the fed sludge was 3.33 m^2/m^3-fed sludge in this case.

Effects of coagulant addition

In the mesh filtration system, the following properties may influence sludge separation performance: sludge floc size and the compressibility or dewatering property of the accumulated sludge at the mesh surface. Since coagulants are commonly used to improve these sludge properties, the effects of the addition of a coagulant were examined.

The results are summarized in Table 5. The volume reduction ratios were similar to those of the cases without a coagulant addition, and the sludge recovery decreased a little. However, the SS of the effluent increased at very high levels (8–50 mg/L). In the case of Run 6, the sludge was settled within 1 h after the addition of the coagulant. It was suggested that the improvement of the sludge settleablity due to the addition of a coagulant led to clarified supernatant, and the cake layer at the mesh surface was not formed effectively. Therefore, when the sludge can be separated effectively with the mesh, it is suggested that the addition of a coagulant may have rather negative effects. Moreover, when the sludge was filtrated immediately after the addition of a coagulant, there was little improvement observed.

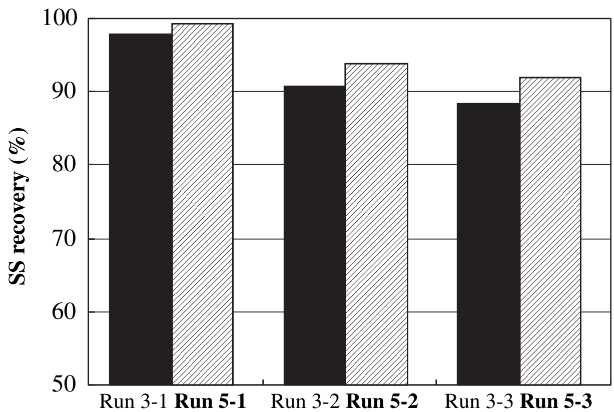

Figure 7 SS recovery

Table 4 Effects of mesh area

Run No.	Run 5-1	Run 5-2	Run 5-3
Mesh opening size (µm)	100	200	500
Initial SS (mg/L)	9,010	9,380	9,100
Final SS (mg/L) [a]	56,200	52,300	49,000
Volume reduction ratio (%)	82.7	83.7	86.7
Filtration period (h)	7	7	7
Effluent SS (mg/L) [b]	3	1	13
SS recovery (%) [c]	99.3	93.9	92

[a] : Without attached SS on the mesh filter
[b] : The effluent obtained at 5–6 min
[c] : Including the attached SS on the mesh filter

Table 5 Effects of coagulant addition

Run No.	Run 6-1	Run 6-2	Run 6-3
Mesh opening size (μm)	100	200	500
Initial SS (mg/L)	9,010	9,380	9,100
Final SS (mg/L) [a]	60,974	50,181	41,370
Volume reduction ratio (%)	87.3	88.7	86.7
Filtration period (h)	7	7	7
Effluent SS (mg/L) [b]	8	36	50
SS recovery (%) [c]	92	91.1	84.7

[a] : Without attached SS on the mesh filter
[b] : The effluent obtained at 5–6 min
[c] : Including the attached SS on the mesh filter

Conclusion

In this work, we examined the performance of mesh filtration as an alternative sludge thickening method. It was indicated that this method can be operated very easily, and the effluent from the system contained very low SS, which can be discharged directly into the environment. The results obtained in this work are summarized as follows.

1. The sludge volume reduction ratios were in the range of 85–95% for all mesh filters within 6–7 hours.
2. In the case of 100 or 200 μm mesh, the average SS of the effluent within 5 min after the start was less than 7 mg/L, although the initial effluent contained high concentration of SS.
3. When 100 μm mesh was used for the sludge of 6,000 and 9,000 mg-SS /L, the recovery rates of SS were more than 90%.
4. The fact that settling of sludge before the filtration did not affect results significantly indicates that this system can be operated under flexible conditions.
5. In the range of the mesh area examined in this work, the thickening performance varied a little.

From the results, the mesh filtration process can be proposed as a simple and effective process for sludge thickening.

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