CHARECTERISTICS OF MBR IN MUNICIPAL WASTEWATER TREATMENT

Takao Murakami*, Syuji Oota

R&D Dept., Japan Sewage Works Agency
5141 Shimo-sasame, Toda, Japan 330-0037
*Corresponding author: murakamit@jswa.go.jp

ABSTRACT

The application of MBR to municipal wastewater treatment has recently begun and it is expected that the application of MBR will increase from now on. The authors investigated several subjects related to MBR. These were influence of organic substances on the filterability of MBR activated sludge, reduction of excess sludge production by MBR and reuse of MBR effluent. The research results are introduced in this paper.

KEYWORDS

MBR, organic substances, filterability, reduction of sludge excess sludge, reuse, Coliphage

1.INTRODUCTION

The MBR has been applied in many fields such as for industrial or on-site wastewater treatment, and there are many such plants in use. However, MBR has not yet been used for municipal wastewater treatment in Japan, because it has not been cost effective as the amount of wastewater to be treated is usually more than that of on-site or industrial wastewater treatment. Nevertheless, the recent decline in the cost of membranes has made it realistic to use MBR for municipal wastewater treatment.

Japan Sewage Works Agency (JSWA) has been conducting a series of studies over several years on using MBR for municipal wastewater treatment, and the results were summarized in "Technical evaluation of MBR" at the end of last year to promote the use of MBR. As a result, five local municipalities have already decided to use MBR and plant design work is now proceeding. The first MBR plant for municipal wastewater treatment in Japan will start operation in 2004, and the application of MBR for municipal wastewater is expected to increase.

This paper outlines the results of several of the studies conducted by JSWA on application of MBR to municipal wastewater.

2. INFLUENCE OF ORGANIC SUBSTANCES ON THE FILTERABILITY OF MBR ACTIVATED SLUDGE

2-1. BACKGROUND OF THE STUDY

Since MBR uses membrane filtration for liquid-solid separation, the condition of activated sludge is sometimes thought to be unimportant. However, the sludge characteristics significantly affect the performance of MBR, as poor filterability will cause membrane fouling and a rapid rise of trans membrane pressure (TMP), which will require frequent chemical washing of the membrane. It is essential to determine the filterability of activated sludge and the factors that affect the filterability for the optimum operation of MBR, and therefore a practical operational index for the filterability of MBR activated sludge is necessary.

This study investigated the influence of organic substances on the filterability of the activated sludge of MBR.

2-2. MATERIALS AND METHODS

A pilot-scale MBR plant with a reactor volume of 4 m^3 was used for the study. The reactor was composed of an anoxic tank and an aerobic tank, with the mixed liquor circulated from the aerobic to the anoxic tank. The plant was located in the experiment yard of JSWA's R&D Department in Toda city. The plant treated 4.1 m^3/d of actual municipal wastewater supplied from the adjacent large-scale WTP which uses a combined system. The flow scheme of the MBR pilot plant used for the study is shown in Figure 1.

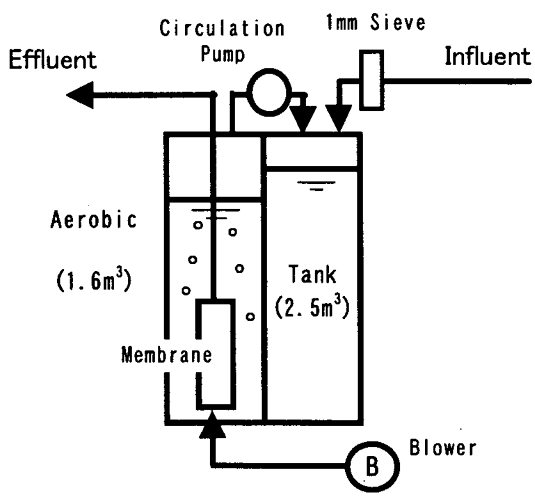

Table 1 Specification of membrane

Material	Polyolefine
Membrane Type	Flat Plate MF
Panel size	490mm × 1000mm × 6mm
Pore size	0.4 μm
Design Permeate Flux	0.4m^3/m^2/d

Figure 1 Pilot plant flow scheme

The dimensions of the MBR were L170 cm, W116 cm, H230 cm and the reactor consisted of an anoxic tank (2.5 m^3) and an aerobic tank (1.6 m^3). The MF membrane unit consisted of seven FP (flat-plate) membrane elements each having a membrane surface area of 0.8 m^2.

Three membrane units were submerged in the aerobic tank. The total membrane surface area was 16.8 m^2. The specifications of the membrane are shown in Table 1. The permeate flux was 0.26 $m^3/m^2/d$.

The primary effluent of the large-scale WTP was fed as influent to the MBR, after pre-treatment by a 1-mm mesh metal sieve in order to prevent damage to the membranes by debris. The MBR was operated with intermittent feeding, i.e. three days with continuous feeding followed by four days with no feeding per week. The feeding rate was 4.1 m^3/d and the membrane permeate flux was maintained at 0.26 $m^3/m^2/d$. The HRT during the feeding period was 24 hours. Aeration as well as circulation from the aerobic tank to the anoxic tank were continued during the no-feeding period. The inflow rate corresponded to 1.74 m^3/d for the whole period on average. The circulation rate was 300% of inflow volume. The BOD-SS load was 0.004 kgBOD/kgMLSS on average.

Chemical washing of the membrane was scheduled to be performed when TMP reached 23 kPa, by injecting 0.5% of NaOCl into the membrane elements from the effluent line. Aeration for oxygen supply and for continuous washing of membrane surfaces required 10–20 L/min of air volume for each membrane element.

An automatic sampler that took 24-hour composite samples was used to take the influent samples. For the effluent, grab samples were used since no significant fluctuations in water quality were observed. The sampling and water quality measurement were done on Monday, Wednesday and Friday every week. Regarding the measurement of dissolved TOC (DOC) of the mixed liquor, MLSS was centrifuged at 3,000 rpm, and then the filtrate that passed through a 1-μm GF/B filter was measured by a Shimadzu TOC analyzer.
Dehydrogenase activity was measured according to the "Wastewater analysis methods". [1] Polysaccharides were measured by the anthrone-sulfuric acid reaction method. Proteins were measured by the Lowry method.

2-3. RESULTS AND DISCUSSIONS

1) Paper filter test as an index of sludge filterability

The paper filter test is often used on site to evaluate the filterability of MBR activated sludge. The paper filter test simply filters 50 ml of activated sludge by a 5C paper filter, and the filterability of MBR activated sludge is judged from the volume filtered in 5 minutes. Usually, if the volume filtered in 5 minutes exceeds 5 ml, the filterability of the sludge is judged to be good. Since the test can be completed quickly using simple tools, the test is suitable for on-site use.

It has been empirically shown that the results of the paper filter test roughly correspond to the filterability of activated sludge. For example, the filtrate volume of the paper filter test depends on water temperature and when water temperature drops, the filtrate volume decreases because of the viscosity of water increases. However, the paper filter test using warmed activated sludge in winter showed that the filtrate volume was not equal to the level at the corresponding water temperature as shown in Figure 2. Therefore, it is clear that the characteristics of activated sludge play an important role, in addition to water temperature, for sludge filterability.

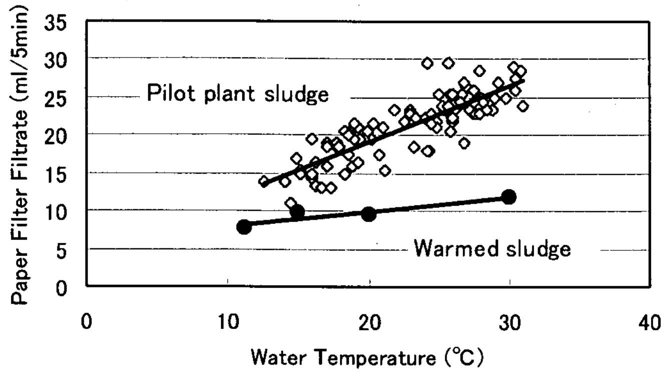

Figure 2 Water temperature and paper filter test result

2) DOC

Figure 3 shows the relationship between DOC of the reactor mixed liquor and water temperature. As shown in the figure, DOC depended on water temperature and tended to increase as water temperature fell. This indicates that more organic substances remain in the reactor mixed liquor when the water temperature is low.

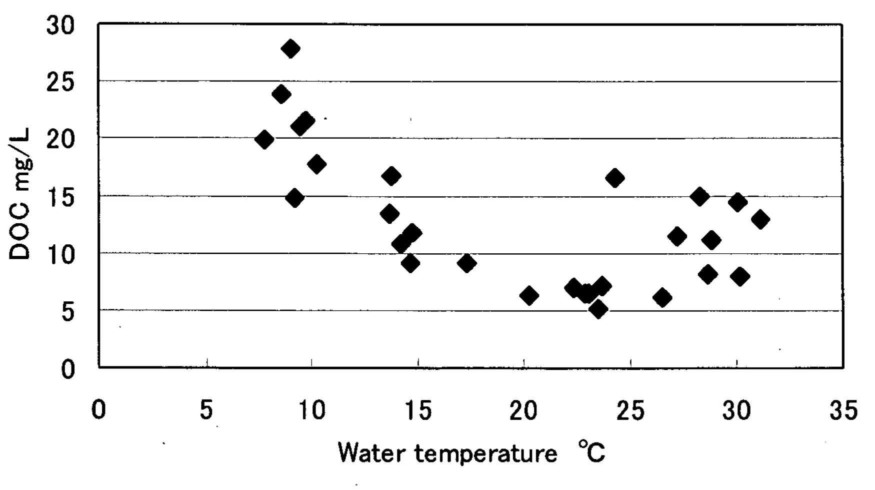

Figure 3 DOC and water temperature in the reactor

Figure 4 shows the filtrate volume of the paper filter test and DOC. The filtrate volume of the paper filter test was clearly related with DOC of the reactor mixed liquor, and decreased as the

DOC concentration of reactor mixed liquor increased.

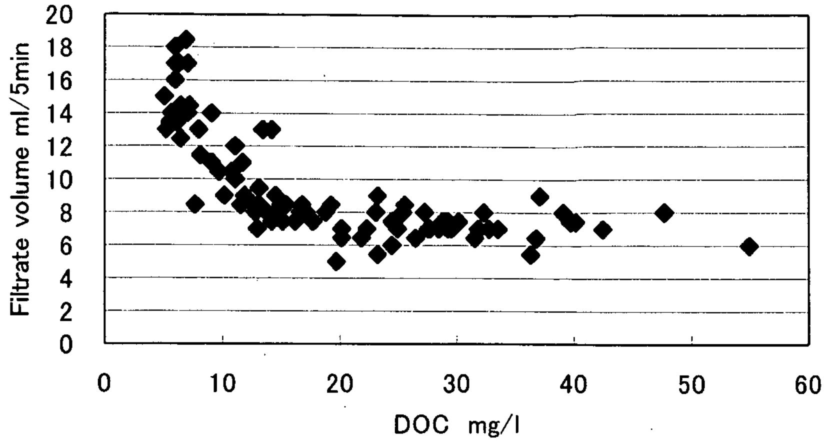

Figure 4 Filtrate volume of the paper filter test and DOC

It is considered that DOC of the mixed liquor represents organic substances including extra-cellular polymeric substances (ESP) that are not captured in the sludge. As shown in the figure, lower DOC resulted in better filterability.

3) Dehydrogenase activity

Dehydrogenase activity (Dt) consists of a substrate-dependent segment (Ds) and endogenous-respiration-dependent segment (De). De was measured with activated sludge that had been rinsed with tap water. Since the measurements showed that De accounted for the major portion of Dt, the influence of organic substances was evaluated based on De.

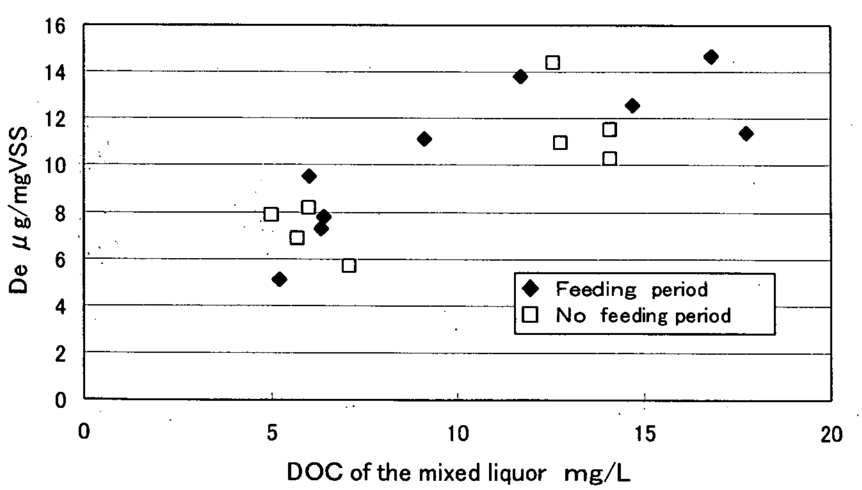

Figure 5 DOC and De

Figure 5 shows the relationship between DOC and De. Figure 6 shows water temperature and De.

As shown in Figures 5 and 6, De depends on DOC of reactor mixed liquor and water temperature. This indicates that the decline in biological activity at low water temperature led to organic substances remaining in the activated sludge, which were represented by DOC.

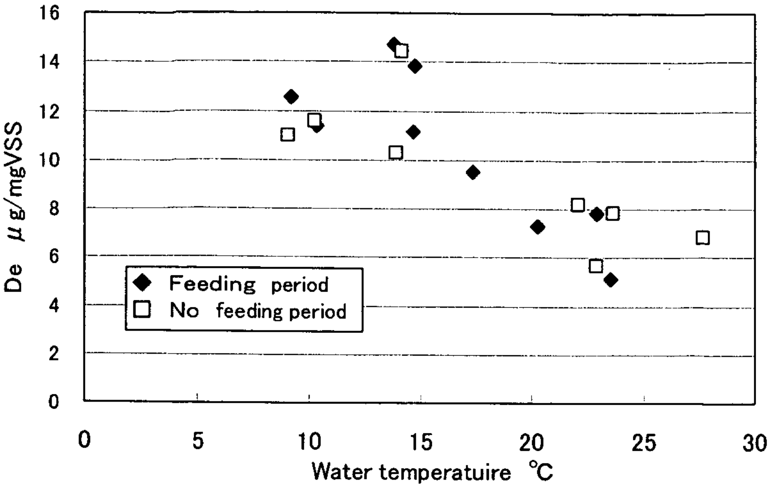

Figure 6 Water temperature and De

4) Polysaccharides and proteins

The behavior of polysaccharides and proteins in the reactor mixed liquor was investigated. Figures 7 and 8 show the change of proteins and polysaccharides concentration respectively. Protein concentration decreased in the reactor mixed liquor compared with that in the inflow and 4 mg/l of protein was detected in the effluent. On the contrary, polysaccharides concentration increased in the reactor compared with that in the inflow, and was below the detectable level in the effluent.

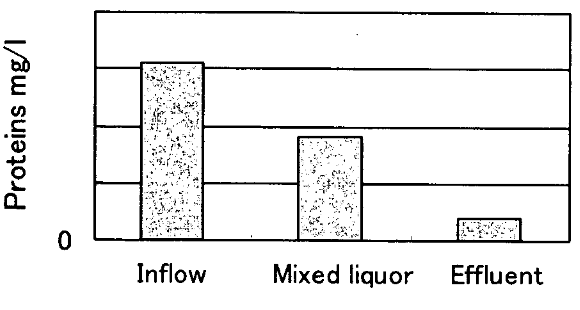

Figure 7 Change of proteins

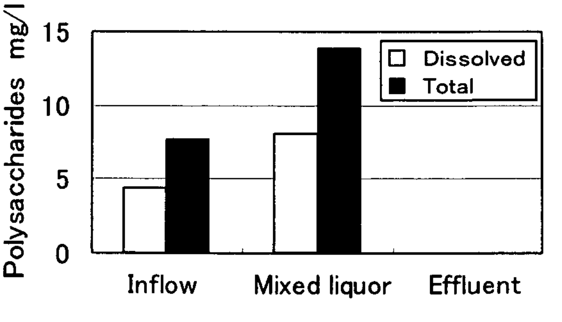

Figure 8 Change of polysaccharides

It has been pointed out that EPS is a major cause of membrane fouling and thus degrades filterability. [2] EPS is the product of metabolic activity of activated sludge microorganisms and consists of polysaccharides and proteins. The reason why polysaccharides increase in the reactor is considered to be that EPS is produced in the reactor and mostly rejected by the membrane, thus increasing the polysaccharides concentration in the reactor on the assumption that polysaccharides are the main component of EPS.

Figures 9 and 10 show the influence of reactor water temperature on protein concentration and on polysaccharides concentration in the reactor mixed liquor.

Protein concentration in the reactor mixed liquor showed no clear relationship with water temperature but polysaccharides concentration in the reactor mixed liquor showed a much closer correlation, increasing as water temperature dropped.

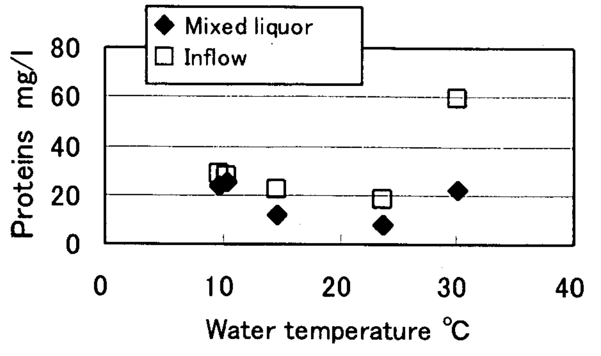

Figure 9 Proteins and water temperature

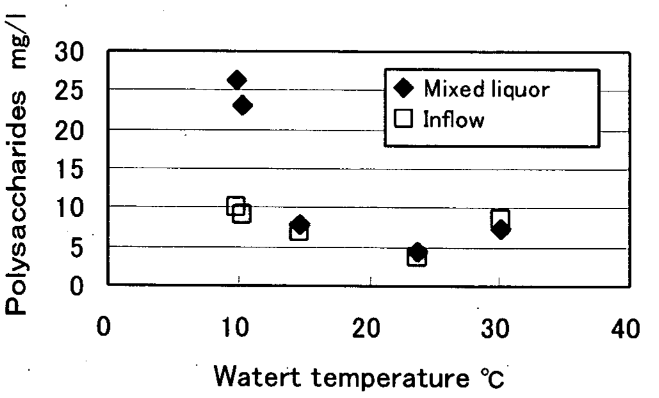

Figure 10 Polysaccharides and water temperature

Figures 11 and 12 show the relationship between DOC and proteins as well as DOC and polysaccharides respectively. The DOC in the reactor was closely related with polysaccharides as shown in Figure 12, but was not closely related with proteins as shown in Figure 11. This indicates that polysaccharides such as included in EPS was the main component of organic substances and could be represented by the DOC in the mixed liquor.

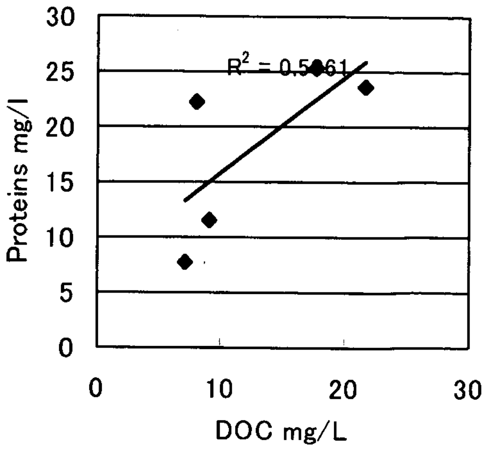

Figure 11 DOC and proteins

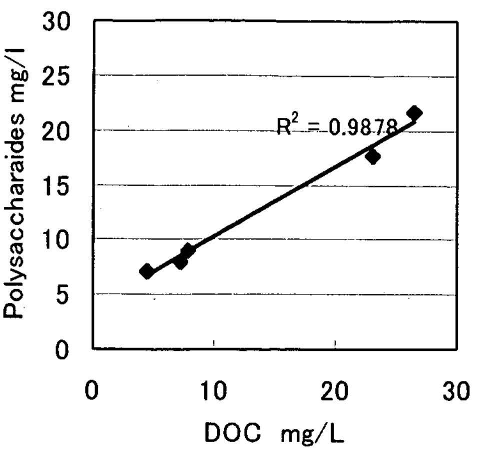

Figure 12 DOC and polysaccharides

5) Index of filterability

From these results, it is considered that DOC in the reactor mixed liquor represents the remaining quantity of organic substances, consisting mainly of polysaccharides. DOC depends on water temperature, suggesting that more organic substances remain in the mixed liquor of the reactor at low water temperature. As already shown in Figure 4, when DOC concentration became high, the filtrate of the paper filter test decreased. These results imply that the filterability declines at low water temperature because larger quantities of organic substances remain in the mixed liquor than at high water temperature.

2-4. CONCLUSIONS

The following conclusions were obtained in the study:

1) The remaining organic substances, mainly polysaccharides, affect sludge filterability and the behavior of such remaining substances can be expressed well by DOC in the mixed liquor.
2) The paper filter test roughly describes the filterability of sludge as an index for daily operation of MBR. However, since the test cannot describe the influence of each factor, periodical DOC measurements should also be performed to correctly determine the filterability.

3. SLUDGE REDUCTION BY INTERMITTENT FEED MBR

3-1. BACKGROUND OF THE STUDY

The treatment and disposal of sludge are serious issues of wastewater management. To reduce the cost of sludge disposal, various processes for reducing sludge production have been developed or proposed recently. Most of these methods are based on the principle that the excess sludge is solubilized either by physicochemical or biological methods, and the solubilized excess sludge is then returned to the reactor to be biologically decomposed. As sludge solubilization methods, ozone oxidation, acid or alkaline treatment, electrolysis and biological method such as the use of thermophilic bacteria for instance are applied. These processes are able to reduce the volume of generated sludge, and almost eliminate it in some cases. However, increased solubilization rate of sludge degrades the effluent quality by increasing the COD level and decreasing the transparency. A wastewater treatment method with less sludge production and yet that does not adversely affect the treated water quality is required.

To meet these two conflicting requirements, the authors focused on the membrane bioreactor (MBR) process. The MBR process can be operated with increased SRT and thus reduces sludge production, which is one of the major advantages of the process. Another significant feature of the MBR process is the high quality of effluent. The MBR process can maintain high MLSS level in the reactor because the process has no gravitational solid-liquid separation. As a result, the MBR process assures operation at a long SRT leading to the reduction of excess sludge production in spite of rather short HRT. The operation of MBR is usually conducted at SRT of about 20 days. However, at longer SRT, further reduction of excess sludge can be expected. The authors studied intermittent feed operation of MBR, which assures long SRT, and consequently sludge reduction by aerobic digestion effects by a pilot plant scale experiment for about one year.

3-2. MATERIALS AND METHODS

This study was conducted at the same time as the above-mentioned study using the same pilot plant.

3-3. RESULTS AND DISCUSSIONS

1) Sludge production

The results of measurement of both influent and effluent are shown in Table 2. Figure 13 shows the course of reactor MLSS and reactor water temperature. The MLSS concentration was about 5,500 mg/l at the beginning and increased to about 8,000 mg/l after 100 days of operation. It then reached 7,000 mg/l at the end of the experiment period after gradual decrease and increase. It is considered that the weak inflow due to storm water was the cause for the temporary decrease of MLSS.

Table 2 Influent and effluent quality

	Influent			Effluent		
	Min	Max	Average	Min	Max	Average
pH	7.4	7.9	7.5	7.2	7.8	7.5
BOD	28.1	98.6	65.1	0.2	1.2	0.5
S-BOD	8.6	43.7	23.1	-	-	-
COD	25.1	77.6	56.6	3.8	6.0	5.0
S-COD	10.9	42.3	23.9	-	-	-
TOC	12.8	99.8	50.5	2.3	5.3	3.5
S-TOC	8.5	27.4	17.2	-	-	-
SS	35	128	75	0	0	0
T-N	15.5	36.5	28.1	4.3	22.2	10.2
T-P	1.7	5.1	3.9	1.7	4.2	2.5

Unit is mg/l except pH
S-BOD, S-COD and S-TOC were for filtered sample by 1 μm GFB filter.

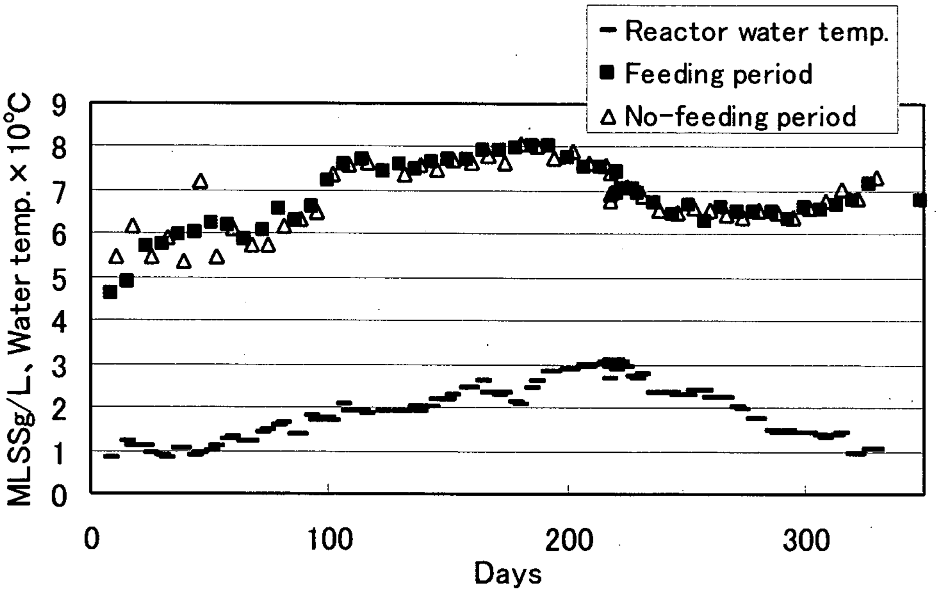

Figure 13 Reactor MLSS and water temperature

The organic content of MLSS, which was initially 82%, decreased to 74% by the 250th day and then slightly increased to 78%, remaining at a stable level thereafter.

During the experimental operation no excess sludge was extracted. If the increase of MLSS and sludge taken for measurement are regarded as excess sludge production, the sludge production rate for the first 100days during which MLSS continued to increase before reaching the stable condition was calculated to be 0.6 gSS/gSSremoved. This value corresponded with that obtained in our former experiment that used only aerobic tank of the same pilot plant and operated it without sludge extraction for 140days. [3] On the other hand, the sludge production rate for the whole experiment period was calculated to be 0.21gSS/gSSremoved or 0.25gSS/gBOD_5removed.

If increased MLSS during the period and sludge taken for measurement are regarded as excess sludge which should have been extracted, the estimated SRT of the experiment operation based on the mean MLSS, 6,900 mg/l, can be calculated to be about 1,000 days. Figure 14 shows the sludge production rate and SRT obtained in several MBR pilot plants treating municipal wastewater. The sludge production rate depends on the SRT of the process. In Japan, MBR is usually operated at SRT of about 20days and therefore the sludge production rate is estimated to be about 0.65gSS/gSSremoved. However, as shown in Figure 14, smaller sludge production rate was obtained under prolonged SRT condition. Davies et al. reported 0.26 gSS/gBOD_5rem of sludge production rate with a 15.5m3 pilot operated at 45days of SRT. [4] These results suggest that small sludge production rate can be expected in MBR when operated at prolonged SRT longer than 30days.

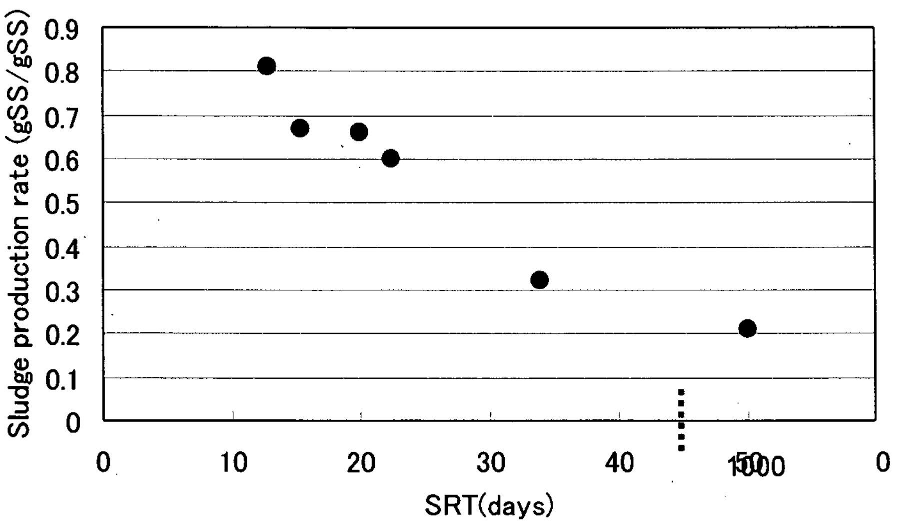

Figure 14 SRT and sludge production rate of MBR

Table 3 shows the sludge production rate used for the design of various suspended growth biological treatment processes in Japan for comparison. It is expected that MBR process produces less excess sludge than other processes at 20days SRT and it can be much smaller under prolonged SRT condition.

Table 3. Design sludge production rate of various processes

Process	Sludge production rate*
CAS	1.00
SBR(High load)	1.00
SBR (Low load)	0.75
Oxidation ditch	0.75
Extended aeration	0.75

*gSS/gSSremoved

2) Membrane fouling

Membrane fouling is the most serious trouble in the operation of MBR. It is pointed out that the production EPS by activated sludge microorganisms is the main cause of membrane fouling. [2] Hamaya et al. reported that pulse high loading feed after a no-feeding period in the intermittent operation because such feed may induce the production of EPS that causes membrane fouling accelerated rapid membrane fouling. [5]

In the experiment, intermittent feeding was continued for about one year, but no rapid membrane fouling was observed and the pilot plant could be operated without chemical washing. Figure 15 shows the course of TMP and permeate flux during the experiment period. TMP showed moderate change and remained below the critical level, i.e.23kPa, at which chemical membrane washing is required.

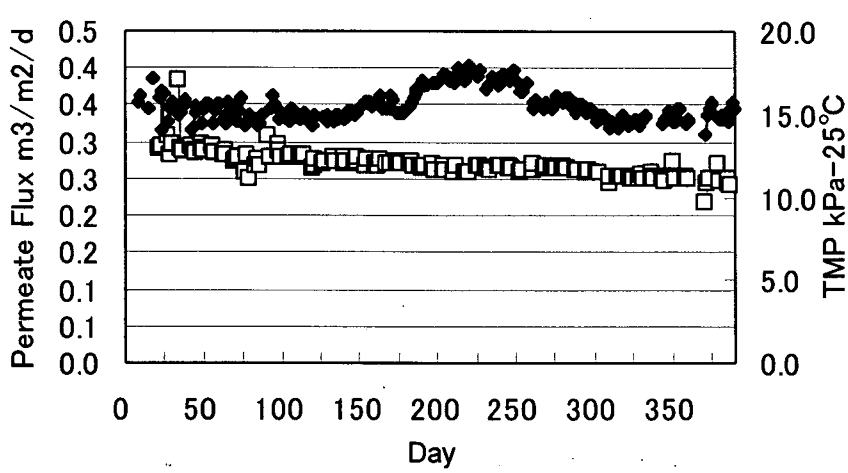

Figure 15 TMP and permeate flux

Figure 16 shows the cumulative concentration of DOC of the reactor mixed liquor during the feeding and no-feeding period respectively. As shown, DOC concentrations were lower during the no-feeding period than in the feeding period. Judging from the result, the reason that filtration could be continued for a long time without membrane fouling is considered that organic substances including EPS were efficiently degraded during the no-feeding period thanks to the very low organic loading condition (0.004gBOD /gMLSS/d).

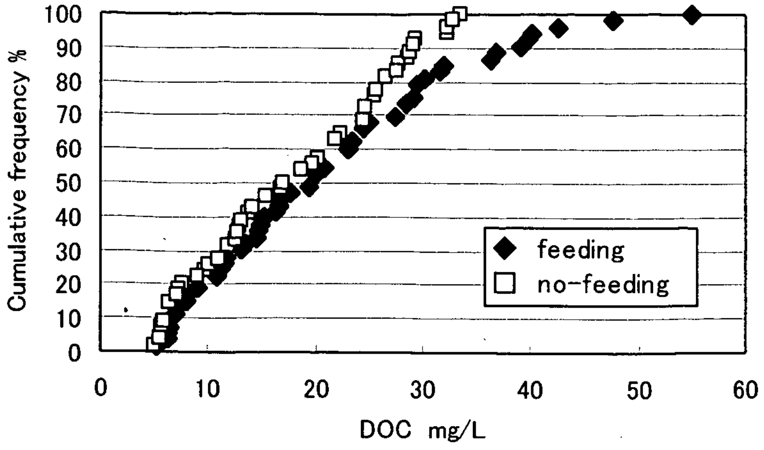

Figure 16 Cumulative frequency of DOC

3-4. Conclusions

The conclusions obtained in this study were as follows:

1) An intermittent feed MBR with low loading was operated for about one year and no excess sludge extraction was necessary during the period.
2) The calculated sludge production rate based on the increase of MLSS for the whole period was 0.21gSS/gSSremoved or 0.25gSS/gBODremoved.
3) The plant showed stable operation and no serious membrane fouling because of the intermittent feed was observed.
4) It is considered that MBR with intermittent feed can reduce excess sludge production and thus can reduce costs for sludge treatment and disposal. In practice, intermittent feed operation of MBR under continuous inflow condition will be enabled by means of preparing several reactor tanks and feeding wastewater into each tank in turn.

4. REUSE OF MBR EFFLUENT

4-1. Background of the study

As emphasized in the 3rd World Water Forum, there will be a shortage of fresh water in many areas worldwide, particularly in Africa and Asia. Fresh water will be an extremely valuable resource in the 21st century, so the reuse of treated wastewater should be further promoted to save fresh water.

One of the advantages of MBR is the excellent quality of its effluent including high removal of bacteria, which is suitable for a wide range of reuse purposes. But any risks inherent in its reuse need to be clearly identified. The authors evaluated the characteristics of MBR effluent for reuse purpose and investigated the removal of Coliphage as an alternative index for viruses. In addition to that, removal of several important endocrine disrupters by MBR was also investigated.

4-2. Materials and methods

For the study, a pilot-scale plant in the JSWA experiment center in Mohka city was used. Figure 17 shows the flow scheme of the plant. The pilot plant treated 25 m^3/d of actual municipal wastewater with an HRT of 6 hours. The reactor consists of an anoxic tank and an aerobic tank, with mixed liquor circulated from the aerobic tank to the anoxic tank. A flat plate-type MF membrane unit with a pore size of 0.4 μm was immersed in the aerobic tank and operated at a permeate flux of 0.63 $m^3/m^2/d$. Raw wastewater from the Mohka wastewater treatment plant, which is a medium-sized WTP employing the CAS process, was supplied to the MBR after removing coarse materials with a 1-mm metal sieve.

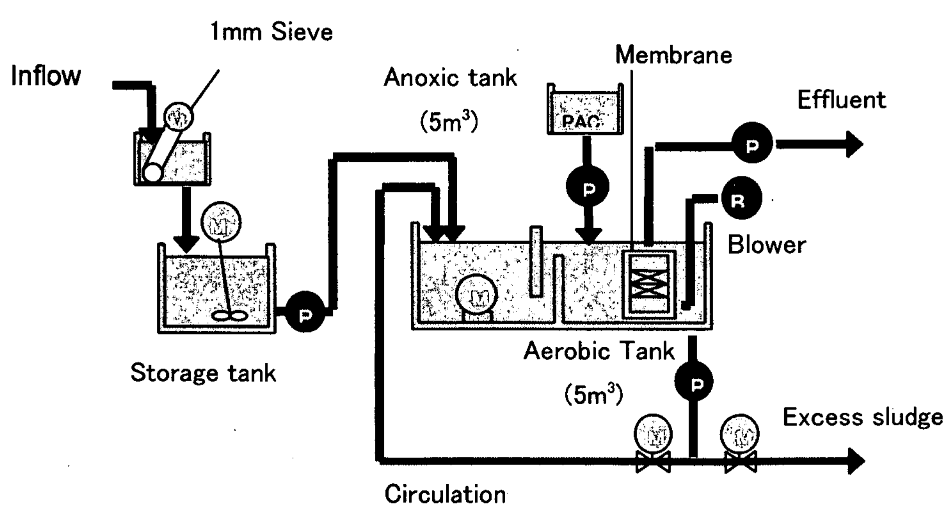

Figure 17 Flow scheme of the pilot plant

Coliform group numbers were measured by the MPN method. *E. coli* K-12F+ was used as the Coliphage host train. Coliphage was measured by the plaque forming method. Endocrine disrupters except 17β estradiol were measured by GC-MS, while 17β estradiol was measured by the ELISA method.

4-3. Results and discussions

1) Characteristics of MBR effluent in view of reuse

Table 4 shows the Japanese guidelines on recycled wastewater for landscaping and recreational use respectively. The MBR effluent was measured twice concerning the items related to purpose of reuse. The results are shown in Table 5. As shown, the MBR effluent satisfied the standards of the guideline except the value of chromaticity for recreational use. The chromaticity of MBR effluent, which was measured twice, was 14 and 20, which were somewhat higher than the required value of 10 for recreational use.

Table 4 The Japanese guidelines on recycled wastewater

	Landscape use	Recreational use
Coliform group	≦1,000CFU/100ml	≦50CFU/100ml
BOD_5	≦10mg/l	≦3mg/l
pH	5.8-8.6	5.8-8.6
Turbidity	≦10	≦5
Odor	Not offensive	Not offensive
Chromaticity	≦40	≦10

Table 5 The results of the measurement

No	Items	Primary inflow	CAS effluent (after chlorination)	MBR effluent
1	BOD_5 (mg/l)	99.7	1.5	<0.5
	TOC (mg/l)	98.7	4.5	3.8
	Chromaticity (degree)	150	20	20
	Odor (-)	septic odor	odorless	soil like odor
2	BOD_5 (mg/l)	207	1.5	0.5
	TOC (mg/l)	73	3.4	2.6
	Chromaticity (degree)	200	20	14
	Odor (-)	septic odor	aromatic odor	odorless

Regarding the remaining color of the MBR effluent, a yellowish-brown color was noticeable. The color originated mainly in urobilin and stercobilin, which are contained in human excreta and are not easily biologically degraded. Ozone or activated carbon treatment would be required for further removal of color from the MBR effluent.

2) Removal of *E. coli* and bacteriophage

As expected, *E. coli* was not detected in the MBR effluent, whereas several hundred were detected in the effluent of the CAS plant treating the same municipal wastewater as shown in Table 6. Coliphage was removed by MBR at an efficiency of 5 log.

Figure 18 shows the change of Coliphage count in inflow and Figure 19 shows those in MBR and CAS plant effluents in 24 hours. MBR showed steady and high removal of Coliphage, which were not detected during the measurement period, whereas Coliphage were present in the CAS effluent.

Table 6 Removal of Coliphage

	Primary Effluent			Effluent		
	mean	max.	min.	mean	max.	min.
CAS	3.6×10^5	1.1×10^6	1.5×10^5	2.7×10^2	4.9×10^2	40
MBR	3.6×10^5	4.9×10^5	1.2×10^5	1	5	0

(PFU/100ml)

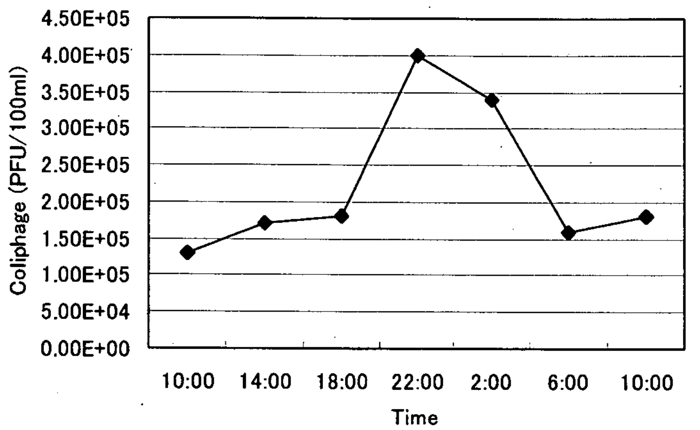

Figure 18 The change of Coliphage in inflow

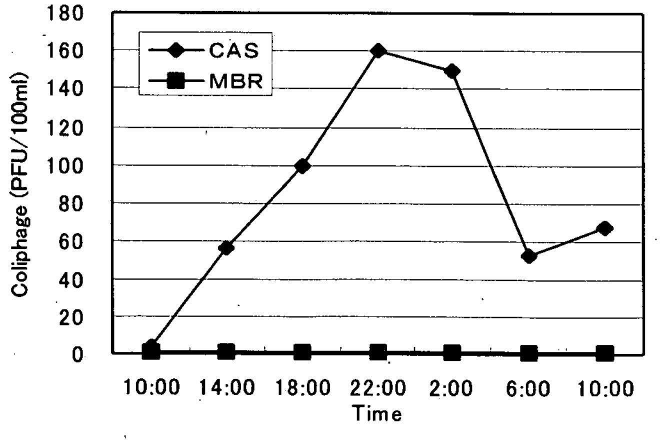

Figure 19 The change of Coliphage in effluent

Table 7 shows the Japanese guideline for viruses for treated wastewater for various purposes of reuse according to the infection risk. This requirement of virus removal is based on final effluent. Since a CAS plant can usually achieve a virus removal efficiency of 3 log, the virus removal efficiency of MBR corresponds about 2 log after final effluent. This value meets the requirement of virus removal efficiency for recreational use for dipping hands and feet at an infection risk of 10^{-2}. These results show that MBR effluent satisfies at least the recommended removal efficiency of viruses for miscellaneous uses such as sprinkling in the Japanese guideline.

Table 7 Required virus removal efficiency for various reuse purposes

Reuse purpose	Target annual infection risk		
	10^{-2}	10^{-3}	10^{-4}
Recreational (dipping the whole body)	2.5	3.8	5.0
Recreational (dipping hands and feet)	1.3	2.3	3.3
Fall and fountain (large scale)	1.5	2.6	3.7
Fishing pond	1.1	2.1	3.1
Sprinkling water for lawn	0.84	1.8	2.8
Flush water for toilet	–	0.43	1.5

(log)

3) Mechanism of Coliphage removal

Although Coliphages are far smaller than the pore size of the MF membrane employed, they were efficiently removed by MF filtration. It has been reported that membrane filtration without activated sludge showed poor removal of Coliphage. [6] It has also been reported that the removal efficiency of Coliphage was affected by the degree of membrane fouling, and that membranes after several weeks of operation showed better removal of Coliphage than new membranes. [7] Therefore, a possible explanation for Coliphage removal by MF membrane is that Coliphages become attached to flocks of activated sludge or are captured in the gel layer that forms on the surface of the membrane.

In this study, the measurement of Coliphage, both in the activated sludge and in the supernatant, showed that 99% of Coliphage were present in the activated sludge, indicating that they attach themselves to the activated sludge. [8] Thus, the mechanism of bacteriophage removal appears to be that Coliphage are held in the activated sludge, attach to the activated sludge flocks, and thus are rejected by the membrane together with the flocks.

However, the Coliphage removal mechanism needs to be investigated further in order to judge whether the MBR stably and efficiently removes viruses.

4) Removal of endocrine disrupters

Several important endocrine disrupters, such as nonylphenol, bisphenol A, DEHP, benzophenone and 17β estradiol in the MBR effluent were measured. The results were compared with the data obtained in the previous nationwide survey on the behavior of endocrine disrupters in many municipal wastewater treatment plants, most of which were CAS plants.

As shown in Table 8, the comparison showed that the endocrine disrupter concentrations in MBR effluent were almost the same as those in the effluents of existing CAS plants, except that the level of benzophenone in the MBR effluent was slightly lower than that in the CAS effluent.

Table 8 Endocrine disrupters in effluent

Substance	MBR	National survey
Nonylphenol	0.1	tr (0.2)
	0.1	
Bisphenol A	0.02	tr (0.02)
	0.03	
DEHP	<0.2	tr (0.4)
	<0.2	
Benzophenone	0.01	0.05
	0.01	
17β estradiol	n.d.	n.d.
	n.d.	

note: The upper row data was measured 19th Sep. 2002
The lower row was data was measured 25th Sep. 2002

4-4. Conclusions

The following conclusions were obtained in this study:

1) MBR effluent has characteristics that make it suitable for wastewater reuse, but a slight yellowish-brown color remained in the effluent. Further treatment, such as by ozone or activated carbon, will be required to remove this color.
2) MBR showed good removal of Coliphage. The removal mechanism appears to be that Coliphages are held in the activated sludge and thus rejected by the membrane together with activated sludge flocks.
3) No significant differences were observed between MBR and CAS in the removal of main endocrine disrupters.

5. PERSPECTIVES ON THE DEVELOPMENT OF MBR IN JAPAN

The application of MBR to municipal wastewater treatment has just begun in Japan and the first MBR plant for municipal wastewater will start operation in FY 2004, with another ten plants beginning operation in the next few years. These are mostly small-scale plants, but the MBR is expected to find various applications such as for renewal, retrofitting and upgrading of existing WTPs. The recent fall in cost of membranes and utility fees will also promote the application of MBR to larger facilities.

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