Membrane Bioreactors (MBR) for Wastewater Reuse

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Abstract

MBR is a wastewater treatment technology that offers many advantages including excellent effluent quality, stable operation performance, a small footprint, reduction of excess sludge production, reuse of effluent, reduction of risk substances and so on. When one takes into consideration that fresh water serves as a precious resource for human beings, the ability to reuse treated water is one of the biggest advantages of using MBR technology.

Judging from the water quality target in the reuse of treated wastewater in Japan, the effluent of MBR using an MF membrane module can be safely utilized for landscape purposes such as streams or in parks in urban areas without the need for any additional treatment. In order to reuse the treated wastewater for recreational purposes it is often the case that colour removal is required.

It was found that MBR shows excellent removal efficiency of viruses, such as Coliphage or *Norovirus*, which is the main cause of food poisoning. It was confirmed that periodical chemical membrane cleaning exerted no negative influence on *Norovirus* removal. Since MBR offers excellent effluent quality as well as stable operation performance even in small-scale plants, the introduction of MBR will contribute to the overall promotion of water recycling in urban areas.

Introduction

The membrane bioreactor (MBR) is a wastewater treatment technology that offers many advantages. In Japan, although MBR have long been used for industrial wastewater treatment or for reuse of wastewater in large buildings and so on, the introduction of MBR in sewerage systems has lagged behind compared with other water related fields. However, the first MBR for municipal wastewater treatment in Japan started operation in March 2005, and this accelerated the introduction of MBR in Japanese sewerage systems. Seven MBR plants for municipal wastewater treatment are in operation at present. In addition, there are some 10 MBR plants currently in the design or planning stage. The number of MBR for municipal wastewater is expected to increase in the years ahead.

The basic flow of the MBR applied for municipal wastewater treatment in Japan is shown in Figure 1. As shown in the figure, immersed type MBR is applied so far. MF membrane module with 0.1-0.4μm of pore size is usually used.

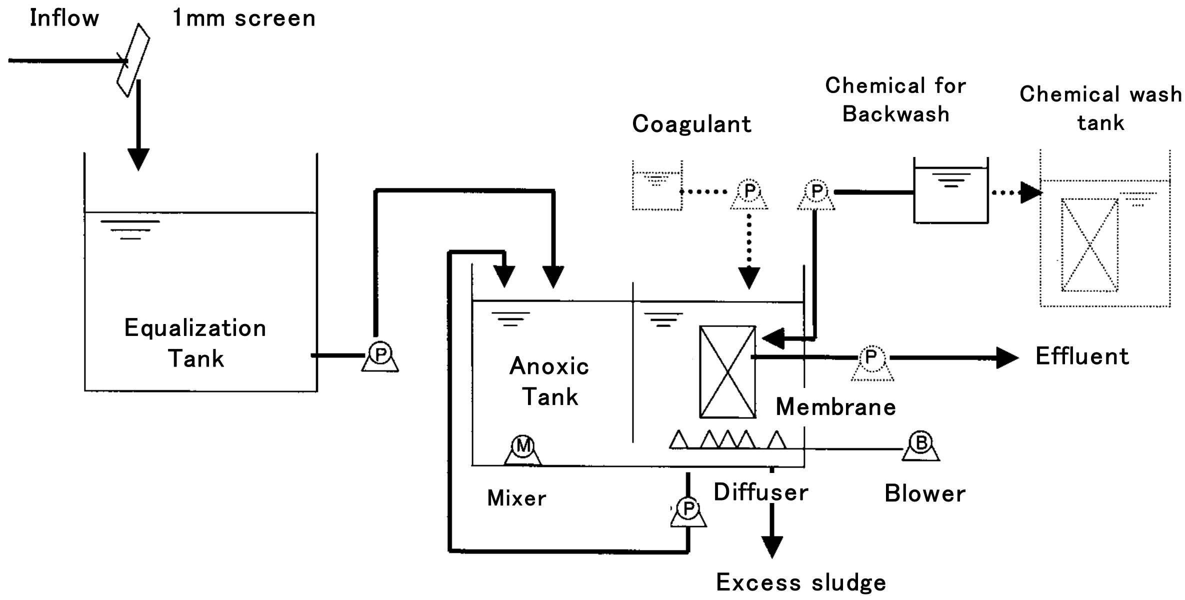

Figure 1. The basic flow of MBR for municipal wastewater.

MBR has the following advantages:
1) Small footprint requirement
2) Stable and excellent effluent quality
3) Nutrient removal
4) Disinfection of effluent is not necessary
5) High removal efficiency of viruses
6) Reduction of excess sludge production

The reuse of MBR effluent is a method of making the best use of these advantages of MBR. But any risks inherent in its reuse need to be clearly identified. In the paper, our research results on effluent reuse and removal of viruses by MBR are introduced.

Evaluation of MBR Effluent Characteristics for Reuse Purpose

Characteristics of MBR effluent in view of reuse

In Japan, 190 million m^3 of treated wastewater, which corresponds to 1.4% of total effluent amount, is reused annually for various purposes including flash toilet, sprinkling, cooling water, landscape or recreational use and so on. Recently the expectation of citizens to reuse the treated wastewater as a water resource in cities for landscape or recreational purposes is growing. The authors evaluated the characteristics of MBR effluent for reuse purposes.

Materials and methods

For the study, a pilot-scale plant in the Japan Sewage Works Agency experiment centre was used. Figure 1 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 an actual medium-sized WWTP employing the CAS process was supplied to the MBR after removing coarse materials with a 1-mm metal sieve.

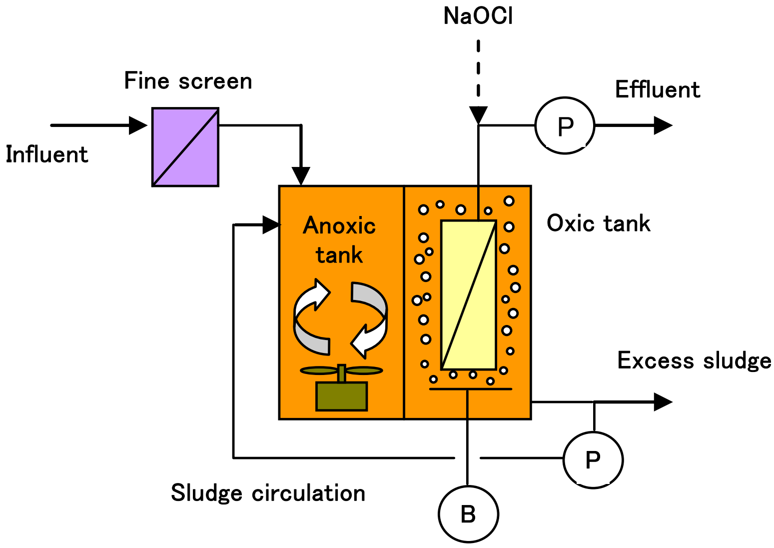

Figure 2. Flow scheme of the pilot plant.

Results and discussions

Table 1 shows the Japanese guidelines on recycle of treated wastewater for landscape and recreational use respectively. The pilot plant MBR effluent was measured twice concerning the requirements shown in the table. The results are shown in Table 2. As shown, the MBR effluent satisfied the required values of the guideline except the value of chromaticity for recreational use. This means that MBR effluent can be used for landscape use purpose, such as for streams or parks in urban area, without any additional treatment. 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 1. The Japanese guidelines on reuse of treated 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

Regarding the remaining colour of the MBR effluent, a yellowish-brown colour was noticeable. The colour 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 the colour from the MBR effluent.

Table 2. 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

Removal of viruses

In order to promote the reuse of MBR effluent, any risks inherent in its reuse such as viruses in case of amenity use of treated wastewater need to be clearly identified. It is reported that a high degree of virus removal can be expected using MBR. (Chiemchaisri et al.,1992, Churchhouse et al., 1999) The authors investigated the removal efficiency of Coliphage and *Norovirus* by MBR.

Norovirus is one of the main causes of infectious food poisoning accompanied by fever and diarrhea. In the winter of 2006-2007, Japan experienced a large-scale outbreak of infectious food poisoning caused by *Norovirus*. Since *Norovirus* is very small in the size (ca.30nm) and is tolerant to chlorine disinfection, efficient removal can not be expected by the conventional wastewater treatment technologies.

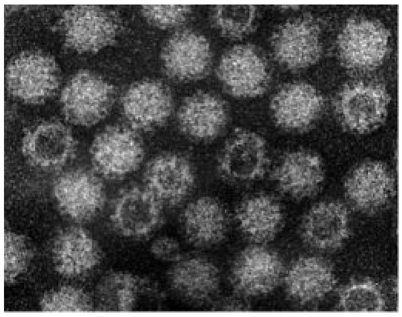

Figure 3. Electron microscopic image of *Norovirus*.
(from the web site of Yokohama-city Public Hygiene Research Center)

Materials and methods

For the study of Coliphage removal, the above-mentioned pilot plant was used. On the other hand, another pilot scale MBR plant with the same flow scheme as Figure 2 was used for the study of *Norovirus* removal. The pilot plant for *Norovirus* study treated the same actual municipal wastewater as the before mentioned plant, but a PVDF hollow fibre MF membrane with 0.4µm pore size was used instead of flat plate-type membrane. The plant treated 48 m^3/d of actual municipal wastewater. The permeate flux was 0.8 $m^3/m^2/d$. The pilot plant had been operating continuously for 15 months before the virus removal research was undertaken. MLSS concentration was maintained between 8,000 and 10,000 mg/L.

E. coli K-12F+ was used as the Coliphage host train. Coliphage was measured by the plaque forming method. The detection of *Norovirus* was based on the Real-time PCR method which is the official method of *Norovirus* detection in foods in Japan. This method detects the number of the copies of *Norovirus* RNA, regardless being active or inert. The taken samples

were first condensed in order to facilitate virus detection.
For the condensation, the sedimentation method using PEG (polyethylene glycol) was applied to influent and activated sludge samples. On the other hand, DEAE cellulose was used for the adsorption and condensation of effluent samples. After the extraction of RNA from the condensed samples and RT reaction, the Real-time PCR procedure was carried out. The limit of detection was 102 copies/L.

Results and discussions

Removal of Coliphage.
Figure 4 shows the change of Coliphage count in inflow and those in MBR and CAS plant effluents in 24 hours. The CAS plant treated the same actual wastewater as the MBR pilot plant. MBR showed steady and high removal of Coliphage, which was not detected during the measurement period, whereas Coliphage were present in the CAS effluent with a maximum value of 160 PFU/100ml.

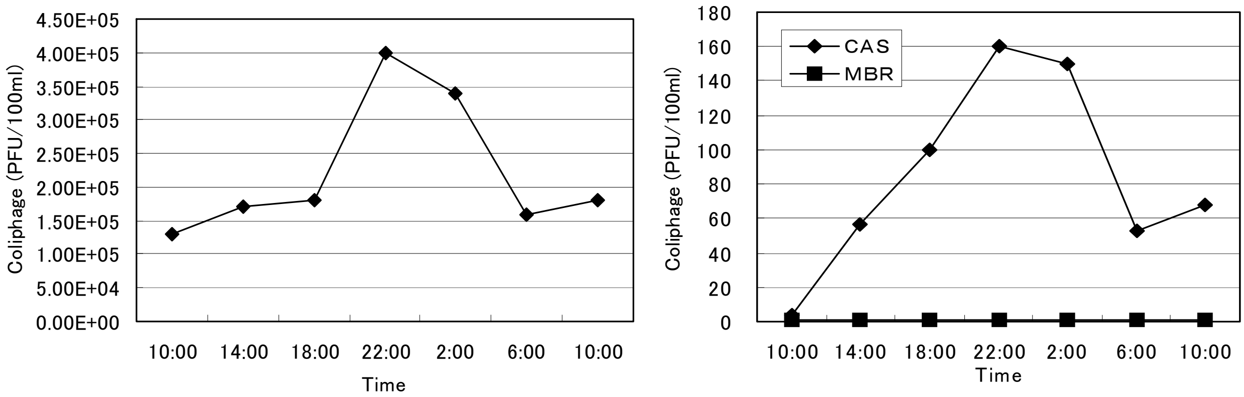

Figure 4. The change of Coliphage in inflow (left) and in effluent (right).

Removal of Norovirus
The pilot plant was operated with a total HRT of 6 hrs, 3hrs for anoxic tank and 3hrs for oxic tank, which is standard for MBR in Japan. Chemical membrane cleaning was carried out once a week using NaOCl solution (100mg/L as Cl) injected from the effluent suction line into the membrane module and then held for 1 hr.

The results of *Norovirus* measurements in influent, oxic tank activated sludge and effluent in are shown in Table 3. Here, G Ⅰ and G Ⅱ mean the different genome types of the *Norovirus* and usually G Ⅱ is mostly responsible for food poisoning. Neither type of G Ⅰ or G Ⅱ was detected in MBR effluent.

Table 3. *Norovirus* measurement results.

	Norovirus type	
	G Ⅰ	G Ⅱ
Influent	4.20E+07	3.50E+08
Oxic tank sludge	1.10E+08	6.20E+07
Effluent	N.D.	N.D.

(Copies/L)

The reason why Colipharges and *Norovirus* of approximately one-tenth of the membrane pore size are almost completely removed by MBR with MF membrane module is considered that since most of the viruses exist in the activated sludge attaching themselves to the activated sludge, they are rejected by membrane (Oota *et al*., 2005).

In order to evaluate the effect of chemical cleaning of membrane, the number of *Norovirus* was measured at 30, 60, and 120 minutes after the chemical membrane cleaning procedure using NaOCl solution. The results are shown in Table 4. If the gel layer on the membrane surface plays an important role on *Norovirus* removal, detection of *Norovirus* must be expected after chemical cleaning, since the gel layer is removed or reduced by chemical cleaning. As shown in the table, Norovirus was not detected in the MBR effluent even shortly after the chemical cleaning procedure. This suggests that the role of gel layer of the membrane surface is less important than the adsorption effect of the activated sludge in *Norovirus* removal mechanism.

Table 4. *Norovirus* measurement results after chemical cleaning.

Elapsed time after chemical cleaning	*Norovirus* type	
	G I	G II
30min	N.D.	N.D.
60min	N.D.	N.D.
120min	N.D.	N.D.

(Copies/L)

Conclusion

MBR effluent has characteristics that make it suitable for treated wastewater reuse, and can be applied to landscape use without any additional treatment. MBR is also able to remove viruses in wastewater effectively, which contributes to epidemic risk reduction in treated wastewater reuse.

Since MBR offers excellent effluent quality as well as stable operation performance even in small-scale plants, the introduction of MBR will greatly contribute to the overall promotion of water recycling in urban areas.

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