Japanese Experience of MBR Application to Municipal Wastewater

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Abstract

The introduction of MBRs has lagged behind compared with other fields of wastewater management in Japan, but four MBR plants started operation successively in 2005. MBR is expected to be increasingly used for municipal wastewater treatment. Although MBR has been used mainly for small scale plants so far, it will likely be applied to larger plants in the future. The MBR is not merely one of many wastewater treatment technologies, but is regarded as a core technology that offers various possibilities. In this context, the research results of virus removal, excess sludge reduction, odor emission and application to BNR process of MBR were introduced.

Keywords: MBR, municipal wastewater, virus, odor, excess sludge, BNR

Introduction

The membrane bioreactor (MBR) is a wastewater treatment technology that offers many advantages. In Japan, although MBRs have long been used for industrial wastewater treatment or for reuse of wastewater in large buildings and so on, the introduction of MBRs 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 will accelerate the introduction of MBRs in Japanese sewerage systems. This paper reviews the present state and perspectives of MBRs for municipal wastewater treatment in Japan and introduces some of JSWA's researches on MBR.

Characteristics of MBRs in Japan

Characteristisof Japanese municipal sewer system

The characteristics of Japanese municipal sewer system, to which MBR are applied, are as follows;

1) Most of sewer system are separate system with the exception of large scale cities.
2) The strength of raw wastewater is rather weak; BOD 200mg/L, SS 170mg/L, T-N 35mg/L, T-P 5mg/L on average.
3) In the middle and small-scale sewer systems, household wastewater occupies the most part.
4) Even in separate sewer systems, considerable amount of infiltration into sewer is

sometimes observed in rainy weather.

5) In small-scale sewer systems, the flow fluctuation is usually high, so that the peak flow amounts to three times of the average flow.

Flow of process

Considering some of the above mentioned characteristics of Japanese municipal sewer system, the basic flow of the MBR for municipal wastewater is as shown in Figure 1.[1]

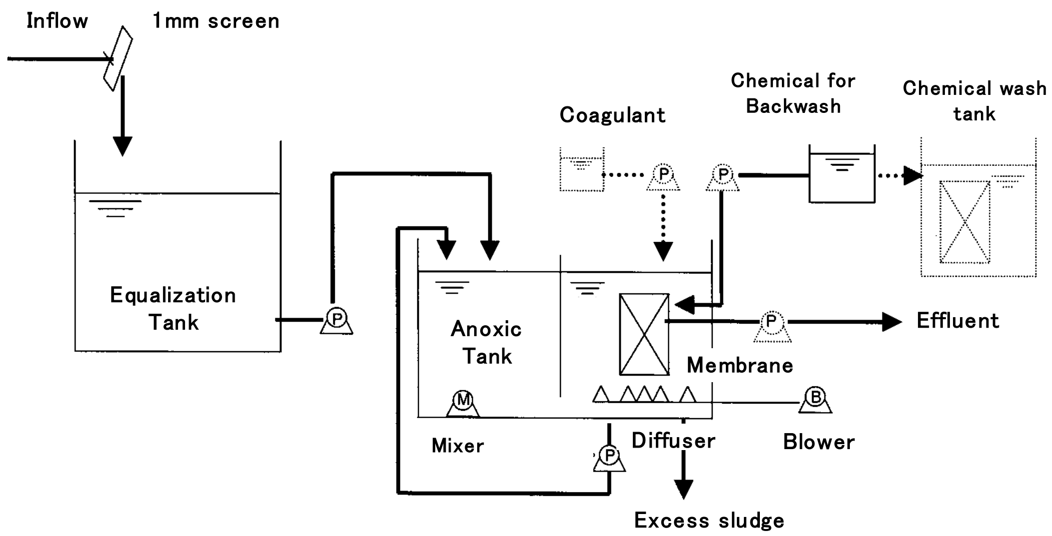

Figure 1 : The basic flow of MBR for municipal wastewater

Pretreatment

Inflow wastewater passes through a fine screen to remove coarse materials. Although a 1-mm screen is standard, a finer screen is required for some types of hollow fiber membrane modules. On the other hand, a coarser 2-3mm screen will suffice for some flat sheet membrane modules. In one pilot-plant study that treated actual wastewater of a separate sewer system, it was shown that fibers, vegetable residues and hairs were the main components of screen debris, with the amount of debris collected on a 1-mm screen being about 27g/m^3 as wet weight and 3g/m^3 as dry weight.

Flow equalization

The MBR is expected to be used mainly for small facilities for the present in Japan. Since the inflow volume fluctuates greatly in a small sewer, it is necessary to stabilize the permeate flux of the membrane module by using a flow equalization tank. The tank requires an HRT of about 4.5 hours based on the average flow.

Bioreactor

The bioreactor consists of an anoxic tank and an oxic tank. The membrane module is immersed in the oxic tank. The HRT of the anoxic tank and the oxic tank are each 3 hours, giving a total of 6 hours for the bioreactor. The mixed liquor is circulated from the oxic tank to the anoxic tank. Since nitrification advances in the oxic tank and pH falls by alkalinity consumption, the circulation helps to restore alkalinity through denitrification in the anoxic tank. Biological nitrogen removal can be achieved by circulation. The nitrogen removal ratio is determined theoretically by the circulation ratio.

Membrane module

For MBR, an MF membrane module with a pore size of 0.1–0.4 μm is usually used. In the design of MBR, the reactor tank is designed first and then the tenderer decides the type of membrane module.

Membrane modules are divided broadly into two categories: flat sheet (FS) and hollow fiber (HF). At present in Japan, flat sheet modules are used more commonly than hollow fiber modules. In the hollow fiber membrane module, new membrane modules are actively being developed and high permeate flux, long-length vertical membrane modules made of PVDF or PTFE are now becoming the mainstream of hollow fiber modules.

As one of the newest membrane modules, the monolith type ceramic MF membrane module has appeared recently. The monolith type module, which has a complicated pore structure, has already been introduced in the treatment of drinking water. Although the cost is still high and the module is considerably heavy, the ceramic module offers high flux and high durability, or long lifetime, and is expected as an effective tool in reducing membrane replacement costs.

Membrane life is an important factor that greatly influences the running cost of MBR. Judging from the various experiences of domestic and overseas MBRs treating sanitary wastewater, the membrane made of organic materials typically lasts at least seven years. In Japan, since the cost of replacing the membrane module after ten years of use is subsidized, ten years is regarded as the target membrane life.

Other equipments

Since no Escherichia coli is detected in the effluent, no disinfection equipment is installed. In the figure, flocculant dosing equipment is installed when phosphorus removal is necessary. Biological phosphorus removal is also possible by preparing an anaerobic zone in the bioreactor. Since the MBR is operated at a high MLSS concentration, the negative influences of DO on the anaerobic zone caused by mixed liquor circulation can be rapidly reduced and thus stable biological removal of phosphorus is possible.

Purpose of MBR application

MBR is thought to be suited for the following conditions;

1) Small footprint
2) Advanced treatment
3) Retrofitting of existing wastewater treatment plants
4) Reuse of treated wastewater
5) Chlorination not used for disinfection

Present state of MBRs for municipal wastewater in Japan

Although the introduction of MBRs has lagged behind compared with other fields of wastewater management, three MBR plants started operation successively in 2005. The first MBR, Fukusaki Plant, has been operating for one and a half year without any serious troubles. The in-line chemical membrane washing was not necessary for the first year.

The operating MBR plants for municipal wastewater treatment as well as MBR plants under construction are shown in Table 1. In addition, there are several MBR plants for municipal wastewater currently in the design or planning stage. The number of MBRs for municipal wastewater is expected to increase in the years ahead.

Name of the plant	Total design capacity (m^3/d)	Capacity for installation (m^3/d)	Membrane Type	Start of operation
Fukusaki	12,500	2,100	Flat sheet	In operation
Kobuhara	240	240	Flat sheet	In operation
Yusuhara	720	360	Flat sheet	In operation
Okutsu	580	580	Hollow fiber	In operation
Daito	2,000	1,000	Flat sheet	September 2006
Kaietsu	230	230	Hollow fiber	April 2007
Zyosai	1,375	1.375	Undecided	March 2008
Heta	3,200	2,140	Undecided	March 2008
Ooda	8,600	1,075	Undecided	March 2009

Notice: 1,000m^3/d roughly corresponds to 3,000PE

Table 1 : MBRs in operation and under construction or in the planning stage

The possibilities of MBR and the related researches of JSWA

Risk reduction of the water environment

It is known that a high degree of virus removal could be achieved by MBR. [2] According to previous research by the authors, it was found that Colipharges and Norovirus of approximately one-tenth membrane pore size were almost completely removed by a MF membrane. It was also found that most of the virus existed in the activated sludge, indicating that they attached themselves to the activated sludge. [3] It is suggested that the virus captured in the gel layer that forms on the surface of the membrane also contributes to virus removal. [4] Therefore it is considered that virus removal is influenced by the chemical washing of the membrane.

The behavior of Norovirus captured in the MBR activated sludge and the influence of the chemical cleaning of the membrane was investigated using a pilot scale MBR which treats 48 m^3/d of actual municipal wastewater. A hollow fiber MF membrane unit with 0.4μm pore size was immersed in the oxic tank and operated at a permeate flux of 0.8 m^3/m^2/d.

The pilot plant was operated with a HRT of 6 hrs in Run-1, in which the oxic tank HRT was 3 hrs. During the experiment however, in order to evaluate the effect of the HRT on virus removal, the total HRT was then extended to 18 hrs in which the oxic tank HRT was 6 hrs in Run-2 and 18 hrs in Run-3 respectively.

The number of Norovirus in the activated sludge decreased with prolonged oxic tank HRT, and the number of GⅠ type in Run –2 was about 1/1000 that of Run-1 as shown in Table 2.

	Run−1		Run−2		Run−3	
Oxic tank tank HRT(hrs)	3		6		18	
Genome type	GⅠ	GⅡ	GⅠ	GⅡ	GⅠ	GⅡ
Influent	4.20E+07	3.50E+08	2.50E+07	1.90E+08	2.50E+07	1.90E+08
Aerobic tank sludge	1.10E+08	6.20E+07	1.50E+06	N.D.	2.70E+05	N.D.
Effluent	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

(Copies/L)

Table 2: Norovirus measurement results for different aerobic tank HRT

This indicates that the aerobic decomposition of the virus, which was adsorbed in the activated sludge and retained in the oxic tank, will progress with the elapse of time.

The number of Norovirus was measured at 30, 60, and 120 minutes after the in-line chemical membrane washing using a 0.3% NaOCl solution. No Norovirus were detected in the MBR effluent after the completion of chemical washing procedure. This may suggest that the role of gel layer of the membrane surface on virus removal is less important than the adsorption effect of the activated sludge.

Reduction of excess sludge production

It is reported that excess sludge production can be reduced in MBR compared to other activated sludge processes. [5] An experiment using two 200L bench scale MBR plant was conducted to investigate the aerobic digestion function of MBR. The HRT of both bench scale plants were 18 hrs. One plant (Plant A) was operated with anoxic tank HRT of 9hrs, while the other plant (Plant B) was operated only under oxic conditions.

Both plants were fed with actual municipal wastewater and were operated continuously for four months without excess sludge withdrawal. Since the experiment was conducted during the winter season, the bench scale plants were heated to maintain the water temperature at 30℃ for the latter part of the experiment. Before the installation of the heater, the water temperature of the bench scale plants was around 15℃.

Plant A showed constantly higher TMP (Trans Membrane Pressure) than Plant B and chemical membrane cleaning was necessary in the last part of the experiment term. On the other hand, TMP of Plant B remained stably low. Excess sludge production rate was calculated based on the phosphorus balance of the process. The sludge production rates based on SS were 0.6-0.7 gSS/gSSin before the installation of the heater. After the installation of the heater, the sludge production rate decreased to 0.3-0.35 gSS/gSSin for both plants. In order to obtain consistency in the excess sludge reduction effect by MBR, measures to prevent heat loss of the MBR reactor during the winter season are required.

Odor emission of MBR

It is expected that MBR emits less odors compared with other activated sludge processes, since MBR has no primary settling tank and sludge is well stabilized under long SRT operations. The results of measurements of main odor components of MBR are shown in Table-3. In the table, the data of other activated sludge processes and primary settling tanks are also shown. Most of the odor component concentrations in the oxic tank exhaust gas of the MBR were lower than those of the CAS (Conventional Activated Sludge) process and the OD (Oxidation Ditch) process except dimethylsulfide. However, the odor component concentration of the air of anoxic tank headspace was higher than those of CAS and OD aeration tanks. It indicates that odor components will be generated under anoxic conditions. From the viewpoint of odor emission prevention, it is recommended to cover the anoxic tanks and ideally keep the headspace in a negatively pressurized condition.

The fine screen is also where odor may be being emitted. It is recommended that the equipment be contained in a building or covering.

Process	Ammnonia	Hydrogensulfide	Dimethylsulfide	Methylmercaptan	Dimethyldisulfide
MBR anoxic tank	0.08	0.074	0.018	0.093	0.002
MBR oxic tank	0.09	0.0009	0.0015	N.D.	N.D.
CAS	0.09	0.0037	0.0035	0.0029	0.0015
OD	—	0.0022	0.0002	0.0003	0.0001
Primary settling tank	0.35	0.59	0.037	0.065	0.005

(ppm)

Table 3: Results of odor measurement of MBR and other process

Application to BNR process

Figure 2 shows a new biological nutrient removal (BNR) process for large facilities. with membrane separation.[6] This process combines the step feed multi-stage nitrification-denitrification process, which is a popular BNR process in Japan, and membrane separation. In a single-stage MBR as shown in Figure 1, in order to obtain nitrogen removal efficiency of more than 80%, circulation ratio of some 400% (R=4) is necessary.

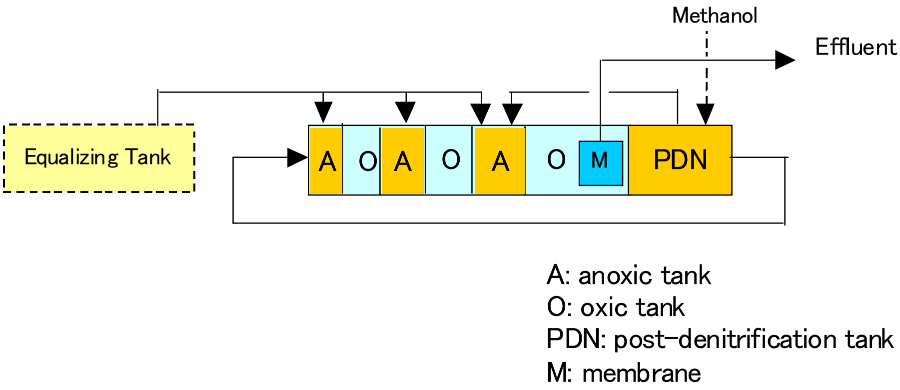

Figure 2 : Flow of the BNR process with membrane

However, in the membrane BNR process shown in Figure 2, a T-N removal efficiency of about 80% is acquired at a circulation ratio of 200%. The experiment results showed that stable nitrification and denitrification could be achieved even in low water temperature period. Good and stable biological phosphorus removal can be achieved if the first anoxic tank acts as an anaerobic tank. This is enabled by adding methanol to the post-denitrification tank and eliminating NOx-N in the returned mixed liquor.

Perspective of the future development of MBR

The MBR will not remain just one of many wastewater treatment technologies, but is expected to become a core technology that will be used for various types of wastewater management. Figure 3 shows the possible deployment of MBR.

In Japan, MBR is expected to be increasingly used for municipal wastewater treatment. Although the MBR has been used mainly for small scale plants so far, it will likely be applied to larger plants in the future.

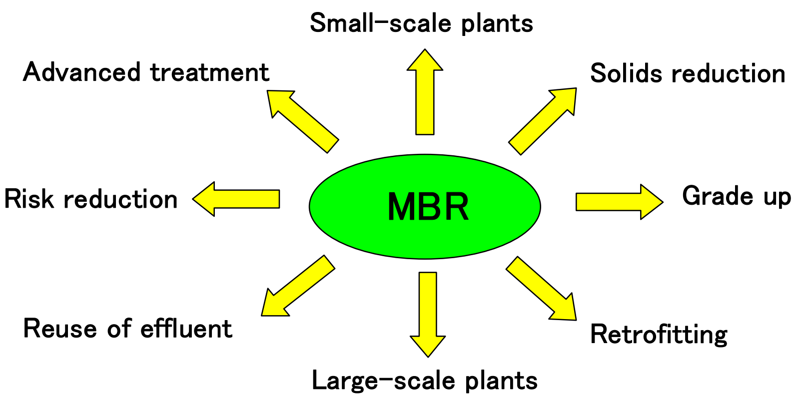

Figure 3 : The possible deployment of MBR

To enable the wider use of MBR for various purposes, the following issues are considered to be essential.

1) Optimization of the design method.
2) Optimization of the maintenance method, especially fouling control and chemical cleaning of membrane.
3) Reduction of membrane cost and prolongation of membrane life.
4) Reduction of energy consumption, especially air supply for membrane cleaning.

JSWA will continue technology development of MBR in cooperation with universities and private enterprises and will conduct the second technical evaluation of MBR based on the data obtained from the four operating actual MBR plants in the near future.

Summary

MBR is gaining a firm position in the wastewater treatment technologies and it offers various possibilities for wastewater management. However, there are still problems to be solved for the wider spread of MBR. The technical cooperation and information exchange with German engineers will greatly contribute to the technology development of MBR.

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Japanese Experience of MBR Application to Municipal Wastewater Treatment

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Introduction of JSWA

- Public organization established by the Government and local municipalities
- Purpose: Support local municipalities in sewage works
- Activities

  Planning/Design/Construction of WTPs

  Technical assistance

  Training of local municipality staff

  R&D

2

Outputs of JSWA Researches on MBR

- "Technical evaluation of MBR "(2003)

  Process configuration

  Operation & maintenance

  Performance

  Conditions of MBR application

  Costs

  etc.
- "The temporary design guideline "(2003)
- Five MBRs are in operation (2006)

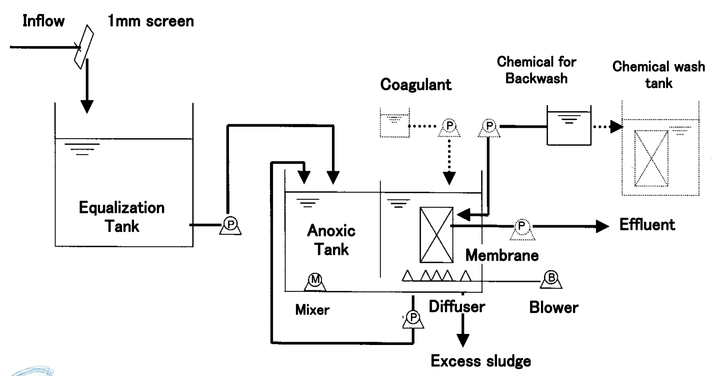
3

Characteristics of Japanese Municipal Sewer System

- Most of sewer systems are separate system.
- The strength of raw wastewater is weak.
- Household wastewater occupies the most part in the middle and small-scale sewer.
- Considerable amount of infiltration in rainy weather.
- High flow fluctuation in small-scale sewer.

4

Basic Flow of MBR



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Pretreatment

- 2-3 mm bar screen for FS
- 1mm or 0.5 mm drum screen for HF
- Equipped with automatic dewatering device

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Flow equalization

- 4.5hrs of HRT for small-scale plants
- Functions as a settling tank bypassing bioreactor in emergency

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Bioreactor

- HRT 3hrs for anoxic tank, 3hrs for oxic tank
- Possibility of the tank volume reduction

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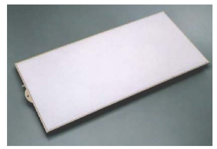
Membrane modules (FS)



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FS Membrane module for large-scale application

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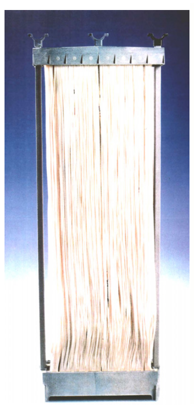
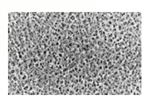
HF Membrane module





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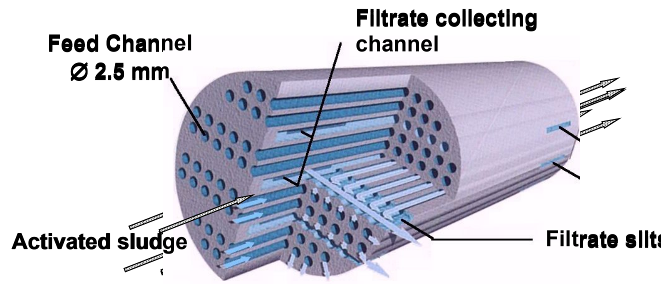
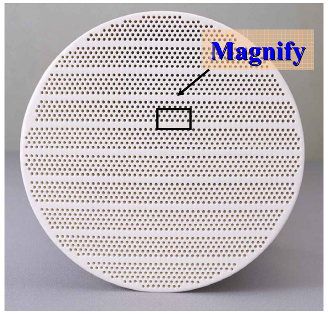
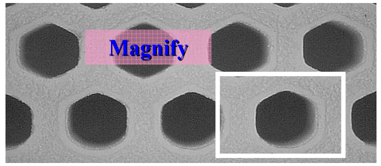
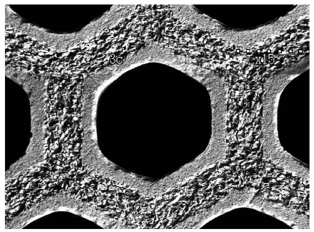
Ceramic monolith membrane module









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Present state of MBRs application for municipal wastewater

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MBRs in operation or under construction

Name of the plant	Total design capacity (m^3/d)	Capacity for installation (m^3/d)	Membrane Type	Start of operation
Fukusaki	12,500	2,100	Flat sheet	In operation
Kobuhara	240	240	Flat sheet	In operation
Yusuhara	720	360	Flat sheet	In operation
Okutsu	580	580	Hollow fiber	In operation
Daito	2,000	1,000	Flat sheet	In operation
Kaietsu	230	230	Hollow fiber	April 2007
Zyosai	1,375	1,375	Undecided	March 2008
Heta	3,200	2,140	Undecided	March 2008
Ooda	8,600	1,075	Undecided	March 2009

Notice: 1,000m^3/d roughly corresponds to 3,000PE

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Purposes of MBR application

- Small footprint
- Advanced treatment (C,N,P)
- Reuse of effluent
- Retrofitting
- Grade up of treatment
- Avoid chrolination in disinfection

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Fukusaki Plant

The first MBR for municipal wastewater in Japan

Started operation from the end of March, 2005
Capacity 2,100m^3/d (Planned Capacity 12,500m^3/d)

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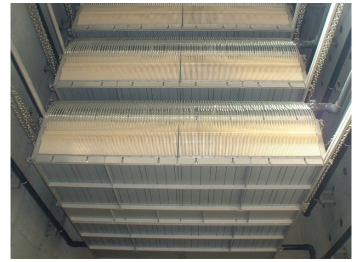
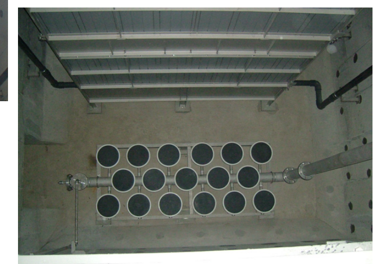
Membrane unit



Fine bubble diffuser



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Kobuhara Plant

240m^3/d（90m^3/d）

Furumine Shrine

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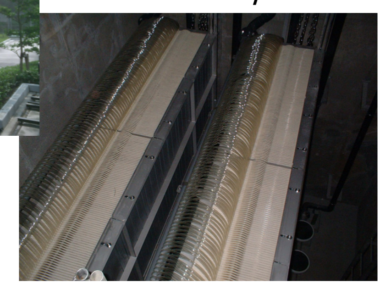
Yusuhara Plant

360m^3/d



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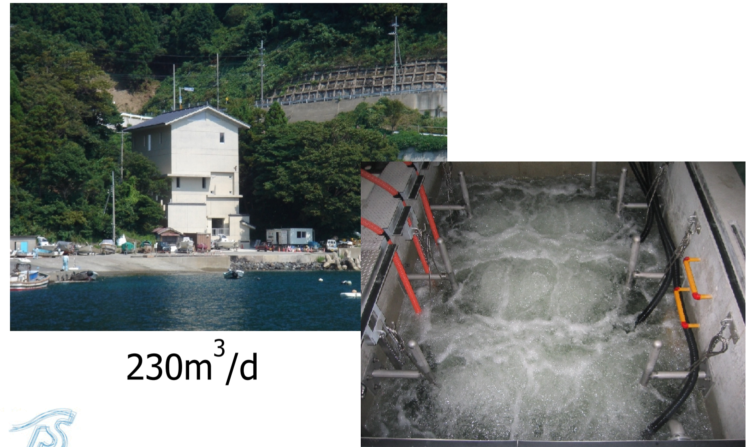
Okutsu Plant

580m^3/d

21

Kaietsu Plant



230m^3/d

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Introduction of JSWA researches on MBR

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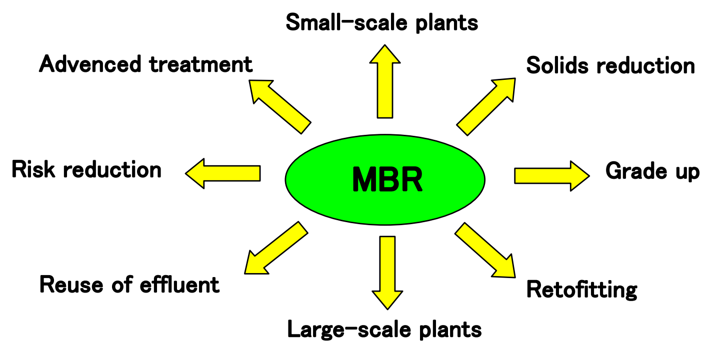
MBR as a core technology



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Risk reduction of the water environment

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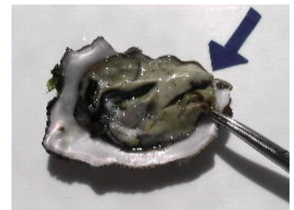
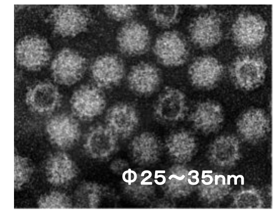
Norovirus

Main cause of food poisoning, especially oyster

Very small in the size

Tolerant toward chlorine disinfection





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Pilot plant

Capacity (m^3/d)	48
MLSS (g/L)	8-10
Membrane module	HF
Material	PVDF
Pore size (μm)	0.4
Flux (L/m^2/hr)	33
TMP (kPa)	<30

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Experimental condition

	Total HRT (hrs)	Oxic HRT (hrs)
Run-1	6	3
Run-2	18	6
Run-3	18	18

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Results of *Norovirus* mesurement

	Run−1		Run−2		Run−3	
Oxic tank tank HRT(hrs)	3		6		18	
Genome type	GⅠ	GⅡ	GⅠ	GⅡ	GⅠ	GⅡ
Influent	4.20E+07	3.50E+08	2.50E+07	1.90E+08	2.50E+07	1.90E+08
Aerobic tank sludge	1.10E+08	6.20E+07	1.50E+06	N.D.	2.70E+05	N.D.
Effluent	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

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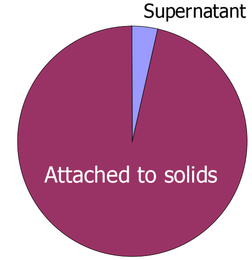
Location of Norovirus



Attached to flocks → Rejection by membrane

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Influence of in-line chemical cleaning

Elapsed time after chemical cleaning	*Norovirus* type	
	GⅠ	GⅡ
30min	N.D.	N.D.
60min	N.D.	N.D.
120min	N.D.	N.D.

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Summery of *Norovirus* removal

- High removal efficiency by MF MBR
- Adsorption of virus to sludge flocks is the reason of removal
- Gel layer on the membrane surface is not important for virus removal

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Sludge reduction by extended HRT operation

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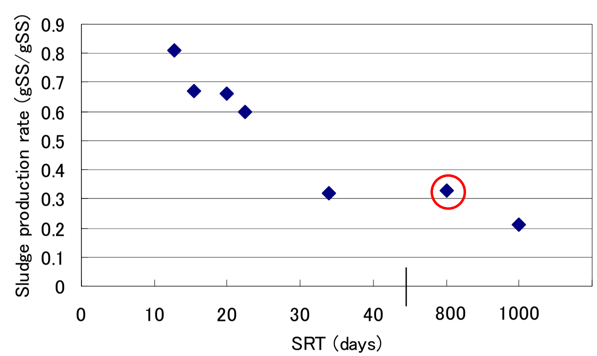
Sludge production and SRT



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- 200L Bench scale MBR with HRT 18hrs
  - A : anoxic 9hrs, oxic 9hrs
  - B : oxic 18hrs
- No big differences between A and B in sludge production
- Small sludge reduction effect at low temperature
- Sludge production depends on process SRT

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Odor emission of MBR

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Results of odor measurement

Process	Ammonia	Hydrogensulfide	Dimethylsulfide	Methylmercaptan	Dimethyldisulfide
MBR anoxic tank	0.08	0.074	0.018	0.093	0.002
MBR oxic tank	0.09	0.0009	0.0015	N.D.	N.D.
CAS	0.09	0.0037	0.0035	0.0029	0.0015
OD	—	0.0022	0.0002	0.0003	0.0001
Primary settling tank	0.35	0.59	0.037	0.065	0.005

(ppm)

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BNR process with membrane separation

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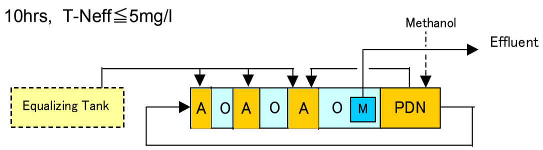
Application of Membrane to Large-scale BNR Process

HRT 10hrs, T-Neff≦5mg/l



A: anoxic tank
O: oxic tank
PDN: post-denitrification tank
M: membrane

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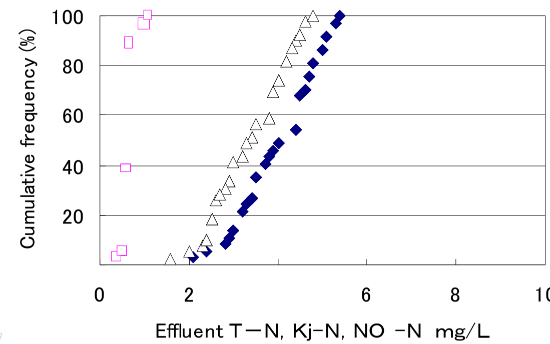
Nitrogen removal



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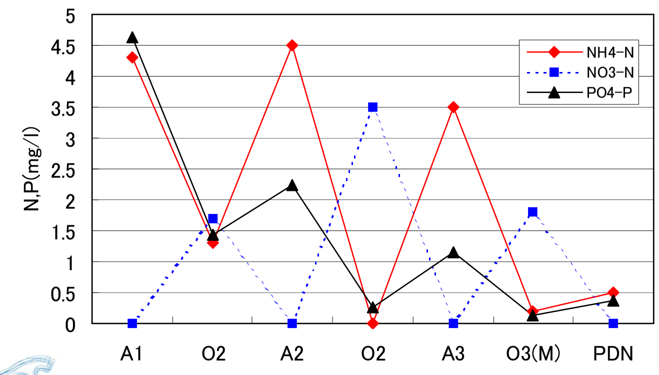
Profiles in each tank



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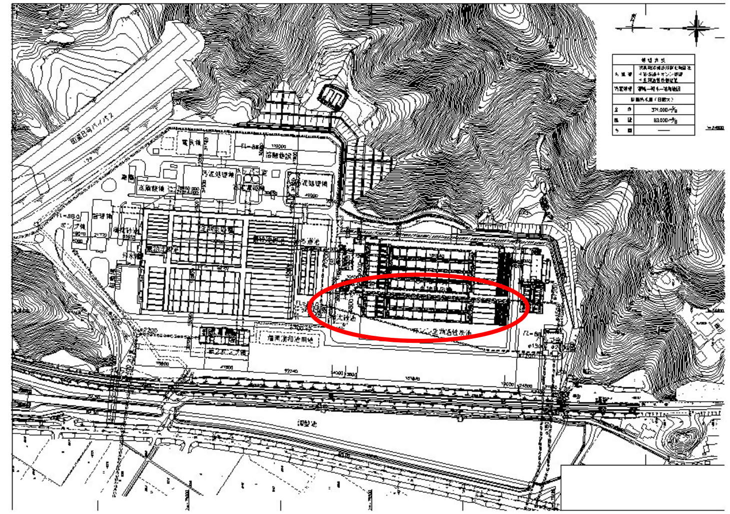

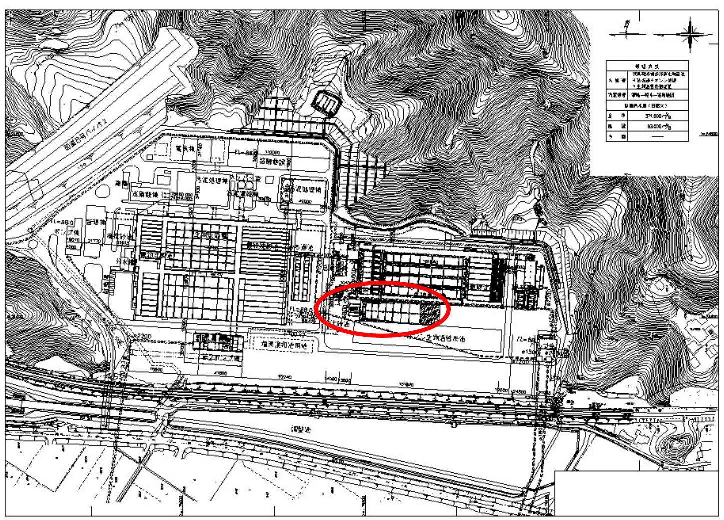

For the wider use of MBR;

- Opimization of the design method
- Optimization of the maintenance methods, especially fouling control and chemical cleaning of membrane
- Reduction of membrane cost and prolongation of membrane life
- Reduction of energy consumption, especially supply air for membrane cleaning are essential

MBR:0.8kWh/m^3, OD:0.6-0.7kWH/m^3

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JSWA starts joint research for large-scale application of MBR with;

Japanese privat

ISA, RWTH Aac

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Vielen Dank für Ihre Aufmerksamkeit

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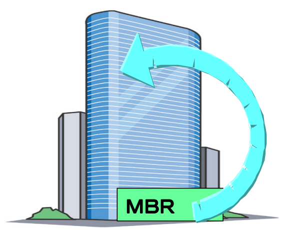
History of MBR application in Japan

- Industrial wastewater

- Reuse in large-scale buildings
  - Flash toilet
  - Sprinkle water



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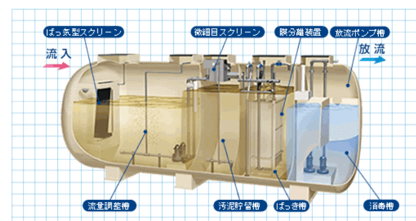
- Small-scale on-site treatment



From Kubota HP

- Night soil treatment

From Hitachi-zosen HP

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