State of The Art of MBR Technology and Its Perspective in Japan

Hiroki ITOKAWA*
Research and Technology Development Division,
Japan Sewage Works Agency (JS)

1. Introduction

Membrane bioreactor (MBR) technology is characterized as a combination of biological wastewater treatment (WWT) and membrane separation, by which biomass can retained in the system without conventional gravity sedimentation. This leads to well-characterized advantages of the technology over conventional activated sludge processes, including smaller reactor footprint, excellent effluent quality, and smaller sludge production (Judd, 2006). MBR has been successfully installed worldwide, not only for small-scale industrial wastewater treatment plants (WWTPs), but also for larger-scale municipal WWTPs (Yang *et al.*, 2006). Japan has been playing an important role in this field, especially by pioneering works regarding submerged MBR systems, as well as developments of a variety of commercial membrane systems.

In this short paper, development and installation of MBR systems in Japan, as well as ongoing R&D projects, are summarized particularly focusing on the application to municipal WWTPs.

2. Development of municipal MBRs in Japan

In Japan, full-scale commercial MBRs started to be installed in early 1980s, as an external cross-flow system. At that time, the principal target was a building-scale wastewater recycling system, which had been motivated by some local governments. As for domestic wastewater treatment, MBR has been used since 1985 for on-site individual house- to district-scale WWT system "*johkaso*". Especially after the "invention" of submerged MBR in late 1980s, MBR market for *johkaso* system has grown rapidly, and the number of installations is, at present, not less than 1,500. MBR has been also installed in nightsoil treatment plants and other small-scale domestic WWTPs since late 1980s, as well as installation to a number of industrial WWTPs.

In contrast to these small-scale WWT systems, application of MBR to larger-scale municipal WWTPs was behind the international trend, where in

* 5141 Shimosasame, Toda City, Saitama 335-0037, Japan e-mail: itokawah@jswa.go.jp

1998 the first full-scale plant was commissioned in UK. In the same year, Japan Sewage Works Agency (JS) launched a R&D project on MBR system development and evaluation for municipal WWTPs. Pilot-scale studies were conducted with four private companies with different membrane systems; two flat sheet (Kubota and Hitachi-Plant) and two hollow fibre (Zenon and Mitsubishi-Rayon) systems. According to the results of the project, in 2003, JS published "MBR Design Recommendations", in which system configuration and design parameters were specified (Table 1). An important feature of the document is that it shows universal design materials for small-scale municipal MBR (less than 3,000 m^3/d), including dimensioning of bioreactors and system arrangement plans, which can be used for any of four membrane systems (one more hollow fibre system from Asahi-Kasei was entitled in 2005). At the same time, JS carried out 2nd phase pilot-scale studies (2001-2004) with five membrane systems, particularly focusing on the reduction of operating costs. Based on these R&D projects and the design materials, the first full-scale municipal MBR was constructed and commissioned in March 2005 (Fukusaki WWTP; 2,100 m^3/d).

Table 1 Parameters specified in JS MBR Design Recommendations

Parameters	Design recommendation
Target capacity	200 - 3,000 m^3/d
Inflow equalization	Prerequisite
Pre-screen	1 mm of opening
Bioreactor configuration	MLE (Pre-denitrification)
Anoxic HRT	3 hr
Aerobic HRT	3 hr
Internal recycle	200%
Membrane system	Submerged, integrate

Table 2 Municipal MBRs operated in Japan

	Name	Operated since	Capacity		Mem. Type
			Present	Future	
1	Fukusaki	Mar 2005	2,100	12,600	FS
2	Kobugahara	Apr 2005	240	240	FS
3	Yusuhara	Dec 2005	400	800	FS
4	Okutsu	Apr 2006	600	600	HF
5	Daitocho	Sep 2006	1,000	2,000	FS
6	Tohro	Mar 2007	125	125	FS
7	Kaietsu	Apr 2007	230	230	HF
8	Jousai	Mar 2008	1,375	1,375	HF
9	Heda	Mar 2008	2,140	3,200	FS

3. Installation of municipal MBRs in Japan

As of the end of 2008, MBRs are operated in 9 municipal WWTPs in Japan, whose capacity ranges from 125 to 2,100 m^3/d (Table 2). Six of them use flat sheet membrane and the others use hollow fibre membrane. According to the JS Design Recommendations, all the plants were designed for pre-denitrification system, in which membrane units were submerged in oxic tanks (integrated system).

4. Ongoing project for larger-scale application

Internationally, there is a trend in MBR market for larger-scale application. Actually, some MBR plants are being constructed/planned whose capacity exceeds 100,000 m^3/d in US and even over 200,000 m^3/d in the Middle East. Considering these circumstances, JS started the 3rd phase pilot-scale project in 2006 toward MBR application to larger-scale municipal WWTPs (more than 10,000 m^3/d). The following points are particularly concerned.

(1) New membrane systems/modules: Some new membrane modules, developed for larger-scale installations, are tested. In addition, a new external MBR system with ceramics membrane from Metawater is evaluated.

(2) Variety of reactor configuration: In contrast to the fixed system configuration based on the present Design Recommendations (MLE with integrated submerged membrane), a MBR system for larger-scale WWTPs has to be more flexible, since the most of the case would be for up-grade of existing WWTPs. On this basis, a variety of system configurations are tested including separate/ external systems, incorporation of EBPR, and the use of primary sedimentation.

(3) New cleaning strategies: An increase in membrane modules in larger-scale MBRs requires more efficient chemical cleaning strategies with less labor. Although the approaches are different among membrane suppliers, new cleaning methods are tested in pilot plants (e.g. automated recovery cleaning, optimization of chemical dose).

(4) Post-treatment for reuse purpose: In order to cope with more stringent reuse requirements, post-treatment systems of MBR effluent using NF/RO membrane are experimentally evaluated and optimized for different kinds of commercial membranes.

5. Future perspective

Although we have almost 30 years of MBR application, we are still on "small-scale" stage concerning installation to municipal WWTPs. More promotion would be necessary to let the technology to be accepted by rather conservative plant operators. On this basis, the Ministry of Land, Infrastructure and Transport has started to prepare a guideline for membrane technology with through discussion in specific committee. In addition, MBR installation to an existing WWTP with 60,000 m^3/d of capacity is now under planning stage. This project will be a touchstone for the future of MBR technology in Japan. Re-consideration of urban water management, together with innovative water reuse scheme, will also favor the technology.

References

Judd,S. (2006) *The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment.* Elsevier, Oxford.

Yang,W., Cicek,N. and Ilg,J. (2006) State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America. *Journal of Membrane Sciences*, 270, 201-211.

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State-of-the-art of MBR Technology and Its Perspective in Japan

Hiroki ITOKAWA

R&TD Division,
Japan Sewage Works Agency (JS),
Japan

Japan Sewage Works Agency

Membrane bioreactor (MBR)

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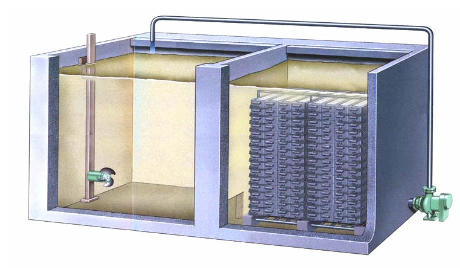
MBR: A combination of biological WWT (e.g. activated sludge) and membrane filtration as a measure for solid-liquid separation.

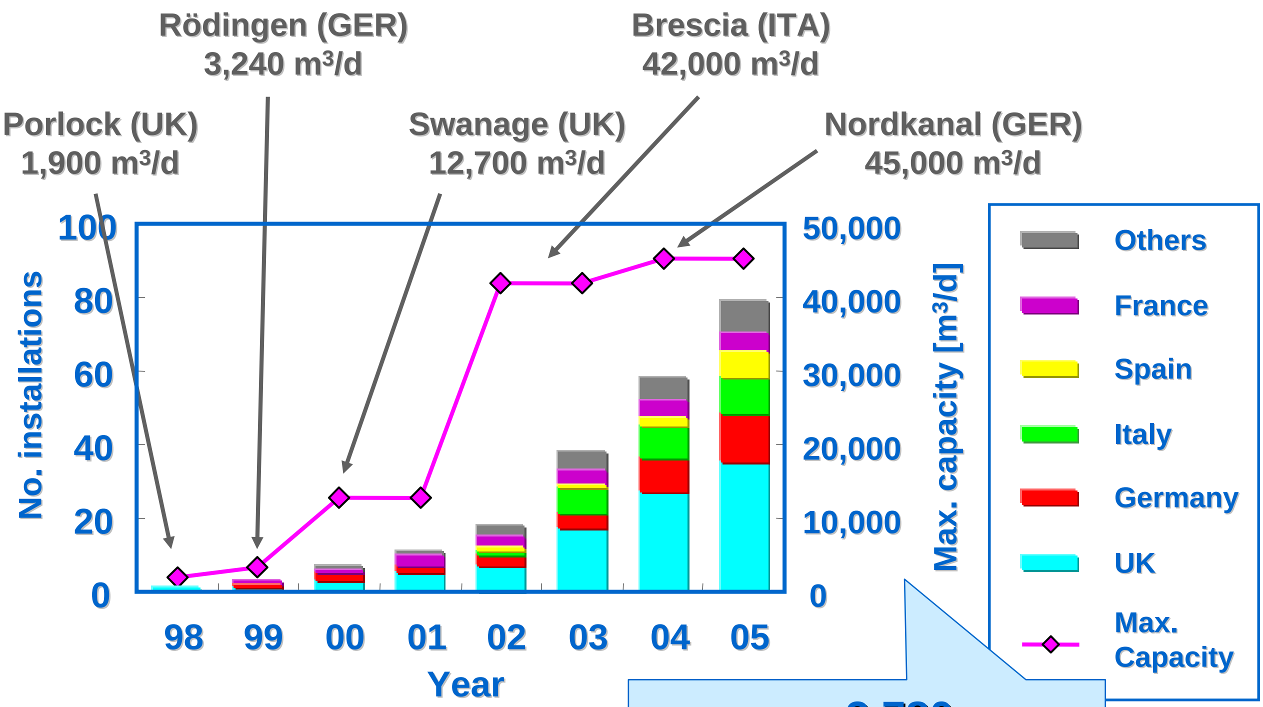
- **Advantages over CAS processes:**
  - Complete rejection of suspended solids.
  - Higher MLSS (>10 g/L).
  - Smaller footprint (< 6hr for BNR).
  - Smaller sludge production.
  - Simple monitoring parameters (e.g. TMP).



- **Installed worldwide, from small-scale on-site WWTPs to large-scale municipal WWTPs.**

- **Full-scale application to municipal WWTPs has just around ten years history.**

MBR - Growing market



Development of municipal
MBR installations in Europe

- Mean : 3,780 m³/d
- Median : 1,300 m³/d

Large MBR projects worldwide

WWTP name	Location	Commissioning	Hydraulic capacity
Jumeirah Golf Estates	Dubai	2010	220,000 m³/d
Palm Jebel Ali	Dubai	2010	220,000 m³/d
Brightwater	USA	2010	144,000 m³/d
Jebel Ali Free Zone	Dubai	2007	140,000 m³/d
International City	Dubai	2007	110,000 m³/d
Johns Creek	USA	2007	93,500 m³/d
Beixiaohe	China	2007	80,000 m³/d
Al-Ansab	Oman	2006	78,000 m³/d
Peoria	USA	2007	75,700 m³/d
Lusail	Qatar	2007	60,200 m³/d
Qinghe	China	2007	60,000 m³/d
Syndial	Italy	2007	47,300 m³/d

Development of MBRs in Japan

Toward larger-scale...

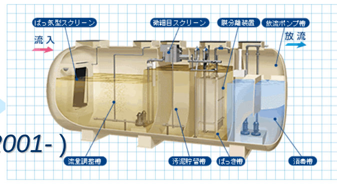
Building-scale on-site WWTPs (*1981-*)

On-site household WWTPs "*johkaso*" (*1985-*)

Night soil treatment plants (*1988-*)

WWTPs for "rural sewerage project" (*2001-*)

Municipal WWTPs (*2005 -*)



MBR for "*johkaso*"

98	99	00	01	02	03	04	05	06	07	08

JS Pilot-scale studies (1st phase)

- Feasibility
- Design parameters
- Operating cost reduction

JS Pilot-scale studies (2nd phase)

JS MBR Evaluation Report

JS Design Recommendations

1st installation

JS Pilot-scale studies (3rd phase)

- Larger-scale application

9 MBRs in operation

Night soil TP

WWTP for rural sewerage project

JS pilot-scale studies (1st phase)

➢ Pilot-scale study with 4 private companies (1998-2001)

- Four membranes (Kubota, Zenon, Mitsubishi Rayon and Hitachi Plant).
- Process evaluation.
- Design and operating parameters.

JS pilot-scale studies (2nd phase)

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➢ Pilot-scale study with 6 private companies (2001-2004)

- Five membranes (Kubota, Zenon, Mitsubishi Rayon, Hitachi Plant, and Asahi Kasei Chemicals).
- Reduction of operating cost by 30%.

Design guideline for municipal MBR

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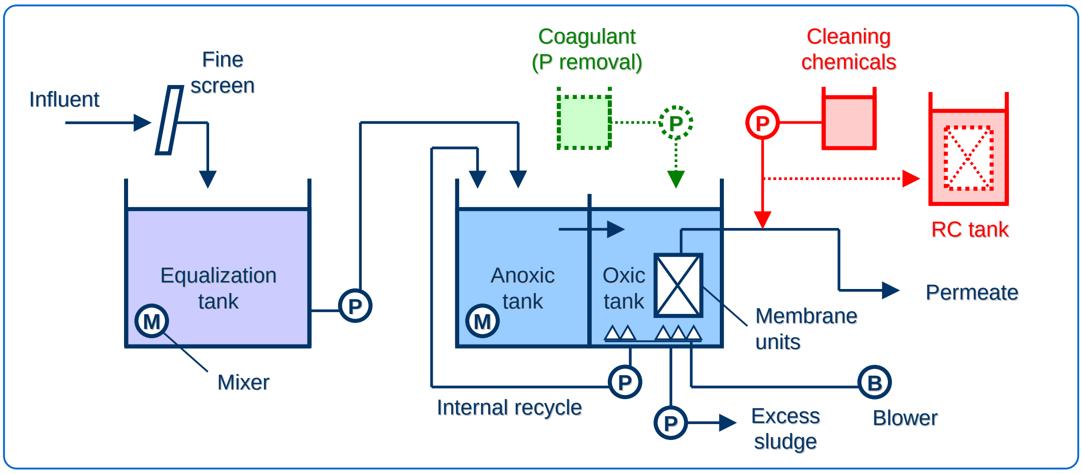
➢ JS Design Recommendations for MBR (2003)

- Fixed process configuration and design parameters.
- Even plant layout is "standardized" regardless of membrane type used.
  * Capacity: 200 - 3,000 m^3/d after flow equalization.



Design guideline for municipal MBR

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➢ JS Design Recommendations for MBR (2003)

- Universal design parameters.

Flow equalization	Prerequisite (4.6 hr, typically)
Fine screen	1 mm
Bioreactor configuration	Pre-denitrification (MLE)
Anoxic HRT	3 hr
Aerobic HRT	3 hr (membrane submerged)
MLSS	10 g/L
Internal recycle	200 % of influent

Municipal MBR installations

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No	Name	Commissioning	Capacity [m³/d]*	Supplier
1	Fukusaki	Mar 2005	4,200 (12,600)	Kubota
2	Kobugahara	Apr 2005	240	Kubota
3	Yusuhara	Dec 2005	400 (800)	Kubota
4	Okutsu	Apr 2006	600	Zenon
5	Daitocho	Sep 2006	1,000 (2,000)	Kubota
6	Tohro	Mar 2007	125	Kubota
7	Kaietsu	Apr 2007	230	Mitsubishi
8	Jousai	Mar 2008	1,375	Asahi-Kasei
9	Heda	Mar 2008	2,140 (3,200)	Hitachi

* A value in the parentheses indicates a full-capacity in future.

Municipal MBRs installations

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Fukusaki WWTP

- 2,100 m^3/d; to be expanded to 12,600 m^3/d
- Kubota FS membrane

Municipal MBRs installations

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Okutsu WWTP

- 600 m^3/d
- GE-Zenon HF membrane

Municipal MBRs installations

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Kaietsu WWTP

- 230 m^3/d
- Mitsubishi HF membrane

Ongoing project

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➤ **3rd phase pilot-scale study with 4 private companies (2006-2009)**

- Four membranes (Kubota, Hitachi Plant, Asahi Kasei Chemicals, and Metawater).
- Demonstrating systems for larger-scale installation.

Asahi Kasei Chemicals (HF)

Metawater (Ceramics)

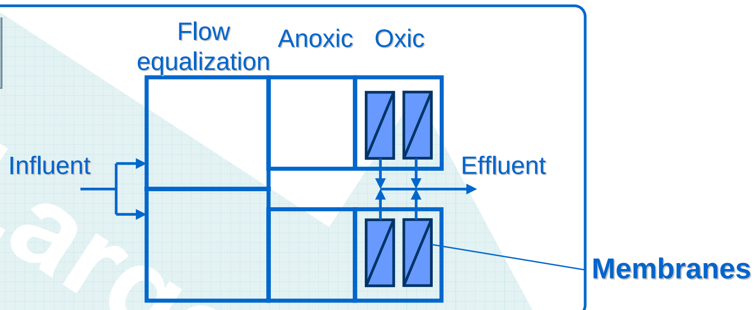
Kubota (FS)

Hitachi Plant (FS)

Toward larger-scale installations

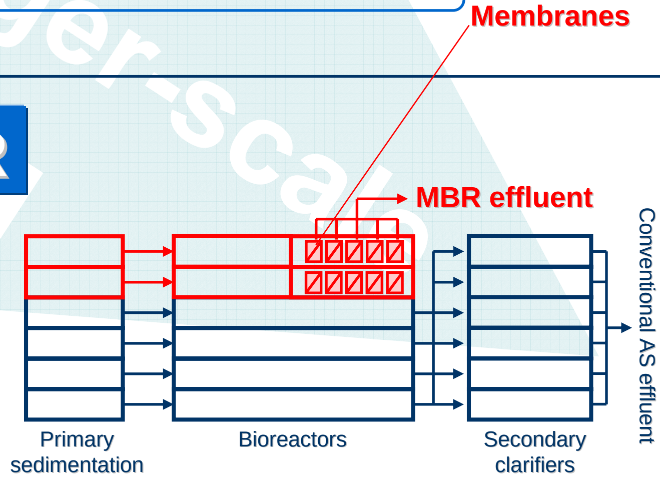
Small-scale MBR

- Less than 3,000 m³/d
- New construction
- Standardized system configuration



Larger-scale MBR

- Larger than 10,000 m³/d
- Upgrade/retrofitting
- System optimization under restrictions of existing facilities

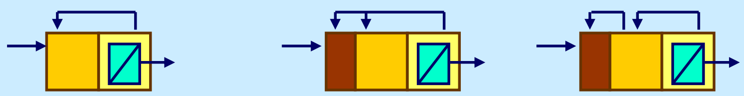


Toward larger-scale installations

- ➢ It is important to design the system fit to existing facilities.
- ➢ A standardized approach is no longer efficient; a variety of system configurations is required.

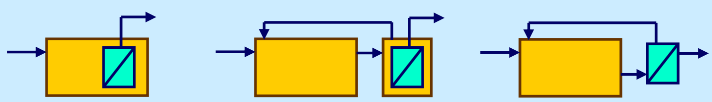
Biological treatment

- N removal (MLE)
- N&P removal (A2O, UCT)



Membrane filtration

- Integrated
- Separated
- External



Quality control/evaluation

- Design manual development
- Computer simulation

Membranes

- Flat sheet

- Hollow fibre

- Ceramics

Toward larger-scale installations 17

➢ In the 3rd phase pilot-scale studies, the following points are particularly concerned.

- New membranes/modules (modules with higher packing density, ceramic membrane...).
- Membrane systems other than integrated ones (separated or external system).
- Optimized internal recycle.
- Incorporation of EBPR.
- Gravity filtration for FS membranes.
- Use of primary sedimentation.
- Improved chemical cleaning (automated RC, optimized doze...).
- Post RO treatment for effluent reuse.

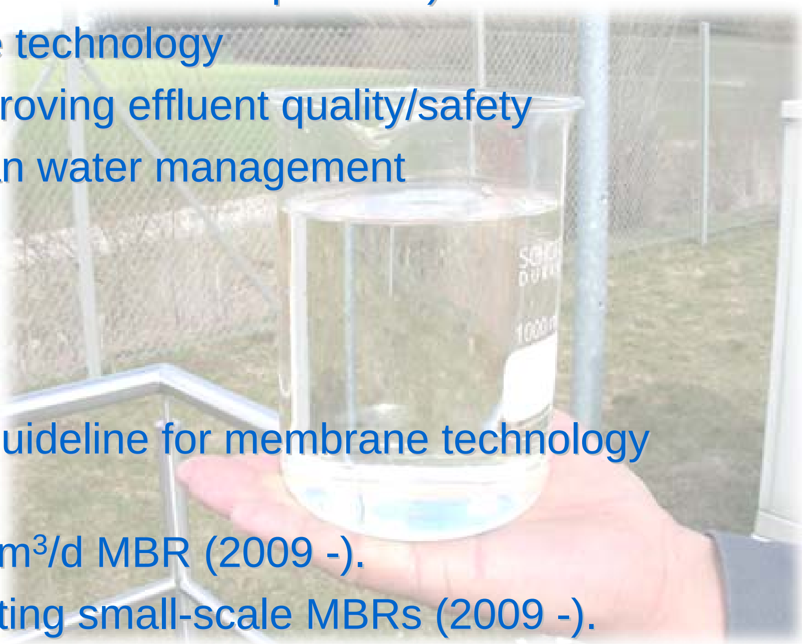
Future perspectives 18

➢ What is necessary for the FUTURE of MBR in Japan

- Cost reduction (construction & operation)
- Acceptance of the technology
- Motivation for improving effluent quality/safety
- Innovation in urban water management

➢ Current topics

- Preparation of a guideline for membrane technology by MLIT (2008 -).
- Design of 60,000 m^3/d MBR (2009 -).
- Evaluation of existing small-scale MBRs (2009 -).

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