Guidelines for Introducing Membrane Technology in Sewage Works: The 2nd Edition

March 2011

Sewage Technical Meeting on Membrane Technology

Introduction

Sanitation coverage in Japan reached 73.3% of the total population by the end of the fiscal year 2009, thanks to steady progress in the implementation of sewage systems. Sewage works still face many problems, however, such as how to improve the water quality in a closed water area, how to construct a sound water circulation system, and how to systematically reconstruct aging facilities.

Membrane technology is expected to be a critical solution for such problems in the future, and Japan is a world leader in terms of the accumulation of the art and know-how of this technology. Aiming to achieve efficient, sophisticated, sewage facilities, our progress with regard to the application of membrane technology is therefore expected.

To encourage broader use of membrane technology through its application, mainly, in medium- to large-scale sewage treatment plants for which demand for reconstruction will increase in the future, it is necessary to improve the conditions required for introduction of membrane technology by local governments. To set technical guidelines, in June 2008, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) launched "Sewage Technical Meeting on Membrane Technology," which was responsible for the above tasks, and as a result of which, the "Guidelines for Introducing Membrane Technology in Sewage Works: The 1st Edition" was issued in May 2009.

Subsequently, the MLIT assessed the classification of the designed effluent water quality according to its suitability for membrane bioreactors (MBR), the recycled nitrification/denitrification process that separates activated sludge with a membrane, or the same process with added coagulant. At the same time, the MLIT launched the "Advance of Japan Ultimate Membrane bioreactor technology Project (A-JUMP)" in fiscal year 2009 to promote the full-fledged penetration of MBR as a foundation of membrane technology for sewage treatment, and implemented "Demonstration of MBR Introduced When Reconstructing Existing Sewage Treatment Facilities" and "Demonstration of MBR Introduced to Satellite Treatment Facilities," which demonstrated the applicability, high performance, and energy saving capability of MBR. The former, in particular, achieved excellent results in energy saving, with approximately 40% lower energy consumption compared to the conventional process. In addition, other organizations began promoting the R&D and demonstration of membrane technology for application in the water business; for example, the New Energy and Industrial Technology Development Organization (NEDO), an independent government agency, launched a water-saving, environment-conscious water recycling project in fiscal year 2009. This technology is expected to achieve higher performance, including increased energy savings.

To reflect the achievements of such demonstration and R&D projects, as well as the latest findings both in Japan and overseas, this document was revised by the Sewage Technical Meeting on Membrane Technology. The revised document contains a significant amount of maintenance management and cost information based on such results and findings, and also describes the overseas trends toward standardization, which is useful information for Japanese companies planning to enter into the water business overseas in the future.

MBR has been increasingly used at large-sized treatment plants worldwide, and movement toward standardization has also been accelerating in various countries. Therefore, we consider that MBR will become a core technology for use when reconstructing, upgrading, or enhancing medium- to large-scale treatment plants also in Japan. We hope that readers use these guidelines to deepen their knowledge on membrane technology.

March 2011
Kazuo Yamamoto
Chairman of the Sewage Technical Meeting on Membrane Technology

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(In random order, as of March 2011)

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Chapter 1 Status of These Guidelines

These guidelines organize both present fundamental information and latest findings on membrane technology used mainly for sewage treatment, and cover the considerations and concerns that should be taken into account when a local government adopts membrane technology in its sewage plants. More specifically, the guidelines describe considerations for adopting membrane technology, especially MBR, as an alternative to the conventional solid-liquid separation method using gravitational sedimentation. They also describe considerations for introducing membrane technology, including MBR, for reclaimed water use. These guidelines roughly consist of the following sections:

An overview of membrane technology and the implications of its installation (Chapter 2)

Considerations regarding the installation of MBR in mainly newly-constructed sewage treatment plants (Chapter 3)

Considerations regarding the installation of MBR in existing sewage treatment plants (Chapter 4)

Considerations regarding the installation of membrane technology for reclaimed water use (Chapter 5)

Membrane technology is still under development, however, which means that it is expected to achieve significantly reduced costs and energy consumption in the future. Therefore, note that the costs and considerations in these guidelines are based on data at present, and should be used only for reference.

Moreover, these guidelines discuss the future development of membrane technology in Appendix I as a reference, because this technology is projected to become a fundamental approach for various applications in future sewage treatment operations, such as in the reconstruction of sewage treatment facilities, the enhancement of processes confined to a limited space, the use of reclaimed water, and the reduction of pathogenic microorganisms and other water system risks.

The first edition of these guidelines (published in May 2009) presented an overview of membrane technology and the possibilities for its installation. The second (revised) edition has additional information on the installation costs and maintenance management based on the findings from demonstrations in the Advance of Japan Ultimate Membrane bioreactor technology Project (A-JUMP*[1]), trends in technological development, and the increased number of membrane technology installations in Japan.

Appendix II provides an overview of the results from the demonstrations in the A-JUMP, while Appendix III describes overseas trends toward standardization of membrane technology in applications other than sewage treatment.

[1] A-JUMP: Advance of Japan Ultimate Membrane bioreactor technology Project

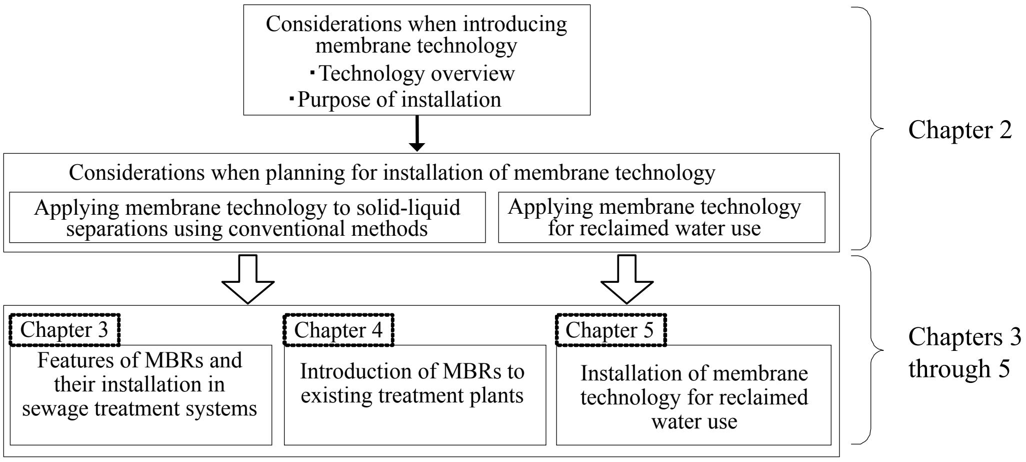


Figure 1-1 Contents of these guidelines

(Definition of Terms)

Membrane treatment: Separation of a target substance from solution using a solid membrane that has a separating function. The substance is separated by size (size separation) or by using dissolution-diffusion phenomena, etc. In some cases, membrane treatment is further classified into several different types, such as those where the membrane alone serves a separating function and those where separation is combined with other treatment processes. In these guidelines, however, both are called "membrane treatment."

Membrane element: A device in which the membrane, its support, and the flow path parts are integrated.

Membrane module: A device in which the membrane element is installed within the water treatment equipment or instrument. There are three types of membrane modules: sheet-like, tubular, and hollow fiber. Among the sheet-like membrane modules, flat sheet membrane modules and spiral wound modules are most common. The tubular type is represented by a module with a small bundle of membrane fibers housed in a case. A typical hollow fiber module is made by bundling several hollow fibers with both ends of the bundle covered by a resin, and with a single or multiple bundles fixed to a case.

Membrane unit: Instrument consisting of a membrane module and other components, such as the aeration section that supplies air necessary for biotreatment, agitation, and membrane cleaning, and the water collection section that draws and collects the filtrate water. Table 1-1 shows examples of a membrane element, membrane module, and membrane unit.

MBR: The abbreviation of "membrane bioreactor," a collective term for various activated sludge processes that separate activated sludge from water with a membrane. MBRs normally use a microfiltration membrane and are classified into three types: the immersed type (integrated type), the immersed type (separated tank type), and the external tank type (See Table 3-1).

Fouling: Situation where adhered substances accumulate on the surface of the membrane and clog the filtration flow path over time. To prevent fouling, it is necessary to conduct regular cleaning (to remove the adhered substances).

Permeation flux (flux): The flow rate of filtration per membrane surface area ($m^3/(m^2 \cdot d)$ -> m/d)

Trans-membrane pressure difference: The pressure required to obtain filtrate water. Also called the "inter-membrane pressure difference," "filtration pressure difference," or TMP (Trans Membrane Pressure).

Conventional process: In these guidelines, this term refers to treatment processes such as the standard activated sludge process, the recycled nitrification/denitrification process, and the anaerobic-anoxic-oxic process specified by the Order for Enforcement of the Sewerage Service Act and notification (No. 530 "Controlling Certification of the Business Plan Caused by the Revised Order for Enforcement of the Sewerage Service Act" by the

Director-General of the City and Regional Development Bureau, MLIT on March 29, 2004).

Paralleled operation of MBR and conventional processes: In these guidelines, this term means the process where an MBR and a conventional process are run in parallel in one treatment plant. Sometimes this system is referred to as a "hybrid MBR."

Facility, Equipment, Instrument, and Device: These terms are defined as follows, in accordance with the "Guidelines for sewage planning and design and instructions[1)]."

Facility: Structure or other large object (sewage facility, treatment facility, etc.)

Equipment: Functions by methodizing operations (pretreatment equipment, membrane treatment equipment, disinfection equipment, etc.)

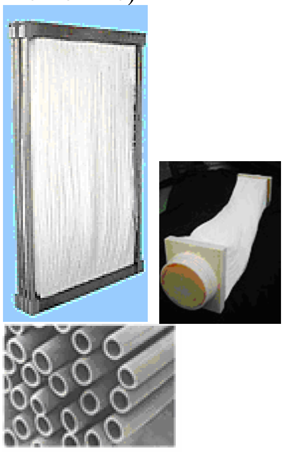
Instrument: Operates as a unit of combined devices (aeration instrument, membrane unit, etc.)

Device: Machines or apparatuses that constitute instruments or equipment, such as membrane modules, etc.

Table 1-1 Examples of membrane elements, membrane modules, and membrane units

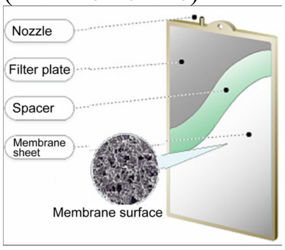
(Examples of membrane elements)

(Hollow fiber type membrane)



Consists of many membranes (hollow fibers) fixed at both ends of the water collecting tube

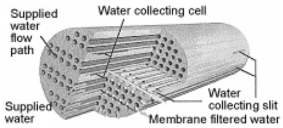
(Flat membrane)



Sometimes called a "membrane module element," a "membrane cartridge," or a "membrane cassette."

Consists of a sheet-like flat membrane installed on a support

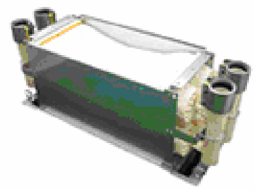
(Monolith membrane)



Consists of a single element having many flow paths, with the membranes sintered (generated) on the surface

(Example of a membrane module)

(Hollow fiber type membrane)

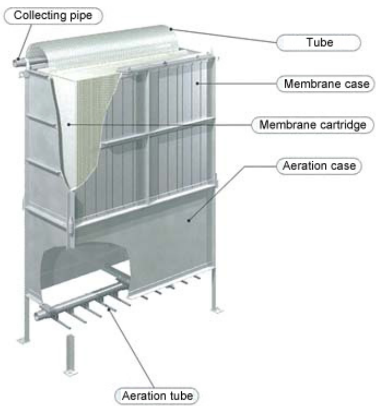


A unit where multiple membrane elements are integrated

(Example of a membrane unit)

(Hollow fiber type membrane)

(Flat membrane)



(Monolith membrane)

Consists of the membrane element, collecting pipe, membrane case, aeration case, and aeration instrument

* There are no strict classifications for the names of the "membrane elements," "membrane modules" and "membrane units." Use of these names varies depending on the type, shape, and manufacturer.

Chapter 2 General Statement

This chapter provides an overview of the fundamental matters relating to membrane technology, such as the membrane separation treatment process represented by MBR, and discusses the significance and current status of its introduction in sewage treatment facilities.

2.1 Overview of membrane technology

2.1.1 Overview of membrane technology and its applicability

(1) Overview of membrane technology

Membrane technology separates substances through a membrane using momentum, such as a pressure difference, a concentration difference, or a potential difference. Removed substances are directly filtered through the membrane or in combination with a biotreatment process or agglomeration.[2)]

(2) Applicability of membrane technology

Membrane technology is applied in a wide range of fields, and therefore has become an indispensable technology for separating and refining substances. It can be applied in the following fields:

- Manufacturing (refinement, concentration, separation, recovery, and dehydration)
- Medical (blood dialysis and artificial lungs)
- Water treatment (seawater desalination, water purification, sewage wastewater treatment, and sewage wastewater recycling)
- Fuel cells

2.1.2 Types of membranes

(1) Pore diameters of the membranes

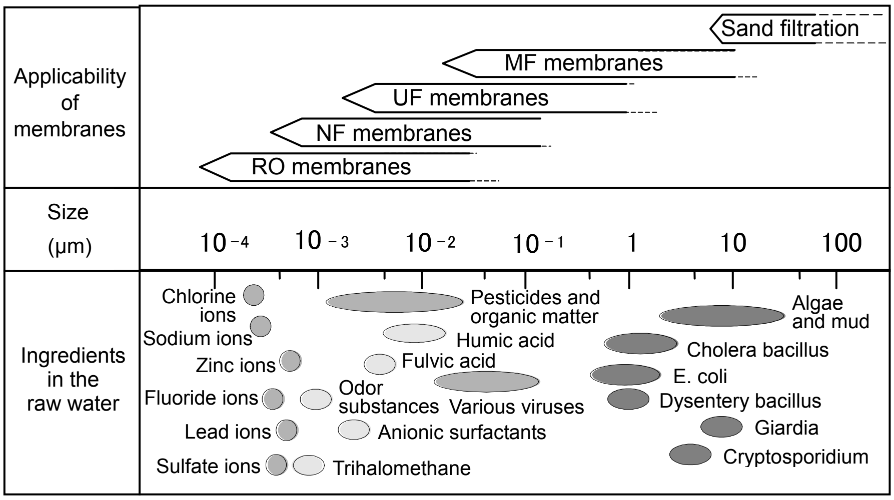
Membranes*[2] used for separation in water purification and wastewater treatment are classified into four categories as follows, in order of the size of the substances to be separated: microfiltration (MF) membranes; ultrafiltration (UF) membranes; nanofiltration (NF) membranes; and reverse osmosis (RO) membranes (See Table 2-1 and Figure 2-1).

[2] Classification of membranes: As classification varies depending on the manufacturer and the field of application, the range of pore diameters and operation pressures overlap (See Figure 2-1). According to the IUPAC (International Union of Pure and Applied Chemistry) definition from 1996, MF membranes refer to those with a pore diameter of > 0.1 µm, UF membranes, 2 nm to 0.1 µm, and NF membranes, < 2 nm.

Table 2-1 Substance characteristics and operating pressures for membrane filtrations

Type of membrane	Substances to be separated (separation performance)	Operation pressure
MF	0.01 to 10 µm particles	Negative pressure to a few 100 kPa
UF	Molecular weight of 1,000 to 200,000	A few 10 kPa to a few 100 kPa
NF	Molecular weight of 200 to 1,000	A few 100 kPa to a few MPa
RO	Molecular weight of up to 350	A few MPa to 10 MPa

Note: Operating pressures vary depending on the raw water characteristics and the targeted water quality. The substances to be separated using the UF and NF membranes are quoted from Reference 3).



* Data from Reference 3)

Figure 2-1 Types of membranes and the substances that they can separate

[1] MF (microfiltration) membranes

With a pore diameter of approximately 0.01 to 10 µm, MF membranes can separate and remove fine particles and bacteria. The MF membranes commonly used for MBR have a pore diameter of 0.1 to 0.4 µm, which is smaller than that of filter paper for SS (suspended solids) measurement (1 µm) and the size of bacteria such as E. coli (generally about 1 µm), enabling the removal of particles, etc. to the point where no SS are detected in the treated water. MF membranes are also used as sterile filtration filters and in similar applications for medical use.

[2] UF (ultrafiltration) membranes

With a pore diameter smaller than those of MF membranes, UF membranes are used for the concentration and filtration of high molecular weight substances with a molecular weight of at least a few thousand, such as proteins. In addition to particles, UF membranes can also remove some viruses and dissolved organic substances.

[3] NF (nanofiltration)/RO (reverse osmosis) membranes[*3]

NF membranes are also called "loose RO membranes" because they are in a broad sense, a type of reverse osmosis membrane. NF/RO membranes separate substances using the difference in their affinity to the membrane material (i.e., molecules and ions); water molecules can be easily dissolved into the membrane material, while the substances cannot. In processes using such membranes, the membrane charge considerably affects the removal mechanism.

(2) Membrane materials

Membranes can be roughly classified by the material from which they are prepared, and are considered to be organic or inorganic.

The organic materials used for MF and UF membranes include polysulfone (PSF), polyethylene (PE), cellulose acetate (CA), polyacrylonitrile (PAN), polypropylene (PP), polyvinylidene fluoride (PVDF), and polytetrafluoroethylene (PTFE), while polyamides are largely used for NF/RO membranes.

Ceramic is the typical inorganic material for MF, UF, and NF membranes, but metal membranes have also been developed.

Table 2-2 lists the typical membrane materials and their characteristics.

Table 2-2 Typical materials and characteristics of membranes

	Main materials	Characteristics
Organic	PVDF, PE (chlorination and hydrophilic treatment[*4]), PP, PTFE, etc.	Heat and chemical resistance vary depending on the materials. Exercise caution when storing or chemically cleaning.
Inorganic	Ceramics (aluminum oxide, titanium oxide, zirconium oxide, etc.)	Superior heat and chemical resistance compared to organic membranes, but caution is required for handling due to their poor impact resistance.

2.1.3 Overview of membrane separation equipment

Table 2-3 shows the classification of membrane separation equipment depending on factors such as the filtration method, the driving pressure method, and the types of membrane modules. Each item in the table is discussed below.

[3] NF/RO membranes: The difference in treatment performance between RO membranes and NF membranes is decreasing. RO membranes are sometimes sub-classified as SWRO (seawater desalination RO membranes) and BWRO (low-pressure RO membranes). The standards for membrane modules for water service classify membranes according to the elimination rate of NaCl; seawater desalination RO membranes eliminate at least 99.0% of NaCl, while RO membranes eliminate at least 93%, and NF membranes 5 to 93%.

[4] Chlorination/hydrophilic treatment: A process for improving the hydrophilic properties and the resistance to chlorine as a countermeasure against fouling, etc.

Table 2-3 Classification of membrane separation equipment

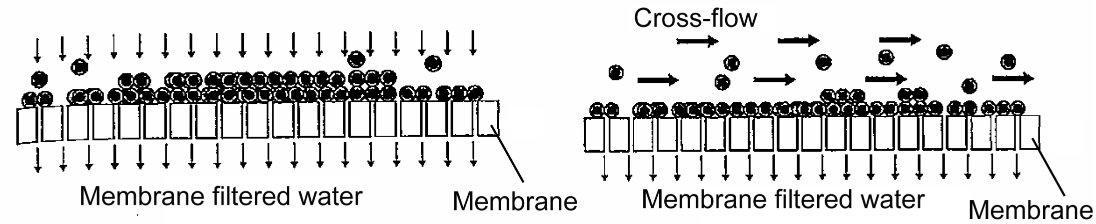
Item	Classification
(1) Filtration method	a) Normal flow filtration b) Cross-flow filtration
	a) Internal pressure b) External pressure
(2) Driving pressure method	a) Pump pressurizing type b) Pump suction type c) Water level difference type
(3) Type of membrane module	a) Hollow fiber b) Flat sheet c) Spiral d) Tubular e) Monolith
(4) Cleaning method of membrane	a) Physical cleaning b) Chemical cleaning

* Data from Reference 4)

(1) Filtration method

1) Normal flow filtration and cross-flow filtration

As specified in Figure 2-2, there are two filtration methods for membrane technology: normal flow filtration (dead-end filtration) and cross-flow filtration.



a) Normal flow filtration **b)** Cross-flow filtration

Data from Reference 2), partially revised

Figure 2-2 Filtration methods (normal flow filtration and cross-flow filtration)

Normal flow filtration requires the suspension of operations at regular intervals in order to remove the accumulated layer of adhered substances that are attached to the membrane as a result of repeated filtration.

Cross-flow filtration, on the other hand, adopts a flow direction paralleled to the membrane surface, which enables constant cleaning of the surface while filtering the water. Filtration and cleaning can be simultaneously achieved, and therefore continuous operation is possible, and the filtration speed can be maintained at a high level. This method, however, requires a high flow level on the supplied water side compared to a permeation flux in order to produce satisfactory parallel flow, which requires higher energy consumption per flux.

2) Internal and external pressure filtration

The internal pressure filtration method supplies raw water to the inside of the membrane (the inside of the hollow fibers or tubes) and discharges treated water to the outside (the outside of the hollow fibers or tubes). The external pressure filtration method, on the other hand, supplies raw water to the outside and discharges treated water to the inside. All of the immersed-type MBRs (discussed later in 3.1) supply raw water to the outside of the membrane; therefore, they are classified as external pressure membranes.

External pressure membranes have a low permeation flux compared to internal pressure membranes, but are compatible with an extensive range of membrane cleaning methods (See (4)), and can be used for raw water containing many suspended particles. As a result, the external pressure type is commonly adopted in the wastewater treatment sector.

(2) Driving pressure method

Membrane filtration requires a trans-membrane pressure difference, or a pressure difference between the supplied (raw) water side and the membrane filtered water side. The trans-membrane pressure difference can be generated in the following ways: use of a pressurizing pump, use of a suction pump, or a water level difference.

a) Pump pressurization: Applies pressure to the supply side of the membrane using a pump.

b) Pump suction: Suctions water from the membrane filtered water side using a suction pump.

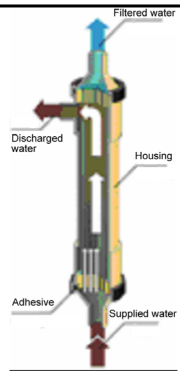
c) Water level difference: Applies pressure on the supply side or suctions water from the filtered water side using the difference in water level between the immersed membrane tank and the water filtration tank, or between the membrane filtered water tank and the supply water tank.

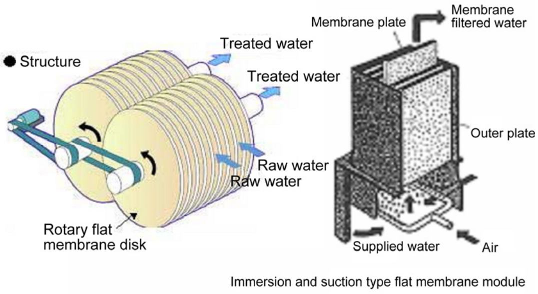
(3) Types of membrane modules

Membrane modules that are typically adopted in water purification and wastewater treatment systems are classified into several types, including hollow fiber, flat sheet, spiral, tubular, and monolith.

Figure 2-3 shows the main types of membrane modules adopted for water purification and wastewater treatment.

<table>
<tr>
<td>Hollow fiber type membrane</td>
<td colspan="2">Hollow fiber type
This type of module has several hollow fiber membranes with an outside diameter of 0.5 to 3 mm. The water is filtered through a macaroni-like hollow tube in the center part of each membrane.
The filling density of the membrane in this type of module can be increased, which enables the realization of more compact equipment compared to other modules.</td>
<td>
Immersion type

Immersion type


External type</td>
</tr>
<tr>
<td rowspan="2">Flat sheet membrane</td>
<td colspan="2">Flat membrane type
This module type uses sheet membranes connected to each other at intervals of 5 to 10 mm.
Water is filtered from the area between the two sheets of the membranes or between the membrane and the spacer.</td>
<td>

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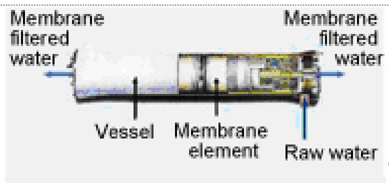
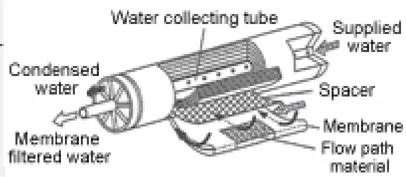
<tr>
<td colspan="2">Spiral wound type
This module type uses a pouch-shaped flat sheet membrane integrated in a roll shape with a net-shaped spacer. The membrane is attached to the pressure vessel and is used as the raw water path. This type of module is commonly used in NF/RO membranes.</td>
<td>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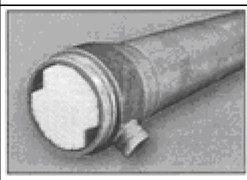
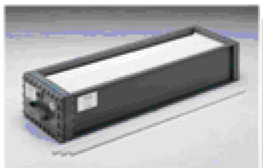
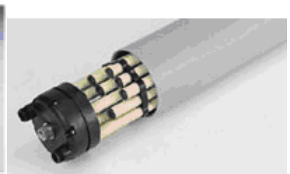
<tr>
<td>Tubular membrane</td>
<td colspan="2">Tubular type
This module type uses bundled cylindrical membranes with an outside diameter of 3 to 15 mm.</td>
<td></td>
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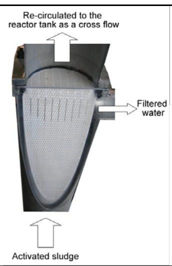
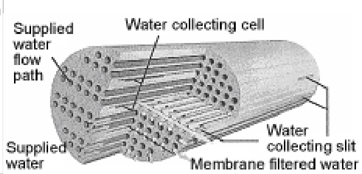
<tr>
<td colspan="3">Monolith type
Many water paths are made on a single element of an internal pressure type ceramic membrane. The membrane is sintered on the surface of the water paths.</td>
<td>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Data from Reference 4) and manufacturer literature

Figure 2-3 Main types of membrane modules

(4) Cleaning methods for membranes

1) Changes in membrane performance

There are two types of changes in membrane performance: degradation and fouling. Degradation is an irreversible change in membrane performance caused by a change in the membrane itself. Fouling refers to an apparent change in membrane performance caused by accumulated substances on the membrane surface or flow paths, including clogging of the flow paths in the membrane module. Such changes in performance due to fouling are often recovered by cleaning the membrane.

Table 2-4 shows the main causes of such changes in membrane performance.

Table 2-4 Main causes of changes in membrane performance

Classification	Cause		Explanation
Degradation	Physical degradation	Consolidation	Permanent deformation of the membrane structure caused by high pressure
		Damage	Breakage of the membrane structure caused by scratches or collisions of solid matter, etc., as well as fatigue breakdown of the membrane structure caused by repeated stresses such as vibration
		Dehydration	Permanent changes in the membrane structure caused by shrinkage, etc., that depend on the membrane material
	Chemical degradation	Hydrolysis	Changes in the membrane material caused by chemical reactions that depend largely on the temperature and pH of the membrane
		Oxidation	Changes in the properties caused by oxidants such as chlorine that depend on the membrane material
	Biological deterioration		Biodegradation, or chemical alteration caused by metabolites, etc., that depends largely on the membrane material
Fouling	Causative substances		Mineral salts, inorganic and organic colloids, dissolved organic substances, adhered microorganisms, suspended substances
	Contamination on the membrane surface	Cake	Accumulation of suspended particles on the membrane surface
		Gel	Gelation of dissolved high molecular weight substances on the membrane surface (caused by concentration polarization) and adhesion of viscous (gelatinous) substances
		Scale	Precipitation of substances that exceed the solubility level due to concentration
		Adsorption	Formation of a layer due to adsorption to the membrane surface
	Contamination inside the membrane (clogging)		Adsorption, precipitation, or clogging inside the fine pores of the membrane, or blocking of the fine pores by air bubbles
	Clogging of the flow path		Clogging of the flow path at the raw water side with solids, etc.

Causative substances for fouling of membranes include mineral salts such as calcium carbonate and calcium sulfate, inorganic colloids such as silica and ferric hydroxide, organic colloids such as proteins, dissolved organic substances, adhered microorganisms, and suspended substances. It is, however, often difficult to actually identify the dominant substances that cause the fouling, as the membranes are exposed to many substances of widely varying types.

In wastewater treatment, where various substances are present at high concentrations, it can be expected that almost every type of factor is present in a complex mixture, so identification of the causative substances is extremely difficult. Moreover, permeability remarkably deteriorates due to the formation of cake and gel layers on the membrane surface. In particular, generation of a gel layer is difficult to predict, as the substances that lead to gel formation are colloidal or dissolved substances that are not measured as solids in normal water quality analyses.

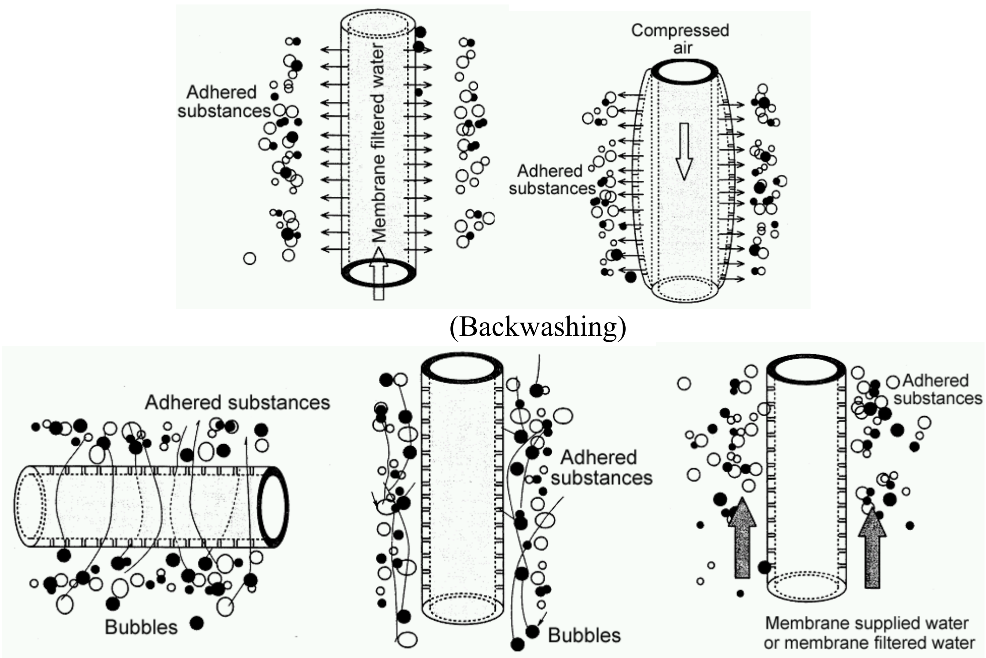
Apart from membrane performance, changes in the trans-membrane pressure difference and permeation flux also occur due to changes in the temperature (liquid viscosity). It is therefore necessary to note that, when the water temperature is low, there is a tendency for the permeation flux to decrease under operation at constant pressure, while the trans-membrane pressure difference tends to increase under a constant flow.

2) Membrane cleaning (countermeasures against fouling)

When using membrane technology, substances are accumulated on the membrane surface and flow paths over time. It is therefore necessary to conduct regular cleaning processes to remove the attached substances. There are two types of cleaning methods: physical cleaning and chemical cleaning.

a) Physical cleaning

Physical cleaning includes backwashing, air cleaning, and flashing, which are used independently or in combination. Figure 2-4 illustrates the main types of physical cleaning used in wastewater treatment.



(Backwashing)

(Air cleaning/air scrubbing) (Flashing)

Data from Reference 14), partially revised

Figure 2-4 Types of physical methods for the cleaning of membranes

・Backwashing

Backwashing is the process where water or air is fed in the direction opposite to the filtration to remove adhered substances on the membrane surface. It is conducted using water pressurized by a dedicated pump or compressed air. The applicability of this process and the upper limit of pressure for cleaning depend on the material and shape of the membrane.

・Air cleaning/air scrubbing

This process removes adhered substances on the membrane surface by vibrating the membrane in water with blown air. It is sometime combined with backwashing.

・Flashing

This process removes adhered substances on the membrane surface by flashing membrane supplied water or membrane filtered water along the surface at a high speed.

b) Chemical cleaning

As membrane filtration continues, clogged substances that are not completely removed by cleaning accumulate at the surface or inside of the membrane. Chemical cleaning is used to remove these substances and to recover membrane performance. Acids and other such cleansing agents are used to remove inorganic substances, while sodium hypochlorite and other such agents are used for organic substances and microorganisms.

When cleaning a membrane, backwashing and chemical cleaning are often used in combination. Use of ozone to reduce fouling is also under consideration, and development of membrane materials with high ozone resistance is also progressing.

2.2 Significance of the installation of membrane technology in sewage plants

2.2.1 Significance of the installation of membrane technology in sewage plants

The Sewerage Vision 2100, which was announced in September 2005, proposes a sewage system that will be sustainable in the next century, with a basic concept of a "Circulation Path" centered around the "utilization and revitalization" of resources for the sustainable development of local communities.

This vision lays out three basic policies for realizing the Circulation Path: (1) the Water Path, which creates a revitalizing and utilizing network for sound water circulation; (2) the Resource Path, which creates a recycling and supply network for halting resource exhaustion and global warming in the future; and (3) Facility Rehabilitation, which realizes a sustainable sewage system responding to upcoming social needs.

To realize the Circulation Path, it is essential to enhance the functions of the sewage system by vigorously introducing new technology.

Membrane technology reliably removes not only SS (suspended solid) ingredients, but also bacteria such as E. coli, and is expected to reduce viruses and other micro- or nano-scale substances; thus, the following effects are anticipated when this technology is installed in sewage treatment plants:

- Improvement in removal performance for contaminating substances
  Extremely pure water containing no suspended solids, and high-level removal of organic matter and contaminating substances, such as phosphorus and nitrogen, that are contained in the suspended solids
- Downsizing of facilities
  Significantly reduced installation space for sewage treatment facilities due to the elimination of certain treatment processes, including the final sedimentation tank
- Easy operation and management (increase in automatically controlled processes)
  Elimination of the need for care of the bulking or sludge-liquid interface, and consequently a reduction in the sludge management burden due to elimination of the final sedimentation tank, plus easy realization of automated operation because systems using membrane technology are mainly controlled by the flow rate of filtration and the trans-membrane pressure difference
- Decrease in generated sludge volume
  Reduction of the generated sludge volume due to self-decomposition of the sludge because systems based on membrane technology have a longer SRT[*5] due to the high level of MLSS[*6]
- Removal of pathogenic microbes (reduction in water system risks)
  Nearly complete removal of contagious cryptosporidium, E. coli, and viruses.

Figure 2-5 shows the system of policies designed to realize the Circulation Path and examples of

5 SRT: Sludge Retention Time
6 MLSS: Mixed Liquor Suspended Solids

feasible approaches using membrane technology.

As shown in the figure, many of the feasible approaches for realizing the Circulation Path require the use of membrane technology, and thus the expectations for this technology are quite high.

In particular, significant emphasis is being placed on the application of MBR in sewage treatment plants, including medium- to large-scale treatment plants and satellite sewage treatment facilities. In the following sections, each approach is explained in detail.

Circulation Path: Basic policies	Circulation Path: Viewpoint	Circulation Path: Measures	Feasible approaches based on membrane technology
The Water Path	The Utilizing Water Path	* Reviving and rehabilitating semi-natural watercourses * Conserving water quality * Improving the degree of independence regarding water resource usage	(1) Downsizing facilities (3) Quickly expanding sewage systems to non-water supply districts (4) Installing advanced processes (5) Increasing reclaimed water use
	The Gentle Water Path	* Creating a water environment that is gentle to people * Creating rich waters and green spaces * Creating water and a green community	(1) Downsizing facilities (4) Installing advanced processes (5) Increasing reclaimed water use (Using satellite facilities, etc.)
	The Protecting Water Path	* Improving public health * Implementing revised anti-inundation measures * Using rainwater, reclaimed water and spring water for disaster prevention * Conserving and rehabilitating the maintenance area ecosystem	(1) Downsizing facilities (5) Increasing reclaimed water use (6) Reducing water system risks (Elimination of pathogenic microbes)
The Resource Path	The Gentle Resource Path	Using biomass	Facilitating methane fermentation with membrane separation (in the R&D phase)
The Facility rehabilitation	Upgrading of functions	Improving the efficiency of maintenance functions and reconstruction	(1) Downsizing facilities (2) Reconstruction: Upgrading functions during reconstruction of sewage facilities using the existing land and civil engineering structures (achieving higher treated water quality, automated monitoring and control processes, and labor savings).

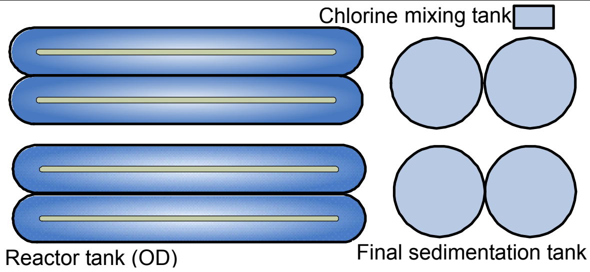
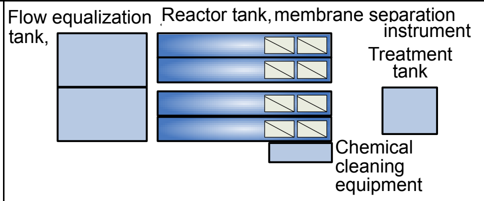
Figure 2-5 Applicability of membrane technology for realizing the Circulation Path

(1) Downsizing of facilities

MBR is expected to enable the significant downsizing of facilities, as it requires no final sedimentation tank, and does not always need a primary sedimentation tank. Moreover, chlorination equipment is not needed during normal operation, but it is only used as emergency equipment in case of malfunction of the MBR. Downsizing is also possible for MBRs used for the treatment of reclaimed water, as a chlorination facility is not necessary if the reclaimed water is collected for landscape use.

Table 2-5 shows a comparison of the facility scales for a standard MBR process and a conventional advanced oxidation ditch process (OD process). The table indicates that the area needed for the MBR process is about one fifth that for the conventional process. As the A-JUMP demonstration project at the Moriyama Water Treatment Center has shown, enhancement of the process is possible by simply using a reactor tank with a capacity nearly equal to that in the standard activated sludge process.

Table 2-5 Comparison of facility scales for a standard MBR process and an advanced OD process (5,000 m^3 per day)

	Advanced OD process	MBR process
Layout image		
Flow equalization tank	—	6 m^W x 11 m^L x 5 m^H x 2 tanks (HRT=3 hr)
Biological reactor	3.5 m^W x 120 m^L x 3 m^H x 4 tanks (HRT=24 hr)	3 m^W x 22 m^L x 5 m^H x 4 tanks (HRT=6 hr)
Final sedimentation tank	φ15 m x 2.5^H x 4 tanks (Surface loading: 8 m^2/m^3 per day)	—
Chlorine mixing tank	3 m^W x 7 m^L x 2.5 m^H x 1 tank (HRT=15 min)	—
Treatment tank	—	6 m^W x 7 m^L x 2.5 m^H x 1 tank (HRT=30 min) (Used for dilution in chemical cleaning. It becomes large if reclaimed water is used.)
Area (comparison)	2,408 m^2 (1)	438 m^2 (0.18) * Excluding the chemical cleaning tank
Administrative building/electric room	—	The administrative building/electric room becomes slightly large as MBR uses a larger-scale blower and other instruments.

* Calculated based on the Guidelines for JS Standard Design. According to these guidelines, facilities for a conventional OD process can be upgraded for advanced treatment without the need for additional space.

(2) Reconstruction of sewage facilities

As construction of sewage systems progresses, the number of aging facilities is increasing. To prevent accidents or shutdowns that may seriously affect daily life and social activities, it is necessary to promote the systematic reconstruction/upgrading of such facilities, as well as to reconstruct the facilities for the purposes of enhancing them or adding reclaimed water use. Under these circumstances, however, lack of space or insufficient process capacity poses obstacles for successful reconstruction.

The installation of an MBR to all or part of the existing facility, however, enables enhancement of the process and increased processing capacity in a limited space while using the existing civil engineering structures (See Chapter 4).

Using membrane technology has another advantage. Because it is a type of physical treatment that ensures solid-liquid separation, it is easy to automate the monitoring and control operations.

(3) Rapid elimination of areas lacking sewage treatment services

Given the current circumstances of a decreasing population, aging society and worsening financial conditions, introduction of MBR, which downsizes facilities, is being accelerated in order to rapidly promote the construction of sewage systems in areas without any treatment plants. As a result of this downsizing, it is possible to construct sewage facilities in a limited space, such as on a mountain or near a coastal area, which is expected to result in the swift elimination of unsewered areas. Moreover, in the Quick Project for unsewered areas proposed by the MLIT, introduction of PMBR,[*7] which aims for cost reduction and shorter working periods, is being promoted.

(4) Installation of advanced processes

Compared to the conventional process, membrane technology removes suspended solids (SS). This technology is also expected to remove nitrogen and phosphorus contained in the SS. Moreover, nitrogen and phosphorus is expected to be significantly removed by using the recycled nitrification/denitrification type of MBR (with coagulant added).

In particular, MBR can be operated with a higher MLSS (generally 8,000 to 15,000 mg/L) compared to the conventional process, which causes decomposition of organic matter and the nitrification/denitrification reaction in a short time. It can also be combined with other processes, including the recycled nitrification/denitrification process, the multi-stage denitrification-nitrification process, and the addition of coagulants. Its optimal operating conditions and applicability to a broader range of industries are now being studied.

As examples of the sophistication of processes with membrane technology, the facility configuration for a recycled nitrification/denitrification process is illustrated in Figure 2-7, and that for an A_2O MBR (membrane UCT process[*8]) is shown in Figure 2-8 (See 2.2.2).

(5) Increasing reclaimed water use

Adopting membrane technology for the use of reclaimed water enables the downsizing of reclamation facilities and an increase in the number of applications for reclaimed water with a higher quality.

MBR treated water, in particular, depending on the intended application, can be reused without the need for further treatment (the ozone process, etc.) in reclamation facilities. Moreover, by integrating MBR facilities into a satellite sewage treatment system, it is expected that low-cost reclaimed water can be obtained in increased places distant from sewage treatment plants.

Table 2-6 lists the quality of reclaimed water obtained using both membrane technology and a conventional process.

A satellite sewage treatment system takes water from sewage pipes upstream of a sewage treatment plant, processes the water to produce reclaimed water, and returns the sludge generated in the process to the sewage pipes (See 5.4 for details).

Figure 2-6 through Figure 2-8 show facility configuration examples using membrane technology for the secondary effluent (NF/RO), and Figure 2-9 illustrates that of the MBR process for reclaimed water (See 2.2.2).

7 PMBR: Package-type ultrasmall-scale membrane bioreactor

8 UCT (University of Cape Town) process: A type of biological simultaneous nitrogen and phosphorus removal process, which is a variation of the A_2O process. It has two circulation paths: nitrification liquid circulation (aerobic tank to anoxic tank) and denitrification liquid circulation (anoxic tank to anaerobic tank).

Table 2-6 Quality of reclaimed water obtained using membrane technology and a conventional process

Classification / Items	Moriyama Water Treatment Center			Tap water
	Water treated by the conventional process Note 1)	Water treated by A_2O MBR Note 2)	Water treated by RO Note 2)	Standards for tap water
pH (-)	7.2	6.7	-	5.8 to 8.6
SS (mg/L)	1	N.D.	-	-
BOD (mg/L)	4.2	1.0	-	-
COD (mg/L)	11	5.7	-	-
TOC (mg/L)	-	-	-	<3
T-N (mg/L)	10.2	4.6	0.9	<10 3)
T-P (mg/L)	0.66	0.38	0.5	-
Number of coli groups (per cm^3)	<30	Not detected (in 100 mL)	-	-
E. coli (per 100 mL)	-	Not detected	-	Shall not be detected
Turbidity (degree)	-	(<0.25 to 1.1)	0.24	<2
Chromaticity (degree)	-	8.8	1.3	<5
Odor (-)	-	-	-	Free of abnormality

Note 1) Annual average quality for FY2009 at Moriyama Water Treatment Center
2) Annual average for water treated in the A-JUMP demonstration facilities at Moriyama Water Treatment Center (June to December 2010). Turbidity is expressed as a range. Data was obtained after treatment and stabilization in order to eliminate the effects of changes in operation conditions for the demonstration.
3) For NO_2^--N and NO_3^--N

(6) Reducing water system risks

One of the challenges in sewage treatment is how to reduce the water system risks.

As indicated in Table 2-6, membrane technology removes most of the E.coli and decreases other bacteria, trace chemicals, and viruses. For example, as indicated in Table 2-7, membrane technology has a high ability to remove cryptosporidium*[9] oocysts compared to sand filtration, at least in water purification. Cryptosporidium oocysts can cause group infections that lead to diarrhea, vomiting, etc., because of their strong resistance to chlorine.

Table 2-7 Removal performance for cryptosporidium oocysts in water purification [6)]

Rapid sand filtration process	2.5 log
Slow sand filtration process	3 log
Membrane filtration Large pore membrane	6 log
MF membrane	> 6 log
UF membrane	> 7 log

Removal of viruses can be achieved using UF membranes with a pore diameter smaller than that of the viruses. There are some reports[7),8),9)] that MBR is also effective for increasing the removal rate of viruses, even when using MF membranes with a pore diameter larger than viruses. Therefore, there is a possibility that MBR can contribute to a reduction of hygienic water system risks in addition to

[9] For cryptosporidium, an elimination ability of approximately log 4 to 5 (99.99 to 99.999%) is considered to be necessary, based on the level of contamination in the raw water, the minimum infectious dose and the infection risk. In actual water purification cases, a log 6 (99.9999%) or higher degree of removal ability has been realized using membrane filtration (See table 2-7).

removing bacteria and protozoa.

Table 2-8 presents the results of an investigation of norovirus detection at MBR facilities. In every investigation, norovirus was not detected in one liter of membrane filtered water. Every result was under the detection threshold value. The log removal rate was indicated as ">**" based on the detection threshold value. Although the removal rate varied according to the norovirus concentration in the influent water, the log removal rate at each facility was 4.6 log to 5.9 log or higher.

Table 2-8 Norovirus detection results at MBR facilities

Treatment plant	Coagulant	Membrane type/shape	Membrane installation position	Usage period	Log removal rate Norovirus (GI + GII)
1	Add	Organic/Flat	Immersed	5 years and 6 months - 5 years and 10 months	> 3.9
2	-	Organic/Flat	Immersed	3 years and 3 months - 5 years and 1 month	> 3.1
3	Add	Organic/Flat	Immersed	11 months to 1 year	> 4.9
4	-	Organic/Hollow fiber	Immersed	4 years and 8 months - 4 years and 10 months	> 2.8
5	-	Organic/Hollow fiber	Immersed	2 years and 8 months - 2 years and 10 months	> 3.9
6	-	Organic/Hollow fiber	Immersed	2 years and 8 months - 2 years and 10 months	> 2.6
7	Add	Inorganic/Monolith	External	10 months to 1 year	> 4.9

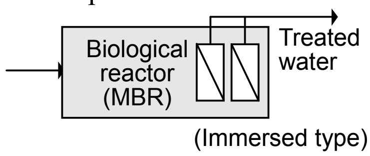
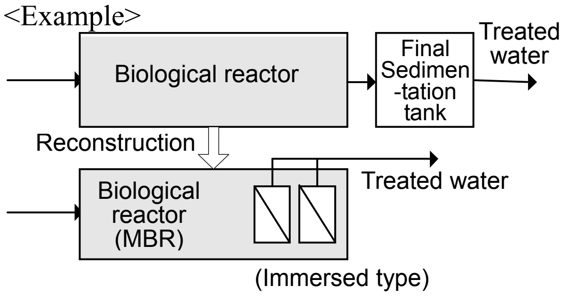
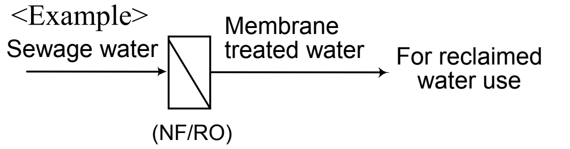
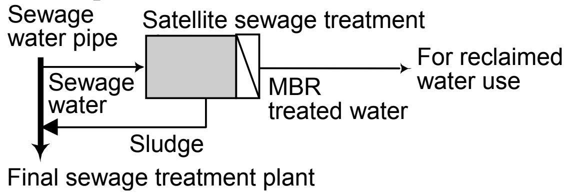
* Each treatment plant was investigated three times.
Range of norovirus concentration in influent water: 1.3×10^4 to 2.8×10^7 MPN-copies/L
Detection threshold value for treated water: 32.8 to 37.5 MPN-copies/L

2.2.2 Example of membrane technology installation at a sewage treatment facility

Recent advances in membrane technology at sewage treatment plants have included the development of low-cost membrane modules and extension of the service life of membranes. Moreover, various research and technical development efforts are exploring diverse aspects of the technology, such as reduction of the cost and energy consumption, etc. This technology is therefore expected to be vigorously adopted by sewage treatment facilities in the future, along with its application in a wide range of other fields, including the construction of a healthy water environment.

Table 2-9 presents examples of the installation of membrane technology in sewage treatment plants according to the intended purpose, while Figure 2-6 through Figure 2-9 illustrate examples of the flow once membrane technology is incorporated into a sewage treatment operation.

Table 2-9 Examples of membrane technology installations

Purpose	Way of introduction	Typical example
Rapid elimination of unsewered areas	Installation of membrane technology for solid-liquid separation that has been conventionally performed by gravitational sedimentation at the final sedimentation tank. ・ Downsizing of facilities ・ Enabling of an advanced process that achieves a shorter HRT with a higher MLSS	Activated sludge in the biological reactor was separated by a membrane to obtain MBR treated water. <Example> 
Reconstruction, including an enhancement of the processes and an increase in the processing capacity	Installation of membrane technology for solid-liquid separation that has been performed by gravitational sedimentation at the final sedimentation tank in the conventional process. ・ Enabling of an advanced process that achieves a shorter HRT with a higher MLSS ・ Improvement of the average quality of the overall treated water by partially installing an MBR in series.	Activated sludge in the biological reactor was separated by a membrane to obtain MBR treated water. <Example> 
Use of reclaimed water	Installation of membrane technology to treat water fed from a conventional process or an MBR in order to make the treated water available for reuse. ・ A wide range of applications is possible through selection of different membranes according to the purpose. ・ Can be used in compact facilities	Membrane technology for secondary effluent sewage water to obtain MBR treated water for use as reclaimed water <Example> 
	Installation of MBR in a satellite sewage treatment plant in order to make treated water available for reuse. ・ With its compact facilities, MBR can be used at places distant from a sewage treatment plant at a low cost, which will increase the number of locations where reclaimed water can be used.	MBR at a satellite sewage treatment plant <Example> 

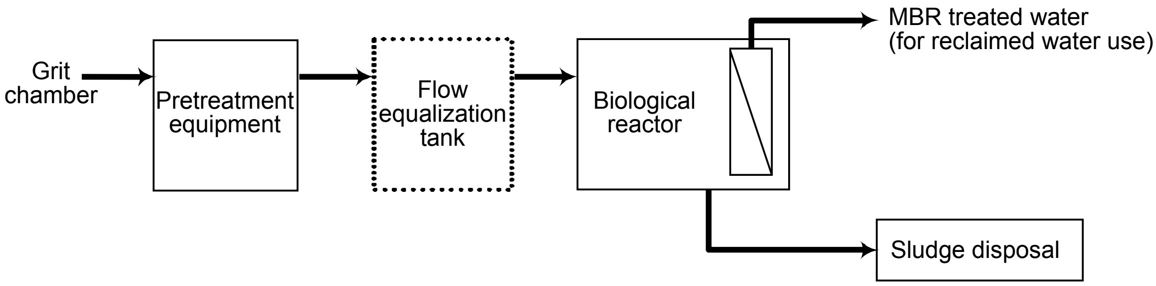


Figure 2-6 Example configuration for an MBR facility

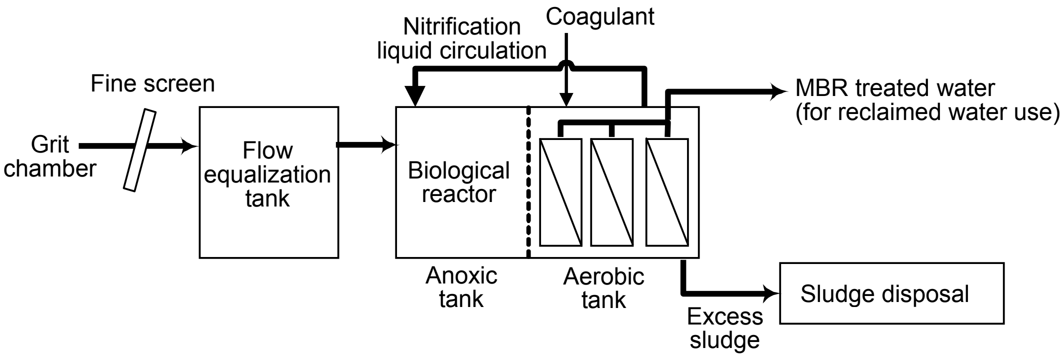


Figure 2-7 Example configuration for a recycled nitrification/denitrification process facility

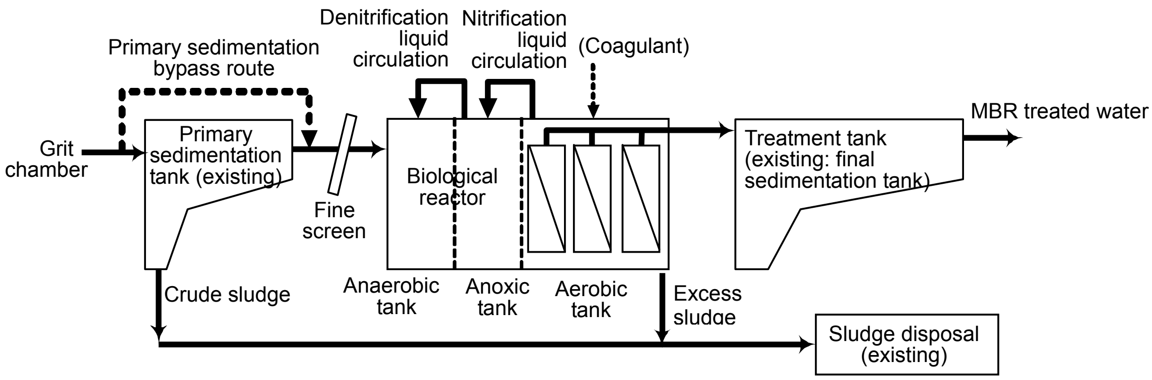


Figure 2-8 Example configuration for an A_2O MBR process (membrane UCT process) facility (Demonstration facility at Moriyama Water Treatment Center)

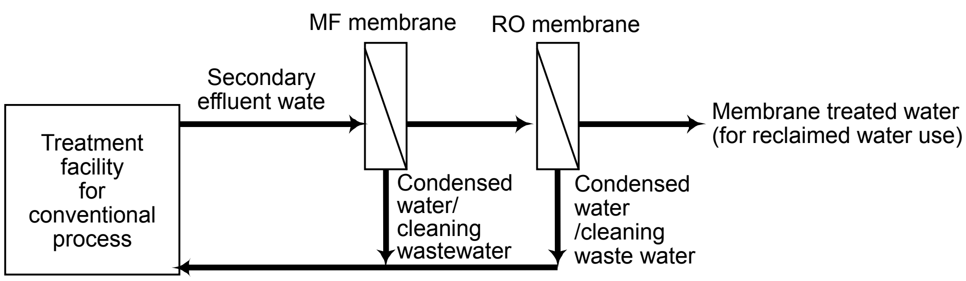


Figure 2-9 Example configuration for a membrane treatment process using secondary effluent (MF+RO)

2.3 Current status of membrane technology used in sewage treatment plants

2.3.1 General evaluation of MBR

In fiscal year 2008, the MLIT established an MBR Assessment and Review Subcommittee (Chairman: Takashi Mino, Professor in the Graduate School at the University of Tokyo) under the Industrial Wastewater Treatment Technology Committee*[10] (Chairman: Tomonori Matsuo, Managing Director of Toyo University) in order to evaluate (general evaluation*[11]) whether MBR should be considered as a general wastewater treatment technology that is applicable nationwide. In February 2010, the subcommittee issued a report stating that the technology could achieve the expected effluent water quality*[12] specified in Table 2-10 when applied to general sewage treatment systems. Table 2-11 presents for reference the required effluent water quality from treatment methods classified according to the Order for Enforcement of the Sewerage Service Act in fiscal 2003 and operational notification*[13].

In addition, MBR needs no final sedimentation tank, which enables the production of high-quality treated water in a limited space. Therefore, it is expected that MBR will be a key technology for solving various problems in sewage treatment in the future, especially when upgrading aging sewage facilities through reconstruction, while still utilizing existing reactors, etc.

Table 2-10 Expected effluent water quality specified in the general evaluation of MBR

Treatment method	Desired effluent water quality (mg/L)		
	BOD	T-N	T-P
Recycled nitrification/denitrification MBR process	10 or less	10 or less	–
Recycled nitrification/denitrification MBR process (only that with coagulant added)	10 or less	10 or less	0.5 or less

Note: A kind of MBR where the activated sludge process is conducted in a biological reactor consisting of anoxic and aerobic tanks.

10 Industrial Wastewater Treatment Technology Committee: Established by MLIT to conduct general evaluations. (The Secretariat is at the Sewerage Investigation Department, National Institute for Land and Infrastructure Management)

11 General evaluation: In this evaluation, a new treatment process is assigned to one of the expected effluent water quality categories and studied to determine whether it is general and applicable nationwide, and to clarify cautions or other matters when adopting such a process.

12 Required effluent water quality: Water quality levels that effluent water from sewage facilities must meet. Based on the Order for Enforcement of the Sewerage Service Act. Article 5, 6-2, a sewage facility manager designates the values for BOD, T-N and T-P.

13 Operational notification: Notice from the Sewerage and Wastewater Management Department, the City and Regional Development Bureau of MLIT No. 530 on March 29, 2004

Table 2-11 Required effluent water quality specified in the Order for Enforcement of the Sewerage Service Act and operational notification

	Designed effluent water			Treatment method
	BOD	TN	TP	
1	To 10	To 10	To 0.5	Anaerobic-anoxic-oxic process (with addition of organic matter and coagulant, combined with rapid filtration)
2			0.5 to 1	Recycled nitrification/denitrification process (with addition of organic matter and coagulant, combined with rapid filtration)
3			1 to 3	Anaerobic-anoxic-oxic process (with addition of organic matter, combined with rapid filtration)
4				Recycled nitrification/denitrification process (with addition of organic matter, combined with rapid filtration)
5		10 to 20	To 1	Recycled nitrification/denitrification process (with addition of coagulant, combined with rapid filtration)
6			1 to 3	Anaerobic-anoxic-oxic process (combined with rapid filtration)
7				Recycled nitrification/denitrification process (combined with rapid filtration)
8			To 1	Anaerobic-oxic activated sludge process (With addition of coagulant, combined with rapid filtration)
9			1 to 3	Anaerobic-oxic activated sludge process (combined with rapid filtration)
10				Standard activated sludge process (combined with rapid filtration)
11	10 to 15	To 20	To 3	Anaerobic-anoxic-oxic process
12				Recycled nitrification/denitrification process
13			To 3	Anaerobic-oxic activated sludge process
14				Standard activated sludge process

Treatment processes classified by the operational notification:

Nearly the same level as the standard activated sludge
* Oxidation ditch process
* Extended aeration process
* Batch activated sludge process
* Oxygen activated sludge process
* Aerobic trickling filter process
* Contact oxidation process

Nearly the same level as the nitrification/denitrification process:
* Nitrification-denitrification using the endogeneous respiration process
* Multi-stage denitrification-nitrification process
* Advanced treatment of the oxidation ditch process

In the general evaluation, MBR systems using a recycled nitrification/denitrification process were evaluated, and based on the results, the following cautions were presented for the planning and designing of MBR facilities.

(1) The general evaluation confirmed the expected effluent water quality only for the recycled nitrification/denitrification process that separates activated sludge using a membrane. The evaluation concluded that other water treatment processes, such as the recycled nitrification/denitrification process, combined with the standard activated sludge or anaerobic-anoxic-oxic process, are considered to achieve the effluent water quality equivalent or higher than that for the process combined with rapid filtration, and that they should be handled as treatment processes achieving the expected effluent water quality for each corresponding category.

(2) At some MICS project facilities that accept sludge from sludge concentration facilities, individual sewage treatment tanks and rural community sewerage facilities, there were cases where the sewage water had properties different from those for ordinary sewage water due to the degree of influence of the return water load on the sewage water. Therefore, such characteristics must be kept in mind when designing equipment.

(3) As the concentration of activated sludge becomes high (high MLSS), the oxygen transfer efficiency of the aeration instrument worsens. It is important that these characteristics be taken into consideration when designing equipment, in order to ensure that sufficient oxygen is always provided.

2.3.2 Current status of the installation of membrane treatment technology at sewage treatment facilities in Japan

(1) Current status of the installation of MBR

The Japan Sewage Works Agency (JS) has been conducting research and studies on MBR and, on March 2003, it issued the "Report on the technology evaluation of MBR"[10)]

In Japan, MBR was first installed for sewage treatment at Fukusaki-cho, Hyogo Prefecture in 2005. Since then, 16 MBRs have been installed as of March 2011, although most of the systems are small-scale due to the restrictions on the effluent water quality and limited space (See Table 2-12). The first large facility for MBR in Japan is now operating at Sambo Sewage Treatment Plant, but it is a temporary installation.

Table 2-12 Adoption of MBR for sewage treatment

As of March 2011

No	Site	Facility's name	Processing capacity (m3/day)		Start of operations	Type of membrane	Remarks
			Current	Planned			
1	Fukusaki-cho, Hyogo	Fukusaki Water Purifying Center	4,200	12,600	April 2005	Flat	
2	Kanuma City, Tochigi	Kobugahara Water Treatment Center	240	240	April 2005	Flat	
3	Yusuhara-cho, Kochi	Yusuhara Water Purifying Center	720	720	December 2005	Flat	
4	Kagamino-cho, Okayama	Okutsu Water Purifying Center	600	600	April 2006	Hollow fiber	
5	Unnan City, Shimane	Daito Water Purifying Center	2,000	2,000	September 2006	Flat	
6	Shibecha-cho, Hokkaido	Toro Final Sewage Treatment Plant	125	125	March 2007	Flat	
7	Wakasa-cho, Fukui	Kaietsu Water Purifying Center	130	230	April 2007	Hollow fiber	
8	Hamamatsu City, Shizuoka	Shironishi Water Purifying Center	1,375	1,375	March 2008	Hollow fiber	
9	Numazu City, Shizuoka	Heda Water Purifying Center	2,140	3,200	March 2008	Flat	
10	Ohda City, Shimane	Ohda Water Purifying Center	2,150	8,600	March 2009	Flat	
11	Nagoya City, Aichi	Moriyama Water Treatment Center	5,000	5,000	January 2010	Flat	Demonstration facility for A-JUMP
12	Shingu-machi, Fukuoka	Shingu Chuo Water Purifying Center	6,060	9,090	March 2010	Flat	
13	Ninohe City, Iwate	Johoji Water Purifying Center	300	300	March 2010	Hollow fiber	Sewerage Quick Project
14	Ohgimi-son, Okinawa	Ohgimi Water Purifying Center	150	300	February 2011	Hollow fiber	
15	Sakai City, Osaka	Sanpou Sewerage Treatment Plant	34,000	60,000	March 2011	Flat	Reconstruction of an existing facility, tentative
16	Misaki-cho, Okayama	Yanahara Water Purifying Center	450	900	March 2011	Hollow fiber	
17	Amakusa City, Kumamoto	Takahama Water Purifying Center	620	620	Planned for April 2011	Hollow fiber	

MBR is expected, however, to be installed at sewage treatment facilities, including medium- to large-scale treatment plants and satellite sewage treatment plants. A description of the challenges for expanding MBR applications is provided in Appendix I as a reference.

(2) Current status of reclaimed water use with membrane technology

Table 2-13 shows the current status of reclaimed water use using membrane technology in Japan.

Table 2-13 Examples of reclaimed water use using membrane technology

Local government	Facility	Purpose/Scale (Configuration of membrane process)	Start of operations	Source
Tokyo Metropolitan	Ochiai Water Reclamation Center	Hydrophilization: 50 m^3/day (Sand filtration->agglomeration->MF membrane->RO membrane)	1993	Reference 2)
Tokyo Metropolitan	Shibaura Water Reclamation Center	Water for toilet washing: 4,300 m^3/day (Biofilm filtration->ozone->MF membrane)	2004	Reference 11)
Osaka City	Ebie Sewage Treatment Plant	Water for landscape use: 40 m^3/day (Water processed with advanced treatment->agglomeration->MF membrane->RO membrane)	1995	Osaka City Sewerage Science Museum
Kobe City	Tarumi Sewage Treatment Plant	Water for landscape use and car washing: 50 m^3/day (Sand filtration->agglomeration->RO membrane)	1993	Reference 12)

2.3.3 Implementation of the Advance of Japan Ultimate Membrane bioreactor technology Project (A-JUMP)

The MLIT has been conducting the "Advance of Japan Ultimate Membrane bioreactor technology Project (A-JUMP)" since the fiscal year 2009 to promote full-fledged penetration of MBR in Japan and overseas. Another goal is to play a leading role in the accumulation of knowledge and findings required for the installation of MBR, because Japanese companies possess world-leading know-how on MBR, and its adoption for the efficient upgrading of sewage facilities is highly expected. As a part of the project, the MLIT demonstrated that the application of MBR has had a significant effect at actual facilities. The knowledge and findings obtained through the demonstrations are reflected in these guidelines in order to make them widely known.

Two demonstration activities for the A-JUMP were conducted in fiscal year 2009: "Demonstration of MBR Introduced When Reconstructing Existing Sewage Treatment Facilities (at Moriyama Water Treatment Center Nagoya City, Aichi Prefecture)" and "Demonstration of MBR Introduced When Constructing Satellite Treatment Facilities (at Miai Pumping Station, Aichi Prefecture.)." Table 2-14 summarizes the results of these activities, which are reflected in these guidelines. The local governments in the areas where the demonstration projects are located and other organizations have continued these demonstrations beyond fiscal year 2009. A description of the achievements of the A-JUMP demonstrations is provided in Appendix II.

2.3.4 Current status of overseas sewage treatment facilities using membrane technology

(1) Current status of MBR installations

MBR was first installed in 1997 at the Porlock treatment plant in the UK, and the number of facilities adopting MBR has been increasing recently. Large scale facilities have begun installing

MBR, and as a result, the number of MBR facilities with a capacity of several tens of thousands of cubic meters per day is growing. Some plants in the US and China that have capacities of over one hundred thousand of cubic meters per day have begun operation. Therefore, the market is expected to expand (See Table 2-15 and Figure 2-10 through Figure 2-13).

Table 2-14 Main items verified in A-JUMP demonstrations

Items related to both demonstrations
・ Cautions on installing the necessary facilities for the introduction of MBR systems (membrane module lifting instruments, cleaning facilities, etc.) ・ Optimal operating conditions for MBR systems ・ Stability of the treatment with respect to quantitative and qualitative changes in the influent sewage water ・ Cautions on treating excessive sludge generated from the MBR system at existing sludge treatment facilities and returning it to sewage pipes ・ Understanding of the cost structures related to installation and operation, as well as a study of the cost reduction.
Items related to the demonstration of MBR in existing facilities
・ Considerations and cautions related to the structures of the existing reactor tanks, etc., to which the membrane module is installed. ・ Usability of the existing air blowers and other equipment.
Items related to the demonstration of MBR in satellite facilities
・ Usability of water treated in the MBR system as reclaimed water

The reasons for installing MBR are mainly two fold: to deal with water quality regulations and to reuse treated water. In some cases, a limited land space may become a trigger for installation of MBR when considering reconstruction or revision. Particularly in places where chronic water shortages are experienced and most of the treated water is required to be reused, MBR has become an attractive candidate, as it produces clean treated water, and the relevant costs have dropped recently (See Appendix I).

Table 2-15 Examples of MBR installations in overseas sewage treatment facilities

Country	Processing capacity (m3/day)	Start of operations	Remarks
UK	1,900	1997	
Germany	3,240	1998	
UK	12,700	1998	
France	4,300	1999	
Italy	42,400	2002	
US	11,800	2002	Current: 23,600 m3/day
Germany	45,000	2004	
Netherlands	18,000	2003	
US	4,540	2003	
US	38,600	2004	
South Korea	70,000	2005	
Oman	78,000	2006	
US	38,200	2006	
US	44,300	2006	
China	30,000	2006	For secondary effluent
US	93,500	2007	
China	80,000	2007	
US	75,700	2007	
Qatar	60,200	2007	
China	60,000	2007	
Italy	47,300	2007	
US	45,400	2007	
US	35,600	2007	
China	30,000	2007	
China	100,000	2007	
US	114,000	2009	
Saudi Arabia	30,000	2009	
UAE	38,000	2009	
US	144,000	2010	
China	110,000	2010	
China	110,000	2010	
China	100,000	2010	
Oman	78,000	2010	
China	150,000	Under construction	
US	117,000	Under construction	
Saudi Arabia	60,000	Under construction	
South Korea	73,000	Under construction	

* Data from References 10), 13), 14), and 15) and from surveys
* In many cases, MBR was introduced at a newly constructed facility or added to an area adjacent to an existing facility.

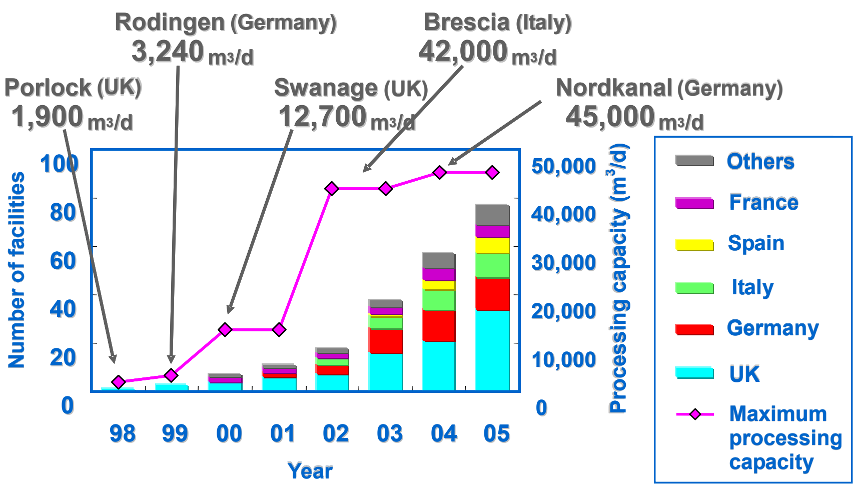
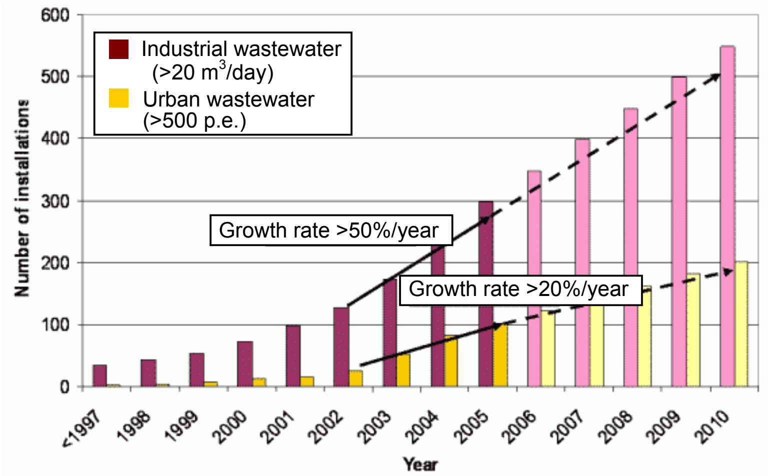


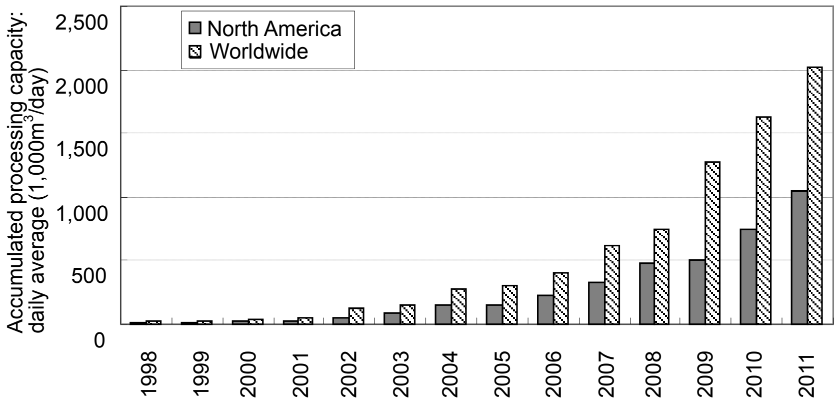
Figure 2-10 The number of MBR installations and the growth in processing capacity at sewage treatment facilities in Europe [16)]



At facilities treating industrial wastewater at 20 m^3/day or more and urban wastewater at 500 p.e. (= about 100 m^3/day) (p.e = population equivalent)

The values for 2006 and later are estimates.

Figure 2-11 Growth of the number of MBR facilities in the EU

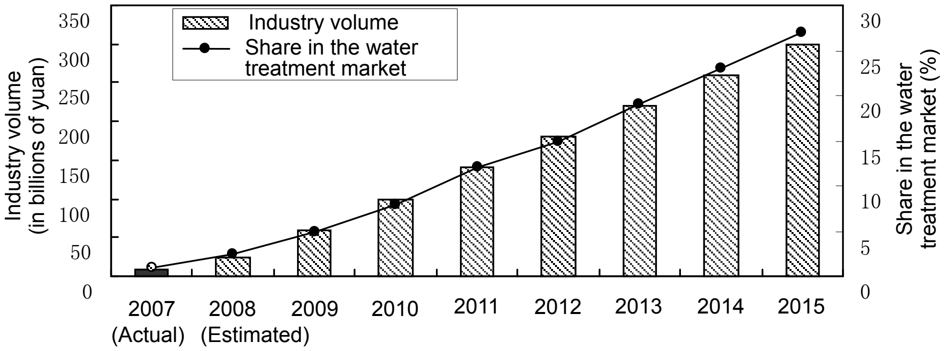


At facilities introducing GE/Zenon MBR systems and having a processing capacity of 1 MGD (about 4,000 m^3/day) or more.

The share of GE/Zenon in the MBR market in the USA and Canada is about 65%.

The values for 2009 and later are estimates.

Figure 2-12 Growth in the size of GE/Zenon MBR systems in the US and Canada[18)]



Data from References 19), 20) and 21)

Figure 2-13 Future estimates for the MBR market in China

(2) Current status of reclaimed water production using membrane technology

Table 2-16 shows examples of reclaimed water production using membrane technology at overseas facilities.

Table 2-16 Examples of reclaimed water production using membrane technology

Data from References 3), 22) and the survey conducted by the Japan Sewage Treatment Plant Constructors Association

Country	Location	Processing capacity (m^3/day)	Start of operations	Configuration of membrane process	Usage
US	West Basin,CA	76,000	1996	Secondary effluent -> MF membrane -> RO membrane	For industrial water, agricultural water and indirect drinking water
US	Gwenett City	34,000	1999	NF membrane*	
Singapore	Juron	35,000	2000	RO membrane*	
Singapore	Kranji	40,000	2002	Secondary effluent -> MF membrane -> RO membrane	
Singapore	Bedok	32,000	2002	Secondary effluent -> UF membrane -> RO membrane	
Kuwait	Sulaibiya	375,000	2005	Secondary effluent -> UF membrane -> RO membrane	
US	Fountain Valley,CA	220,000	2006	Secondary effluent -> MF membrane -> RO membrane	
Singapore	Ulu Pandan	166,000	2006	Secondary effluent -> MF membrane -> RO membrane	
Singapore	Changi	228,000	2008	Secondary effluent -> MF membrane -> RO membrane	
China	Qinghe	80,000	2008	UF membrane*	
China	Ningxia	78,000	2008	Secondary effluent -> MF membrane -> RO membrane	
Australia	Luggage Poin	66,000	2008	Secondary effluent -> MF membrane -> RO membrane	
Singapore	Changi	228,000	2010	Secondary effluent -> MF membrane -> RO membrane	
China	Qinghe	180,000	2010	UF membrane*	
Qatar	Doha	439,000	2011	Secondary effluent -> UF membrane -> RO membrane	

(3) Share of Japanese membrane manufacturers in the overseas market

Figure 2-14 illustrates the share of Japanese membrane manufacturers in the overseas market. They enjoy 60% of the total share for all type of membranes and 70% for SWRO membranes. The share of MF membranes and UF membranes, many of which are applied to MBR, is 43% (including LP membranes*[14]). Figure 2-15 shows the growth of accumulated processing capacity and the share of large MBR facilities in the world. As of 2009, Japanese manufacturers supply approximately 40% of the membranes used in large MBR facilities.

[14] LP (large pore) membrane: A membrane with a pore diameter larger than that of MF membranes, and mainly used for separating particles of 1μm or larger. For SWRO and BWRO membranes, see footnote *2 on p.5.

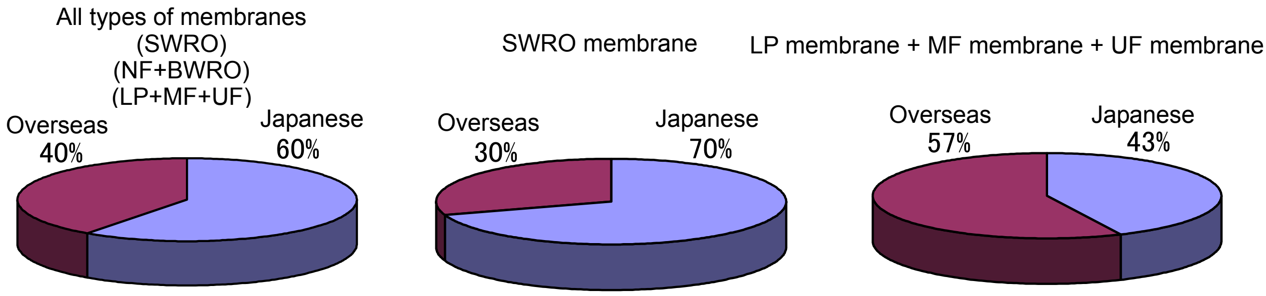


Figure 2-14 Portion of membrane shipments from Japanese companies used for water treatment [3)]

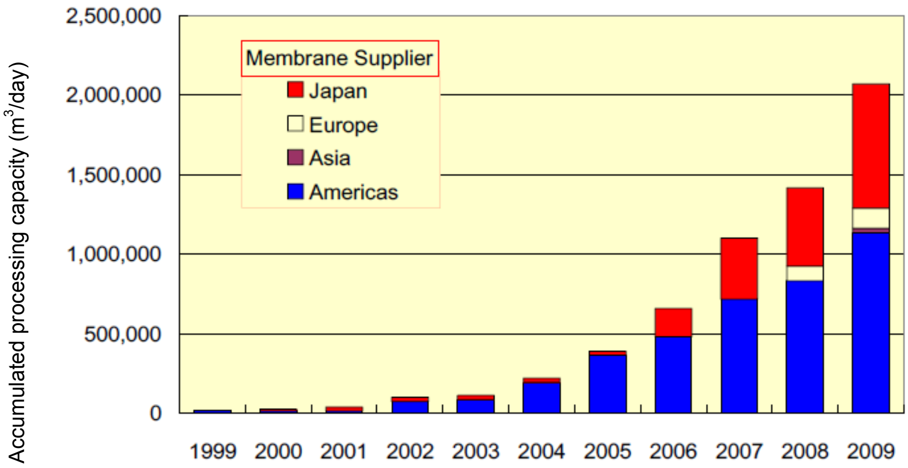


Figure 2-15 Growth of accumulated processing capacity and share of the worldwide membrane market for large MBR facilities (with a capacity of more than 10,000 m^3/day) [15)]

2.3.5 Trends toward standardization

(1) Trends in Japan

In fiscal year 2009, NEDO conducted the study "Basic research on overseas trends toward standardization of MBR technology," in which they investigated the needs for standardization of MBR technology, and considered the details of standardization in order to review strategies for expanding standards to foreign countries. The above basic research program also investigated the needs for international standardization of MBR technology in Japan.

(2) Trends overseas

1) EU

In EU countries, investigation of standardization with the aim of promoting MBR installation is already progressing. In November 2008, a workshop consisting of concerned parties announced CWA15897[*15] (See Appendix III), which is not a basis for the standardization and has no binding force, but provides a basis for the standardization. As the effective period for this agreement is 3 years after its announcement, discussions will be made to decide whether to cancel or extend the agreement, or upgrade it to a higher level after 3 years.

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[15] CWA: CEN Workshop Agreement, an agreement of the European Committee for Standardization (Comité Européen de Normalisation). Member countries bear no obligation to adopt it as their national regulations.

2) US

At this point, there seems to be no specific movement toward standardization. The EPA*[16], however, has submitted a fact sheet*[17] concerning MBR (See Appendix III).[24)]

In the US, different states have different regulations and standards. California's Title 22, for example, specifies the water quality that can be used as reclaimed water, and requires that proposals for membrane technology be submitted to the CDPH*[18] in order to apply for and obtain an approval. This ordinance has become a model in other states to the point where it is practically used as a national certification system in the US (See Appendix III).

The standards for reclaimed water quality in California are based on the agglomeration/sedimentation, sand filtration, and disinfection processes for secondary effluent. For other treatment processes, it is necessary to obtain an approval from CDHS that the proposed alternative process ensures the same reliability.

Table 2-17 shows the standards for MBR treated water specified by CDHS in 2001.

Table 2-17 Standards for MBR certification

Turbidity	・ 5%*[19] values for 24 hours shall not exceed 0.2 NTU*[20]. ・ All measurement values for 24 hours shall not exceed 0.5 NTU.
Viruses (Reference)	A challenge test in which coliphage is added to activate sludge shall be conducted. (Standards for testing were not specified)

* A test is conducted under the operating conditions with a constant permeation flux and twice-daily 2-hour peaks (twice the normal permeation flux).

Title 22 requires several months of pilot plant tests by a third party at an actual sewage facility, and after the facility satisfies the requirements, an approval is issued that contains the test site, name of the membrane manufacturer, the membrane material, the shape, the pore diameter, the treatment processes, the permeation flux, the trans-membrane pressure difference, and the turbidity evaluation results.

Although Title 22 is just a regulation in California, it is referenced by other states and treated as requirements for MBR in bidding. As a result, many manufacturers obtain this approval.

3) China

In China, a study group mainly consisting of members of Tsinghua University is conducting research on MBR. Some large scale MBRs have been designed by the design department of the University, and investigation is under way through operational management.

In 2010, the Government issued a national standard for immersed-type hollow fiber modules (See Appendix III). Moreover, the State Environmental Protection Administration of China (SEPA)

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16 EPA: Environmental Protection Agency

17 Fact sheet: a report stating actual conditions

18 CDPH: California Department of Public Health

19 5% value refers to 5% from the highest value among all specimens, which means to be equivalent to 95% from the lowest value.

20 NTU: Measurement unit for turbidity. When a standard solution containing a polymer is evaluated by scattered (reflected) light measurement for turbidity, the result is expressed in NTUs (Nephelometric Turbidity Units).

is promoting sectoral standardization of technical requirements for MBR systems for small-scale sewage treatment plants (See Appendix III, public comment was held in 2010).

Chapter 3 Features of MBRs and their installation in sewage treatment systems

This chapter describes the fundamental issues related to MBRs and summarizes the considerations and economic efficiency, etc., for cases where they have been installed in sewage treatment plants.

3.1 Features of MBRs

MBRs for the separation of activated sludge using a filtration membrane have the following features:

- Continuous treatment of activated sludge, because the treatment function is not affected by changes in the sludge sedimentation conditions.
- The downsizing of treatment facilities, depending on the setting of the BOD-SS load, because a high MLSS can be maintained for the reactor tank.
- Provision of treated water directly for reuse, because the water is pure and can be used as reclaimed water without ozone treatment, etc., in a reclamation facility, depending on its purpose.

(1) Overview of MBRs

An MBR uses a membrane to conduct solid-liquid separations, which is conventionally achieved via gravitational sedimentation in the final sedimentation tank. It is expected to enable enhancement and stabilization of such processes. Figure 3-1 illustrates the mechanism of solid-liquid separation using a membrane.

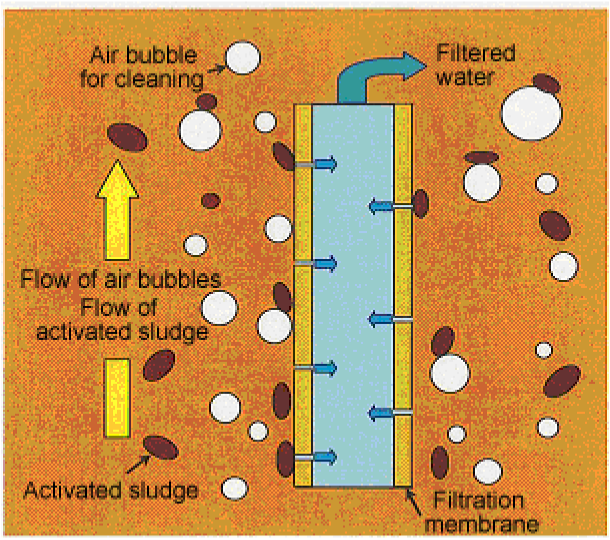


Figure 3-1 Conceptual diagram of a solid-liquid separation using a membrane (Immersed type MBR)[10)]

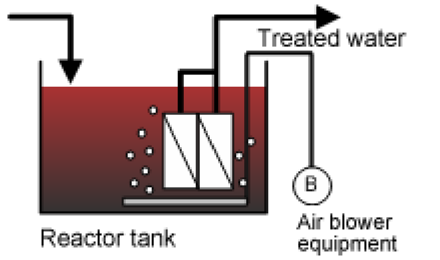
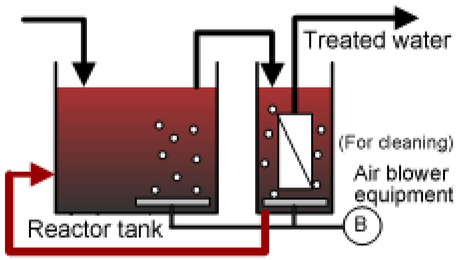
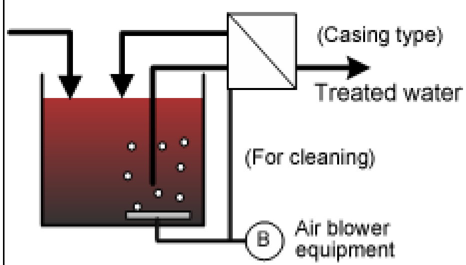
Depending on the location of the membrane module installation, an MBR is classified into 3 types: the immersed type (integrated type), the immersed type (separate tank type) and the external type (see Table 3-1).

The immersed type of MBR has the membrane module immersed in the tank and filters the water using the water level difference or pump suction. The external type of MBR uses the membrane element housed in a container called a "casing," and filters the water using the water level difference or a pump: the supplied water (raw water) is pumped into the casing, or the membrane filtered water is suctioned from the casing.

While a pump is generally used for suctioning the treated water, the immersed type using the water level difference combined with pump suctioning is being considered as a way to save energy[25)].

All of the MBRs actually used in Japan are of the integrated type, while the use of the separate tank type is increasing at large scale facilities overseas[26), 27)].

Table 3-1 Types of installations of membrane modules in MBRs

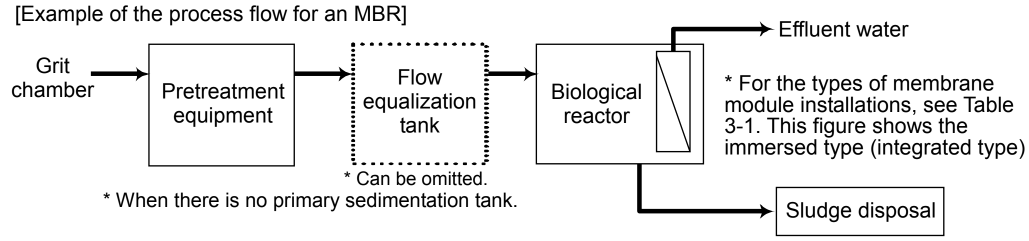
Immersed type (integrated type)		• Most commonly adopted. • Process configuration is simple. • Aeration equipment in the reactor tank can also be used for cleaning of the membrane module. • By linking with other systems, or by installing multiple membrane units, this approach eliminates the need to stop the reactor tank during inspection, repair and replacement of the membrane module.
Immersed type (separate tank type)		• It is possible to select the aeration equipment necessary for biotreatment and backwashing depending on the specifications (fine bubbles or coarse bubbles). • It can operate with an MLSS for the reactor that is higher than that for the membrane separating tank. • By linking with other systems, or by installing multiple membrane units, this approach eliminates the need to stop the reactor tank during inspection, repair and replacement of the membrane module. • It consumes a large amount of energy because it requires a pump for sludge circulation. • It requires high construction costs compared with the integrated type. • It enables easy immersion cleaning (the membrane separating tank can be used as the chemical solution cleaning tank).
External type		• It can maximize the permeation flux, which leads to a decrease in the number of membrane modules. • It can handle the time fluctuation most flexibly. • It achieves easy control of sludge circulation, etc. • By linking with other systems, or by installing multiple membrane units, this approach eliminates the need to stop the reactor tank during inspection, repair and replacement of the membrane module. • It consumes a large amount of energy because it requires a pump for sludge circulation. • It enables easy chemical solution cleaning.

Note: The features (advantages and disadvantages) stated in the above table may change, depending on the improvement or development of membrane modules or the introduction of novel techniques for operation management.

(2) Major facility configurations for MBRs

Figure 3-2 illustrates the basic process flow for an MBR as compared to that of the standard activated sludge process for a newly-constructed treatment plant.

MBRs incorporate the pretreatment equipment (fine screens, etc.), the biological reactor and membrane module, and if necessary, the flow equalization tank. Unlike conventional processes such as the standard activated sludge process, an MBR process does not always need a primary sedimentation tank and requires no final sedimentation tank because it uses a membrane to separate the solids. Moreover, the disinfection equipment can be omitted if the MBR process is equipped with a system to add solid chlorine, etc., in case of emergencies. Thus, the MBR facility configuration tends to be simple.



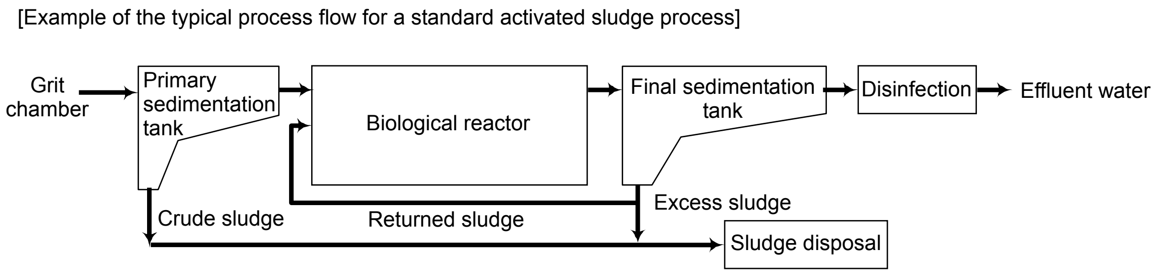


Figure 3-2 Comparison of facility configurations for MBRs and the standard activated sludge process

Figure 3-3 and Figure 3-4 illustrate the major facility configurations for the process flow for MBRs that remove nitrogen and phosphorus.

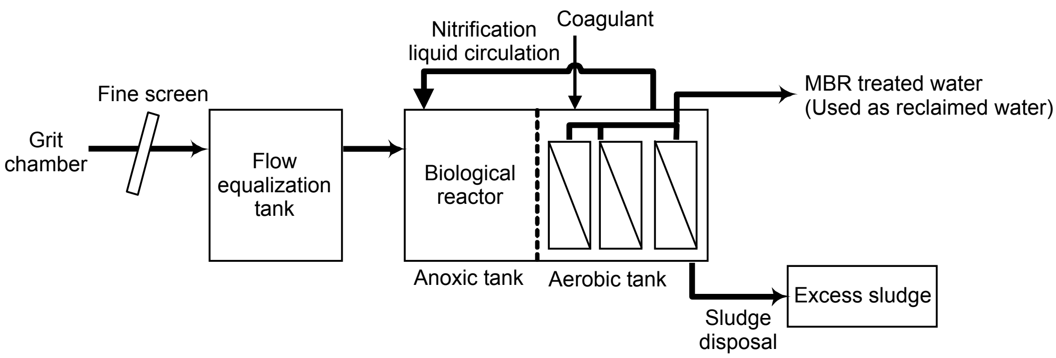


Figure 3-3 Example of a facility configuration for the recycled nitrification/denitrification process (repetition)

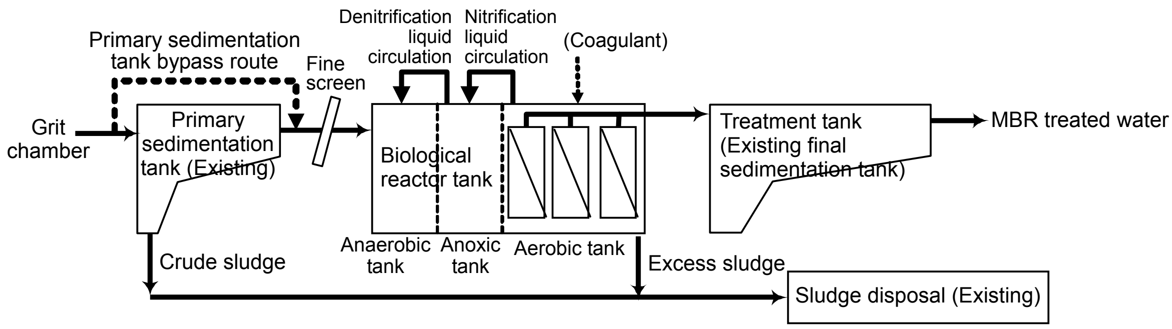


Figure 3-4 Example of the facility configuration for an A_2O MBR (membrane UCT) process (at the MBR demonstration facility in the Moriyama Water Treatment Center) (repetition)

(3) Features of MBRs

1) Features of MBR configurations

MBRs have the following configuration features:

[1] No final sedimentation tank is required, and the primary sedimentation tank and permanent disinfection equipment can be omitted or scaled down through a review of the operational conditions.

[2] A high MLSS can be maintained in the biological reactor, which enables excess sludge to be drawn directly from the tank for dehydration, thereby omitting the need for sludge concentration equipment.

[3] A flow equalization tank may be required to cope with influent flow rate fluctuation.

[4] The area required for membrane treatment equipment is small, and is generally 1/5 that of the OD process and 1/3 that of the standard activated sludge process.

[5] The influent water to the biological reactor must be treated using a fine screen of about 1 mm to protect the filtration membrane.

[6] Monitoring and control systems can be easily automated.

2) Features of MBR treatment functions

MBRs have the following features with respect to their treatment functions:

[1] Because no final sedimentation tank is required, management of the solid-liquid separation and the returned sludge is unnecessary, enabling simpler maintenance management.

[2] Because a high MLSS can be maintained in the biological reactor, water can be treated in a shorter time than with the conventional process.

[3] Pure and highly transparent treated water with few detected SS is obtained. Moreover, better removal of organic matter is achieved, because the treated water contains fewer SS as compared to that obtained with the conventional process.

[4] Because an MF membrane with a pore diameter of 0.4 µm or less is typically used, E. coli can be removed (demonstrated using stained specimens with the minor axis at 0.4 to 0.7 µm and the major axis at1.0 to 3.0 µm[28]).

[5] MBR treated water can be used for landscaping applications without further treatment. Moreover, it can be used as water for sprinkling or toilet washing if residual chlorine is retained.

[6] Because an MBR process requires long sludge retention times (SRT), nitrification readily occurs during the treatment process. Therefore, nitrogen removal is expected to occur via a biological nitrification/denitrification reaction by incorporation of an anoxic zone in the biological reactor.

[7] A greater volume of phosphorus can be removed by adding a coagulant. Moreover, a lower phosphorus concentration is achieved in the treated water, as fewer SS are contained in the treated water compared to the conventional process.

[8] Because MBRs can maintain a high MLSS and a long SRT, the sludge generation rate[1)] can be reduced by about 30% compared to the standard activated sludge process. This level is the same or lower than the level of the OD process, which generates less sludge.

[9] An MBR process attains the same level of excess sludge dewaterability as that of the OD process.

3.2 Factors to consider when installing MBR facilities

Before installation of an MBR facility, it is important to review the facility with respect to its capacity and other necessary features based on the various expected conditions, such as the quality of the influent and treated water, the necessary land acquisition, etc., and then select an optimal membrane and installation method based on the intended purpose, while also considering various aspects such as the economics, maintenance management and energy efficiency.

When reviewing and planning an MBR system, consider the major MBR facility configuration and its characteristics thoroughly. Figure 3-5 summarizes the steps involved in such a review.

Conditions to review (3.2.1)
Water temperature
Designed influent/effluent water quality
Designed water volume

↓

Review of MBR
Countermeasures for water volume fluctuation (3.2.2)
Primary sedimentation tank (3.2.3)
Pretreatment (3.2.4)
Reactor tank (3.2.5)
Membrane module (3.2.6)
Disinfection equipment (3.2.7)
Sludge treatment equipment (3.2.8)
Other cautions (3.2.9)

↓

Cautions for operation management (3.3)

↓

Cost review (3.4)

Figure 3-5 Steps involved in the review of an MBR system

3.2.1 Conditions to review

When planning for the installation of an MBR, determine the following conditions that will ensure stable treatment performance: (1) water temperature; (2) design influent/effluent water quality; and (3) design flow rate.

(1) Water temperature

It is known that a drop in normal water temperature by one degree C lowers the permeation flux by 2%[10] during periods when the water temperature is low, because the filtration rate decreases due to water viscosity and other reasons. Therefore, determine the required area for the membrane module based on the lowest value of the monthly averages.

If the influent flow rate fluctuates with the seasons, set the required area for the membrane module so that it is appropriate for the largest expected load, keeping the fluctuations in influent flow rate and water temperature for the different seasons in mind.

(2) Design influent/effluent water quality

If the MBR operates with a relatively high MLSS, nitrification is promoted in the reactor. Therefore, when setting the designed influent water quality, it is also necessary to set the specifications for the dissolved BOD*[21], alkalinity, T-N*[22] and other parameters required for ensuring nitrification.

In general, the specified values for the designed effluent water quality in the recycled nitrification/denitrification process (with coagulant added) are as follows: BOD at 10 mg/L or less, T-N at 10 mg/L or less and T-P*[23] at 0.5 mg/L or less. Figure 3-6 shows the cumulative frequency distribution of the BOD and T-N for the treated water at five demonstration plants (all used the recycled nitrification/denitrification MBR process, two with hollow fiber type membranes, two with flat membranes, and one with a ceramic membrane.) The results indicate that MBR treated water is of better quality than that of the standard activated sludge process, with a BOD of 2 mg/L or less and a T-N of 10 mg/L or less.

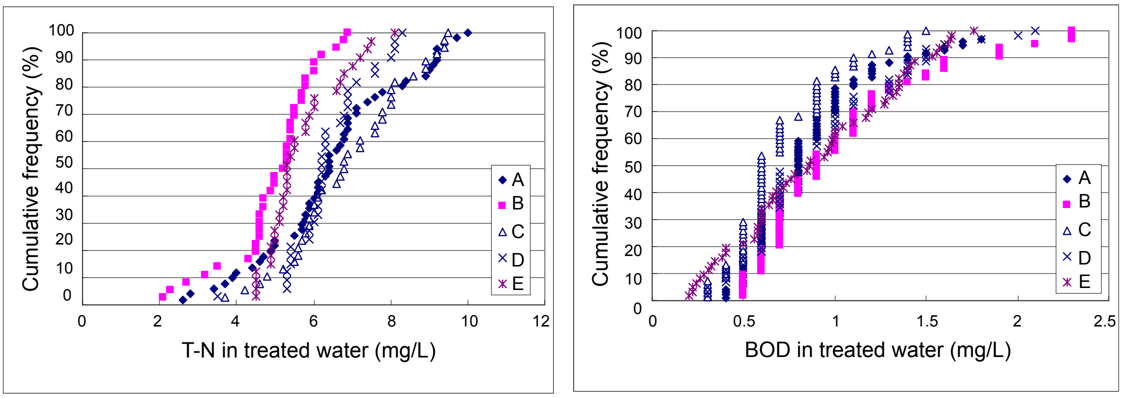


Figure 3-6 Cumulative frequency distribution for the BOD and T-N values of treated water at demonstration plants[10)]

(3) Design flow rate

When planning MBR facilities, the design maximum daily flow rate must be applied as a rule. The membrane permeation flux has an upper limit, however, and the flow exceeding the limit cannot be filtered. If the time fluctuation is too large to control with the filtration capacity of the membrane alone, other measures will be necessary. Therefore, carefully set the designed water volume with these issues in mind (see 3.2.2).

3.2.2 Countermeasures for flow rate fluctuation

> To control the water volume fluctuation that exceeds the treatment capacity of the MBR, review the mechanisms for maintaining the fluctuations within an appropriate range.

Although the use of an MBR ensures stable treated water quality, the treatment capacity depends on the permeation flux. To deal with excessive flow for a short period (several hours), it is necessary to set the rated permeation flux within an appropriate range. At the A-JUMP demonstration facility in the Moriyama Water Treatment Center, the MBR was operated with a permeation flux set at 1.5 times the daily average flow rate as daily fluctuations.

21 BOD: Biochemical Oxygen Demand
22 T-N: Total Nitrogen
23 T-P: Total Phosphorus

If the influent flow exceeds the penetrating power*[24] of the membrane, the water level of the reactor tank will rise, which may lead to reverse flow to the upstream equipment or overflow from the reactor tank. Therefore, it is necessary to cope with the influent flow rate fluctuation through the use of a flow equalization tank, by adjusting the water level of the reactor tank, or by controlling the permeation flux of the membrane, etc.

At actual small-scale facilities in Japan, a flow equalization tank is designed so that the fluctuation rate (maximum hourly flow rate/maximum daily flow rate) reaches 1.0 after adjustment, considering the maximum daily flow rate and influent fluctuation patterns within a day. If the intraday influent fluctuation pattern is unknown, it can be estimated based on the data from similar treatment facilities.

At medium- to large-scale facilities, the flow fluctuation rate is generally smaller than that at small-scale facilities. Larger construction costs are, however, necessary to realize a fluctuation rate of 1.0, because a very large capacity flow equalization tank is required. Therefore, it is important to review all possible countermeasures against flow fluctuations other than the use of a flow equalization tank, including operational management methods for the entire treatment plant, and decide whether or not a flow equalization tank is necessary and if so, then determine what size. Be sure to consider the case of an increase in the influent flow rate due to rainy weather.

One of the alternative countermeasures (other than the use a flow equalization tank) is the installation of a membrane that is large enough to cope with the peak influent flow rate. Note that, however, as the size of the membrane increases, the relevant costs also rise. Another option is to use a reactor tank that is large enough to contain the water level fluctuations, but the frame of the tank becomes larger with this method. Moreover, it is necessary to consider the impact of the water level fluctuations on the control of the trans-membrane pressure difference, as the water pressure at the membrane changes according to the fluctuations in the water level.

When using MBR for combined sewage systems, the influent flow rate during rainy weather must also be considered. To treat an influent flow exceeding the above fluctuation rate, countermeasures such as primary treatment are required.

When conducting parallel operations using both MBR and conventional processes, it is possible to control the flow rate fluctuations by changing the water distribution between the MBR and the conventional process (see details in Chapter 4.)

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[24] Penetrating power: a.k.a. water penetrating power. One of performance and quality items for membranes defined in the "Regulations for performance surveys on membrane modules for water service", as published by the Association of Membrane Separation Technology of Japan. It is defined as the permeation flux [$m^3/(m^2 \cdot d)$, m/d] at 25 °C and a constant trans-membrane pressure difference (100 kPa for MF/UF membranes) based on a filtered water volume that is determined using the specified testing method. In the above regulations, the penetrating power for a MF/UF membrane is rated as 0.5 $m^3/(m^2 \cdot d)$ or higher at 25 °C; however, this value differs from the penetrating power of the actual water that is treated in the membrane module due to the difference in the supplied water quality, because the rating is calculated using water purified by the specified process (see Reference 31).

3.2.3 Primary sedimentation tank

> Although a primary sedimentation tank is not mandatory, review the process to determine if a primary sedimentation tank (and of what size) would enable optimal operation, taking into account the features of MBRs stated in section 3.1.

MBRs can maintain a high MLSS in the reactor tank, which ensures necessary treatment performance without the need for reduction of the pollution load in a primary sedimentation tank. Therefore, a primary sedimentation tank is not mandatory.

If the MLSS in the reactor tank is too high, however, greater power is required for the air supply, and the membrane's permeability decreases, which may result in insufficient performance of the MBR. In such cases, consider the installation of a primary sedimentation tank to reduce the load on the reactor tank.

The following effects are expected as a result of the installation of a primary sedimentation tank:

- Equalization of the flow
- Reduction in the solid load on the fine screen
- Stabilization of the nitrification process with a longer SRT in the reactor tank
- Reduction in the amount of oxygen required at the reactor tank

It is important to note, however, that installation of a primary sedimentation tank is projected to affect the denitrification and biological dephosphorylation processes, along with an increase in the generated sludge volume (including crude sludge),, due to the reduction in the organic loading at the reactor tank. Because biological dephosphorylation requires a certain amount of solids to draw the phosphorus together with the excess sludge, it is necessary to consider bypassing the primary sedimentation tank.

In all of the small-scale treatment plants in Japan in which an MBR has been introduced, a flow equalization tank, but no primary sedimentation tank, has been installed

3.2.4 Pretreatment

> To protect the membrane module, install appropriate pretreatment equipment such as a fine screen.

To protect the membrane surface and to suppress fouling, installation of pretreatment equipment at the inlet of the reactor tank is recommended. Pretreatment equipment is generally installed prior to the flow equalization tank, if such a tank is incorporated into the process.

There are several types of fine screens[*25]: bar screens, drum screens and mesh screens. The pore

[25] The optimal pore size varies depending on the types of membrane module, process flow, operation method (cleaning of screen, cleaning and inspection of membrane), condition of influent sewage water, etc. In a certain case, the pore size of 0.5mm was adopted to take precedence in protection of membrane.

size*[26] of the fine screens adopted at small-scale facilities in Japan is 0.5 to 1 mm. The optimal pore size depends on the type of membrane module, the process flow, the operating methods (cleaning of the screen, cleaning and inspection of the membrane), and the conditions of the influent sewage water. It is necessary to taking these factors into account when selecting the type and pore size of the screen.

Serious troubles that can occur during MBR operation include breakage of the membrane and clogging. According to an analysis of membrane replacements in the UK, many of the breakages were caused by foreign substances flowing into the reactor tank or the membrane separation tank due to improper installation of the screen, or other reasons.[10)] Therefore, it is important to properly install and maintain the fine screen to prevent breakage and clogging of the membrane by foreign substances.

3.2.5 Reactor tank

When planning for a reactor tank, set the specifications for the (1) MLSS, (2) retention time and (3) required air flow rate, while exercising appropriate caution based on the features of MBRs stated in section3.1.

Figure 3-7 illustrates an example flow chart for determination of the capacity of an MBR treatment facility.

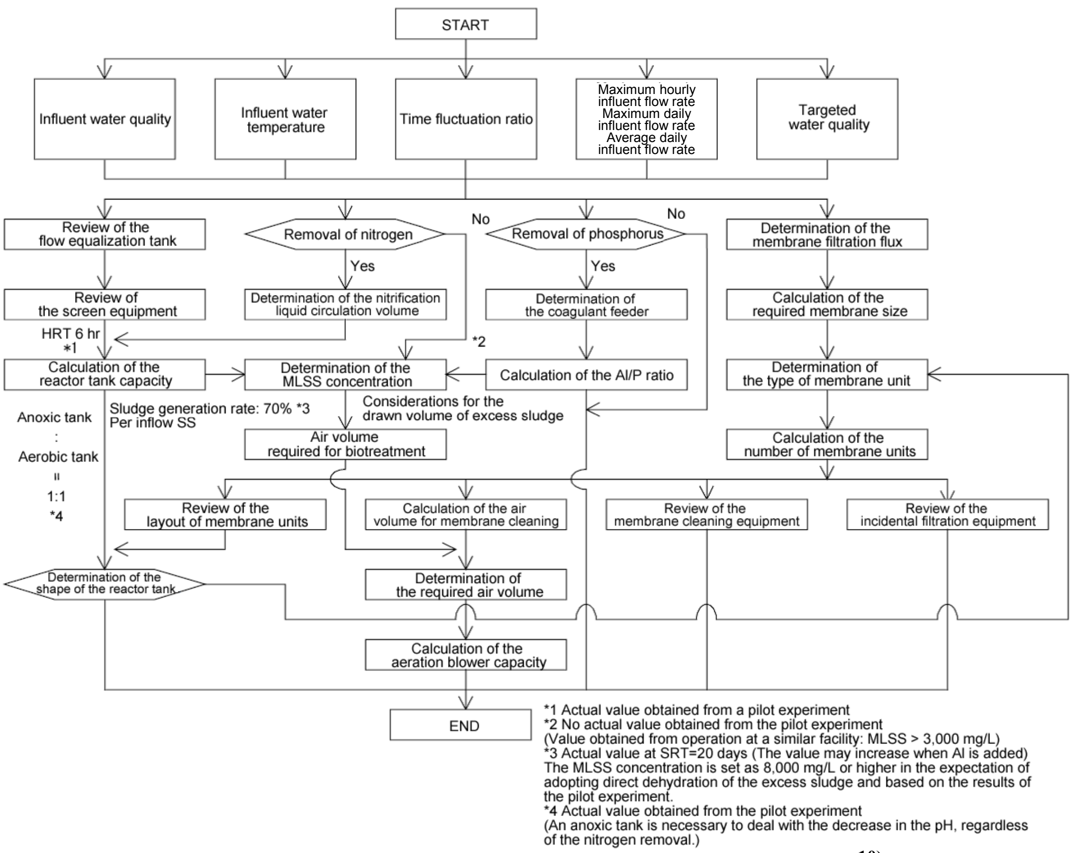

Figure 3-7 Example flow chart for capacity calculations[10)]

[26] At a separate tank type MBR facility installed overseas, two fine screens are installed; one with a pore size of 2 to 6 mm. before the rector tank, and the other with that at 0.5 to 1 mm between the reactor tank and the membrane separation tank.

(1) MLSS

In MBR, the MLSS in the reactor tank is higher than that of the standard activated sludge process; it is set at about 8,000 to 15,000 mg/L in existing systems[10)]. The achieve a higher MLSS, the capacity of the reactor tank must be reduced, but it is also necessary to maintain a balance with the required air flow rate.

Raising the MLSS as high as possible to reduce the capacity of the reactor tank has a considerable cost reduction effect, especially when installing MBRs in medium- to large-scale facilities.

From a maintenance management viewpoint, however, it is necessary to strictly confirm the range of the MLSS that can be stably managed. For example, when using an immersed type (integrated type) MBR, the MLSS in the section where the membrane module is installed tends to be higher than that in other sections due to the flow of the treated water. The MLSS at such sections is not equal to the average MLSS, which requires extreme care, especially at a facility where the reactor tank has a high aspect ratio. It is important to understand the distribution of the MLSS flow direction and the differences between the MLSS values at typical measurement locations and the average MLSS.

Furthermore, because the sludge viscosity and fluidity change with increasing MLSS, it is necessary to exercise caution regarding the fluidity (agitability) within the reactor tank, the fouling of the membrane, and the decline of oxygen transfer efficiency.

(2) Retention time

As for the retention time[*27] of the reactor tank, in the case of immersed type (integrated type/separate tank type) membranes, the retention time should be set so that it reflects the capacity of the tank that contains the membrane module.

When the MBR includes a process for the removal of nitrogen, the retention times of the aerobic and anoxic tanks should be set according to the influent water quality, the water temperature, the influent flow rate, and the MLSS.

Because the concentration of the MLSS is higher and the SRT is longer in an MBR process, the biological reaction characteristics are different from those in the conventional activated sludge process (MLSS at about 1,000 to 3,000 mg/L). Therefore, setting of the retention time requires further investigation, as the retention time set with the conventional parameters (BOD-SS load, A-SRT needed for nitrification, denitrification speed, etc.) are too low. Based on past results in Japan, a retention time of 6.0 hours is common for the recycled nitrification/denitrification process, while the demonstration facility at the Moriyama Water Treatment Center using an A_2O MBR process (membrane UCT process) operates with a retention time of 6.3 (summer) to 7.8 (winter) hours. In the EU countries, a retention time of 3.0 to 8.5 hours[*28]has been reported[16)].

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[27] The technology evaluation by JS assumes that the volume of the membrane module itself is included in the capacity of the reactor tank when determining the retention time. It is therefore unnecessary to add the volume of the module. In cases where the retention time is set to be extremely short, or where the membrane module, incidental equipment, etc. significantly affect the actual volume of the reactor tank, however, it is important to review the necessity of adding this volume.

[28] Among 17 surveyed facilities, 8 use a circulation process for the water treatment, 7 use a totally aerobic process, 1 uses UCT, and 1 uses an intermittent aeration process.

(3) Effective water depth

For the immersed type (integrated type), the effective water depth of the reactor tank should be set based on the membrane module and incidental equipment to be installed. Normally, the water surface of the reactor tank is set at several tens of centimeters higher than the upper end of the membrane module in order to prevent the membrane surface from drying. In particular, when the water depth of the reactor tank is expected to vary because the tank is designed to manage to fluctuations in the flow, it is necessary to determine the lowest expected water depth and the position of the upper end of the membrane module.

(4) Required air flow rate

Determine the required air flow rate based on the oxygen flow rate needed for biotreatment and the air flow rate necessary for air cleaning.

For the immersed type, the membrane module is immersed in the reactor tank, and the membrane surface is cleaned with an air-liquid mixture flow by aeration from underneath the membrane. Therefore, air can be used for both biotreatment and cleaning.

Presently, air cleaning often requires more air than biotreatment. The technology evaluation by JS[10)] specifies the standard design value of total air flow rate for the immersed type (integrated type) as 23 times the maximum daily influent flow rate. At the same time, however, technology developments targeted at energy savings are progressing rapidly, and thus this air blow factor is expected to decrease. The A-JUMP demonstration facility (Moriyama Water Treatment Center[*29]) operates with an air blow factor at 13.8 to 14.9 when using influent water from the Water Treatment Center mixed with water taken from the primary sedimentation tank (with a mixing ratio at 7:3). It is expected that the air flow rate required for air cleaning will be reduced in the future as progress is made in the technical development of membrane modules; however, reduction in the air flow rate for air cleaning may lead to an insufficient air flow rate for biotreatment. In such a case, it is necessary to consider installation of an auxiliary aeration instrument in addition to the aeration instrument for the membrane module.

Various studies have been conducted on the reduction of the air flow rate. For example, there is a process in which a long membrane module is placed vertically along the tank to effectively use air for cleaning (deepening of the reactor tank). One study[30)] found that the required air flow rate for the immersed type (separated tank type) could be reduced by setting the MLSS in the aerobic tank to a lower value (6 to 15%) as compared to that used in the immersed type (integrated type). Another study [31)] showed that the air flow rate could be reduced by about 20% using aeration equipment that produces diffuse, fine bubbles. Finally, for the conventional process, it has been reported[32)] that intermittent operation of the air cleaning equipment decreases the air flow rate by 1/2 to 1/3.

[29] Energy saving measures such as setting the effective water depth of the reactor tank at 7.0 m, using air-lift pump instead of mechanical pump in transport circulated sludge, as well as conducting membrane separation with gravity not by pump suction, are being taken.

3.2.6 Membrane modules

Selection of the membrane module is an important factor for ensuring stable operation and easy maintenance management of the MBR. Therefore, thoroughly review the following points with regard to the membrane module: (1) type, (2) installation method, (3) service life, and (4) cleaning process.

(1) Selecting the type of membrane module

Although there are various types of membranes used in MBRs, MF membranes (pore diameter at 0.1 to 0.4 μm) are the most common.

Table 3-2 describes the specifications for each membrane module currently used.

Table 3-2 Specifications for different membrane module types

Item	Flat (Company A)	Hollow fiber (Company B)	Ceramic (Company C)	Tubular (Company D)
Permeation flux (m/d)	0.7	0.6 - 0.7	≤2.6	1.2 - 1.44
Trans-membrane pressure difference (kPa)	≤20	10 - 50	20 - 80	10 - 50

* From hearings of the Japan Sewage Treatment Plant Constructors Association (2008.9)

The permeation flux of the membrane refers to the treated water flow rate per membrane surface, not the treatment performance per installation area. Therefore, when selecting a membrane module, review the size of the installation area in addition to the permeation flux. "Technical Information to Consider When Installing Membrane Technology" in Appendix I describes examples of the specifications for membrane modules and layout examples used for MBR in actual facilities in Japan.

(2) Installation configurations for the membrane module

Decide the installation configuration of the membrane module (the immersed type (integrated type), immersed type (separate tank type) and external type) by comparing and evaluating the conditions, such as the required air flow, type of membrane module, efficiency and manageability of cleaning, and costs.

The immersed type (integrated type) has been adopted more often than the immersed type (separate tank type) and external type. As of 2010, all MBRs installed in sewage treatment plants in Japan are the immersed type (integrated type).

The immersed type (separate tank type) and external type are easy to operate without stopping the reactor tank by linking it with other systems during membrane cleaning and inspection. In addition, they can be expected to have reduced air flow requirements when using aeration, in which specialized aeration equipment introduces finely dispersed bubbles into the reactor tank for cleaning of the membrane module.

Adoption of the separate tank type has been increasing overseas[11)] because the reactor tank can still be operated during membrane cleaning and inspection, which leads to easy maintenance management. According to a survey conducted in the EU[26)], 8 out of 15 surveyed MBR treatment plants (capacity: 1,600 to 45,000m^3/day) used the separate tank type MBR.

When selecting the installation configuration of the membrane module, make sure to consider the current situation and future trends in technical development and adoption, operational control concerns, and the possibility of changing the type and installation configuration of the membrane module at the time of its replacement (i.e., consideration of compatibility), etc.

(3) Service life of the membrane

A notification from MLIT[*30] states that the service life of the membrane unit is 15 years and that of the membrane cartridge is 10 years. Note that, however, these figures may vary according to not only the type and the installation configuration of the membrane module but also the cleaning methods and frequency, as well as the condition of the raw water (foreign substances, etc.).

The filtration membrane in an MBR can be kept functioning by maintaining the necessary permeation flux through physical or chemical cleaning (as shown in Figure 3-8). When a membrane is used for a long time, however, clogs remain even after cleaning that reduced the membrane filtration performance. When this situation occurs, it is necessary to replace the membrane. The interval of replacement is difficult to precisely predict, as it depends largely on the type of membrane, condition of the raw water, and the status of operation, etc. According to operation data in the UK (Table 3-3), for example, only 3% of membranes are replaced during the first 7 years of operation.

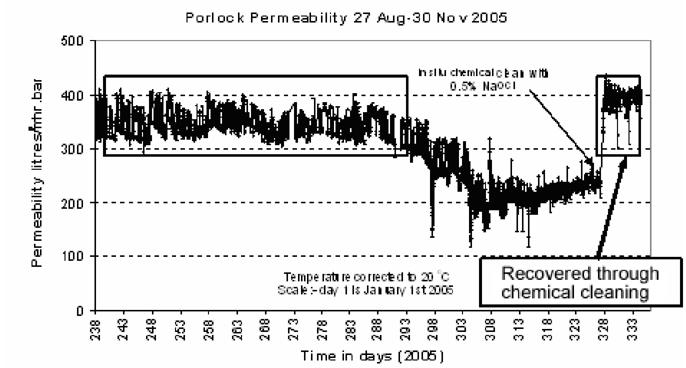


Figure 3-8 Aged deterioration of the permeability at the Porlock treatment plant in the UK[33)]

[30] Notification by MLIT (No. 77, issued by the Manager of the Sewerage Works Division, MLIT on June 19, 2003)

Table 3-3 Service life and replacement of membranes (results in the UK)[10)]

Service life	Number of membranes in use	Number of membranes replaced	Rate of replacement (%)
1	85,000	162	0.2
2	73,936	227	0.3
3	36,036	514	1.5
4	15,386	29	0.2
5	15,386	16	0.1
6	4,286	20	0.5
7	686	≤15	2.9

Among the MBR facilities in Japanese sewage treatment plants, the Fukusaki Water Purifying Center in Hyogo Prefecture has a record of about 6 years of operation, but has not yet needed to replace the membrane. Figure 3-9 shows the accumulated data on membrane replacement rates (as a percentage of the number of facilities) obtained from a survey on water treatment tanks and industrial wastewater treatment facilities. Because the wastewater conditions at the surveyed facilities are different from those of urban wastewater, the service life of the membranes may differ. According to the survey, however, 50% of facilities that installed an MBR in 1998 had not replaced the membrane at all within 7 years, and 45% of those that installed an MBR in 1996 or before had not replaced it within at least 9 years.

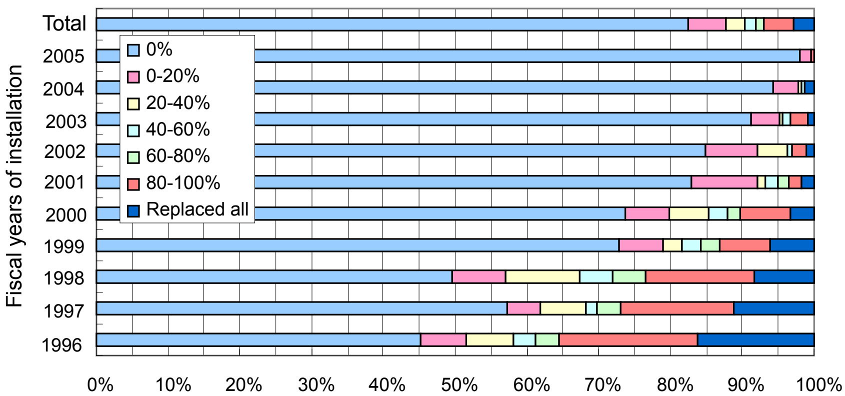


Figure 3-9 Ratio of facilities that replaced membranes (in water treatment tanks and industrial wastewater treatment facilities)[34)]

It is important to improve membrane durability and properly manage operations in order to extend the service life of the membranes.

To improve the membrane durability, use of a material that has a high chemical resistance (PVDF, etc.) is being reviewed and developed.

To extend the service life through operational management, the following measures should be noted:

- Installation of fine screens and ensuring their proper operation
- Chemical cleaning at the proper frequency and concentration

- Smoothing of the operating load by flow equalization (avoiding operations with permeation fluxes or trans-membrane pressure differences exceeding the design value to the extent possible)
- Maintaining the concentration of inorganic solids in the reactor tank as low as possible (scratch prevention).
- Avoiding rough handling at the time of installation and lifting of the membrane, and preventing the membrane from drying out.

(4) Cleaning processes

As described in Chapter 2, there are two cleaning processes: physical cleaning and chemical cleaning. Thoroughly consider the chemical costs and equipment, the efficiency and manageability of cleaning, and the possibility of combining several processes.

When cleaning an immersed type MBR, constant strong aeration (air cleaning) is usually conducted to prevent accumulation of a cake that leads to fouling. Chemical cleaning is also conducted regularly to remove the fouling that occurs when the trans-membrane pressure difference becomes large. Figure 3-10 depicts the major chemical cleaning processes and Table 3-4 describes their mechanisms.

In chemical immersion cleaning, the membrane module is taken out and placed in a cleaning tank filled with a chemical solution for a certain period of time. Therefore, it is inevitable that the treatment performance of the MBR will decline and related lines will be suspended during cleaning. This disruption of operations should be considered carefully when planning an upgrade of an MBR facility to a medium- or large-scale, and special precautions should be taken to prepare for the case where the membrane module cannot be used for a certain period of time.

Figure 3-11 shows the process flow for recovering the trans-membrane pressure difference by cleaning.

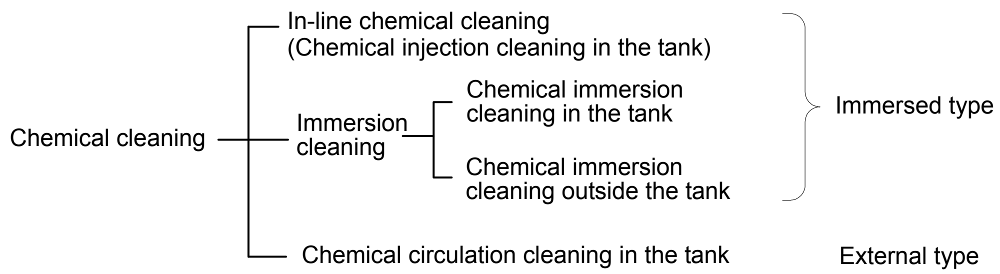
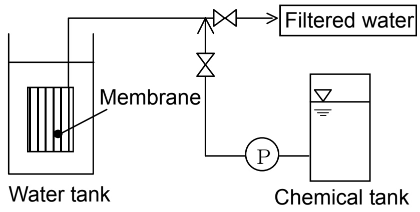
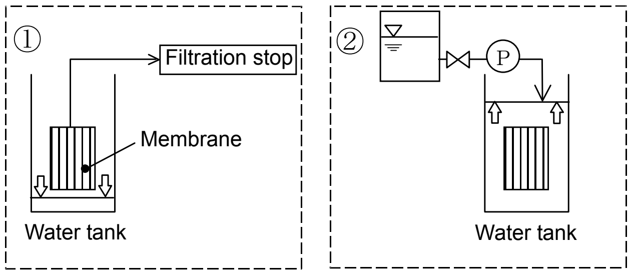
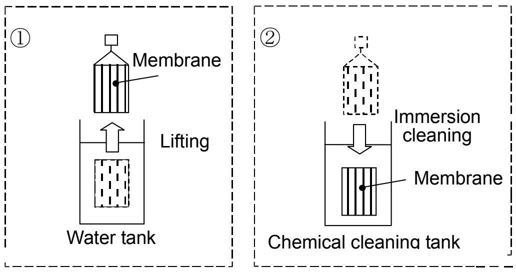
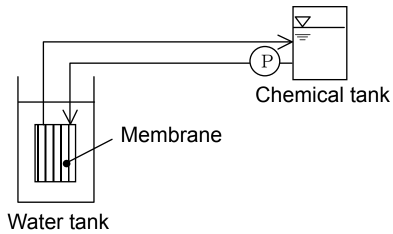


Figure 3-10 Major chemical cleaning processes

Table 3-4 Mechanisms of different chemical cleaning processes

<table>
<tr><td colspan="2">In-line chemical cleaning (internal chemical injection cleaning)
The membrane is immersed in the tank (or casing), and a chemical solution is poured from the secondary (filtered water) side to clean the membrane</td><td>
</td></tr>
<tr><td rowspan="2">Immersion cleaning</td><td>Internal chemical immersion cleaning
The membrane is immersed in the tank (or casing) and (1) activated sludge is drained out, and then (2) a chemical solution is poured in to fill the tank or the casing in order to clean the membrane.</td><td>
</td></tr>
<tr><td>External chemical immersion cleaning
(1) The membrane is taken out from the tank (or casing), and then (2) immersed in the chemical cleaning tank filled with a chemical solution. After cleaning, the membrane is re-installed into the original tank (or casing).</td><td>
</td></tr>
<tr><td colspan="2">Internal chemical circulation cleaning
The membrane is immersed in the tank (or casing). A chemical solution is poured from the secondary (filtered water) side, and simultaneously, the chemical solution is discharged from another part of the membrane to clean the membrane by circulation of the chemicals.</td><td>
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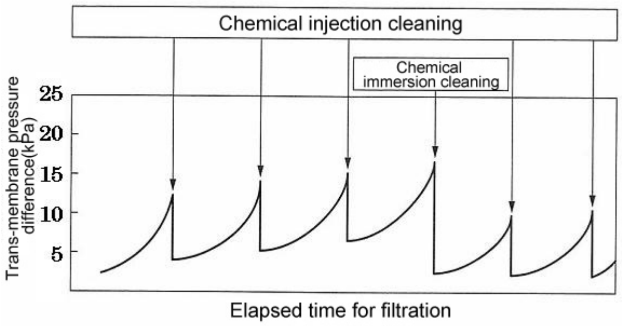


* "Chemical injection cleaning" refers to in-line chemical cleaning. Although the cleaning frequency varies depending on the membrane manufacturer, many perform this cleaning process about once a week.

* "Chemical immersion cleaning" is generally performed about once a week, although some manufacturers do not recommend it at all.

Figure 3-11 Changes in the trans-membrane pressure difference due to cleaning[4)]

3.2.7 Disinfection equipment

Disinfection equipment is recommended as an emergency countermeasure in case there is a malfunction of the MBR.

MBR removes E. coli by membrane filtration. The general evaluation[35)] states that "almost no E. coli is found in treated water." The technology evaluation by JS[10)] concludes that permanent disinfection equipment is not necessary for MBR treated water, but it may be required as an emergency countermeasure in the case of a malfunction, such as membrane breakage, to enable the addition of chlorine, etc.

3.2.8 Sludge treatment equipment

When selecting sludge treatment equipment, it is important to consider the features of MBR described in section 3.1 in order to decide on the appropriate sludge treatment process and to conduct material balance calculations.

(1) Sludge treatment process

Because an MBR requires no final sedimentation tank, the excess sludge is drawn directly from the membrane module installation (the end of the reactor tank, membrane module-installed tank, or casing).

In an MBR, MLSS is concentrated at a high level (generally 8,000 to 15,000mg/L), and the drawn excess sludge can be directly dehydrated. The number of dehydrators that are required depends significantly on whether the excess sludge (at a concentration of at about 10,000 mg/L) is directly dehydrated, or if it is first concentrated (to a concentration of about 30,000 to 50,000 mg/L). Therefore, select a sludge treatment process by thoroughly comparing the advantages/disadvantages of the possible processes, including those with/without concentration steps, in view of the economic efficiency (initial costs and running costs) and manageability.

Of the 10 MBR treatment plants in Japan that were put into service by fiscal year 2008 with a treatment capacity of 125 to 4,200 m^3/day, seven plants use direct dehydration without a concentration process, and the other three transport the sludge to other treatment plants (data from "Statistics of Sewerage" and hearings with treatment plants).

(2) Material balance

In planning a facility that includes a sludge treatment system, the material balance of the sludge should be calculated in principle.

An MBR is expected to decrease the excess sludge generation per SS inflow. It has been reported[10) that the sludge generation rate is about 60 to 70% of the inflow (removed) SS when no coagulant is added. If coagulant is added to remove phosphorus, however, it is necessary to account for the increase in generated sludge volume due to the coagulant addition.

3.2.9 Other cautions

In planning and reviewing an MBR installation, be sure to consider the following additional points: (1) the membrane unit lifting instrument, (2) the water level design, and (3) the facility layout

(1) Membrane unit lifting instrument

The lifting instrument at the upper part of the membrane unit is used to carry the membrane in/out, and for inspection, repair, chemical immersion cleaning, etc. of the membrane. Review the installation of the lifting unit, taking into consideration the unit layout and weight, the covering structure, the height below the beam, the load it can withstand, etc. Moreover, make sure that the membrane unit can be completely lifted onto the slab, and that enough space (height and area) is available for the both the lifting operation and for the operators, in order to ensure the safety of the lifting process.

(2) Water level design

Review the water level design of the treatment facility so that water flows smoothly, based on the outside water level of the effluent destination, the water level for the sewage pipe at the treatment plant, and the designed ground level of the plant.

In cases where, at a relatively small-scale MBR facility, the sewage water is pumped from the flow equalization tank to the reactor tank, and the treated water is suctioned from the membrane module using a pump, the water level of each tank can be set comparatively freely. At medium- to large-scale facilities, however, pump equipment with a large capacity is used. In such cases, it is desirable, from the viewpoint of saving energy, to review the water levels in the adjacent equipment in order to realize gravity flow.

(3) Facility layout

Prepare a layout plan for the pretreatment equipment, flow equalization tank, reactor tank, control building, sludge building, etc., that matches the site conditions, while considering the efficient use of the equipment, including the membrane module and the immersion cleaning tank.

(4) Others

Consider the impact of the facility on the surrounding environment. In particular, implement countermeasures against the release of odors from the flow equalization tank.

3.3 Cautions for operation management

The following sections discuss the cautions that must be taken when managing the operation of an MBR treatment facility, most of which were identified in a report presenting the results of a survey of issues relating to the management of MBR-based systems[36)].

3.3.1 Management systems at MBR treatment facilities

Manage the facility using personnel who are permanently stationed at the facility, or conduct patrols on a regular basis.

Of the 12 MBR facilities in Japan with a treatment capacity of 125 to 6,060 m^3/day that were put into service by the fiscal year 2009, only three have permanently stationed personnel, while the others conduct patrols one to three times a week, as most are small-scale plants. Thus, it can be concluded that MBR can be managed using a system equivalent to that implemented for other OD processes. For solid-liquid separation, in particular, the control and automation of system monitoring is easier than it is for conventional methods that separate solids by sedimentation, as MBR uses a membrane. Many treatment plants conduct patrols at times when the dehydrator is operated or residue screening is carried out.

3.3.2 Daily management items

Effective daily management activities at MBR facilities confirm that the system is being properly operated by measuring the DO, MLSS, trans-membrane pressure difference, etc.

Many MBR facilities measure the water temperature, pH, transparency, DO, trans-membrane pressure difference, etc. on a daily basis, and regularly confirm the condition of the activated sludge by judging its permeability through paper filter. Some treatment plants conduct visual inspections to confirm the air flow rate and aeration/air cleaning conditions(to confirm that there are no deviations), etc.

Table 3-5 lists the main operational monitoring items that should be checked daily.

Table 3-5 Main operational monitoring items to be checked daily

Process component	Monitoring items
Aerobic tank	DO, MLSS, permeability with paper filter, etc.
Effluent water	Water temperature, pH, transparency (SS and turbidity), simplified water quality analysis (with COD or ammonium nitrogen), etc.
Instruments	Trans-membrane pressure difference, flow rate of filtration

[1] DO in the aerobic tank: When the MLSS concentration is high, the oxygen transfer efficiency decreases. Therefore, it is important to confirm the level of dissolved oxygen in the aerobic tank to prevent insufficient biotreatment.

[2] MLSS in the aerobic tank: When the MLSS concentration is excessively high, it causes a decrease in the oxygen transfer efficiency and clogging. Therefore, it is necessary to maintain an adequate MLSS. As the settings for the MLSS differ depending on the inflow characteristics and membrane conditions of the treatment plant, it is desirable to determine the optimal value through operational management. It is also necessary to ensure a long enough SRT to maintain the nitrifying bacteria.

[3] Permeability with a paper filter[10]: Be aware that, if the permeability of the activated sludge through filter paper is 5 mL/5 minutes or less, the filtration performance of the membrane equipment may be reduced. An increase in the trans-membrane pressure may occur even with adequate permeability, due to contamination of the membrane. Therefore, it is necessary to frequently check the permeability.

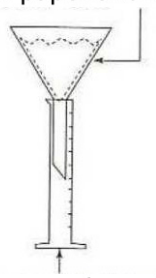


Figure 3-12 Method for measuring the permeability with paper filter[11]

[4] Transparency of membrane filtered (effluent) water: Confirm the level of SS in the effluent to ensure that there is no membrane breakage or abnormality in the piping.

[5] Simplified water quality analysis of membrane filtered water: It is necessary to confirm that the DO level in the aerobic tank is sufficient by analyzing the membrane filtered water for COD or ammonium nitrogen using a colorimetric method.

[6] Trans-membrane pressure difference: It is important to understand the conditions that lead to clogging and to conduct efficient cleaning in order to ensure efficient daily operation. Therefore, the trans-membrane pressure difference should be monitored for indications of fouling, and an effective chemical cleaning routine should be planned. It is desirable that the trans-membrane pressure difference be continuously monitored so that countermeasures can be immediately implemented if sudden clogging occurs, and also to confirm the effectiveness of chemical cleaning.

3.3.3 Initial operation

> The initial operation of an MBR facility should be conducted with seed sludge of known composition.

(1) Input of seed sludge

It is recommended that seed sludge from the sludge stream that will be processed by the facility be used. If seed sludge is brought in from another facility, it is recommended that a fine screen be used first to screen out any foreign substances.

(2) Permeation flux

To prevent clogging of the membrane caused by insufficient decomposition of organic matter, set the daily permeation flux at a low level according to the influent flow rate at the start of operations, and then gradually raise the value while confirming the composition of the sludge.

(3) Foaming in the reactor tank

Use an alcohol deformer to prevent foaming in the reactor tank. Do not use a silicone deformer, as this type of compound causes clogging.

3.3.4 Cleaning of the membrane

Conduct proper cleaning to prevent or remove fouling on the membrane.

There are two types of cleaning processes; one prevents fouling and the other removes it. Various methods are available depending on shape and material of the membranes, so select an appropriate method based on the specific membrane characteristics, while considering the following points: (1) the cleaning effect, (2)the energy consumption, and (3) the quantity of work.

(1) Cleaning for the prevention of fouling

Under normal operating conditions, fouling is restrained using the art of the filtration operation and through aeration cleaning (air scrubbing) with coarse bubbles. Some existing treatment plants also have incorporated an in-line cleaning system using a low-concentration chemical solution (sodium hypochlorite) to the normal filtration operation with the aim of reducing the frequency of cleaning to remove fouling, which is described in (2). Table 3-6 describes examples of cleaning using the filtration operation. In these examples, cleaning is conducted by using intermittent filtration, backwashing, air scrubbing, and cross-flow filtration, independently or in combination. As shown in the Table, these processes are automated to operate in a short cycle, so additional cleaning is not conducted.

Table 3-6 Examples of time schedules for membrane cleaning

Plant		Cleaning operation	Type of membrane
A	Aeration cleaning on the membrane surface	Continuous	Organic/ flat
	Counter pressure cleaning	None	
	Filtration operation	Filtration for 13 minutes -> Interval for 2 minutes (repeated)	
B Note 1)	Aeration cleaning on the membrane surface	15 minutes of aeration during a filtration operation	Organic/ flat
	Counter pressure cleaning	None	
	Filtration operation	Filtration for 15 minutes -> Interval for 105 minutes (repeated)	
C	Aeration cleaning on the membrane surface	Continuous	Organic/ hollow fiber
	Counter pressure cleaning	0.5 minutes during an interval between the filtration operations	
	Filtration operation	Filtration for 9 minutes -> Interval for 1 minute (repeated)	
	Chemical injection cleaning	Once a week, automatic in-line cleaning with a low-concentration chemical (sodium hypochlorite at several hundred ppm for 1 hour)	
D	Aeration cleaning on the membrane surface	Continuous	Organic/ hollow fiber
	Counter pressure cleaning	1 minute during an interval between the filtration operations	
	Filtration operation	Filtration for 9 minutes -> Interval for 1 minute (repeated)	
E	Aeration cleaning on the membrane surface	Continuous	Organic/ hollow fiber
	Counter pressure cleaning	None	
	Filtration operation	Filtration for 13 minutes -> Interval for 2 minutes (repeated)	
F Note 2)	Cross-flow	Membrane cleaning by cross-flow, except counter pressure cleaning and chemical injection cleaning (Air bubbles are mixed simultaneously.)	Inorganic/ monolith
	Counter pressure cleaning	Simplified counter pressure cleaning (for an extremely short time) and counter pressure cleaning are used. See the column below for the timing.	
	Filtration operation	Filtration for 10 minutes -> Interval (simplified counter pressure cleaning) Filtration for 10 minutes -> Interval (simplified counter pressure cleaning) Filtration for 10 minutes -> Interval (simplified counter pressure cleaning) Filtration for 10 minutes -> Interval (simplified counter pressure cleaning) Filtration for 5 minutes -> Interval (counter pressure cleaning for 2 minutes) (repeated)	
	Chemical injection cleaning	10 to 20 times/day (Filtration is stopped during chemical injection cleaning)	

Note 1) The process takes a long interval time to avoid excess aeration and save energy, as the inflow water volume is low.
Note 2) Demonstration facility

(2) Cleaning for the removal of fouling

When the trans-membrane pressure difference rises during normal operation, oxidants such as sodium hypochlorite are generally used to remove fouling of the adhered organic matter. In cases where fouling is not removed by the oxidant, however, acids, including oxalic, citric, or diluted sulfuric acid, or alkalis, including sodium hydrate, may be effective. It is important to consider the cause of the fouling and the chemical resistance of the membrane material when selecting the type of chemical solutions and determining the time needed for the work, etc..

Existing facilities use immersion cleaning and/or in-line cleaning methods depending on the shape and material of the membrane. Table 3-7 and Table 3-8 present an outline of each method and issues that should be considered prior to their application.

(1) Immersion cleaning: The membrane unit is lifted up from the reactor tank and immersed in a tank filled with a chemical solution.

(2) In-line cleaning: The membrane unit remains immersed in the reactor tank, and a chemical solution is injected from the outlet of the filtered water.

Table 3-7 Outline of the immersed cleaning method and issues to be considered prior to application

Frequency	Once every one to two years (per unit)	
Working hours	One to two days per chemical	
Type of chemicals and their concentrations	Sodium hypochlorite	1,000 to 5,000 ppm
	Oxalic acid	2,000 to 20,000 ppm
Details of the process	・ Lift the membrane unit from the reactor tank and manually wash it with water if sludge is attached to the unit. ・ Immerse the unit in the tank filled with the chemical solution. (For several hours to overnight, depending on the type of chemical solution) ・ Lift the unit from the chemical solution tank and rinse the chemical solution. ・ Install the unit in the reactor tank.	
Issues	・ Lifting of the unit and removal of the sludge on the membrane requires manpower. ・ Because the treatment performance declines (or operations are suspended) during this work, it is necessary for the facility to carefully plan when the cleaning process will occur and have systems in place for dealing with the reduced performance.. ・ The amount of chemicals used varies depending on the shape of the immersion tank. ・ Note that some membranes cannot be allowed to dry completely due to their material composition.	

Table 3-8 Outline of the in-line cleaning and issues to be considered prior to application

Frequency	Once every several months (per unit)	
Working hours	Several hours	
Type of chemical and its concentration	Sodium hypochlorite	2,000 to 5,000 ppm*
	Oxalic acid	1%
Details of works	・ Stop filtration and close the valve. ・ Inject the chemical solution at the appropriate concentration. ・ After one to two hours have passed, open the valve and restart filtration.	
Issues	・ Although the mixing and injection of the chemical solution are automated in many cases, sometimes manpower is required for system operation and for opening/closing of the valve. ・ Because the treatment performance is reduced during this process, it is necessary for the facility to carefully plan when the cleaning process will occur and have systems in place for dealing with the reduced performance. ・ Because the chemical solution may seep out from the membrane and affect the activated sludge in the tank, it is necessary to carefully determine the concentration of the chemical solution and the immersion time. ・ Because the filtered water immediately after the cleaning contains high concentrations of the chemical solution, it is important to carefully consider the discharge destination for this water, as well as necessary steps for neutralizing or reducing the solution as required.	

* Automated in-line cleaning that is conducted once a week using sodium hypochlorite at several hundreds of ppm for one hour is classified as "cleaning for preventing fouling." For "cleaning for removing fouling," however, sodium hypochlorite at a concentration as high as 2,000 to 5,000 ppm is required.

(3) Treatment of the waste water generated during the cleaning process

When conducting in-line cleaning (using sodium hypochlorite), the concentration of the chemical solution should be as low as possible to avoid any effects on the biotreatment system. Immediately (and for about several tens of minutes) after in-line cleaning, it may be necessary to confirm the residual chlorine concentration and return the filtered water back to the inflow side, among other treatment options.

In many cases, the cleaning wastewater is neutralized and then returned to the inflow side of the facility after its concentration is confirmed. In such cases, it is necessary to dilute the returned water with treated water to reduce the impacts on the biotreatment or to gradually discharge the water so as not to significantly raise the load all at once. Because citric acid, which is used in acid cleaning, becomes a high concentration BOD source, water generated in this cleaning process is often gradually discharged to avoid any effects on the biological reaction and to reduce the risk of membrane clogging that can occur as a result of suctioning of the membrane when there is untreated BOD present.

3.3.5 Control methods

Proper control of the filtration equipment, aeration rate, circulation rate, etc. is critical for ensuring optimal performance.

Because the operating time of the filtration equipment, the aeration rate, the circulation rate, etc. directly affect energy consumption, the recommended methods described below have been developed for controlling these operational parameters. Additional review is necessary, however, as optimal values for operation vary depending on the specific operating conditions at individual plants.

(1) Control of the filtration time

It is not necessary to operate the filtration equipment continuously; some plants halt membrane filtration and aeration cleaning early in the morning and in the middle of the night when the influent flow rate is low, thereby saving energy.

[Example]

When there is no inflow and the membrane filtration equipment is not functioning, aeration of membrane cleaning is also halted, and only aeration to prevent corruption of the activated sludge is conducted.

Plant A: Aeration for 5 minutes during 60 minutes

Plant B: Aeration for 5 minutes during 120 minutes

(2) Control of the aeration rate

The ability to adjust the aeration so that it is just adequate to control the ammonium nitrogen concentration in the effluent water and DO in the aerobic tank leads to energy savings.

(3) Control of the circulation rate

When conducting the nitrification liquid circulation process to remove nitrogen, or the biological simultaneous nitrogen and phosphorus removal process, it is important to use an appropriate circulation rate. During the times when the influent is low, it is possible to conduct intermittent operation of the circulation pump to achieve the optimal circulation rate, which leads to a reduction in the circulation of excessive nitrification liquid and sludge, thereby saving energy. Furthermore, circulation homogenizes the MLSS at the area where the membrane module is installed with the MLSS at other areas in the reactor tank.

3.3.6 Replacement of the membrane

Replace the membrane regularly or when it is broken or damaged.

Of the MBR facilities used in sewage treatment plants in Japan, the facility at the Fukusaki Water Purifying Center (Hyogo Prefecture) has been operating for about 6 years, but has not experienced the need to replace its membrane.

At MBR facilities where the membrane is used in sewage treatment tanks and night-soil treatment plants, there are cases where the membrane module was replaced because of damage, etc. after it was lifted from the tank for inspection and manually cleaned. In these cases, however, the conditions, such as the raw water characteristics, are different from those of sewage water.

3.3.7 Countermeasures in case of membrane breakage

It is necessary to be able to diagnose the need for emergency countermeasures in the case of membrane breakage.

If it is necessary to monitor possible membrane breakage due to the requirements for the effluent, or if it is difficult to swiftly take countermeasures against an unexpected accident at a large-scale facility, then continuous measurement of the turbidity (using a turbidity meter) is effective for diagnosing potential problems.

If reducing the risk at the effluent destination is strongly requested, it can be achieved by automatically injecting chlorine upon detection of a breakage based on the automatic turbidity measurements, etc.

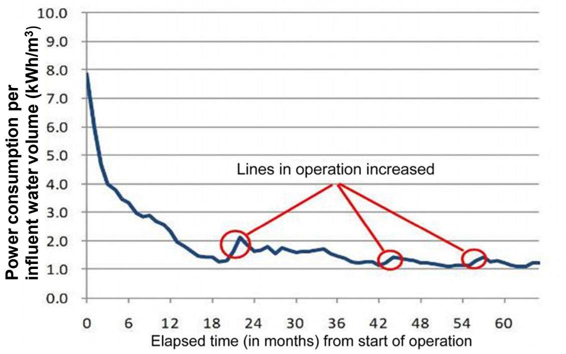
3.3.8 Power consumption

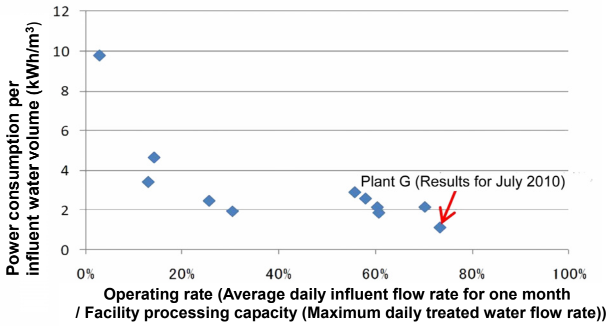
Provide measures to save energy by understanding the future operating rates of the facility, and by designing the facility considering the initial low inflow rate during the early stages of operation.

(1) Changes in power consumption

Figure 3-13 illustrates the changes in the power consumption per influent water volume (daily average for each month) at Plant G, beginning from the start of operation. As the influent water volume increases, the operating rate also rises, which enables efficient operation and leads to a drop in power consumption per influent water volume. When the number of lines in the operation increases, however, both the operating rate and power consumption rise.

Figure 3-14 shows the relationship between the operating rate and the power consumption of 11 MBR facilities in Japan, where power consumption is calculated in the same manner as in Figure 3-13. Because the operating rate and power consumption are related to each other, it is necessary to particularly take into account the predicted influent water volume during the early stages of operations when designing a facility.





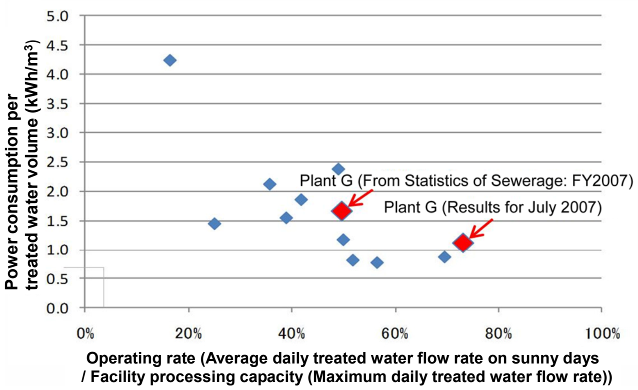
Power consumption is calculated based on the purchased electric power in the entire treatment plant.

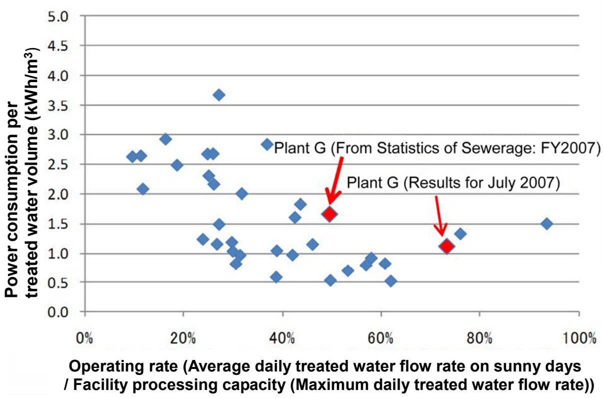
Figure 3-13 Changes in the power consumption per influent water volume at an MBR facility (Plant G)

Figure 3-14 Relationship between the operating rate and the power consumption at 11 existing MBR facilities in Japan

(2) Comparison of the power consumption for a conventional treatment process

Figure 3-15 shows a comparison of the operating rates and power consumption per treatment water volume at Japanese facilities adopting the recycled nitrification/denitrification MBR process and the conventional process (recycled nitrification/denitrification process) with a capacity of 1,700 to 14,800 m^3/day and a median value at 4,700 m^3/day, and Figure 3-16 illustrates the same comparison of MBR facilities in Japan with a capacity of 446 to 8,000 m^3/day and a median value at 1,550 m^3/day and those of a similar scale that have adopted the advanced OD process,.





* The data for the recycled nitrification/denitrification process and advanced OD process were taken from the "Statistics of Sewerage: FY2007[37)]" report.
* The power consumption is calculated based on the purchased electric power in the entire treatment plant.
* All MBR, recycled nitrification/denitrification and advanced OD processes use a sludge treatment system including a process for mechanical dehydration.

Figure 3-15 Comparison of the operating rates and power consumption per treated water volume of facilities using an MBR process (Plant G) and those using the recycled nitrification/denitrification process

Figure 3-16 Comparison of the operating rates and power consumption per treated water volume of facilities using an MBR process (Plant G) and those using the advanced OD process

As shown in Figure 3-15, the MBR and recycled nitrification/denitrification processes have similar results, while the MBR process consumes a little bit more power than the advanced OD process, as can be seen in Figure 3-16.

According to the MLIT report[38], the A-JUMP demonstration facility (the Moriyama Water Treatment Center) reduced its power consumption by about 40% compared to the conventional MBR, which indicates that a greater reduction in power consumption can be expected for the above-mentioned conventional MBR via the introduction of the following energy saving measures:

- Reduction of the circulation pump energy using air lift pumps
- Reduction of the filtration energy using a siphon-type gravity filtration process
- Reduction of the auxiliary aeration energy by controlling the DO and ammonia levels
- Reduction of the membrane cleaning energy by adopting intermittent aeration cleaning (which shortens the aeration time as much as possible by repeating aeration and non-aeration in a cycle of a few seconds)

3.3.9 Sludge generation rate

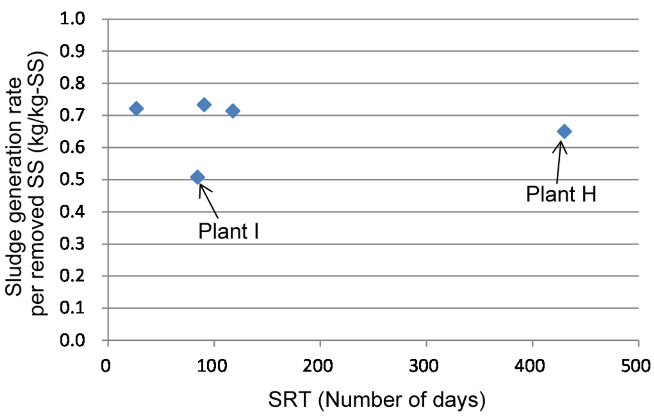
MBR reduces the sludge generation rate per removed SS by maintaining a high MLSS and a long SRT; however, a decline in the oxygen transfer efficiency and an increase in the energy required for aeration may occur due to the high MLSS. Therefore, it is necessary to plan an adequate sludge drawing volume.

As MBR discharges no SS into the effluent water, all of influent SS becomes removed SS.

(1) Relationship between the sludge generation rate per influent SS and the SRT

Figure 3-17 shows the relationship between the sludge generation rate per influent SS and the SRT. The SRT is generally long (27 days at the shortest). Sludge generation rates of four treatment plants (excluding Plant I) are 0.65 to 0.73 kg/kg-SS. As shown in the following [Reference] the Figure, the sludge generation rate for the MBR process is lower than that for the standard activated sludge process, and equal to or a bit lower than that for the recycled nitrification/denitrification or OD processes. The rate at Plant I, at 0.51 kg/kg-SS, is lower than the above values, but this result seems to be due to a decrease in the sludge volume through the use of a chemical solution, as Plant I conducts in-line cleaning using low concentration sodium hypochlorite once to a few times per week.

An excessive rise in the MLSS in order to increase the SRT may lead to a decline in the oxygen transfer efficiency, which in turn results in an insufficient oxygen content and reduced performance. Moreover, a reduced oxygen transfer efficiency may lead to an increase in the aeration energy required for agitation. Therefore it is important to exercise cautions when raising the MLSS.



[Reference][1), 29)]
Example of sludge generation rates per removed SS for each treatment process

Water treatment process	Sludge generation rate per removed SS
Standard activated sludge	1
Recycled nitrification/denitrification	0.79
OD	0.75

- Existing 5 MBR treatment plants (2 use flat membrane while 3 use hollow fiber membranes)
- Calculation of the sludge generation rate was achieved as follows:

Plant H: Because the MLSS is high and the sludge drawing period is long at about 100 days, the value was obtained by subtracting the difference in the MLSS before and after the sludge drawing. Because it is situated in a cold area, the influent water temperature is low.

Other plants: The following formula was used.

Sludge generation rate per removed SS = (Generated sludge volume) / ((average concentration of influent SS) x (influent water volume))

If a coagulant was added during the process, the sludge generated from the coagulant was subtracted.

Figure 3-17 Sludge generation rates per removed SS and SRT

(2) MLVSS/MLSS ratio

Figure 3-18 illustrates the of MLVSS[*31] to the MLSS at Plant H. Although the interval of sludge drawing is 100 days or longer and the SRT is 400 days or more, the average ratio of the MLVSS/MLSS[*32] remains nearly constant at approximately 0.8. Therefore, it may be considered that there is no accumulation of inorganic matter in the inflow SS and that the microbial activity of the activated sludge does not decline.

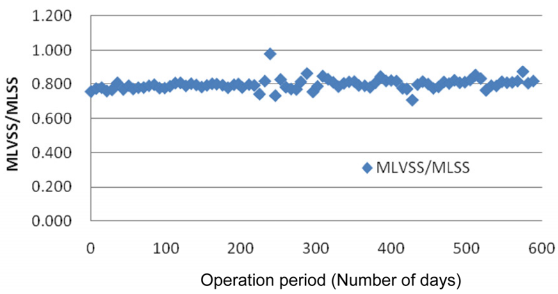


Figure 3-18 Changes in the MLVSS/MLSS ratio over time

[31] MLVSS: Mixed Liquor Volatile Suspended Solids (nearly equal to the organic suspended solids).

[32] MLVSS/MLSS: Concentration of organic suspended solids in the activated sludge, which is used as an index of the microbial biomass in the activated sludge. When the non-biodegradable inorganic matter accumulates, the concentration decreases and the biotreatment activity is halted, even with a high MLSS concentration.

3.4 Cost review

To determine the costs of a newly installed MBR, compare the costs with those for the conventional process, considering the factors that cause an increase or decrease in the construction and maintenance related costs.

3.4.1 Major costs associated with the installation of an MBR

Table 3-9 summarizes the factors that leads to an increase or decrease in the cost of an MBR installation compared to a conventional process.

With respect to construction costs, land acquisition and civil engineering costs are expected to decrease, because an MBR process does not require a final sedimentation tank and uses a smaller reactor tank. Membrane modules have few economies of scale at the present, but the price of membranes is declining, and the development of low-cost membrane modules is progressing. Appendix I presents data related to membrane costs that indicate that such costs have been reduced to about 1/5 in 10 years (from 1994 to 2004) in the EU[39)]. With regard to maintenance, however, there are factors that lead to both cost increases and cost decreases for MBR processes. Maintenance is easier because the facilities are smaller and the final sedimentation tank is eliminated, and the sludge generation rate decreases, all of which contribute to cost reduction. Power consumption increases, however, due to the need for an air blower, and there are also membrane replacement costs that are not associated with the conventional process.

It is expected, however, that both the construction and maintenance management costs will decrease through the market expansion of membrane technology and as advances in technology development continue.

Table 3-9 Main factors affecting the cost of installation of MBR at a newly constructed facility

From Reference 39)

	Cost decreasing factors	Cost increasing factors
Construction costs	○Small-scale facility with less equipment ・Final sedimentation tank is not necessary ・Permanent disinfection equipment can be omitted ・Sludge concentration can be omitted ・Sand filtration equipment is not necessary ○The capacity of the biological reactor can be lowered ○Less space is required	●The following facilities and equipment are added to the conventional process: ・Membrane module ・Membrane cleaning equipment ・Fine screen ・Flow equalization tank ● Increase in required performance for the air blower
Maintenance management costs	○Easy sludge management is possible ○Use of disinfectant can be reduced ○Generated sludge volume can be lowered ○Maintenance management work is reduced with a simple facility configuration	●Management and replacement costs for the membrane module ●Cost of the chemical solution required for cleaning the membrane ●Increased power for the air blower
Cautions	・MBR is still under development, and further cost reductions are expected through future market expansion of membrane technology. ・Various MBR systems are being developed, and their features and costs differ significantly.	

3.4.2 Basic policies for cost reviews

When reviewing the costs associated with the installation of an MBR to a newly-constructed sewage treatment plant, determine the treatment capacity, required treatment water quality and site conditions, and then calculate the costs for construction, maintenance and land acquisition, and compare those costs with the costs for a treatment facility achieving the same performance with a conventional process.

When comparing the costs, however, note that MBR is still under development, and that the costs for MBR differ significantly depending upon the adopted technology and the site conditions, and ensure that the latest information for MBR processes is used.

These guidelines present information useful for cost reviews through case studies with hypothetical conditions. These studies have been conducted by the working group (WG) established at the Sewage Technical Meeting on Membrane Technology, and through the cooperation of the seven manufacturers participating in the working group (participants).

3.4.3 Information and assumptions pertaining to the case studies

- These case studies target four types of facility scales, as described in Table 3-10, and the costs for newly constructed treatment plants using an MBR or the conventional process are reviewed.
- The studies use a recycled nitrification/denitrification type MBR, which was assessed in the general evaluation by the Industrial Wastewater Treatment Technology Committee in February 2010. Details of the system, including the membrane separation method and the way that flow

fluctuations are handled, are based on proposals by individual participants (see Table 3-12.) An overview of the MBR systems proposed by the individual participants is included in Appendix I.

- For the conventional process, the studies use the "advanced oxidation ditch process" followed by chlorination at the rapid filtration process. For the facility with a capacity of 1,000 m^3/day, however, the POD process[*33] is alternatively used.
- These studies assume no land acquisition costs.

Table 3-10 Assumptions made for the case study reviews (when constructing a new facility)

Item		Conditions to review
Target to review		● MBR with the recycled nitrification/denitrification process (without a primary sedimentation tank) ● Each company suggested specifications such as civil engineering structures, etc. (except for those specified by the Secretariat) ● Water level design: Influent water level after pumping-up: GL+0.5 m; effluent water level: GL-1.0 m
Scope of review	Civil engineering issues	● A concrete frame is used, while the cover is omitted in the proposal. ● The space for installing equipment such as the piping gallery is included in the review.
	Water treatment equipment	● All incidental equipment (air blower equipment, membrane cleaning equipment, coagulant addition equipment, etc.) required for the MBR process, in addition to the reactor tank equipment (membrane separation equipment, agitator, pumps, etc.) ● The control board for the MBR devices and equipment is included in the water treatment equipment.
	Electrical equipment	Power, instrumentation and control equipment to operate the MBR equipment is included for review, while the power receiving/transforming, non-utility generation and central supervisory control equipment are out of scope of the project.
	Lifting pump	Out of the scope
	Sludge treatment	Out of the scope
Treatment capacity		● 4 cases (500, 1,000, 2,500, 5,000 m^3/day) per line are assumed ● However, two systems for each case are reviewed with consideration of the maintainability (membrane cleaning) (500 m^3/day x 2 lines, 1,000 m^3/day x 2 systems, 2,500 m^3/day x 2 systems, 5,000 m^3/day x 2 systems)
Daily flow fluctuation		An assumption of 1.4 times the average daily flow rate with a peak twice a day, and the maximum daily flow rate continues for 8 hours.

Table 3-11 Design water quality (when constructing a new facility)

Water quality item	Influent water quality (mg/L)	Design effluent water quality (mg/L)
T-BOD	200	10
S-BOD	100	-
SS	180	-
TN	35	10
TP	4.0	-

33 POD: prefabricated oxidation ditch

Table 3-12 Overview of MBR systems targeted for review (when constructing a new facility)

Item	Outline of system
Type of membrane	Hollow fiber membrane x 4; flat membrane x 2; ceramic membrane x 1
Membrane separation process	Immersed type (integrated type) x 5; immersed type (separate type) x 1; external type x 1
Biotreatment method	Recycled nitrification/denitrification process x 7
Control of flow fluctuation	Flow equalization tank x 4; flux fluctuation controlling equipment x 3
Pretreatment equipment	Influent screen x 7

3.4.4 Cost calculation methods

(1) Method for calculation of the construction costs

Based on the following principles, the construction costs were calculated for each of the following types of equipment: civil engineering, machinery, and electrical.

- Civil engineering: Based on the drawings presented in each proposal, the amount of concrete, mold, reinforcement, scaffolding and construction work was roughly calculated to determine the construction costs. Piling and other fundamental activities, as well as the soil improvement work, were not considered.
- Machinery: The direct device costs were calculated based on the device list and unit prices presented in each proposal, and then the result was multiplied by a coefficient (1.6 in all cases) to determine the addition cost of the construction work. This coefficient was chosen based on the average construction work/device cost ratio for constructing existing MBR water treatment facilities for sewage plants. For the conventional process, the direct device costs were calculated based on the device list and unit prices determined by capacity calculations, and then the result was multiplied by a coefficient (1.8) to determine the cost of the construction work.
- Electrical: The electrical equipment work costs presented in each proposal were used as supplied.

(2) Method for calculation of the utility costs

Based on the following principles, the electrical energy costs and chemical costs were calculated as utility costs.

- Electrical energy costs: all of the electricity consumption quantities presented in the proposals were added to calculate the total electricity consumption. This result was then multiplied by the unit price to determine the electrical energy costs.
- Chemical costs: these costs were calculated by multiplying the quantity of chemicals presented in the proposals (chemicals for membrane cleaning for MBR, and disinfectant for the conventional process) by their respective unit prices.

(3) The life cycle cost (LCC) concept

The concept of life cycle costs (LCC) was based on the following principles.

- Construction costs (initial costs per year), maintenance costs (electrical energy costs and chemical costs per year) and repair costs (3% of the device costs excluding the membrane unit) were included for calculating the LCC.

- Initial costs were determined by totaling the yearly costs for each piece of equipment, which were calculated by dividing the initial costs for each piece of equipment by its service life. The service life of buildings and civil engineering structures was set to 50 years, while that of machinery and electrical equipment was determined based on the years* designated in the notifications from MLIT.
- The above notifications set the service life of "the membrane cartridge" at 10 years, and that of "the membrane unit" at 15 years for membrane treatment facilities. After review, however, WG concluded that it was more realistic that the membrane should be replaced as a unit, not as a module. Therefore, it was decided that either 10 or 15 years would be used as the service life of the membrane unit, depending on the proposals by the individual participants.

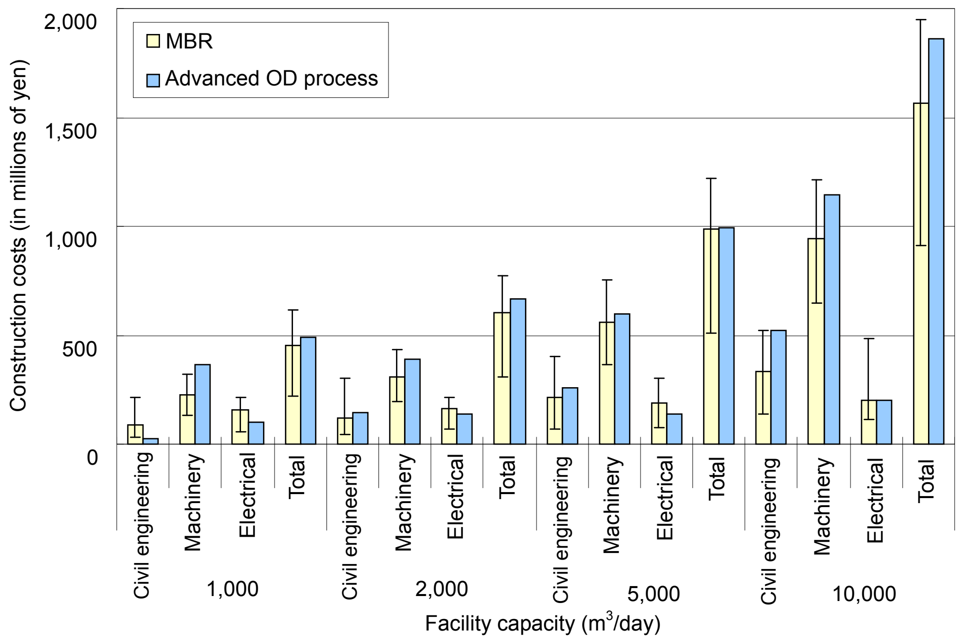
  * The number of years specified in the attached table in "Re-constructing sewage facilities" (No. 77, Notification by the Manager of the Sewerage Works Division, MLIT, issued on June 19, 2003)

3.4.5 Example cost reviews

This section shows the results of the cost calculations for the installation of an MBR at a newly constructed sewage treatment plant. This review assumes no land acquisition costs.

Depending on the system adopted, MBR is advantageous with regard to costs.

1) Construction costs



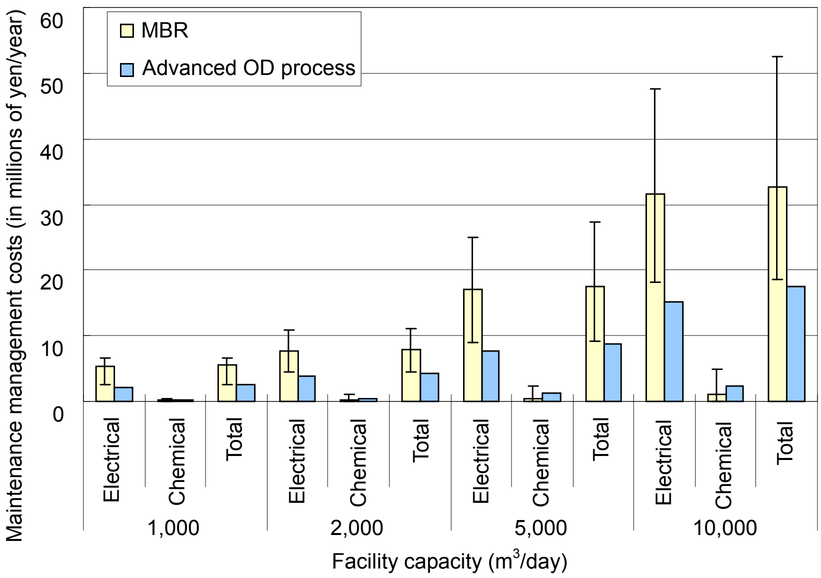
* In the Figure, the vertical bars for the MBR process indicate the median values, while the thin lines represent the maximum and minimum values.

Figure 3-19 Comparison of construction costs

- When comparing the median values, there is no significant difference in construction costs (the total of the civil engineering, machinery and electrical equipment costs) for the MBR and conventional processes. Note that, however, the costs for MBR vary according to the systems used, and therefore may become significantly lower than those for the conventional process.

- At the facilities with a capacity of 1,000 m^3/day, because the POD process is used for the conventional process, the costs for the OD tank is included in the machinery costs. Therefore, the total costs for both processes are nearly equal, because the machinery costs for the conventional process are higher than those for the MBR process, while the MBR process requires more civil engineering costs than the conventional process.
- At the facilities with a capacity of 2,000 to 10,000 m^3/day, an MBR is advantageous with regard to the civil engineering costs, because it requires less space. Machinery and electrical equipment costs are about the same for both processes.
- According to the technical evaluation[10)], at many facilities with a capacity of 3,000 m^3/day or more, the MBR process has higher construction costs than the OD process. In this review, however, the construction costs are nearly equal for both processes at the facilities with a capacity of 5,000 m^3/day, and at the facilities with a capacity of 10,000 m^3/day, the MBR process is advantageous compared to the OD process.

2) Maintenance management costs

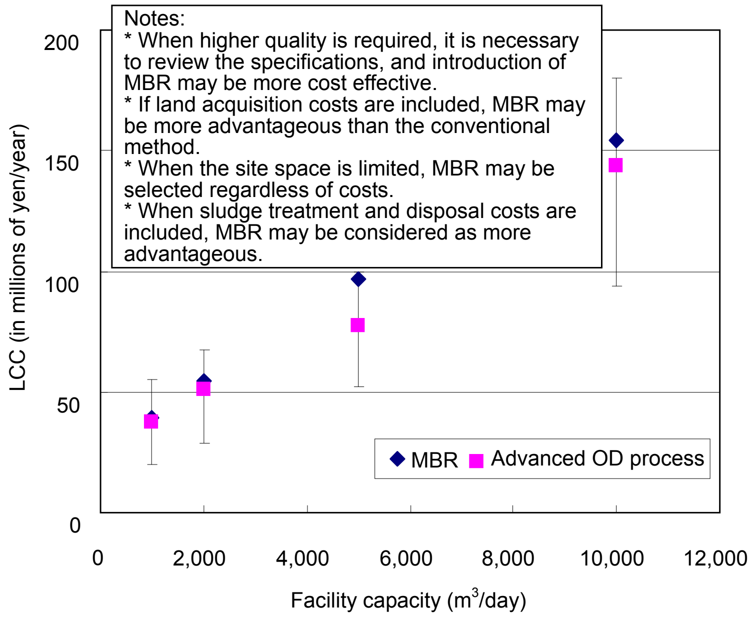


* In the Figure, the vertical bars for the MBR process indicate the median values, while the thin lines represent the maximum and minimum values.

Figure 3-20 Comparison of maintenance costs

- For both MBR and the conventional processes, the electrical energy costs represent most of the maintenance management costs.
- The electrical energy costs for the MBR process are generally larger than those of the conventional process. They may drop to the same level as those for the conventional process, however, depending on the MBR system adopted.

3) LCC

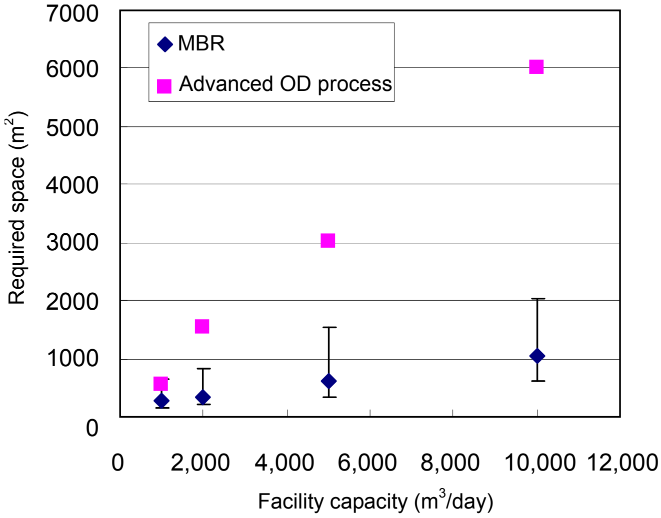


* In the Figure, the vertical bars for the MBR process indicate the median values, while thin lines represent the maximum and minimum values.

Figure 3-21 Comparison of LCC

- When comparing the median values, the LCC for the MBR and conventional processes are nearly equal at the facilities with a capacity of 1,000 m^3/day and 2,000 m^3/day. The LCC for the conventional process are lower at facilities with a capacity of 5,000 m^3/day or 10,000 m^3/day. An MBR process may be more advantageous, however, depending on the system adopted.
- As described in 4), an MBR requires significantly less space than the conventional process. Therefore, if the land acquisition costs are included, MBR may be more advantageous.
- As the scale of the facility increases, the difference in the LLC for MBR and the conventional process decrease.

4) Required space



* In the Figure, plots for the MBR process indicate the median values, while the bars represent the maximum and minimum values.

Figure 3-22 Comparison of required space

- Use of an MBR requires less space than the conventional process; when comparing the median values, the required space for an MBR is approximately 1/2 that for the conventional process at the facilities with a capacity of 1,000 m^3/day, and at the facilities with a capacity of 10,000 m^3/day, it is only about 1/6 of that for the conventional process.
- MBR may be selected regardless of costs when the site space is limited.

5) Additional considerations regarding this cost review

The cost results presented here are based on calculations of hypothetical conditions. Actual costs may vary significantly depending on the facility design conditions or future technological developments, as well as the considerations shown in Table 3-13.

Table 3-13 Additional notes on this cost review (for the construction of a new facility)

Issues to consider when evaluating the results of this cost review	● In this review, the specifications of each process were prepared based on the assumption that the treated water for the MBR and conventional processes is of the same quality. When a higher quality is required due to regulations on water quality or use of reclaimed water, it is necessary to review the specifications. Installation of an MBR may be more cost effective. ● MBR may be selected regardless of the cost calculation results when the site space is limited. ● The land acquisition cost is not included in this review, but if it is included, MBR may be more advantageous than the conventional method. ● Sludge treatment and disposition costs are not included in this review, although MBR actually generates less sludge than the conventional method. From a comprehensive viewpoint including sludge treatment, therefore, MBR may be considered as more advantageous.
Issues to consider regarding the prerequisites of this cost review	● For an MBR process, this review considered the range of pretreatment equipment (including the flow equalization tank) to water treatment equipment (the primary sedimentation tank was omitted). ● For the OD process, this review considered the range of equipment from the separation tank to the chlorination equipment. ● For both processes, the lifting pump, the deodorization equipment and the sludge treatment facility were out of the scope of the review.

Chapter 4 Introduction of MBRs to existing treatment plants

Introduction of MBRs to existing treatment plants tends to progress in a stepwise manner, which leads to the parallel operation of the MBR and conventional processes. This chapter describes considerations for parallel operations and its economic efficiency, etc.

4.1 Features of the parallel operation of MBR and conventional processes

Parallel operation of MBR and conventional processes, which occurs when an MBR is installed in existing treatment plants, has the following features:

- The size of the reactor tank can be downsized, and the final sedimentation tank can be eliminated, thereby enhancing the processes and increase the treatment capability in a limited space and using existing buildings.
- The treated water quality can be achieved by adjusting the flow rate distributed to the MBR and the conventional process.

Introducing MBR to existing treatment plants is effective for enhancing the processes or boosting their capacity in a limited space and using existing structures, because the size of the reactor tank can be reduced and the final sedimentation tank can be omitted, although addition of some equipment, such as for flow equalization and pretreatment, is required.

Installation of an MBR at existing treatment plants can fulfill the following objectives:

- Rapid improvement of the treated water quality to meet environmental standards and conditions for water use at the effluent destination
- Reduction of water system risks for users of the reclaimed water and at the effluent destination.
- Ensure reuse of water with a specified flow rate
- Upgrading of a facility in a stepwise manner in a limited space while maintaining the current treatment capacity

Figure 4-1 shows a diagram with the steps required for the installation of an MBR during reconstruction of a facility. Use of an MBR can ensure that the current treatment capacity is maintained during reconstruction, while requiring no additional buildings, and at the same time achieving enhancement of the process.

Hypothetical conditions:

- Reconstructing/upgrading the standard activated sludge process facility with a processing capacity of 50,000 m^3/day (10,000 m^3/day for each tank)
- It is possible to stop one tank (by upgrading the normal aeration equipment, etc.)
- The processing capacity per tank after introducing MBR will be 1.3 times that of the standard activated sludge process. (5,000 m^3/day for the standard activated sludge process, 6,700m^3/day for MBR, according to Table 4-3 in "4.3 Cost review.")
- The required space for the conventional process (recycled nitrification/denitrification process) is 1.75 times that for the standard activated sludge process (When HRT for the standard activated sludge process is eight hours and that for the recycled nitrification/denitrification process is 14 hours)

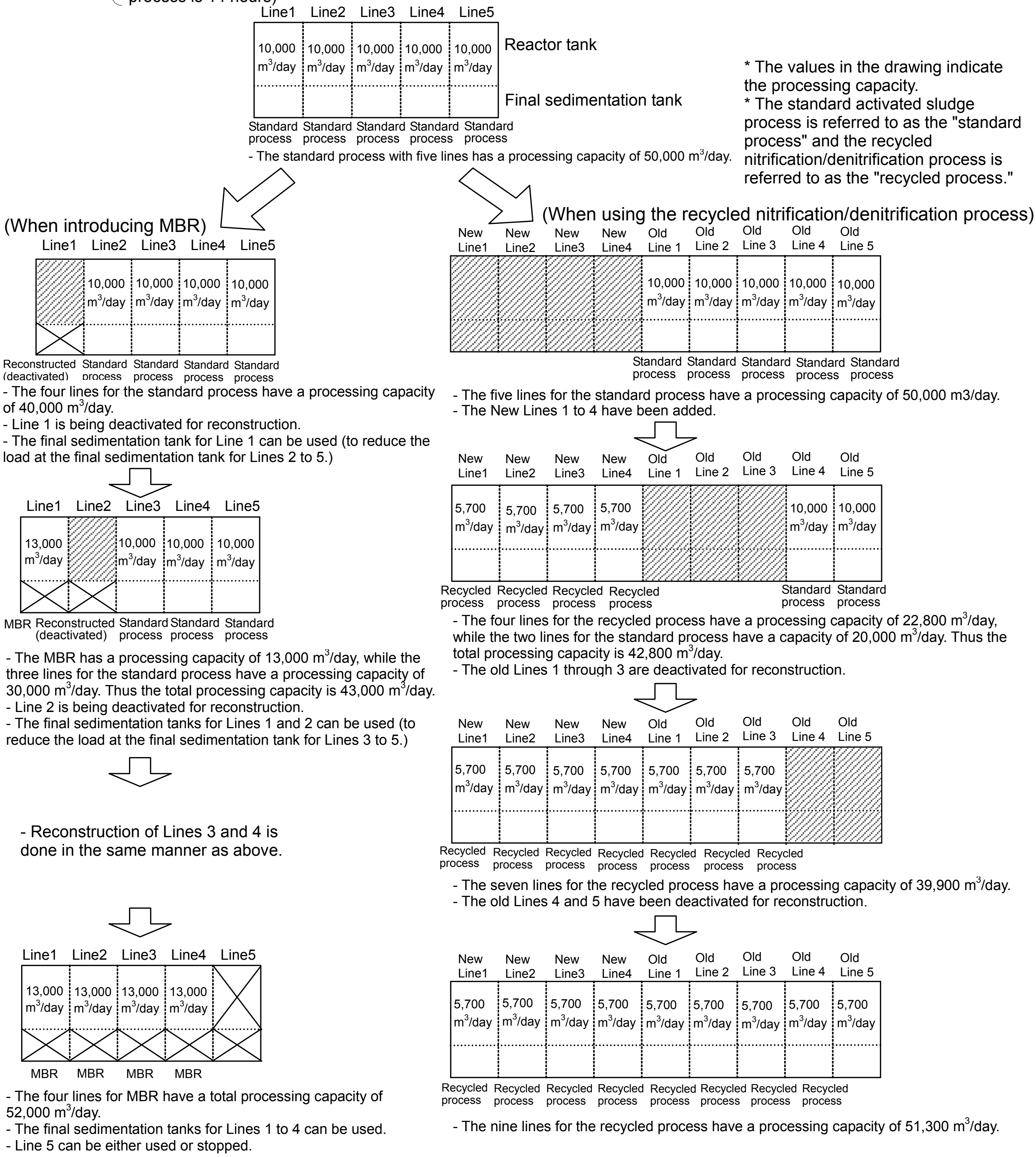


Figure 4-1 Diagram for reconstructing/upgrading an existing plant with an MBR

4.2 Considerations regarding parallel operation of an MBR and a conventional process

When an MBR and a conventional process are run in parallel, it is necessary to consider the following matters: determination of the water distribution, control of the flow fluctuation, utilization of the final sedimentation tank, etc. (See Figure 4-2.)

When conducting parallel MBA and conventional processes, there two cases, the addition of MBR to a new line (addition of new line), and the modification of an existing line (modification of existing line).

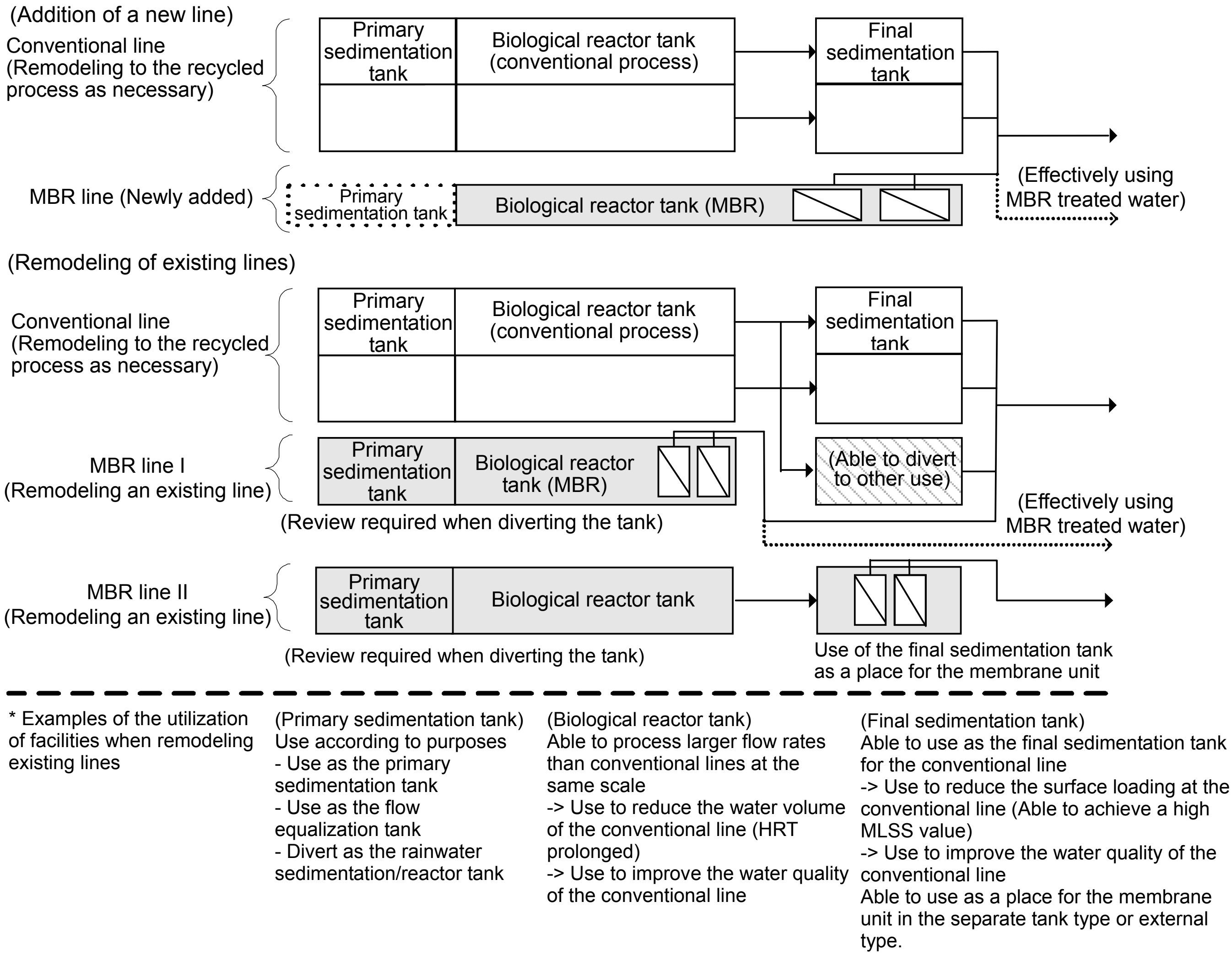


Figure 4-2 Schematic of parallel MBR and conventional processes

Figure 4-3 shows a process flow diagram for use when reviewing parallel MBR and conventional processes. Specific issues to consider are explained in the sections below.

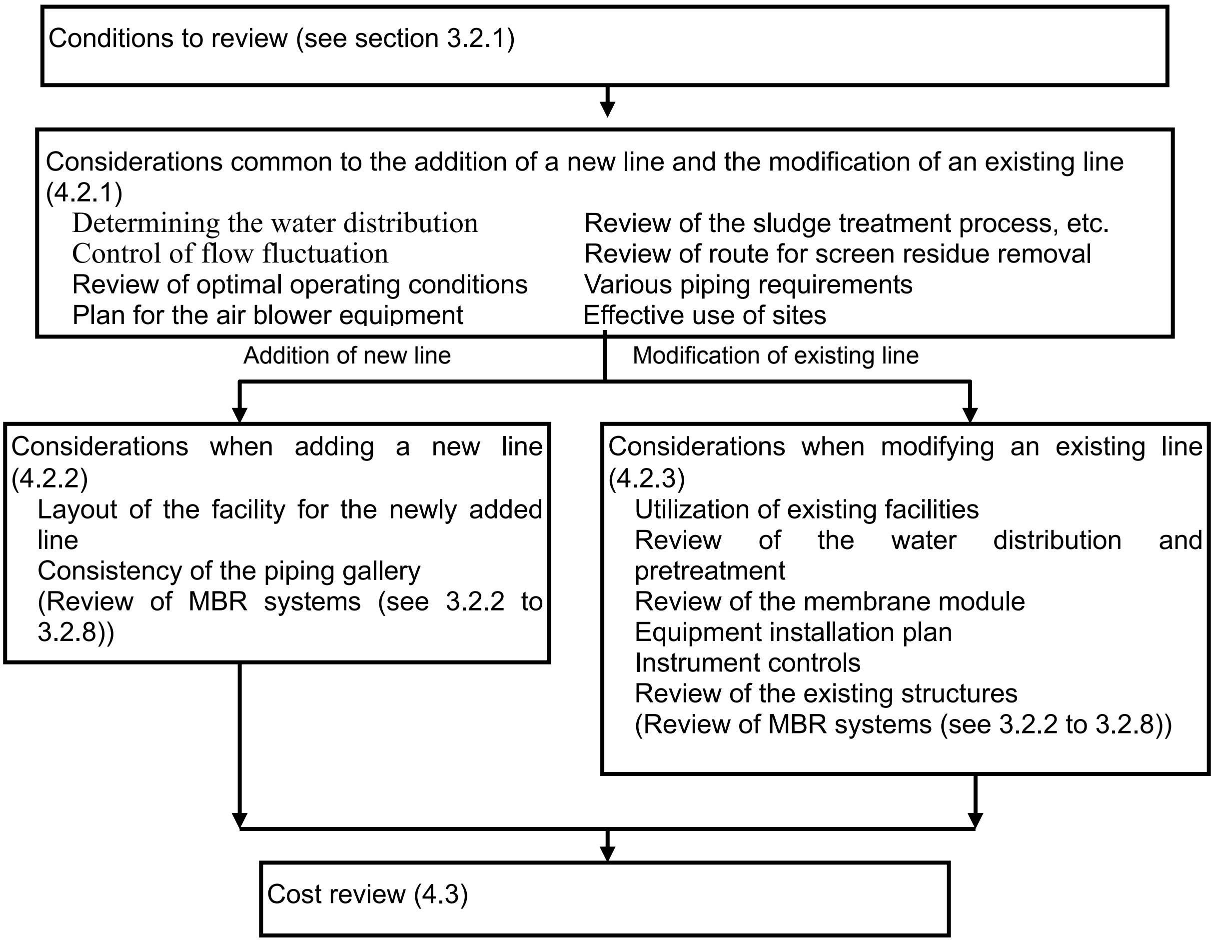


Figure 4-3 Flow diagram for use when considering parallel MBR and conventional processes

4.2.1 Considerations common to the addition of a new line and the modification of an existing line

> When conducting parallel MBR and conventional processes, it is necessary to determine if there is adequate water distribution for the MBR and the conventional lines, how the flow fluctuation will be controlled, and what the optimal operating conditions should be, etc.

(1) Determining the water distribution

The necessary retention time for the reactor tank of an MBR is shorter than that for the conventional method, including the standard activated sludge process. Therefore, the MBR line can process a greater volume of water if the capacities of the reactor tanks are the same.

As a result, the flow rate fed to the conventional process line can be reduced, which leads to a longer retention time, and the overall process is enhanced. It is therefore possible to improve the quality of the treated water in the entire treatment plant (the weighted average of the values for the treated water quality at each line) by installing an MBR in some of the lines.

Thus, when installing parallel MBR and conventional processes, it is necessary to determine the optimal distribution of flow rate for each process through a comprehensive review of all relevant factors, including the economic efficiency, ease of maintenance, and equipment layout.

(2) Countermeasure for flow fluctuation

Normally, the influent flow rate significantly fluctuates due to seasonal or time changes in the flow rate, effects from rainfall, etc. When using an MBR, the maximum treated water flow rate cannot exceed the upper limit of the permeation flux for the membrane; water exceeding the limit cannot be fed to the MBR line. Therefore, it is necessary to check for proper flow control.

In line with the progress of membrane technology, the applicability of higher permeation fluxes has also increased, enabling the control of flow fluctuations in the MBR line to a certain extent. It is desirable, however, to equalize the load fluctuation from the viewpoint of maintenance management, because fluctuations affect the necessary frequency of membrane cleaning. Thus, it is necessary to thoroughly review the distribution of the flow rate to the MBR and conventional processes.

It is necessary to adequately distribute the influent flow rate to the entire treatment plant between the parallel MBR and conventional processes. The volume of water that cannot be treated in the MBR line must be fed to the conventional process line, but in such a case, the treatment capacity (retention time, surface loading in the final sedimentation tank, etc.) of the conventional process line must be adequate, and actions must be taken as required to adjusting the flow rate.

(3) Review of optimal operating conditions for the parallel operation of MBR and conventional processes

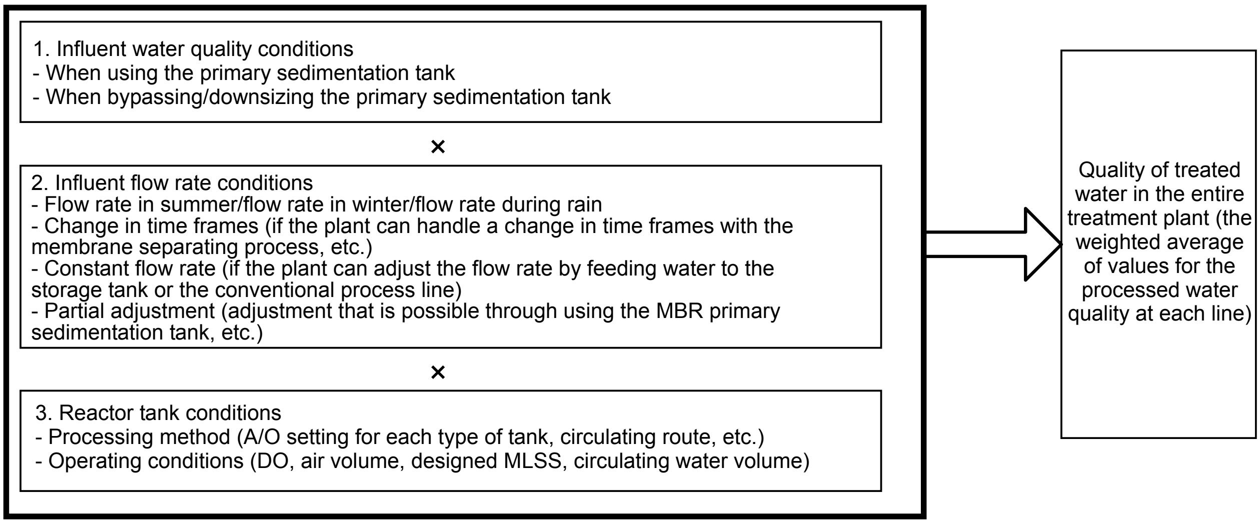
When parallel MBR and conventional processes are functioning, different types of process lines are operating in the same treatment plant.

Therefore, a plan for this type of operation must be prepared not only by considering the requirements of each process, but also by considering the optimal combination of the processes, including the treatment capacity, cost effectiveness, and ease of maintenance management, all of which differ depending on the combination of treatment processes.

For parallel MBR and conventional processes, the operating conditions for the conventional process line change according to the number of MBR lines and water inflow conditions. It is therefore necessary to carefully consider the type of equipment and determine what is suitable for the changed operating conditions.

In particular, when an MBR is being installed in an existing facility, a review of the operating conditions is required in order to ensure that existing equipment is effectively utilized.

Figure 4-4 presents an example of the issues to consider when verifying the treatment of the water quality for the entire treatment plant.



* Note that the inflow conditions for the conventional process line change depending on those for the MBR line.

Figure 4-4 Examples of issues to consider when verifying the treated water quality for the entire treatment plant

(4) Plan for the air blower equipment

When conducting parallel operations, it is necessary to take into consideration the pressure loss difference of the instruments and the control response, etc. for the air blower equipment.

(5) Review of the sludge treatment process, etc.

The MBR line requires no primary sedimentation tank, and therefore no primary sedimentation tank sludge is generated, which often leads to a higher excess sludge concentration. To solve this problem, it is necessary to review the sludge treatment processes when taking the treatment of the sludge from the conventional process lines into account. Moreover, if the excess sludge generated in the MBR line is treated at existing sludge treatment facilities, it is necessary to determine the facilities and equipment that must be installed to achieve the desired treatment efficiency, while also considering the differences in the characteristics of the excess sludge from the MBR line and that of the conventional process line.

(6) Review of the sludge treatment process, etc. from the pretreatment equipment

Addition of a new MBR line means that screen residues and oily mud are generated at the pretreatment equipment. Therefore, it is necessary to create a new, efficient removal process that also takes into consideration the existing residue generation. The selection of pretreatment equipment for the new line that is appropriate for the influent water conditions at the sewage treatment plant must also be achieved.

(7) Various piping requirements

MBR equipment requires various piping, including those for air, filtered water, and chemicals. When designing and installing this piping, it is important to consider the possibility of sharing the piping at the existing facility. Practical maintenance scheduling and work flow considerations and the operation of valves must also be taken into account.

4.2.2 Considerations when adding a new line

When installing an MBR in a newly added line in order to conduct parallel MBR and conventional processes, note the difference in flows of these processes, and conduct a review to achieve an appropriate facility layout.

An MBR process requires less space than that of a conventional process. When laying out the MBR facility, appropriately adjust the size with respect to the existing treatment facilities, and review the following issues while considering the efficiency of the water and air flow and maintenance operations.

(1) Layout of the facility for the newly added line

A newly added (MBR) line has no final sedimentation tank and is equipped with a reactor tank with a geometry that is different from that of the tanks used in existing lines. Therefore, review the layout of the new lines so as to use the treatment plant site efficiently.

(2) Consistency of the piping gallery

Review the installation position and structure of the piping gallery for a newly added line while considering the layout of the piping gallery, air blower room, electrical room, and sludge treatment equipment for the existing water treatment facilities.

4.2.3 Considerations when modifying an existing line

When installing an MBR by modifying a part of an existing water treatment facility in order to conduct parallel MBR and conventional processes, it is necessary to review the utilization of the existing primary and final sedimentation tanks, as well as newly added equipment, etc.

(1) Utilization of existing facilities

1) Primary sedimentation tank

The MBR lines can achieve a high MLSS at the reactor tank, and thus the necessary treatment performance can be achieved without the use of a primary sedimentation tank to lower pollution load (see 3.2.3 "Primary sedimentation tank" of Chapter 3.) Exercise special caution, however, before removing the primary sedimentation tank, because the tank is often used as a simple treatment facility for rainwater when the combined sewage system is used.

If it is decided not to use the existing primary sedimentation tank, consider diverting it to other uses, such as for the flow equalization, rainwater storage, or biological reactor tank.

2) Final sedimentation tank

When the final sedimentation tank is no longer required due to introduction of an MBR, it can be diverted for various uses, such as the final sedimentation tank for the conventional process lines, or as a tank for the membrane filtered water, or for emergency flow equalization, etc.

Use of the final sedimentation tank for the conventional process line reduces the surface loading at other final sedimentation tanks for these lines, which makes it possible to achieve a higher MLSS than before with the same flow rate.

When using an external or separate tank type MBR, the final sedimentation tank can be used as the installation site for the membrane module.

Table 4-1 Examples of alternative uses for the final sedimentation tank

	Regular equipment and facilities	Emergency equipment and facilities
MBR-specific facilities	Chemical cleaning tank, membrane filtered water tank	Emergency flow equalization tank
	Installation site for the membrane module for an external or separate tank type	
Facilities for other uses	Final sedimentation tank for the conventional process line	
	Reactor tank	
	Rainwater storage	

3) Air blower equipment

Since the MLSS is high and aeration for cleaning is required for the MBR process, the blown air flow rate required per reactor tank line is expected to be higher than that for the conventional process. Moreover, there may be a case where the appropriate pressures differ for the MBR and the parallel conventional process lines due to difference in the aeration method.

To solve such problems, add additional or upgrade the existing air blower equipment as necessary and according to the air flow rate required for the MBR line. When adding or upgrading the air blower equipment, determine whether to use a shared piping system with the conventional process lines, or to lay out new independent piping in view of the maintenance management plan.

4) Disinfection equipment

Because existing disinfection equipment often uses sodium hypochlorite, review the possibility for using the existing disinfection equipment as the chemical cleaning equipment when installing an MBR. Such equipment includes a sodium hypochlorite storage tank, a sodium hypochlorite transfer pump, a chemical dilution tank and a chemical injection pump.

(2) Review of the water distribution and pretreatment

1) Review of the water distribution

Because MBR involves solid-liquid separation using a membrane, the influent flow rate to the MBR line must be appropriately distributed to restrict flow rate fluctuations. Use the existing distribution or primary sedimentation tanks, or consider the construction of a new distribution facility as necessary.

2) Installation point for the fine screen

Modifying the facility for an MBR line requires the installation of a new fine screen. Review the installation point in view of the layout of the existing treatment plant.

3) Review of the flow equalization methods

The flow equalization tank capacity is calculated based on past results, including changes with time and the weather. But it is also necessary to review other flow equalization measures, such as equalization through the changing of the trans-membrane pressure difference, to prevent the need for excessively large flow equalization tank. When installing an MBR in part of an existing water treatment facility that has a primary sedimentation tank, consider the use of the primary sedimentation tank as the flow equalization tank.

(3) Review of the membrane module

1) Installation of the membrane module

For the immersed type (integrated type), the membrane module is installed inside the existing reactor tank. Therefore, it is necessary to exercise caution with regard to the water depth and the bulkhead position, and to conduct a structural review.

For the immersed type (separate tank type), the membrane module is installed inside the existing reactor tank and final sedimentation tank. Therefore, it is necessary to consider the location of bulkheading of reactor tank and to conduct a structural review.

For the external type, the membrane module is installed on the upper part of the reactor tank, inside the piping gallery, or at the inner space of the final sedimentation tank, and therefore it is necessary to review the different possibilities for installation based on the available space and the existing structures.

2) Delivery route for the membrane module

When introducing an MBR to a medium- to large-scale existing sewage treatment plant, it is necessary to install a number of membrane modules. Therefore, a preliminary review of the delivery route for the MBR equipment is recommended to ensure that the design of this aspect of the system matches the existing maintenance management flow or delivery route.

(4) Equipment installation plan

Other equipment required for an MBR treatment line include a lifting instrument for the membrane module, chemical cleaning equipment, an immersion cleaning tank, a filtered water tank, and various piping and instrument controls. Therefore, it is necessary to review the possibility of sharing some of the existing facilities.

(5) Electrical and instrument controls

It is necessary to understand the design and layout of the existing electrical and instrument controls in order to determine whether to add the MBR-related electrical and instrument controls to the existing equipment, or to install independent systems. Install the instrument controls at a position easily accessible for maintenance, while considering the layout of the existing equipment.

(6) Review of the existing structures

1) Modification of the existing building

When it is necessary to modify the existing building to make an opening for bringing in equipment or to install the inter-tank bulkhead and covering, confirm the bar arrangement drawing and structural calculation sheets for the structure, and reinforce it as necessary.

When modifying an existing frame that has not been in use for a long period of time for installation of the MBR, conduct leak testing by filling with water to check for water leaks before starting the work, and repair the frame as necessary.

2) Adjustment of the water level

When installing an MBR in an existing water treatment facility, it is necessary to thoroughly study the water level of the existing systems so that the MBR can match it. Review the possibility for the installation of a fine screen, flow equalization tank, and MBR equipment for the restricted water level.

3) Installation of various piping

When conducting parallel MBR and conventional processes, it is recommended to install piping for air, sewage water, filtered water, and sludge that are dedicated for the MBR and separate from the existing piping, because the operating conditions differ for the two sets of piping.

Table 4-2 summarizes the considerations for the cases of the Moriyama Water Treatment Center and the Sambo sewage treatment plant, where MBR was introduced by reconstructing existing treatment plants.

Table 4-2 Cases to review when installing an MBR at a reconstructed existing facility

		MBR demonstration facility at the Moriyama Water Treatment Center	MBR facility at the Sambo sewage treatment plant
1. Utilization of existing facilities	Primary sedimentation tank	The tank was used as a facility for rainwater since a combined sewage system is used. In fine weather, it is used to feed a part of the effluent water from the grit chamber to the primary sedimentation tank, so as to improve phosphorus removal efficiency.	A part of the tank is used as the installation space for the fine screen and chemical cleaning equipment, and the rest is used as the primary sedimentation tank.
	Final sedimentation tank	The final sedimentation tank is used as a filtered water storage tank.	The final sedimentation tank was removed and the site was diverted to highway use.
	Air blower equipment	— (Temporary air blower equipment was newly installed and dedicated for the demonstration facility, considering the effects on the existing facilities.)	Existing air blower equipment was diverted for membrane cleaning use, and auxiliary air blower equipment for aeration was newly installed.
	Disinfection equipment	— (Chemical cleaning equipment was newly installed.)	— (Chemical cleaning equipment was newly installed.)
2. Review of the water distribution and pretreatment	Review of the water distribution	Raw water is lifted with a pump separately from the existing systems as the flow rate for the MBR line is smaller than that for the existing facilities.	Preferentially distributing a specified flow rate of water to the existing facilities, and feed the rest to the MBR line.
	Installation point for the fine screen	After lifting the raw water with the pump, it is filtered with a fine screen. The fine screen was installed on the upper part of the reactor tank for other lines adjacent to the MBR line.	The fine screen was installed at a part of the existing primary sedimentation tank (2 water paths).
	Flow equalization method and equipment plan	The flow conditions for constant flow and flow rate fluctuation patterns were set for specific experiments.	The flow rate of filtration was increased as the countermeasure to a certain fluctuation ratio. When the fluctuation exceeded the ratio, simple discharging was conducted.
3. Review of the membrane module	Installation of the membrane module	Twelve (200 sheets x 2 stages) immersed type (integrated type) membrane modules were installed. The units were stacked in 2 stages to save space.	An immersed type (integrated type) membrane module was installed. Depending of the reactor tank width, a 300-sheet unit or a 400-sheet unit was installed.
	Delivery route for the membrane module	The existing path for the treatment facility is used, and there has been no problem in maintenance management of the existing facilities.	The membrane module was carried in to the upper part of the reactor tank using a crane, since that part does not have a double covering structure.
4. Equipment installation plan		Equipment was installed on the upper part of the reactor tank where the MBR was installed, and on those of other systems adjacent to the MBR.	A fine screen and chemical cleaning equipment were installed inside the existing primary sedimentation tank. The existing blower equipment was used for the MBR.
5. Instrument controls		A temporary high-pressure power-receiving/transforming panel and MBR control panels were installed for the demonstration facility separate from the existing equipment.	Power control equipment was installed for the MBR line. The power was supplied from the existing electrical equipment.

Table 4-2 Cases to review when installing an MBR at a reconstructed existing facility (continued)

		MBR demonstration facility at the Moriyama Water Treatment Center	MBR facility at the Sambo sewage treatment plant
6. Review of structures	Modification of existing civil engineering structures	The existing reactor tank was modified in order to make an opening for bringing in equipment and installing the bulkhead inside the tank. A structural review was conducted, and the existing bulkhead inside the equipment was also reinforced in order to install equipment on the slab of the reactor tank.	A part of the primary sedimentation tank wall was reinforced. The existing baffle plate for swirling flow was removed to install equipment inside the reactor tank.
	Adjusting the water level	– (As it is a demonstration facility, effluent water from the grit chamber and primary sedimentation tank is lifted.)	Structures matched the water level at the existing facilities.
	Installing various piping	The piping was separately installed considering the effects on the existing facilities.	The existing air pipe was diverted for membrane cleaning use.

Note: Since the Moriyama Water Treatment Center is a demonstration experiment facility, the above table includes the actions for or restrictions on the experiments.
The issues that are not relevant or those for which a review was omitted are enclosed in brackets to indicate that they are references.

4.3 Cost review

When reviewing the cost effectiveness of an MBR installation at an existing treatment plant, thoroughly consider utilization of existing facilities when calculating the costs for a newly installed line and for the modification of an existing line, as well as those for maintenance, and compare the costs with those for a conventional process that attains the same performance level.

4.3.1 Basic policies for cost reviews

When reviewing costs for the installation of an MBR to existing treatment plants, calculate the costs for construction and maintenance for a modified existing line and a newly installed line, and compare the costs with those for modification (or new construction) of a facility without an MBR would have the same performance as an MBR. If it is necessary to acquire new land, the land acquisition costs should also be included in the costs.

When calculating the construction and maintenance costs, assume various facility conditions such as the treatment capacity, designed water quality, and general design data. Note that the calculated costs vary significantly depending on the technology and site conditions used. Make sure to use the latest information based on the features and issues described in 3.4.1 of Chapter 3. In the future, market expansion and further research and development on MBR is expected, which will further lower construction and maintenance costs for this technology.

These guidelines present cost review information based on case studies with hypothetical conditions. These studies have been conducted through the cooperation of seven companies participating in our working group, as was the same for the case studies presented in Chapter 3.

4.3.2 Information and assumptions pertaining to the case studies

- These case studies target a medium- to large-scale virtual sewage treatment plant (using the standard activated sludge process with a treatment capacity of 50,000 m^3/per day) that requires reconstruction for process enhancement.
- The method selected for reconstruction of an existing plant to include MBR covers parameters such as the type of biotreatment or filter separation process and the treatment capacity per line after reconstruction, and is based on proposals by individual participants (see Table 4-5.) An overview of the MBR systems proposed by individual participants is included in Appendix I.
- For the conventional process, the studies use the "anaerobic-anoxic-oxic process (where organic matter and a coagulant are added, and the rapid filtration process is simultaneously used)" as this process achieves the same designed effluent water quality as that of an MBR, according to the Order for Enforcement of the Sewerage Service Act.
- The studies also used "the multi-stage denitrification-nitrification process (where coagulant is added and the rapid filtration process is simultaneously used)" for comparison, as this process is highly likely to become a candidate for actual installations, although it does not achieve the same designed effluent water quality as that with MBR, according to the Order for Enforcement of the Sewerage Service Act.
- These studies assume no land acquisition costs.

Table 4-3 Assumptions made for the case studies (when reconstructing existing facilities)

<table>
<tr><th colspan="2">Item</th><th>Conditions to review</th></tr>
<tr><td colspan="2">Target to review</td><td>● A line of the existing sewage treatment plant using the standard activated sludge process, for which improvement of the treated water quality is planned. The current treatment capacity for the line is 5,000 m^3/day.
● The reactor and final sedimentation tanks have no existing equipment, etc.</td></tr>
<tr><td rowspan="5">Scope of review</td><td>Civil engineering frame</td><td>The areas where the wall, floor, etc. were removed and new equipment was added are reviewed, while the covering was omitted in the proposal.</td></tr>
<tr><td>Pretreatment facility</td><td>● The pretreatment facility was included for review.
● The primary sedimentation tank can be used for flow equalization.</td></tr>
<tr><td>Water treatment equipment</td><td>● All incidental equipment (air blower equipment, membrane cleaning equipment, coagulant addition equipment, etc.) required for the MBR process, other than reactor tank equipment (membrane separation equipment, agitation equipment, pumps, etc.)
● The control board for the MBR devices and equipment was included in the water treatment equipment.
● Sharing of the air blower and other equipment with the existing systems was not considered.</td></tr>
<tr><td>Sludge treatment</td><td>Out of the scope</td></tr>
<tr><td>Electrical equipment</td><td>Power, instrument and control equipment for operating the MBR equipment are reviewed, but sharing with existing systems (power receiving/transforming and central supervisory control equipment) was not considered.</td></tr>
<tr><td colspan="2">Treatment capacity</td><td>5000 m^3/day</td></tr>
<tr><td colspan="2">Daily flow fluctuation</td><td>An assumed fluctuation of 1.4 times the daily average flow rate that peaks twice a day, and the daily maximum flow rate continues for 8 hours.</td></tr>
</table>

* For the overview of hypothetical existing treatment plants, see the Appendix I.

Table 4-4 Design water quality (when reconstructing existing facilities)

Water quality item	Influent water quality (mg/L)	Effluent water from the primary sedimentation tank		Treated water quality targeted (mg/L)
		Water quality (mg/L)	Removal rate (%)	
T-BOD	200	120	40	3.0
S-BOD	100	80	20	-
SS	180	90	50	1.0
T-N	35	30	14.3	10.0
NH_4-N	25	25	-	-
NO_3-N	-	-	-	9.0
T-P	4.0	3.2	20	0.5
S-T-P	2.0	2.0	-	-

Table 4-5 Overview of MBR systems targeted for review (when reconstructing existing facilities)

Item	Outline of system
Type of membrane	Hollow fiber membrane x 4; flat membrane x 2; ceramic membrane x 1
Membrane separation method	Immersed type (integrated type) x 5; immersed type (separate type) x 1; external type x 1
Biotreatment method	Recycled nitrification/denitrification process x 4; biological dephosphorylation (anaerobic-anoxic-oxic process) x 2; biological dephosphorylation (UCT) x 1 * The coagulant addition equipment will be installed by the seven companies.
Control of flow fluctuation	Flow equalization tank x 5; flux fluctuation controlling equipment x 2
Pretreatment equipment	Influent screen x 7
Existing primary sedimentation tank	Two used as the primary sedimentation tank; 4 used as the flow equalization tank

4.3.3 Cost calculation methods

See 3.4.4 of Chapter 3.

4.3.4 Examples of the cost reviews

This section shows the results of the cost calculations for the installation of an MBR to enhance the processes (incorporating the nitrogen and phosphorus removal process) at an existing sewage treatment plant using the standard activated sludge process. This review assumes no land acquisition costs.

1) Water treatment capacity and necessary space

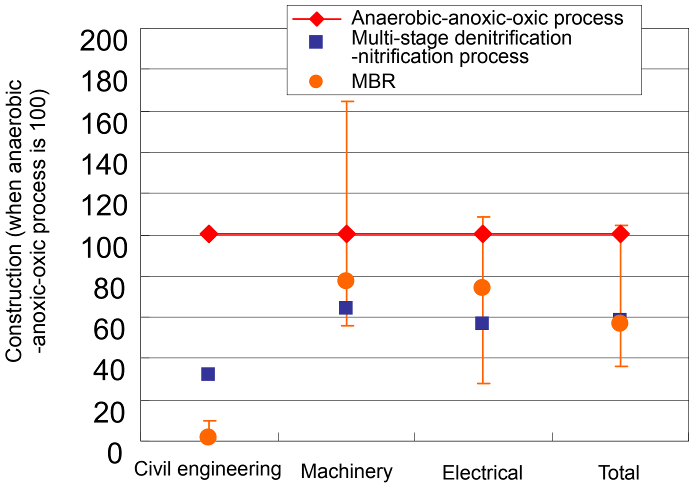
Table 4-6 Comparison of water treatment capacities and necessary space

	Anaerobic-anoxic-oxic process (A_2O process)	Multi-stage denitrification-nitrification process	MBR	
			Min to Max	Median
The number of lines required (those requiring construction of civil engineering frames)	23 (13)	14 (4)	7 to 9	8
Treatment capacity (m^3/day)	50,600	50,400	53,600 to 56,000	55,350
Treatment capacity per line (m^3/day)	2,200	3,600	6,000 to 8,000	6,700
Required space (A_2O only =100)	100	59.5	20.6 to 34.8	20.7

- In addition to the existing 10 lines, construction of civil engineering frames is required for 13 lines and four lines for the anaerobic-anoxic-oxic process (A_2O method) and multi-stage denitrification-nitrification processes, respectively. For the MBR process, on the other hand, a treatment capacity of 50,000m^3/day can be achieved with fewer lines than that required for the existing facilities. Therefore, the space required for MBR (median) is 1/5 that for the A_2O process.
- The water treatment capacity per line for the MBR process is about three times that for the A_2O process, and two times that for the multi-stage denitrification-nitrification process.
- With the above-mentioned space-saving features, MBR has various advantages, including: (1) the

ability to achieve process enhancements while maintaining the existing capacity; (2) the ability to eliminate/minimize the load at other treatment plants with reconstruction and installation of an MBR. Therefore, when the site space is limited, it is possible to install an MBR regardless of the costs.

2) Construction costs

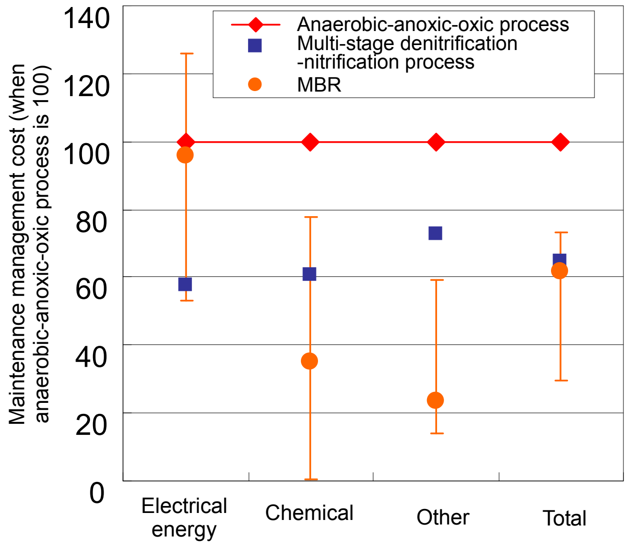


* Compared by assuming that the value for the anaerobic-anoxic-oxic process is 100.
In the Figure, the plots for MBR indicate the median values, while the bars represent the maximum and minimum values.

Figure 4-5 Comparison of the construction costs

- As shown in the previous section, MBR requires no additional civil engineering frames, while the conventional process does. Therefore, MBR is highly advantageous with regard to construction costs.
- The costs for machinery and electric equipment tend to be lower with an MBR, because the A_2O process requires more lines.

3) Maintenance management costs

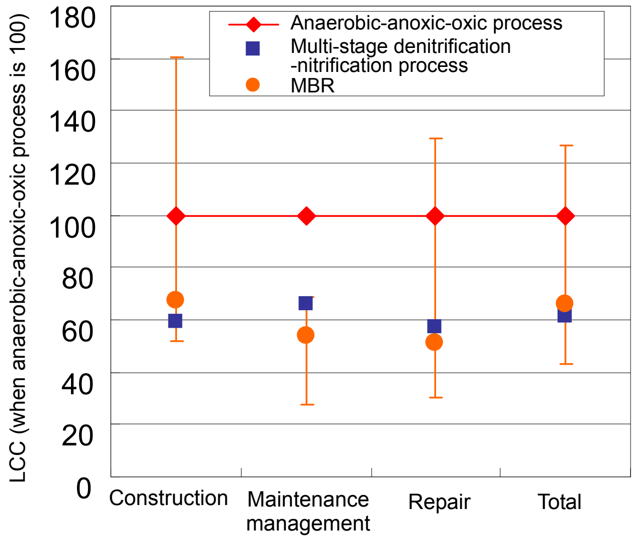


* Compared by assuming that the value for the anaerobic-anoxic-oxic process is 100.
"Other" constitutes repair and maintenance costs for the later stage treatment process.
In the Figure, the plots for MBR indicate the median values, while the bars represent the maximum and minimum values.

Figure 4-6 Comparison of the maintenance management costs (annual)

- The electrical energy costs are similar for the MBR and A_2O processes, while they are higher than those for the multi-stage denitrification-nitrification process.
- The chemical costs for the MBR process are significantly lower than those for A_2O process, because the A_2O process requires methanol as an added organic substance. The costs for the MBR process also tend to be lower than those for the multi-stage denitrification-nitrification process, because some MBRs use the biological phosphorus removal method, which requires no coagulant, while the multi-stage denitrification-nitrification process always requires coagulant to remove phosphorus.
- Note that "Other" for the MBR process does not include the membrane replacement costs.

4) LCC



* Compared by assuming that the value for the anaerobic-anoxic-oxic process as 100.
In the Figure, the plots for MBR indicate the median values, while the bars represent the maximum and minimum values.

Figure 4-7 Comparison of the LCC

- The LCC for the MBR process are lower than those of the A_2O process, although the LCC vary depending on the MBR system adopted.
- Similarly, the median LCC for the MBR process is slightly higher than that for the multi-stage denitrification-nitrification process, but the actual LCC may be lower than those for the multi-stage denitrification-nitrification process depending on the MBR system adopted.

5) Additional considerations regarding this cost review

The above cost review results are based on calculations for hypothetical conditions. Note that the costs required may vary significantly depending on the facility design conditions and future technological developments, as well as the considerations shown in Table 4-7.

Table 4-7 Additional notes on this cost review (when reconstructing existing facilities)

Issues to consider when evaluating the results of this cost review	● In this review, the specifications for each process were prepared based on the assumption that the quality of the treated water was equal for the MBR and conventional processes. When a higher quality is required due to regulations on water quality or use of reclaimed water, it is necessary to review the specifications. Installation of an MBR in this case may be more cost effective. ● MBR may be selected regardless of the cost calculation results when the site space is limited. ● The land acquisition cost is not included in this review, but if it is included, an MBR may be more advantageous than the conventional method. ● When reconstructing a treatment plant having a tight treatment capacity, An MBR process may be selected because of its higher water treatment capacity per area compared to the conventional process. ● Sludge treatment and disposition costs are not included in the review, although the MBR process actually generates less sludge than the conventional method. From the comprehensive viewpoint that includes sludge treatment, therefore, an MBR may be considered as more advantageous.
Issues to consider when regarding the prerequisites of this cost review	● For the installation of an MBR by reconstructing an existing facility, this review considered the range of equipment from pretreatment to the MBR treated water (while the inflow equipment for the upper flow from the primary sedimentation tank was out of the scope of the study). ● For reconstruction for the conventional processes, this review considered the range of equipment from the primary sedimentation tank to the rapid filtration equipment. ● In all cases, the sharing of the machinery and electrical equipment with existing facilities was not assumed (for example, power, instrument, and control equipment are the subjects of the review, while the power receiving/transforming equipment was out of the scope of the study). Sludge treatment facilities were also out of the scope of the study. ● In this cost review, the costs for one line were first calculated for both the MBR and conventional methods, and then those for the entire treatment plant were calculated by multiplying the costs per line by the number of lines.

Chapter 5 Installation of membrane technology for reclaimed water use

This chapter describes the expected effects of using membrane technology for reclaimed water use, as well as selection of the membrane and treatment flow, considerations for installation of the membrane, and issues regarding operation management, economic efficiency, etc.

5.1 Demand for reclaimed water use

> To expand the demand for reclaimed water use, it is important to supply the quality and quantity of water that meets the needs of consumers. Toward that end, the development of reclamation technology and the reduction of costs are eagerly anticipated.

The number of facilities that use externally reclaimed water has rapidly increased since the early Heisei period and quadrupled in the last 20 years, and the applications of reclaimed water have also rapidly expanded. Previously, it was used mainly for the cleaning and washing of streets and in factories, but now it is utilized as municipal water in a variety of ways, including for landscape use, hydrophilization and river maintenance. (See Figure 5-1 and Figure 5-2)

On the other hand, the reclaimed water utilization rate (volume of externally reused water/volume of effluent water) in Japan is less than 2%[40]. To promote its use in the future, an increase in water quality and a reduction of the costs are needed to further expand the potential applications. To achieve these goals, the further development of membrane technology and advancement of technical knowledge is essential.

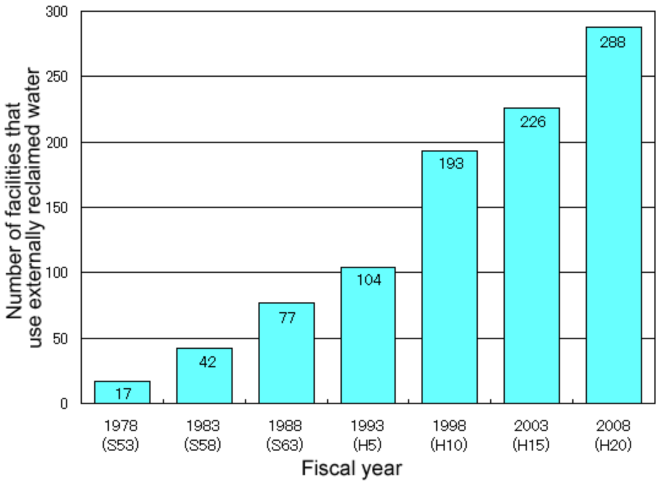


Figure 5-1 Growth in the number of facilities using (externally) reclaimed water [37]

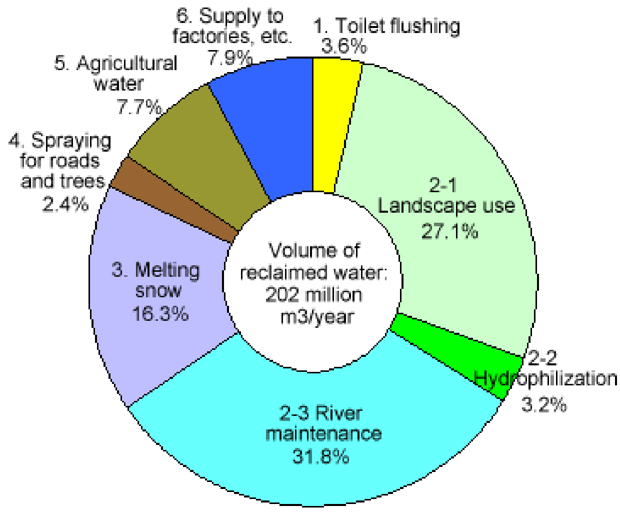


Figure 5-2 Reclaimed water use by application (in FY2008)[37]

5.2 Expected effects by introduction of membrane technology for reclaimed water use

Introduction of membrane technology for reclaimed water use is expected to have the following effects.

・The quality of reclaimed water becomes good and stable.

・Reclaimed water that can be used for a variety of purposes is obtained.

MBR treated water can be used without further treatment, depending on the application.

If membrane technology is employed for the preparation of sewage water for reuse, it is necessary to select the type of membrane and treatment flow according to the water quality required for the intended application.

(1) Stable quality of the treated water

As the particle diameter of the suspended substances captured in the membrane treatment process is much smaller than that treated by conventional sand filtration equipment, this process can capture almost all suspended substances, which reduces the adhesion of substances to the effluent pipes and the growth of chironomid midges. Furthermore, using RO membranes, etc., can eliminate substances that cause coloring and odor at the molecular level, which thus makes it possible to consistently obtain water of high quality.

(2) Extensive range of applications

Membrane technology has numerous positive effects ranging from reduction in the coliform count to improvements in turbidity related to aesthetic maintenance. This technology is expected to achieve a water quality with turbidity and chromaticity properties at a level similar to that obtained by activated charcoal adsorption and ozone oxidation, and to reduce the coliform count to a level equal or higher than that of chlorination, ozone disinfection and ultraviolet disinfection.

Table 5-4 shows examples of the quality of MBR treated water. The water in these examples satisfies the standard values specified for water for sprinkling, toilet flushing, and landscape applications, and can be used for a variety of purposes. For landscaping applications, MBR treated water can be used without disinfection, assuming that the water is not touched directly by a human.

If water for sprinkling, toilet flushing or hydrophilization requires additional disinfection to sterilize E. coli, chlorine should be injected according to the standards for residual chlorine as specified in Table 5-1.

5.3 Considerations when installing membrane technology for reclaimed water use

When installing membrane technology for reclaimed water use, the type of membrane and treatment process must be carefully selected, because the required features and performance depend on the quality of the raw water that has been treated in preceding processes (secondary treatment, advanced treatment, MBR treatment, etc.), as well as the quality required for each application.

Figure 5-3 shows examples of membrane technology installations for reclaimed water use.

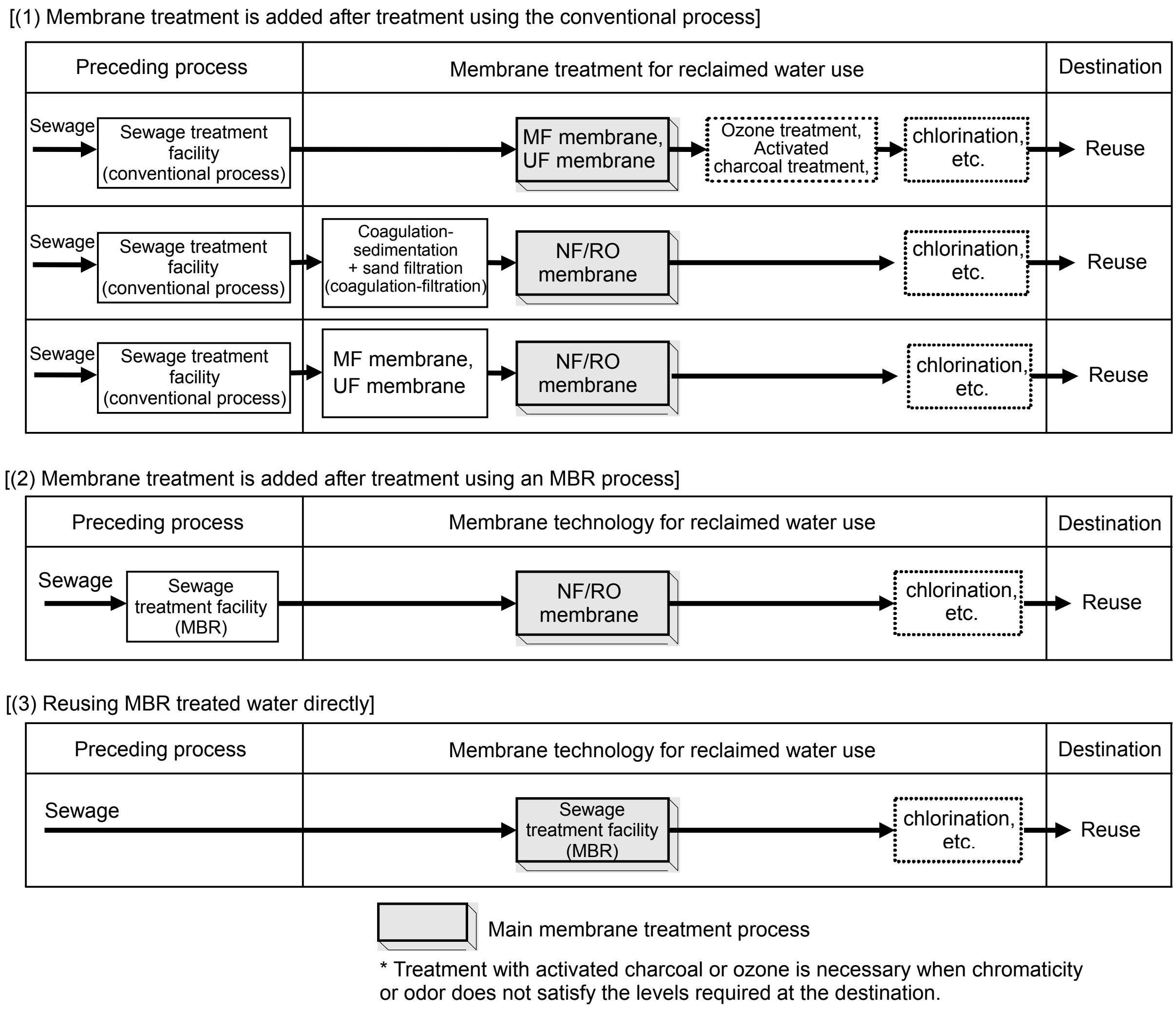


Figure 5-3 Examples of membrane technology that can be installed for reclaimed water use

Review the following issues when introducing membrane technology for reclaimed water use:

- Intended application and target quality of the reclaimed water
- Supply flow rate
- Installation location
- Facility configuration
- Type of membrane
- Treatment flow

・ Treatment of condensed water generated during membrane treatment

・ Issues related to operational management

Figure 5-4 shows a flow diagram for the review process when installing membrane technology for reclaimed water use. Individual issues to review are explained in the sections below.

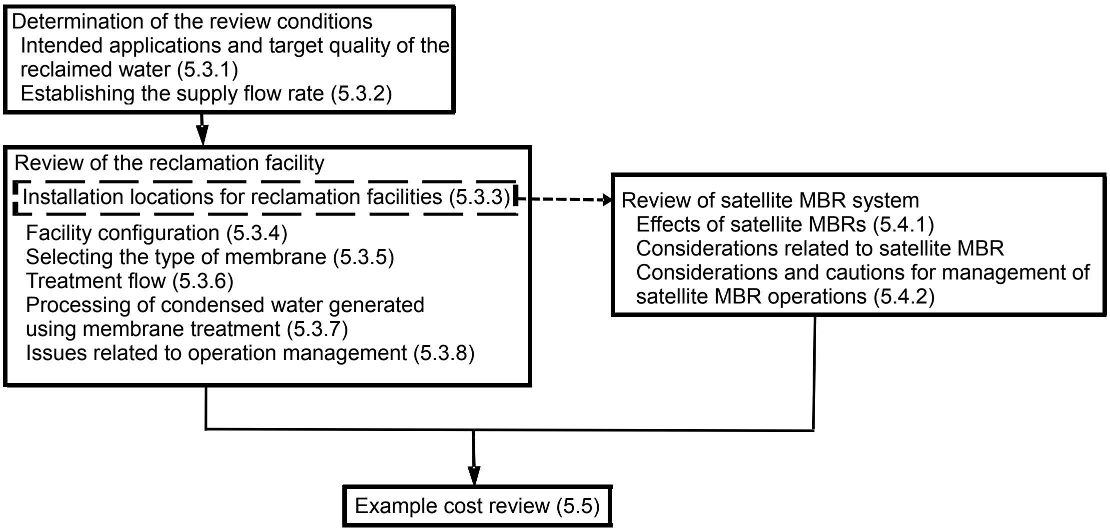


Figure 5-4 Flow Diagram for the review process when installing membrane technology for reclaimed water use

5.3.1 Intended applications and target quality of the reclaimed water

Set the target quality of the reclaimed water according to the water quality standards for its intended applications.

(1) Intended applications

Reuse of sewage water is supposed to have the following applications, based on past results in Japan. Among them, membrane technology is effective for producing reclaimed water for applications a) to c) by improving the water quality. Therefore, these specific uses are the focus of section (2) and the rest of the chapter.

a) General service water: water for toilet flushing, sprinkling and car washing

b) Municipal water: water for sprinkling and cleaning (parks, roads, sewers, etc.)
water for landscape use, hydrophilization, and ambient water ("babbling" waterways, ponds, etc.)
water for extinguishing fires, preventing fires, removing snow and melting snow, etc.

c) Industrial water: water as a raw material, cooling water, water for cleaning, boiler water, for temperature control, etc.

d) Agricultural water

e) Water for river (urban waterways) maintenance

f) Groundwater recharge

Industrial water includes water supplied directly from the sewage treatment plant to private facilities, etc., as well as water supplied to industrial water suppliers as an alternative water source. In either case, the recipient conducts any further treatment, etc. to achieve the quality demanded for its intended applications.

Overseas, reclaimed water is also used as a resource for tap water (indirect use) and for recreation (bathing).

(2) Water quality standards for individual applications

[1] Standards, etc. for reuse of sewage water

"Manual for Standards for Reclaimed Sewage Water Quality"[41)] reviews the technical standards concerning the reuse of sewage water with the goal of ensuring the hygienic safety and properties of the treated sewage water as well as prevention of the corrosion and clogging of pipes, and sets the water quality standards for individual applications (See Table 5-1).

Table 5-1 Technical standards for reclaimed water use (standards for water quality and facilities)*

Place where the standards apply	Item	Toilet flushing	Spraying	Landscape use	Hydrophilization
Exit of the reclamation facility	E. coli	Not detected (100 mL of water is inspected using a specific enzyme substrate culture medium method)		Number of coli group bacteria: 1000 CFU/100 mL (Tentative standards)	Not detected (100 mL of water is inspected using a specific enzyme substrate culture medium method)
	Turbidity	2 degrees or less (Targeted control value) Note)		2 degrees or less (Targeted control value)	2 degrees or less
	pH	5.8 to 8.6			
	Appearance	Not unpleasant			
	Chromaticity	-- (Not specified) (Set the standard values according to the user requirements, etc.)		40 degrees or less	10 degrees or less
				(Set higher standard values according to the user requirements, etc.)	
	Odor	Not unpleasant (Set the odor intensity according to the user requirements, etc.)			
Responsibility boundary	Residual chlorine	Free residual chlorine: 0.1 mg/L or Combined residual chlorine: greater than or equal to 0.4 mg/L (Targeted control value)		-- (Not specified)	Free residual chlorine: 0.1 mg/L or Combined residual chlorine: greater than or equal to 0.4 mg/L (Targeted control value)
		* If chlorine is additionally injected at the destination, the process may be conducted according to a separate agreement, etc.	* Not applied when residual chlorine is not necessary. * If chlorine is additionally injected at the destination, the process may be conducted according to a separate agreement, etc.	* Not specified, because this type of water may be treated with a process other than chlorination from the viewpoint of ecosystem conservation, and is not supposed to be touched by humans.	* Not applied when residual chlorine is not necessary. * If chlorine is additionally injected at the destination, the process may be conducted according to a separate agreement, etc.
Standards for the facility		The facility must function at a level equal to or superior than that for sand filtration.			The facility must function at a level equal to or superior than that for coagulation-sedimentation + sand filtration.

Note) Targeted control value: Different from the standard value, which must always be satisfied; the target value to be satisfied to the extent possible during operation of the reclamation facility.
* From Reference 41)

[2] Standards for use of general service water in buildings

The Ordinance for Enforcement of the Act on Maintenance of Sanitation in Buildings specifies the hygienic standards for general service water (See Table 5-2).

Table 5-2 Quality standards for general service water*

Item	Standard value	Place where standards apply
E. coli	Not detected	Reclamation water tank
Turbidity	2 degrees or less	
PH	5.8 to 8.6	
Appearance	Almost transparent	
(Chromaticity)	Not specified (included in the above)	
Odor	Not abnormal	
Residual chlorine	Free residual chlorine: 0.1 mg/L or Combined residual chlorine: greater than or equal to 0.4 mg/L	Hydrant
Remarks	Purpose of general service water: (1) spraying, (2) landscape use, (3) cleaning and (4) toilet flushing. At Specified Buildings*, however, raw water that contains night soil shall not be used for purposes other than toilet flushing. * Places such as performance facilities, assembly halls, libraries, museums, art galleries, amusement centers, stores, offices, schools, and hotels that have floor space of 3,000 m2 or more and that accommodate a large number of people.	

* Specified in "Hygiene standards for general service water" of the Ordinance for Enforcement of the Act on Maintenance of Sanitation in Buildings.

[3] Standards for industrial water quality

As for the standards for industrial water quality, the Japan Industrial Water Association has determined the "Standard Water Quality" and METI has also determined the "Water Quality Which Satisfies 90% of Consumers" based on surveys. There are also quality levels at which consumers judge water to be suitable for boiler water and cooling water (See Table 5-3).

Table 5-3 Standards for industrial water quality

Item	Unit	Supplied quality of industrial water			
		Standard water quality *1	Determined by METI (90% value) *2	Boiler water *3	Cooling water *3
Water temperature	^{o}C		15 to 25		
Chloride ion	mg/L	<80	<40	10	15
Electrical conductivity	mS/m				150
pH	-	6.5 to 8.0	6.7 to 7.9	7	7.5
M-alkalinity	mg/L	<75	<70		50
Residue after total evaporation	mg/L	<250	<220	100	
Total hardness	mg/L	<120	<90	50	50
Turbidity	Degree	<20	<10	5	10
Iron	mg/L	<0.4			0.5
Manganese	mg/L	<0.2			
COD	mg/L			2.0	2.0
BOD	mg/L				1.0

Source: "Survey report on quality of industrial water (FY2004)" by METI.
*1: Standard for supplied quality of industrial water (determined by Japan Industrial Water Association)
*2: The range of water quality that is considered to be satisfactory for 90% of consumers
*3: Desired quality of industrial water classified by its application

(3) Comparison of the quality of water treated with membrane technology and the standards for reclaimed water quality, etc.

MBR treated water satisfies all of the standard values with regard to water for toilet flushing, sprinkling and landscape use. In particular, E. coli and coliform groups are not detected in MBR treated water even without chlorination. On the other hand, the chromaticity exceeds 10 degrees in some cases, so it is necessary to note this value when membrane treated water is used for hydrophilization, depending on the facilities that use water, and on the consumers' requirements (See Table 5-4).

For water for toilet flushing at buildings, etc. (see Table 5-2 above), there is a regulation concerning residual chlorine that requires consumers or suppliers to inject chlorine even when E. coli is not detected.

Table 5-4 Comparison of MBR treated water quality with the standards for sewage water reuse

Item (Unit)	MBR treated water at the Moriyama Center	MBR treated water at the Miai Satellite	Reference (technical standards for reclaimed water use[41])		
			For toilet flushing and sprinkling	For landscape use	For hydrophilization
E. coli (per 100 mL sample)	Not detected	Not detected	Not detected	-	Not detected
Coliform count (CFU/100 mL)	Not detected	Not detected	-	1,000 or less	-
pH (-)	6.7 (6.6 to 7.1)	6.7 (6.2 to 7.0)	5.8 to 8.6	5.8 to 8.6	5.8 to 8.6
Turbidity (Degree)	(<0.25 to 1.1)	0.4 (0.1 to 0.7)	2 or less (Targeted control value)	2 or less (Targeted control value)	2 or less
Odor (-)	-	Odor index 20 to 26 Note	Not unpleasant	Not unpleasant	Not unpleasant
Chromaticity (Degree)	8.8 (7.4 to 11)	11 (5.7 to 14)	-	40 or less	10 or less
BOD (mg/L)	1.0 (0.3 to 2.5)	1.0 (0.5 to 1.8)			
COD (mg/L)	5.7 (4.6 to 7.0)	6.0 (4.3 to 8.0)	-	-	-

* Quality of MBR treated water: Data for the Moriyama Center are averages from June through December 2010, with the range enclosed in parentheses. These data were obtained after the water was treated and stabilized, in order to exclude any effects due to changes in operating conditions for demonstration purposes. Data for the Miai Satellite are averages from April through December 2010, with the range enclosed in parentheses, and obtained after the water was treated and stabilized, in order to exclude any effects due to changes in operating conditions for demonstration purposes.

Note: Odor index = 10 x Log (odor concentration): data from FY2009
For example, the odor index for an odor concentration of 1000 (when no odor is detected after the water is diluted 1/1000) is 30.
(Reference: The regulation standard odor index for the odor of discharged water as specified by the Offensive Odor Control Law is within the range from 31 to 37.)

Table 5-5 shows a comparison of MBR treated water quality and the standard values for reclaimed water use, while Table 5-6 presents a comparison of RO membrane treated water quality and the standard values for reclaimed water use.

In the case of water for industrial use, the pH and total evaporated residue may slightly exceed the standard values. For applications requiring high quality water, such as cooling water, it is necessary to remove the COD with an RO membrane, etc. (See Table 5-5.)

Table 5-5 Comparison of MBR treated water quality and the standards for industrial water

Item	(Unit)	MBR treated water at the Moriyama Center	MBR treated water at the Miai Satellite	Standard values for the quality of industrial water
Chloride ion	(mg/L)	34 (27 to 39)	60 (51 to 75)	<80
pH	(-)	6.7 (6.6 to 7.1)	6.7 (6.2 to 7.0)	6.5 to 8.0
M-alkalinity	(mg/L)	41 Note 1 (35 to 50)	37 (28 to 48)	<75
Total evaporated residue	(mg/L)	220 (200 to 260)	250 (200 to 290)	<250
Total hardness	(mg/L)	—	40 Note1 (37 to 43)	<120
Turbidity	(Degree)	— (<0.25 to 1.1)	0.4 (0.1 to 0.7)	<20
Electrical conductivity	(μS/cm)	290 (250 to 340)	390 (350 to 460)	<1500 Note 2
COD	(mg/L)	5.7 (4.6 to 7.0)	6.0 (4.3 to 8.0)	<2 Note 2

* Quality of MBR treated water: Data for the Moriyama Center are averages from June through December 2010, with the range enclosed in parentheses. These data were obtained after the water was treated and stabilized in order to exclude any effects due to changes in operating conditions for demonstration purposes. Data for the Miai Satellite are averages from April through December 2010, with the range enclosed in parentheses, and were obtained after the water was treated and stabilized, in order to exclude any effects due to changes in operating conditions for demonstration purposes.
Note 1: Data from FY2009.
2: Required quality for cooling water

Table 5-6 Comparison of RO membrane treated water quality and the standards for reclaimed water use

Item	Example in Reference	Moriyama Water Treatment Center	Standard values for reclaimed water use Note 1		
	NF/RO membrane treated water Note 2	RO membrane treated water Note 3	For toilet flushing and sprinkling	For landscape use	For hydrophilization
BOD	<2 mg/L	-	-	-	-
T-N		0.9 mg/L			
T-P	-	-	-	-	-
E. coli	Not detected	-	Not detected	Coliform count: 1,000 CFU/100 mL or less	Not detected
Turbidity	<1 degree	0.24 degrees	2 degrees or less	2 degrees or less	2 degrees or less
pH	5.8 to 8.6	-	5.8 to 8.6	5.8 to 8.6	5.8 to 8.6
Appearance	Transparent	-	Not unpleasant	Not unpleasant	Not unpleasant
Chromaticity	<1 degree	1.3 degrees		40 degrees or less	10 degrees or less
Odor	Odorless	-	Not unpleasant	Not unpleasant	Not unpleasant

Note 1: Standard value for reclaimed water use[41)]
2: Quality of water obtained by filtering the secondary effluent with an NF/RO membrane[2), 42)].
3: Quality of water obtained by filtering A_2O-type MBR treated water with an RO membrane. The values are averages from June through December 2010, obtained after the water was treated and stabilized, in order to exclude any effects due to changes in operating conditions for demonstration purposes.

5.3.2 Establishing the supply flow rate

> Set the maximum daily and hourly water supply flow rate based on results of research and a review of the flow rate of demanded water for individual applications and that of the suppliable water, while considering possible changes in the flow rate of water used by consumers.

(1) Demand flow rate for individual applications

In order to know the exact flow rate demand for individual applications, conduct a survey or hold hearings with consumers to get an overview of the use of reclaimed water at their facilities, including the applications for the reclaimed water, the flow rate, etc.

(2) Supply flow rate

Review the supply flow rate of reclaimed water based on actual data for the capacity and influent flow rate at the facility, considering seasonal changes in influent flow rate, as well as changes over time, etc. When applying membrane technology for reclaimed water use, note that the return of condensed water may have effects on the sewage treatment function and the effluent water quality, depending on its utilization rate (supply flow rate of reclaimed water/influent flow rate).

5.3.3 Installation locations for reclamation facilities

> In principle, install the reclamation facility at a location where it is easy to convey sewage water from the sewage treatment facility. If the destination for the reclaimed water is too far, consider the installation of a satellite sewage treatment system to reduce costs for water conveyance.

Generally, a reclamation facility is installed within the sewage treatment plant, and the consumers of the reclaimed water are limited to the areas adjacent to the plant. When the distance between the sewage treatment plant and a consumer facility is large, water conveyance costs often account for most of the costs for the reclaimed water use.

In order to prevent an increase in conveyance costs, consider installation of a satellite sewage treatment system. This system takes water for treatment from the sewage pipes adjacent to and upstream of the consumer facility, which can significantly reduce the costs by shortening the distance for water conveyance. Therefore, when reviewing the installation location for a reclamation facility, it is also necessary to consider the location of a possible satellite sewage treatment system.

A review of satellite sewage treatment systems is discussed in section 5.4.

5.3.4 Facility configuration

> Review the configuration of the reclamation facility considering the use of reclaimed water and the type of using facility.

Depending of the application of the reclaimed water and the type facility that will be using it, the flow rate demand may change considerably, such as for toilet flushing in office buildings. In addition, some facilities are significantly affected by the suspension of the water supply, while others, like those using water for landscaping, can deal with a reductions, if the suspension is limited within a certain range. If the reclamation plant will be serving facilities that will be significantly affected by suspension of supply, then countermeasures should be taken, such as the installation of 2 lines for reclamation, the establishment of a reservoir with a certain capacity, and granting permission to consumers to prepare water supply pipes, etc. When water supply suspension is tolerable to a certain extent, then consider a simplified configuration, such as that using only one line that operates within the range where the facility can handle the suspension of supply.

If a consumer has multiple applications or water quality requirements, allocate one line for the water conveyance system from the sewage treatment plant to that customer, and, in order to reduce costs and to expand usage, locate the treatment equipment at a later stage in the area adjacent to the consumer facility so that it is separate from the reclamation facility at the plant.

5.3.5 Selecting the type of membrane

Select a membrane suitable for the raw water quality and targeted reclaimed water quality.

Water treated in a conventional process or an MBR process is used as the raw water in the reclamation process. In many cases, MBR treated water satisfies most of the requirements for reclaimed water, excluding chromaticity, therefore it requires no additional processing.

It is common that SS, turbidity and E. coli (coliform groups) must be removed from water treated in the conventional process. If water treated in the conventional process is used as the raw water, and the supply flow rate of reclaimed water is smaller than the water treated in the conventional biotreatment, it is possible to immerse a membrane into the reactor tank to obtain the reclaimed water, in the same manner as an MBR process.

If it is necessary to reduce the chromaticity, it can be achieved by using an RO membrane independently or in combination with ozone or activated charcoal treatment. When combining MBR and ozone treatment, ozone treatment is conducted after the membrane treatment.

When combining ozone treatment with a membrane treatment other than MBR, the ozone treatment can be conducted before or after the membrane treatment. If it is conducted before the membrane treatment, consider using an ozone-resistant membrane to prevent deterioration of the membrane by residual ozone.

When water of a higher quality is required for industrial use, it is necessary to treat the water using an NF or RO membrane. For water that was treated in the conventional process, pretreatment such as coagulation-sedimentation and filtration is required, but MBR treated water can be directly treated with an NF/RO membrane.

Table 5-7 and Table 5-8 show the types of membranes and the quality of sewage treatment water (secondary effluent) that should be used as the raw water, and the quality of the membrane treated water. These data were obtained from an actual reclamation system for the treatment of sewage water using a membrane. In Table 5-7, the coliform count, turbidity, COD and BOD are reduced for water treated with an MF/UF membrane, but the values for the other items are the same as those for the secondary effluent. For water treated with an NF/RO membrane, on the other hand, not only are the coliform count, turbidity, and BOD lowered, but the chloride ion, phosphorus, mineral salts and other dissolved substances are reduced, and the chromaticity and total hardness are improved.

Table 5-7 Examples of membrane types and the quality of the membrane treated water[42)]

Item	Unit	Secondary effluent	Membrane treated water	
			MF/UF membrane	NF/RO membrane
PH	-	6.5 to 7.5	6.5 to 8.0	5.8 to 8.6
Coliform count	Number/mL	3,000 or less	Not detected	Not detected
M-alkalinity	mg/L	50 to 100	Same as secondary effluent	50
Residue after total evaporation	mg/L	About 300	Same as secondary effluent	20 to 150
Chloride ion	mg/L	About 100	Same as secondary effluent	10 to 40
Total hardness	mg/L	50 to 100	Same as secondary effluent	1 to 20
Turbidity	Degree	5 to 10	$\leq$1	$\leq$1
Chromaticity	Degree	20 to 40	$\leq$15 (with coagulant added)	$\leq$1
COD	mg/L	10 to 15	$\leq$10	$\leq$1
BOD	mg/L	5 to 15	$\leq$3	$\leq$1
T-N	mg/L	15 to 25	Same as secondary effluent	1 to 8
T-P	mg/L	1 to 3	$\leq$2 (with coagulant added)	$\leq$0.03

Table 5-8 Example of the quality of water treated with a combination of ozone treatment and membrane treatment (MF)[43)]

Analysis item / Sample Item	Raw water (Secondary effluent)	Water treated by biofilm filtration	Water treated with ozone resistant membrane
Appearance	Yellow flocks are floating	Fine yellow flocks are floating	Transparent
Odor	Slight mold smell	Slight mold smell	Slight ozone smell
COD (mg/L)	15.0	13.4	8.1
SS (mg/L)	10.3	3.2	0.0
Turbidity (Degree)	9.4	5.2	<0.1
Chromaticity (Degree)	(40)	(36)	3
Ammonium nitrogen (mg/L)	12.2	3.7	-
Nitrite nitrogen (mg/L)	1.43	-	ND
Coliform group (Number/mL)	4.8×10^2	-	0

Note: The figure for chromaticity in parenthesis is the measurement value for water filtered with 5C filter paper.

5.3.6 Treatment flow

Consider the addition of either of the following processes to the main membrane treatment process as necessary:

* A treatment process to restrain clogging and deterioration of the membrane for stable treatment

* A treatment process to achieve a level of quality of the membrane treated water that conforms to the targeted water quality for the individual applications

Treatment processes for reclaimed water that use membrane technology are roughly divided into three categories: the main membrane treatment (MF/UF, NF/RO) processes; the processes for the prevention of clogging and deterioration of the membrane to ensure stable treatment; and the processes for achieving a level of quality for the membrane treated water that conforms to the targeted water quality for the individual end-use applications.

(1) Main membrane treatment process

The main membrane treatment process for obtaining reclaimed water is roughly further classified into two categories: processes conducted after an MBR or conventional process; and processes that are based only on an MBR (see Figure 5-3).

In the case where membrane treatment is conducted after the conventional process, it is necessary to consider the use of a treatment process to prevent clogging and deterioration of the membrane to ensure stable treatment based on the frequency of clogging and other conditions (this process is detailed in (2).)

(2) Treatment to prevent clogging and deterioration of the membrane

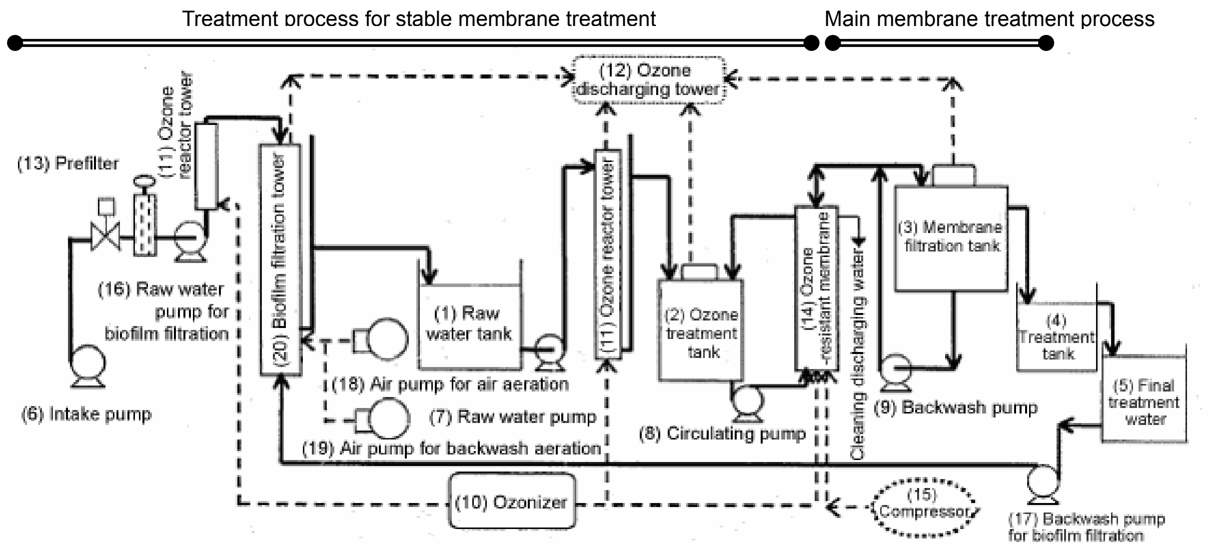
At a treatment facility that handles sewage water containing nutrient salts such as ammonium nitrogen, etc., biofouling (fouling caused by microorganism such as bacteria) readily occurs. Therefore, it is quite important to install systems to reduce and if possible, prevent such fouling.

During the review, therefore, thoroughly consider the features of the selected membrane, such as the frequency of clogging, etc.

1) Use of an MF/UF membrane in the main membrane treatment process

When using an MF/UF membrane in the main membrane treatment process, sometimes sodium hypochlorite is used to control biofouling. Note that, however, chlorine facilitates the deterioration of the membrane, depending on its material. To avoid membrane deterioration, use of a membrane that has chlorine resistance and treatment with ozone or ultraviolet light are proposed as countermeasures.

Figure 5-5 shows an example of a facility that has adopted an MF membrane for the processing of sewage water for toilet flushing use.



* In addition to an ozone resistant membrane, a ceramic membrane is used

Figure 5-5 Example of the facility configuration for (MF) membrane treatment at the Shibaura Water Reclamation Center, Tokyo[11)] [Water for toilet flushing]

2) Use of an NF/RO membrane in the main membrane treatment process

When using an NF/RO membrane in the main membrane treatment process, additional physicochemical methods, such as sand filtration, are commonly considered for the removal of foreign substances that can damage the NF/RO membrane, as well as the use of an MF/UF membrane for cost reduction and downsizing of the equipment.

It is also important to note that research and development of new membrane materials that are more resistant to fouling and that significantly recover their filtration ability through cleaning is underway. Moreover, development of technology to simplify the needed equipment and to extend the filtration period is also progressing.

Table 5-9 shows an example of the equipment used with MF and RO membrane for the treatment of sewage water used for hydrophilization.

Table 5-9 Specifications for the sewage water reclamation equipment at the Ochiai Water Reclamation Center, Tokyo[2)]

Item	MF membrane	RO membrane	Treatment flow
Material	Polypropylene	Piperazine polyamides	Secondary effluent ⇨ Strainer ⇨ MF membrane ⇨ RO membrane ⇨ Reclaimed water
Removal ability	0.2μm	Salt removal: 97%	
Element's shape	External pressure, hollow fiber	4 inches, spiral	
Number of membranes	15, 2m^2 each	12	
Membrane filtration flux	2.2m/d	0.6m/d	
Backwash	Every 20 minutes	-	
Water recovery rate	92%	77%	
Water penetration pH	6.5	6.5	
Disinfectant	Without residual chlorine	With residual chlorine of 1 mg/L or less	
Scale inhibitor	Not used	Not used	

3) Use of an MBR with the preceding processes

Because MBR can remove foreign substances and prevent fouling, if an MBR is installed prior to an

NF/RO membrane, other MBR contributes to the reduction of fouling of the NF/RO membrane, which enables the simplification of the facility.

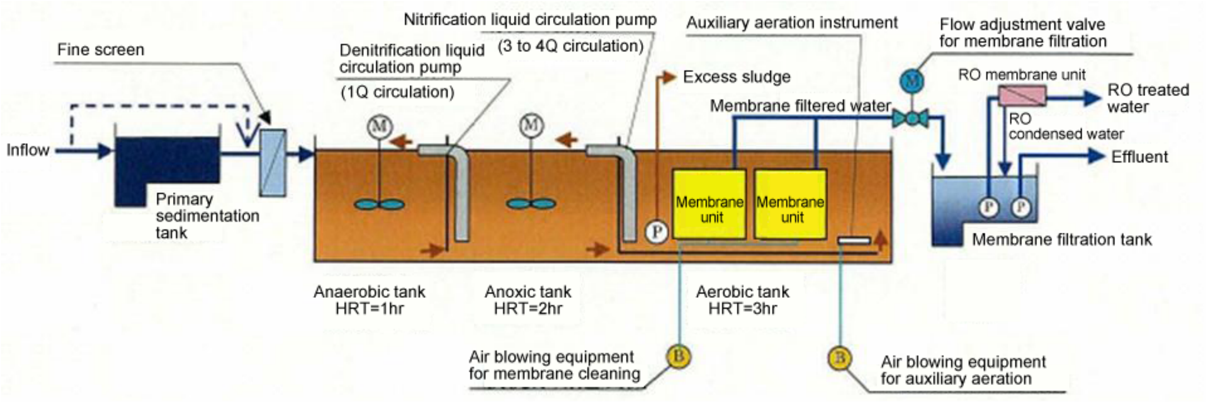


Figure 5-6 Treatment flow at the Moriyama Water Treatment Center (A_2O type MBR + RO membrane)

(3) Treatment processes to achieve a level of quality for the membrane treated water that conforms to the targeted water quality for individual applications

Depending of its intended applications, it may be necessary to further heighten the water quality of the reclaimed water, such as improving the chromaticity caused by dissolved substances or reducing the risk of bacterial infection, etc. In such cases, treatment equipment should be added following the membrane treatment as necessary.

MBR treated water or reclaimed water filtered with an MF/UF membrane after the conventional process can be used for landscaping without chlorination, because few E. coli are detected in it. For toilet flushing, etc., however, note that the regulations concerning residual chlorine are different (see Table 5-1 and Table 5-2).

5.3.7 Processing of condensed water generated using membrane treatment

Review the countermeasures required to manage the backwash of condensed water that is generated during membrane treatment, depending on the operating conditions at the treatment facility.

When a considerable volume of sewage water is treated with an NF/RO membrane, a large volume of condensed water that contains a high concentration of salt and hard-biodegradable organics is backwashed to the sewage treatment facility. Because this water may cause damage to the sewage treatment functions and lead to failure to achieve the necessary effluent water quality that satisfies the standards, it is necessary to take measures to manage the backwash.

As possible countermeasures, consider again the supply flow rate, the separation of the raw water supply system and the backwash water system, and independent treatment of the condensed water (with activated charcoal treatment, advanced oxidation, etc.).

5.3.8 Issues related to operation management

Management of the operation of membrane treatment processes that are the main processes for water reclamation most particularly involves the control of fouling (clogging), the monitoring of clogging and deterioration, and performance of chemical cleaning and other measures in case membrane clogging/deterioration occurs, but also includes management of the quality and flow rate of the raw water and the reclaimed water in order to ensure a stable supply of water.

Secondary effluent, advanced process treated water, sand filtered water, MBR treated water, etc. are all assumed ass possible sources of the raw water used in the main membrane (MF/UF or NF/RO) treatment process. The situations where fouling occurs differs depending on the features and type of the membrane used, and therefore the equipment and operating conditions necessary for the control of fouling also vary widely.

This section discusses general issues related to the management of at reclamation operations based on membrane treatment (with MF/UF or NF/RO membranes) using sewage water as the raw water. Recent technical developments and a survey of actual operating conditions are also discussed. For information on the operational management of MBR, see section 3.3 in Chapter 3.

(1) Management of the quality and flow rate of the raw water and the reclaimed water

- If the main membrane treatment uses an NF/RO membrane, the flow rate of raw water supplied should be determined by taking into consideration the raw water quality, the targeted reclaimed water quality, the recovery rate of the reclaimed water, etc., and should be automatically controlled using a constant pressure control or constant flow control device[44)]. Fluctuations in the flow rate demand should be managed by changing the permeation flux within a certain range.
- Generally, the FI value*[34] is used to control the quality of the raw water for an NF/RO membrane treatment process[45)]. If an MBR is used before the NF/RO membrane treatment process, management of the operation is easier because the FI value is stabilized.
- When monitoring the quality of the reclaimed water, achievement of the targeted values for each of the water quality standards for the individual applications should be confirmed.

(2) Management of operations in order to control fouling on the membrane

1) Control of fouling on the membrane

- Conventional methods for the control of fouling include coagulation-sedimentation and coagulation-filtration. Chlorine injection and the addition of scale inhibitors, however, have been more commonly used recently[44)]. Other methods include ozone pretreatment[11), 46)] and UV treatment[45)].

[34] FI: Fouling Index, an index that shows the trace turbidity of the water supplied to the membrane

・Select the operating conditions, such as the fouling control methods and the injection rate of any chemicals, in view of the raw water quality, the membrane features and the targeted reclaimed water quality. In RO membrane treatment, there is a flow rate[46), 47)] for which the MF/UF membrane treatment is used as a fouling control treatment.

2) Monitoring of membrane clogging and deterioration

・When monitoring membrane clogging and deterioration, of the need for chemical cleaning and membrane replacement is based on the permeability flow rate, the trans-membrane pressure difference and the permeation flux. To detect damage to the membrane, monitor the quality of the filtered water, etc.[46)]

・If the membrane deteriorates or breaks, it is necessary to record the required date for resumption of operations, the replacement frequency, the replacement rate, etc., in order to understand the duration of the suspension.

・It is important to preliminarily decide what measured will be taken to supplement the reduced flow rate of reclaimed water that results due to suspension of operations.

3) Chemical cleaning of the membrane

・Membrane cleaning methods and the chemicals used for each differ depending on the cause of the fouling - inorganic scale or biofouling. The process is normally automated, however, with oxalic or citric acid used for inorganic scale-related fouling and alkali or hypochlorous agents used for biofouling[44), 46)]. Note that, however, some chemicals facilitate deterioration of the membrane depending on its material (see chemical cleaning of MBRs in section 3.3.4 of Chapter 3).

・The frequency of chemical cleaning depends on the method for control of fouling, etc. It has been reported[46)] that MF membranes with ozone pretreatment are cleaned two to four times per year, while MF membranes with coagulation pretreatment are cleaned one to two times per month, and RO membranes with coagulation and MF membrane pretreatments are cleaned about once a month.

(3) Others

* Note that a change in the water quality during water conveyance (N-BOD and residual chlorine when NH_4-N remains), as well as troubles at the destination location of the reclaimed water (chromaticity, odor, growth of algae and chironomid midges) can occur (see the "Manual related to Standards for Reused Sewage Water Quality"[41)]).

5.4 Review of satellite MBR systems

5.4.1 Effects of satellite MBRs

By introducing an MBR to a satellite treatment facility, further cost reductions for the facility are expected.

(1) Overview of satellite reclamation systems

A satellite treatment system incorporates an intermediate treatment facility that intakes sewage from sewage pipes before they reach the sewage treatment plant to facilitate reclaimed water use in distant areas (see Figure 5-7). Sludge generated at the satellite treatment facility is not disposed of independently, but is conveyed through sewage pipes for centralized treatment at the core facility. When the destination of the reclaimed water is too far from the sewage treatment plant, which means the conveyance distance gets too long, it may be more advantageous to use a satellite treatment system that takes sewage directly from sewage pipes, etc. adjacent to the destination and then reclaims and supplies it.

In many actual instances of reclaimed water use in Japan, the destinations are limited to the areas adjacent to the sewage treatment facilities due to the conveyance costs. By introducing satellite treatment systems, it is anticipated that demand for reclaimed water should increase with supply to a wider area at a lower cost.

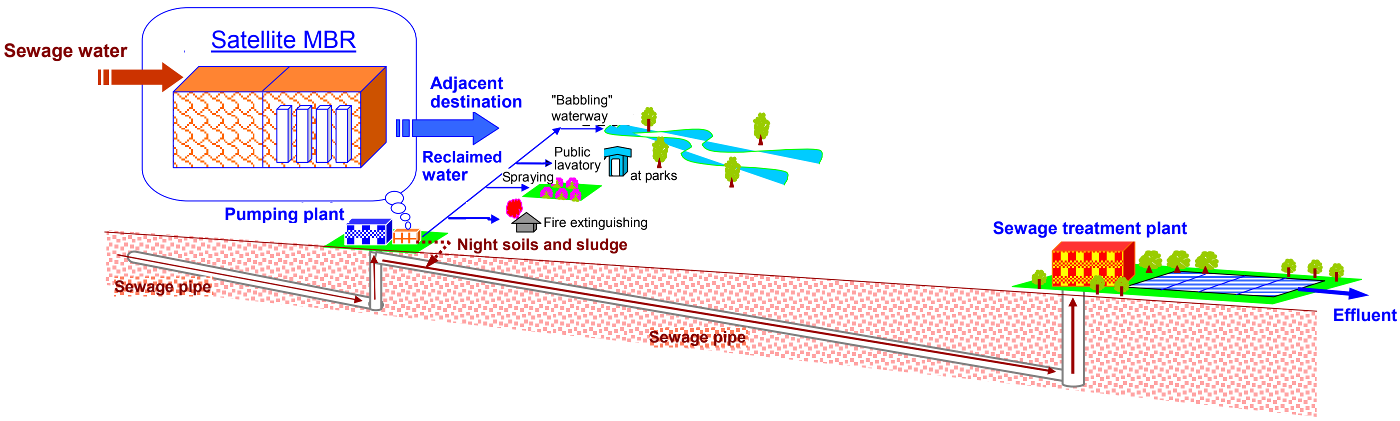


Figure 5-7 Image of reclamation at a satellite treatment facility

However, if a satellite treatment facility uses conventional biotreatment combined with sand filtration, etc., at a later stage, its configuration becomes complicated and the feasibility is decreased. The effects specific to satellite MBRs and the issues that should evaluated when considering a satellite MBR installation are described below. See Chapter 3 for the issues specific to MBRs, and see section 5.3 above for the issues that should be considered when adding an RO membrane, etc. in a process following an MBR process.

(2) Effects of satellite MBRs

Installing a satellite MBR is expected to reduce the total costs for reclamation for the following reasons: reduced water conveyance costs; usability without further treatment for certain applications because it easily meets the water quality required for landscaping, etc.; reduced space demands (about two-thirds of that for a single tank anoxic-oxide process, which itself requires a comparatively small space).

Compared to conventional biotreatment technology, an MBR has the following advantages:

[1] Enhanced and stabilized treated water quality regardless of variations in the raw water quality

[2] Simplified flow for the reclamation facility (downstream processes such as strainers and sand filtration can be omitted)

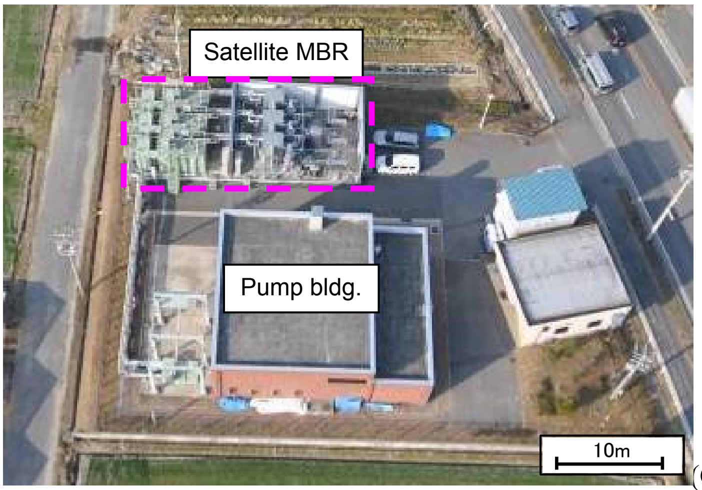
[3] Easy maintenance management (remote control and monitoring allow for the possibility of unmanned operations)

[4] Reduced footprint (installation is possible within a relay pump station, etc.)

[5] Operating conditions are easily adjusted to changes in flow rate demand within a certain range (permeation flux can be raised as much as about 1.5 times without reducing the quality of the reclaimed water)

Furthermore, pretreatment equipment is not necessary when ozone treatment and RO membrane equipment are installed following the MBR in order to expand the applications for the reclaimed water.

Figure 5-8 shows the demonstration equipment for the satellite MBR installed at the Miai Pumping Station, Aichi Prefecture.



(Capacity: 240 to 360 m^3/day)

Figure 5-8 Demonstration equipment for the satellite MBR installed at the Miai Pumping Station, Aichi Prefecture

5.4.2 Considerations and cautions for management of satellite MBR operations

When installing a satellite MBR and managing its operation, it is necessary to review and exercise caution regarding how to secure the necessary flow rate of raw water (raw sewage water), how to handle the sludge generated by changes in the water quality and the reclamation treatment, how to manage the wastewater produced in the membrane cleaning process, and how to lay out the equipment in order to supply reclaimed water at a stabilized quality and flow rate.

(1) Securing the raw water flow rate

Raw water used in satellite MBRs is unprocessed sewage water running through sewage pipes. If the area upstream of where the wastewater is discharged is small, the water flow rate within a day greatly fluctuates. Therefore, it is important to consider carefully the capacity of the reclamation facility and supply flow rate of the reclaimed water, taking the minimum raw water flow rate at nighttime into account.

(2) Changes in raw water quality

If the area upstream of where the wastewater is discharged is small, the influent water quality within a day greatly fluctuates. Therefore, it is necessary to understand this load fluctuation in order to determine how to control and minimize its effects, such as with the installation of a sedimentation tank or a flow equalization tank preceding the MBR. At locations where the water flow rate is sufficiently similar to that of the desired reclaimed water flow rate, it is possible to install a flow equalization tank in the satellite facility to intake the required water volume during the times when the water quality is relatively stable.

(3) Handling of sludge and membrane cleaning wastewater generated at the satellite MBR

When returning sludge and membrane cleaning wastewater generated by reclamation treatment back to sewage pipes, note that odor or corrosion due to accumulation and decomposition of sludge and screen residues within the pipes can cause problems. In particular, when the reclaimed water flow rate is larger than the water flow rate in the sewage pipes, caution is required, and the intake situation at the downstream locations must be considered.

[1] Because sludge and screen residues may accumulate in the sewage pipes to which they are returned, confirmation that there is no place where such sludge and residues can easily accumulate, such as at inverted siphons and poor slopes, including bends and slack areas in the downstream sewage pipes is necessary.

[2] If there is the possibility of corrosion due to the accumulation of sludge or screen residues in existing pumping wells and sewage pipes to which they are returned, it is necessary to consider remodeling of the facility, drawing of the sludge, and adjusting the frequency or period of time for lifting.

[3] If there is the possibility of sewage pipe corrosion at the facility to which the sludge or screen residue is returned, it is necessary to consider countermeasures such as corrosion protection or

deodorization.

(4) Layout of the equipment

[1] Position the intake pump at a place where the returned water, including the sludge, is not flowing into, and place the other process equipment after the intake pump, to the extent possible, at a site where the water is conveyed by gravity flow. Figure 5-9 illustrates a layout example for a satellite MBR (in a relay pump station.)

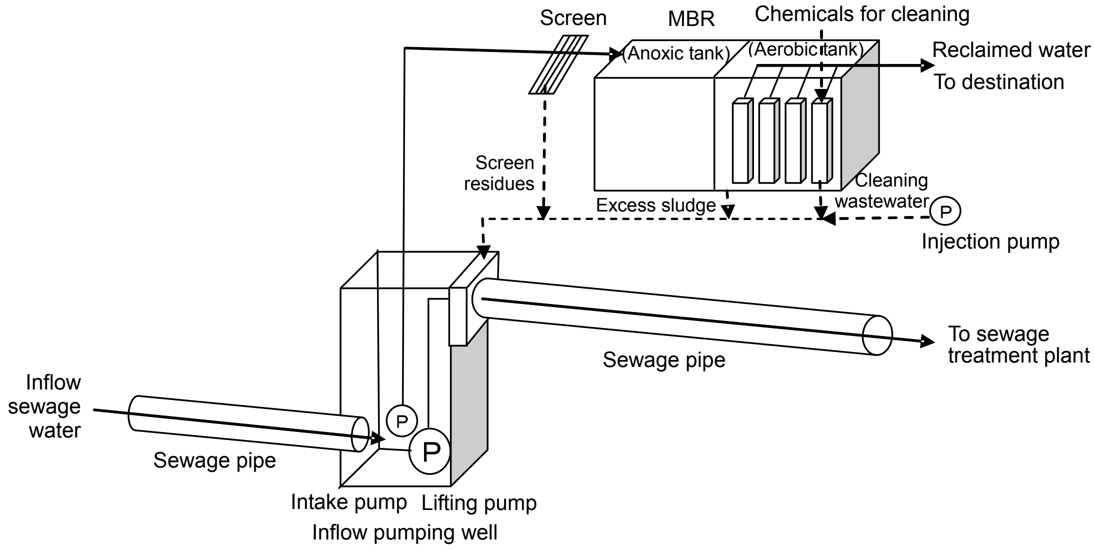


Figure 5-9 Layout example for a satellite MBR (in a relay pump station)

[2] In principle, convey the sludge and screen residues by gravity flow, and consider the use of water injection equipment, etc., accordingly.

[3] If the satellite MBR is adjacent to residential areas, parks, etc., consider taking steps to prevent noise and odor issues, such as installing the equipment that may cause these problems indoors.

[4] In principle, place the electric and measuring equipment on the MBR side. Be sure, however, to carefully consider the position in the case where the MBR system is automatically monitored and controlled.

5.5 Example cost review

> When reviewing the cost effectiveness of installing membrane technology for reclamation facilities, thoroughly consider the treatment flow that is suitable for the intended applications for the reclaimed water and the required quality, the costs for conveying water to the destination, and the possibility of securing the space for a satellite treatment facility, and compare the costs for utilization of existing facilities with those for constructing a new satellite treatment facility and those when a conventional process is used that provides the same performance.

5.5.1 Basic policies for cost reviews

When reviewing the costs for installation of membrane technology including MBRs for reclamation facilities, consider the treatment flow, costs for conveying the water to its destination, and the possibility of securing space for a satellite facility. Then, calculate and compare the costs for construction, maintenance, etc., for use of an existing facility and the construction of a new satellite facility. In addition, compare the costs with those of a conventional process that attains the same performance. If it is necessary to acquire new land, then land acquisition costs should also be included in the costs.

When reviewing such costs, note that these costs significantly differ depending on the technology and the site conditions adopted, and use the latest information. In the future, market expansion and further research and development on membrane technology is expected, which will further lower construction and maintenance management costs for this technology.

These guidelines present information useful for cost reviews through case studies based on hypothetical conditions. The studies have been conducted by the working group established at the Sewage Technical Meeting on Membrane Technology and through cooperation of seven manufacturers participating in the working group.

5.5.2 Information and assumptions pertaining to the case studies

These case studies target a facility reclaiming water for multiple purposes (water for toilet flushing, landscape use, hydrophilization, and industrial use) that utilizes an existing treatment plant or that utilizes a newly constructed satellite facility, and calculates and compares the LCC for facilities where MBR is used and where a conventional method is used. In all cases, the flow rate of the reclaimed water is assumed to be 500 m^3/day.

In the case where an existing facility is utilized, the costs are calculated assuming that the secondary effluent from an existing sewage treatment plant (using the standard activated sludge process) is treated with the newly added process at a later stage.

In the case where a new satellite treatment facility is constructed, the costs are calculated assuming that the facility is constructed in a relay pump station near the destination for the reclaimed water.

Moreover, the costs are calculated for both MBR and conventional processes. Among the conventional processes actually adopted at small-scale facilities, the extended aeration process (single-tank anoxic-oxide process) was selected for review, as this process can stably remove organic matter and requires a comparatively small space without a primary sedimentation tank.

The cases to review and the post-treatment process required for each case were decided according to the "Manual Related to Standards for Reused Sewage Water Quality[41]." These case studies assume no land acquisition costs.

Table 5-10 List of cases and post-treatment processes for review (for reclaimed water use)

Method of treatment / use of reclaimed water Process		Toilet flushing	Landscape use	Hydrophilization	Industrial use
Utilization of an existing treatment plant	Conventional (standard) process + post-treatment	Rapid filtration + chlorination	Rapid filtration + UV	Coagulation-sedimentation (simultaneous coagulation) + rapid filtration + ozone + chlorination	Rapid filtration + MF + RO
Construction of a new satellite treatment plant	MBR + post-treatment	Chlorination		Ozone + chlorination	RO
	Conventional process (extended aeration process*) + post-treatment	Rapid filtration + chlorination	Rapid filtration + UV	Coagulation-sedimentation (simultaneous coagulation) + rapid filtration + ozone + chlorination	Rapid filtration + MF + RO

* Extended aeration process (single-tank anoxic-oxide process)

Table 5-11 Assumptions made for the case studies (when constructing a new satellite treatment plant)

Item		Conditions to be reviewed
Details		● A satellite sewage treatment system (capacity: 500 m^3/day) is newly constructed in the relay pump station near the destination.
Scope of review	Civil engineering frame	● Civil engineering frame is made of concrete. ● Space for installation of equipment such as the piping gallery is also reviewed (to make it as compact as possible) ● If an air blower or electrical equipment is to be installed inside the building, include the building as well.
	Water treatment equipment	● All incidental equipment (air blower equipment, membrane cleaning equipment, coagulant addition equipment, etc.) required for the MBR process, in addition to reactor tank equipment (membrane separation equipment, agitator, pumps, etc.) are reviewed. ● Deodorization equipment is out of the scope. ● The control board for the MBR devices and equipment is included in the water treatment equipment. ● Sharing equipment with the existing facility is not considered. An air blower room, etc. is independently prepared.
	Electrical equipment	● Power, instrument and control equipment for operating the MBR equipment is included for review, but sharing with existing equipment (power receiving/transforming equipment, etc.) is not considered.
	Others	Each Participant clarified the method, frequency period of time, etc. for chemical cleaning in order to establish the period of time in which reclaimed water cannot be conveyed due to cleaning.
Treatment capacity		500 m^3/day
Daily flow fluctuations		An assumption of constant flow without fluctuation.

Table 5-12 Design water quality (for reclaimed water use)

Water quality item	Influent water quality	Targeted treated water quality (MBR)	Examples of targeted treated water quality (after post-treatment)			
			Toilet flushing	Landscape use	Hydrophilization	Industrial use
BOD (mg/L)	200	10	10 or less	10 or less	10 or less	10 or less Note 1
S-BOD (mg/ L)	100	-	-			-
SS (mg/ L)	180	-	-			-
T-N (mg/ L)	35	10	-	10 to 20 Note 1	10 to 20 Note1	10 to 20 Note 1
T-P (mg/ L)	4.0	-	-	1 to 3 Note 1	1 to 3 Note 1	1 to 3 Note 1
E. coli	-	-	Not detected Note 2	-	Not detected	-
Turbidity (degree)	-	-	2 Note 2	2	2	10 Note 3
Chromaticity (degree)	-	-	-	40	10	-
Residual chlorine (mg/ L)	-	-	Free: 0.1 or Combined: 0.4 Note 2	-	Free: 0.1 or Combined: 0.4 Note 2	-
Total hardness (mg-$CaCO_3$/L)	-	-	-	-	-	70 Note 4
Chloride ion (mg/L)	-	-	-	-	-	50 Note 5

Note 1: The limit is considered to be necessary for controlling the slime in pipes and the removal of nutrient salts.
2: According to the "Manual Related to Standards for Reused Sewage Water Quality" (issued by MLIT in 2005).
3: According to the "Report of the survey on the quality of industrial water" (issued by METI in 2004), water quality is set at the level that satisfies 90% of consumers.
4: According to the "Report of the survey on the quality of industrial water" (issued by METI in 2004), a range that satisfies 90% of consumers is adopted.
5: According to the "Guidelines for water quality used for refrigeration and air conditioning equipment" (Issued by The Japan Refrigeration and Air Conditioning Industry Association in 1994), the quality standards for make-up water for cooling towers is adopted.

Table 5-13 Overview of MBR facilities targeted for review (for reclaimed water use)

Item	Details of results
Type of membrane	Hollow fiber membrane x 4; flat sheet membrane x 2; ceramic membrane x 1
Membrane separation method	Immersed type (integrated type) x 6; external type x 1
Biotreatment method	Recycled nitrification/denitrification process x 7 (*Two companies installed a coagulant feeder)
Pretreatment equipment	Influent screen x 7

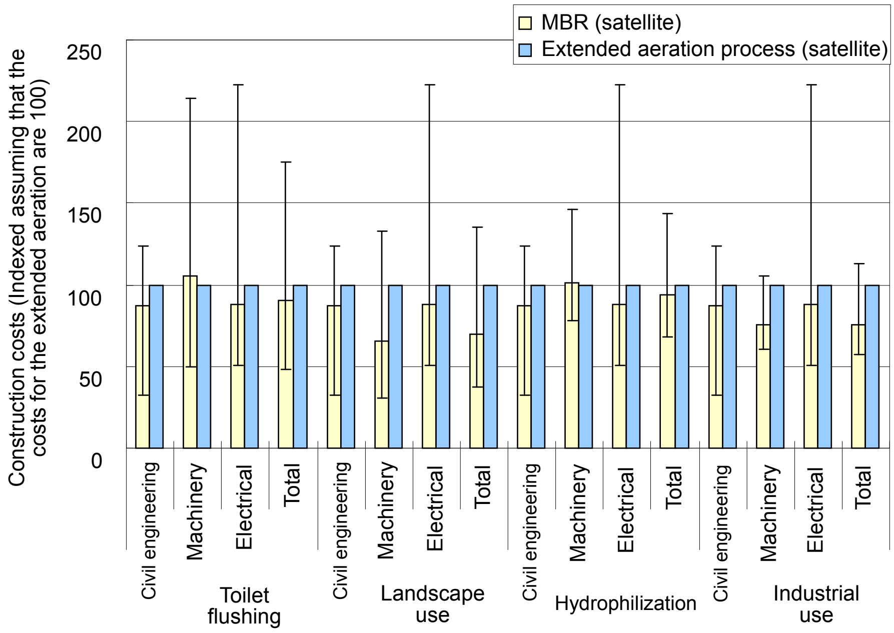
5.5.3 Cost calculation methods

See Chapter 3 (3.4.4).

5.5.4 Example cost reviews

The results of this cost review are shown below. This review assumes no land acquisition costs.

1) Construction costs

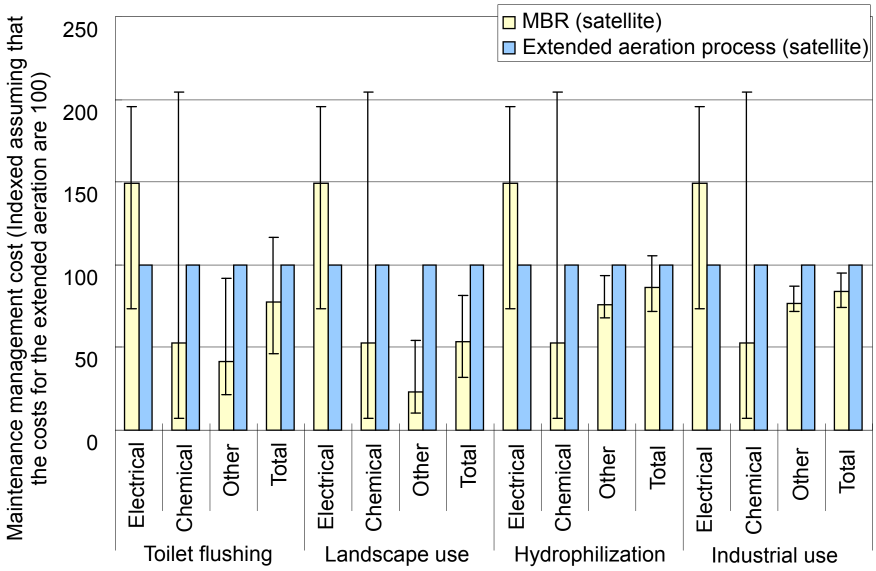


* Compared by assuming that the costs for the extended aeration process are 100.
In the figure, the vertical bars for the MBR process indicate the median values, while the thin lines represent the maximum and minimum values.

Figure 5-10 Comparison of construction costs (when constructing a new satellite treatment system)

- An MBR process is slightly advantageous with regard to costs for civil engineering, due to its space-saving features, etc.
- The costs for machinery tend to be higher with an MBR process than those with the conventional process, as the MBR process requires chlorination and ozone treatment to produce water for toilet flushing and hydrophilization. For water for landscape use, on the other hand, the costs tend to be lower with an MBR process, because no post-treatment processes are required. An MBR process is advantageous for industrial water as well, because it does not require a post-treatment process consisting of "Rapid filtration + MF", which is necessary in the conventional process.
- The costs for electrical equipment vary significantly depending on the MBR system adopted, but when comparing the median values, they are a little bit lower for an MBR process than the conventional process.

2) Maintenance management costs

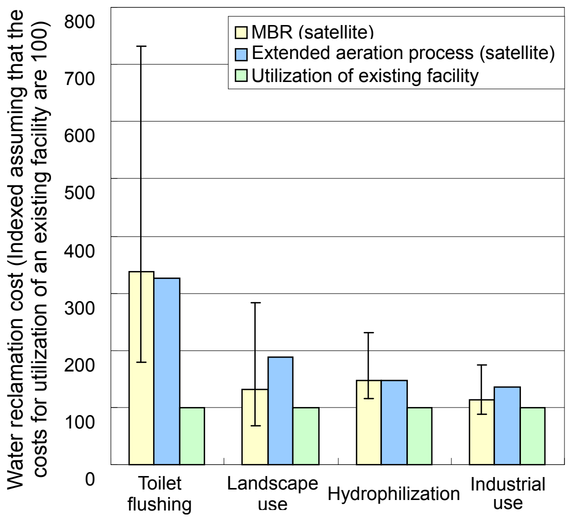


* Compared by assuming that the costs for the extended aeration process are 100.
"Other" constitutes repair costs and maintenance costs for the later stage treatment process.
In the figure, the vertical bars for the MBR process indicate the median values, while the thin lines represent the maximum and minimum values.

Figure 5-11 Comparison of maintenance management costs (annual) (when constructing a new satellite treatment system)

- The electrical energy costs tend to be higher with the MBR process than that with the conventional process for any use of the reclaimed water.
- The total maintenance management costs are lower with the MBR process for every use of the treated water due to the fact that the MBR requires less post-treatment processes, etc.
- Note that "Other" for the MBR process does not include membrane replacement costs.

3) LCC

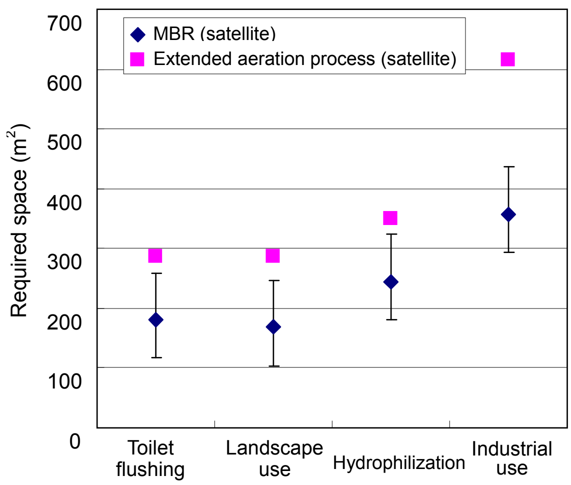


* Compared by assuming that the costs when utilizing an existing facility are 100.
In the figure, the vertical bars for the MBR process indicate the median values, while the thin lines represent the maximum and minimum values.

Figure 5-12 Comparison of LCC (assuming that the costs when utilizing an existing facility are 100)

- When comparing the LCC for a newly constructed satellite treatment plant using an MBR process to one using the conventional process, the MBR process may be advantageous depending on the MBR system adopted. Generation of treated water for landscaping and industrial use has lower LCC when an MBR process is used when comparing the median values, because the post-treatment processes for the conventional process have relatively high costs.
- When comparing the LCC for a newly constructed satellite treatment plant using an MBR process to the utilization of an existing facility, the results vary depending on the use of the reclaimed water. When the water is intended for toilet flushing, the LCC with the new satellite treatment plant using an MBR process is much higher than that for the existing facility, because the latter requires relatively fewer costs. When the water is intended for landscaping and hydrophilization, which involves relatively high costs for the post-treatment process, the LCC with the new satellite treatment plant using an MBR may be lower than that of the existing facility, depending on the MBR system adopted.

4) Required space



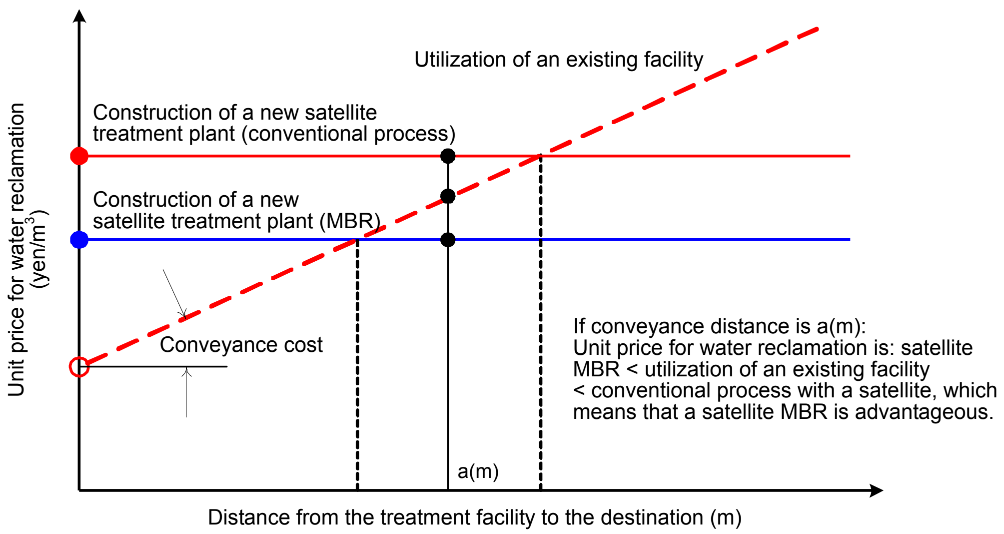
* In the figure, plots for the MBR process indicate the median values, while the bars represent the maximum and minimum values.

Figure 5-13 Comparison of the required space (when constructing a new satellite treatment system)

- An MBR process requires less space than the conventional process when they are used in a newly constructed facility for any intended application of the reclaimed water.

5) Necessity for considering the conveyance costs to the destination

In an actual review, it is necessary when comparing the costs of utilizing an existing facility and the construction of a new satellite treatment plant to add the conveyance costs to the destination to the above described costs.



* When constructing a new satellite treatment plant, the costs for water reclamation with the conventional process may be less than those with an MBR, depending on the facility planning.

Figure 5-14 Diagram of a cost review with added conveyance costs

6) Additional considerations regarding this cost review

The above cost review results are based on calculations for hypothetical conditions. Note that the costs required may vary significantly depending on the facility design and future technological development, as well as the considerations shown in Table 5-14.

Table 5-14 Additional notes on this cost review (for reclaimed water use)

Issues to consider when evaluating the results of this cost review	● Because the site space of the existing facility is not considered, the MBR process may be advantageous when the site space is limited.
Issues to consider when regarding the prerequisites of this cost review	(When utilizing an existing facility) ● The costs are calculated assuming that 500 m^3/day of effluent water at the existing facility are treated using the standard process for reclaimed water use. ● The post-treatment process is a subject of this cost review, while the intake pump, deodorization equipment and sludge treatment facility are out of the scope of the study. (When constructing a new satellite treatment plant) ● For the MBR process, the equipment from the pretreatment stage through to the reservoir tank for the reclaimed water is the subject of this review, assuming no final sedimentation tank. ● For the conventional process, the equipment from the primary sedimentation tank through to the reservoir tank for the reclaimed water is the subject of this review. ● In both cases, the costs are calculated assuming that a new satellite treatment facility (capacity: 500 m^3/day) is constructed in a relay pump station near the destination for the treated water. The intake pump, sludge treatment equipment and deodorization equipment are out of the scope of the study.

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