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Present State of Membrane Filtration for Water Treatment in Japan

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Abstract: Membrane filtration systems have been focusing and increasing rapidly in the filed of drinking water treatment because of several reasons. We describe briefly the present state of membrane filtration processes for drinking water treatment in Japan: including background, objectives, membrane suppliers, and some cases of actual plants.

Keywords: *membrane filtration, drinking water, Japan status*

1. Introduction

Membrane filtration technology for water treatment started by the development of cellulose acetate RO membrane followed by development of a wide range of membranes and research on solute separation mechanism. Membrane filtration processes, including RO, NF, UF, and MF, has been the essential separation technologies for a wide of industry: for example, semiconductor, pharmaceutical, food processing industries. Recently, membrane filtration processes have been increasing rapidly in the field of drinking water supply, and this may be caused by the following reasons: development of new membranes and engineering technology, requirement for safety drinking water. Membrane filtration technologies for drinking water supply are classified into the following two categories.

(1) Fresh water treatment: MF, UF, and NF

(2) Desalination of seawater or brackish water: RO and low pressure RO

MF and UF membranes can remove particulate matter effectively and are applied as an alternative technology for sand filtration. The plants installed UF and/or MF have been increasing rapidly for drinking

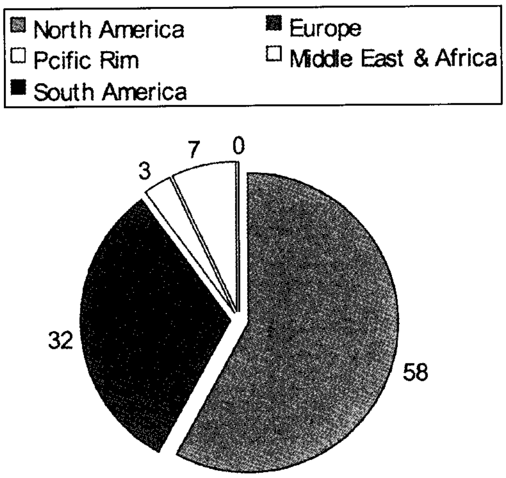

Fig. 1. MF/UF regional distribution (%).

water treatment. Global capacity of MF and UF plants reached 4.917×10^6 m^3/day in 2002, and will be 10.945×10^6 m^3/day in 2003 [1]. However, 80% of the plants are constructed in North America and Europe as shown in Fig. 1. The share of drinking water supply is 63% of globally installed MF and UF plants in 2002 [1,2]. In Europe its share reaches 75% as shown in Fig. 2.

MF and UF processes have the following advantages: (1) reduction of risk for pathogenic organisms such as Cryptosporidium and Gialdia, (2) flexible applicability for wide range of plant capacity (even for

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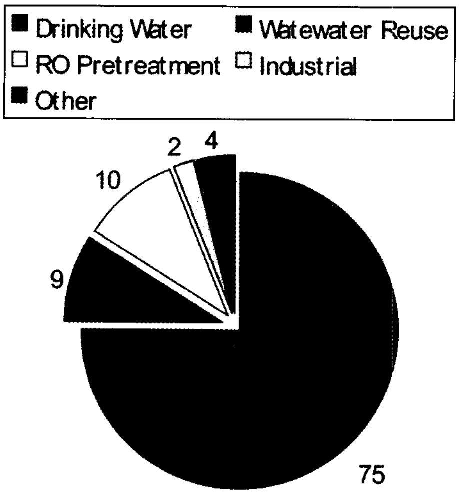

Fig. 2. MF/UF application in Europe (%).

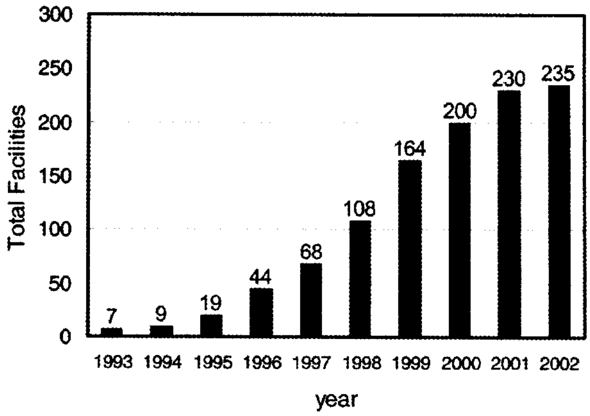

Fig. 3. Accumulated facilities (Japan).

small-scale plants), and (3) automated operation and saving both space for the plants and operators. It is no use to say that higher quality water can be obtained from the membrane processes.

NF processes have also been increasing: NF membrane is used for softening and removal of hazard organic micropllutants such as pesticides.

In this paper, we describe briefly the state of application of membrane filtration for drinking water supply in Japan.

2. National Projects on Membrane Technology for Drinking Water Supply in Japan

MAC21(Membrane Aqua Century 21): 1991-1993

Objective: solid separation technology with membrane filtration system for water treatment

Results: the followings were published.

"The guideline for installation of membrane treatment plant for small scale water treatment facilities"

"The manual for operation and maintenance of membrane filtration system in small scale facilities"

ACT21(Advanced Aqua Clean Technology For 21st Century): 1997-2001

Goal: innovation of water treatment technology and improvement of efficiency of solid separation, disinfections, etc.

Objectives:

(1) Excellent removal performance for pollutants
(2) Down sizing and simplification of facility, and easy operation and maintenance
(3) High reliability

Subjects concerning membrane technology:

(1) scale up of membrane module
(2) membrane cleaning technology
(3) development of high performance membranes (high flux membrane, tolerance for chlorine and ozone)
(4) development of low desalting and low pressure membranes to remove low molecular weight organic compounds
(5) risk assessment for water treatment system equipped with membrane filtration units, and
(6) development of treatment technology for the wastewater from the membrane treatment process.

3. Present State of MF and UF Plants in Japan

In Japan, the first MF and UF plants for drinking water treatment were constructed in1993. Thereafter the results of the project "MAC21" were published and membrane plants have increased rapidly. The trend of installation of membrane plants and total capacity are shown in Figs. 3 and 4 [3]. The number of the

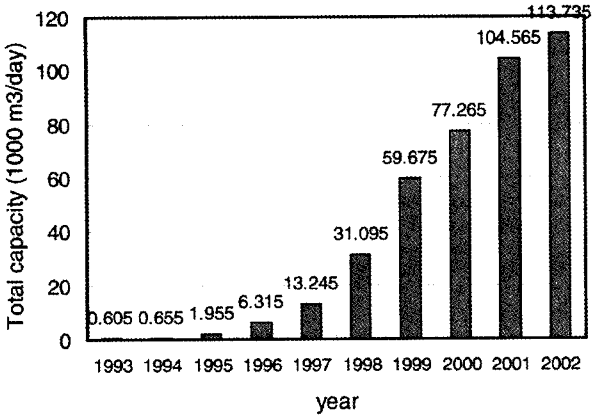

Fig. 4. Accumulated capacity (Japan).

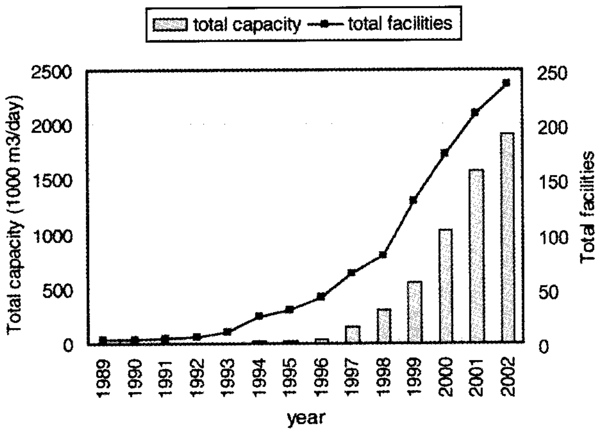

Fig. 5. Accumulated facilities and capacity (USA).

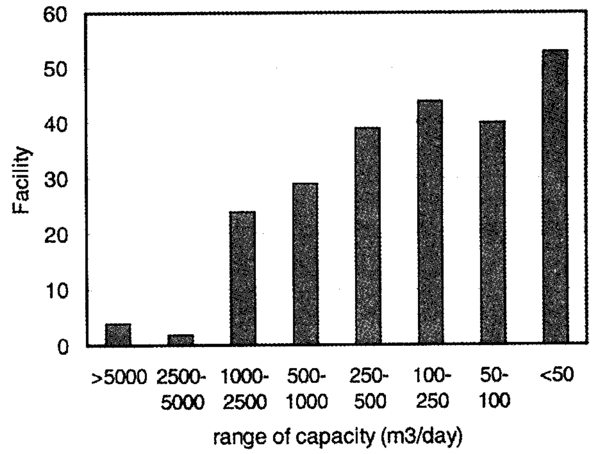

Fig. 6. Distribution of facility based on capacity (Japan).

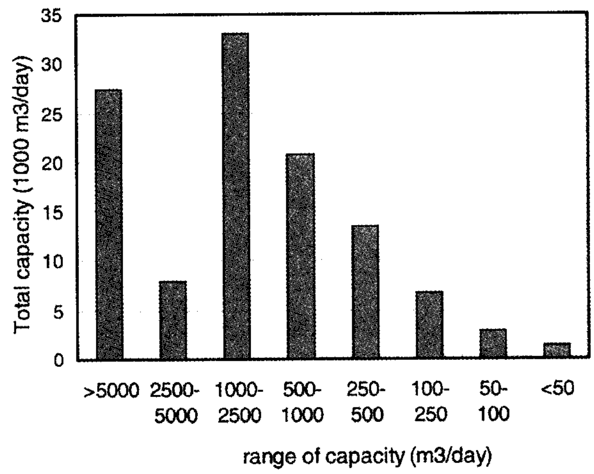

Fig. 7. Distribution of capacity (Japan).

facilities installed membrane separation plants is 235 facilities and the total capacity is 113,748 m^3/day (June 1, 2001).

It is well known that in USA ca. 400,000 persons were infected with Cryptosporidium in 1993. As a result membrane filtration plants have been increasing in USA as shown in Fig. 5 [2]: the total capacity is ca. 10 time of that in Japan. Even in Japan, 8705 persons were infected with Cryptosporidium via drinking water in 1996, and thereafter installation of membrane filtration plant was accelerated to reduce the risk from Cryptosporidium.

It is also an important factor that membrane process can reduce effectively trihalomethanes (THMs), byproducts of chlorination, in drinking water. MF and UF does not reject THMs directly but can remove THM precursor such as humic substance. Since these membranes can reject pathogenic microbes effectively, chlorine dosage for disinfection can be reduced and this may also be effective to reduce THMs production. Another advantage of these membrane systems is that membrane treatment plants are operated automatically and required fewer operators than conventional treatment plants.

As expected easily from Figs. 3 and 4, almost facilities in Japan are small scale ones: only 4 facilities have the capacity of more than 5000 m^3/day. The distribution of facility based on capacity is shown in Fig. 6 and 7. Almost of small scale facilities locate in countryside or mountain village, because the

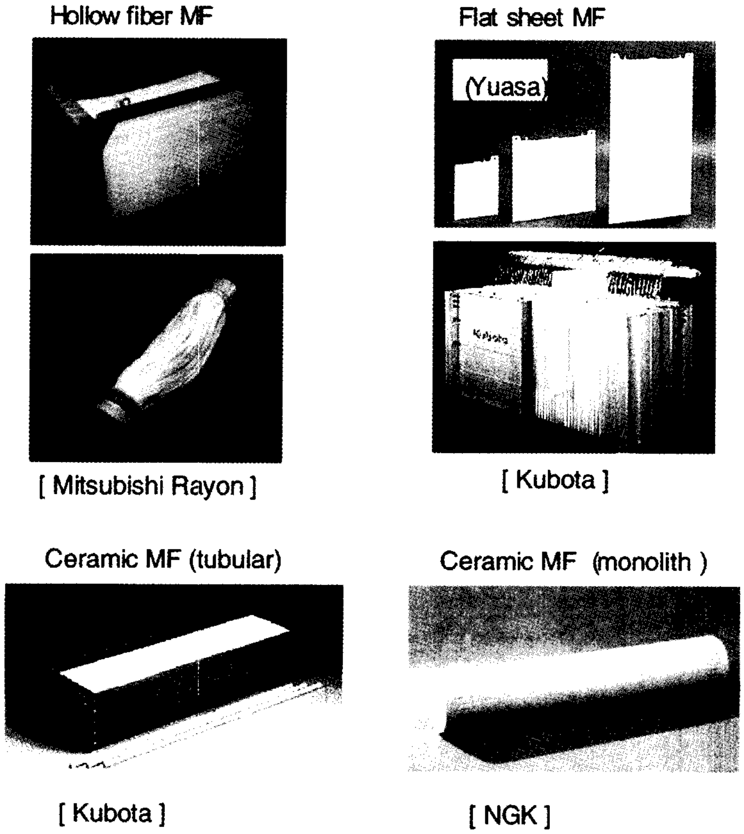

Fig. 8. Examples of membrane modules.

requirement for higher water quality has increased in these region. Membrane filtration plants have the following advantages for small-scale facilities: small area requirement for the plant, automatically operation, remote monitoring, and possibility of remote operation. It is one of the important subjects for small-scale facilities to operate by fewer engineers because of financial limitation.

4. MF and UF Membrane Suppliers in Japan

MF and UF membranes are characterized by several properties such as pore size or MWCO, materials (polymeric, ceramic), permeate direction (out-to-in or in-to-out), a range of applied pressure, and shape of membrane (flat sheet, tubular, capillary, hollow fiber, monolith), morphology of membrane module, tolerance to oxidants (Chlorine and ozone), etc. Some examples of membrane modules are shown in Fig. 8. A wide range of membranes is available and has been used actually for drinking water treatment as shown in Figs. 9 and 10 [4]. The kinds of membranes and membrane suppliers in Japan are summarized briefly in Table 1.

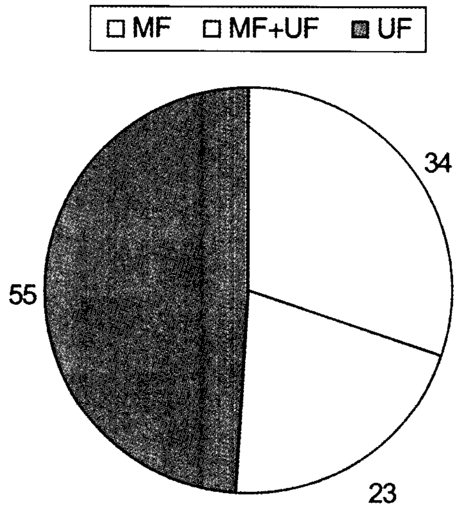

Fig. 9. Membrane types for drinking water treatment.

Table 1. Available MF and UF Membranes for Drinking Water Treatment (Japan)

Membrane supplier	Class	Material	Pore size/ MWCO	Module type (pressure side[1])	Filtration mode[2]
ASAHI KASEI	MF	PVDF	01 μm	hollow fiber (Ex)	DE + CF
	UF	PAN	80 kDa	hollow fiber (Ex)	DE + CF
AQUASOURCE	UF	Celluloseic	100 kDa	hollow fiber (In)	DE + CF
DAICEN MEMBRANE SYSTEMS	UF	CA	150 kDa	hollow fiber (In)	CF
KURARAY	MF	PVA/PSF	0.1 μm	hollow fiber (In)	DE
	UF	Polysulfone	13 kDa	hollow fiber (Ex)	CF
KUBOTA	MF	ceramic	0.1 μm	tubular (Ex)	submerged
NGK Insulators	MF	ceramic	0.1 μm	monolith (In)	DE
MITSUBISHI RAYON	MF	PE	0.1 μm	hollow fiber (Ex)	submerged
TORAY	UF	Polyacrylonitrile	100 kDa	hollow fiber (Ex)	DE
YUASA	MF	PO	0.25 μm	flat sheet (Ex)	submerged
VENDI	MF	Polypropylene	0.2 μm	hollow fiber (Ex)	
ZENON	MF	PVF	0.1-0.4 μm	hollow fiber (Ex)	submerged

1) Ex: external, In: internal ; 2) CF: cross flow, DE: dead end

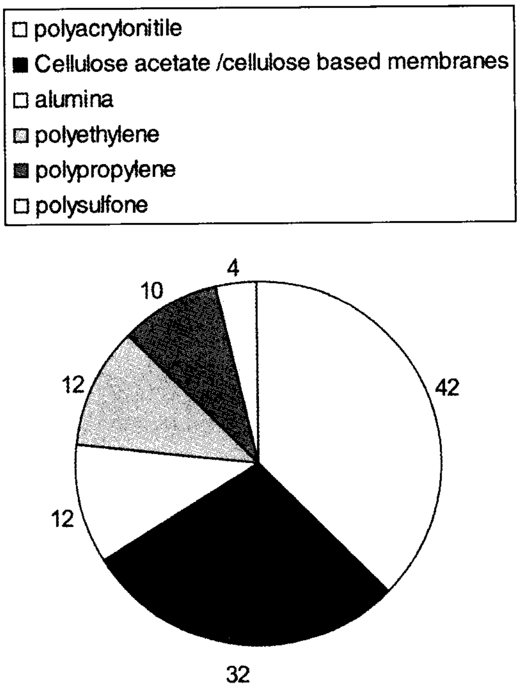

Fig. 10. Membrane materials for drinking water treatment.

5. MF and UF Systems for Drinking Water Treatment

Membrane separation systems are classified into the following two categories: (1) pressurized water is fed into membrane units (UF, MF), including cross flow and dead end filtrations, (2) permeate is withdrawn by a suction pump (submerged MF), where aeration is conducted at the bottom of the membrane units to provide sufficient flow rate at the membrane surface. The schematic diagrams of these systems are shown in Fig. 11.

MF and UF membranes can remove particulates directly, however it is an important subject to prevent membrane fouling and clogging which decrease productivity seriously. In many plants coagulants are added to prevent the fouling and clogging. In the case of submerged membrane system, coagulants can be added directly into a tank equipped with membrane units. In other cases, membrane separation is carried out after coagulation process.

Another problem is to control biofouling, which reduces productivity and induces degradation of polymeric membranes by attacking microbes. In order to remove biofouling layer, membranes are washed periodically (a few times a year) with the solution containing hypochlorite or ozone. However, the procedure must be designed carefully, because some membranes are damaged seriously by the oxidants.

6. Cases of Membrane Filtration Plants.

The largest plant in Japan was constructed at Seo, Imaichi-shi, Tochigi prefecture, in 2001, and its capacity is 10,000 m^3/day. The outline of the plant and the water treatment performance are summarized in

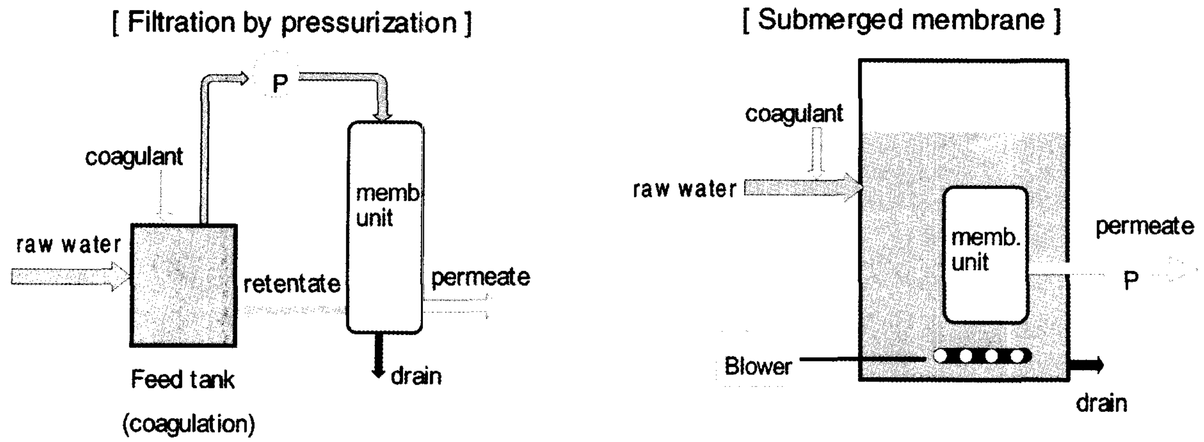

Fig. 11. Schematic diagram of membrane filtration system.

Table 2. Out Line of the Plant in Imaichi-shi, Japan

Membrane	UF, MWCO:150 kDa CA, hollow fiber, area: 6480 m^2 (54 $m^2 \times 120$) cross flow type
Filtration Conditions	flux control (0.015-0.023 MPa) flux: 0.93-1.7 m^3/m^2/day permeate: 6,000-10,000 m^3/day
Memb.washing	interval: 60 min; period: 60 sec
Water recovery	89-90%
Chlorination	0.41-0.89 mg-Cl/L
Solar panel	100 kW (area: 1430 m^2)
Running cost	chemicals: 0.33 Yen/m^3 Electric power: 0.19 kWh/m^3*

* low electric power consumption due to solar panels

Table 3. Water qualities in Imaichi-shi, Japan

Item		Raw water	Permeate
pH		7.3	7.3
Turbidity		1.1	<0.1
Color		2	<1
Organic matter[1)]	[mg/L]	1.0	0.3
Hardness	[mg/L]	34	33
Fe	[mg/L]	0.03	<0.03
Mn	[mg/L]	<0.005	<0.005
Bacteria[2)]	[CFU/mL]	>300	0
E. coli		+	-

1) $KMnO_4$ consumption, 2) standard plate count bacteria

Table 4. Comparison of Costs (490 m^3/day)

Item	Conventional	Membrane
Capital cost (Yen)	251.7×10^6	178.4×10^6
running cost (Yen/year)	7.98×10^6	6.89×10^6
Net working rate		
40% (Yen/m^3)	115.4	94.7
70% (Yen/m^3)	71.9	81.7

Tables 2 and 3 [5]. The system is operated automatically via a remote monitoring system, which monitors continuously the operational situation such as flow rate, water level, pressure, turbidity, pH etc. One of the features of this plant is that solar panels are equipped with because of the following reasons: use of clean energy, saving energy, and taking precautions against disaster.

We can see a case study evaluated the costs of a small-scale plant by Nakanojo-machi, Gumma prefecture: capacity of 460 m^3/day, compared between a conventional process (coagulation, sedimentation, rapid sand filter) and a membrane filtration process [6]. As shown in Table 4, membrane filtration process can reduce both capital and running costs. The highest cost is personal expenses for conventional process, but chemical cost is the highest for membrane system.

7. RO and NF Plants for Drinking Water Supply

Desalination is another membrane technology to produce drinking water. This system is required for islands and the region where it is difficult to obtain fresh water. A large-scale desalination plant (RO:

Table 5. Out line of Okinawa Seawater Desalination Center

Max. Capacity	40,000 m^3/day (at 40% recovery)
RO membrane	PA composite spiral-wound membranes Nitto Denko (NTR-70WC-S8) and TORAY (SU-820)
RO system	5,131 m^3/day/train × 8 Trains; 63 vessel (7 row × 9 stacks)/ Train 6 RO elements/vessel flux: 13 m^3/day/element ; normal pressure: 6 to 6.5 MPa
Pretreatment	coagulation ($FeCl_3$), sedimentation, dual media filtration and sand filtration chlorination (NaClO)
Water quality	<360 mg/L of TDS or <720 S/cm
Construction expense	Total: 34.7 billion yen
Running costs	electric power : 5.36kWh/m^3 ; chemicals: 0.104 US$/$m^3$ staff members: 13 persons (on 3 shift)

Table 6. Out line of Seawater Desalination Facility in Fukuoka (under construction)

Max. Capacity	50,000 m^3/day (at 60% recovery)
UF membrane	PS spiral-wound memb. (255 filters × 12 units; 0.2 MPa)
High pressure RO membrane	CTA hollow fiber memb. (420 filters × 5 units; 8.3 MPa)
Low pressure RO membrane	PA composite spiral-wound memb. (240 filters × 12 units; 1.5 MPa)
Schedule of supplying	construction: 2000-2005 supply: 2005

40,000 m^3/day) was constructed in Okinawa and the out line of the facility is summarized in Table 5 [7]. At present a larger capacity plant (50,000 m^3/day) is under construction in Fukuoka and will start service in 2005: the out line is also summarized in Table 6 [8]. In this system, seawater is obtained thorough seabed and fed to UF units for pretreatment, and desalted by high-pressure RO units followed by low-pressure RO units. Even in this process, however, it is difficult to reject effectively boron and fluoride in order to meet the regulation levels for drinking water quality: this may be caused by the fact that almost all of these species exist in nonionic form.

NF filtration systems have attracted attention recently for drinking water treatment. NF membranes have intermediate character between RO and UF membranes: low desalting property but high rejection rate for multi-valence ions. NF membranes are used for both softening and removal of hazardous organic micropollutants such as herbicides and pesticides as well as THM precursors. Almost all NF plants constructed in this decade are located in the USA as shown in Table 7. The largest plant is constructed in Mery-sur-Oise, France: its capacity is 140,000 m^3/day, (1999).

8. Future of Membrane Treatment System

Membrane filtration systems have very high performance for drinking water treatment. Membranes filtration can produce high quality and safety water and be applied even for small sale facilities as well as large scale ones. The number of membrane filtration plants is and will be increasing rapidly in Japan. Moreover, it is believed that larger capacity plants will also be planning. Membrane filtration system is a new drinking water treatment technology and must propagate widely in near future.

References

1. Furakawa, D. H., World Status of the Technology, Microfiltration Coference (2002) San Diego, California
2. Jacangero, J., Current Status of the Technology in the United States, Microfiltration Coference (2002) San Diego, California
3. Nagai, Y., J. Jpn. Water Research Center, No.23, 4-9 (2002)
4. Kamatani, H., 2nd Seminar on filtration and

membrane filtration technologies for drinking water in future (1999)
5. Saito, T., New Memb. Technol. Symp. 2002 (Jpn), Tokyo, p.1-2-1 (2002)
6. Yamamoto, M., Seminar on the present states and future of membrane plants for drinking water treatment (Jpn), p.54-60 (2002)
7. Iwahori, H., et al., "Japan Today" 2002, JETRO Exhibition, Abu Dhabi, UAE (2002)
8. http://www.f-suiki.or.jp/kaitan