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총 설

Membrane Roles in Potable Water Treatment

Yasushi Maeda

Dow Chemical Japan Limited Gotemba, Shizuoka, Japan
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야쓰시 마에다

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1. Introduction

Due to more stringent regulations in drinking water, membrane separation has been playing an increasingly important role. Seawater desalination by reverse osmosis is a typical example and has been used world-wide. Although the existing technology based on coagulation and media filtration is well established and reliable technology, with the advance of industrial and agricultural activities it is difficult for this technology to remove contaminants such as nitrate and synthetic organic chemicals. To meet the drinking water standards and produce higher quality water, several membrane filtration research programs have been initiated which include Japanese MAC21 and New MAC21 projects[1]. In this paper, potable water application of reverse osmosis (RO) and nanofiltration(NF) and their case histories will be explained in more detail.

2. Drinking Water Standard

In Japan the drinking water quality standards were revised in December 1992 and enforced from December 1993[2]. The new standard consists of two parts. One is the quality standard for health related contaminant level and the other is the standard for acceptability of tap water. Health related contaminant levels are shown in Table 1. Compared

Table 1. Japanese Drinking Water Quality Standards

Contaminants	Standard mg/L	Contaminants	Standard mg/L
General bacteria	100/ml	1,2-Dichloroethane	0.004
E. Coli.	ND/100ml	1,1-Dichloroethylene	0.02
Cyanide ion	0.01	cis-1,2-Dichloroethylene	0.04
Mercury	0.0005	Dichloromethane	0.02
Lead	0.05(0.01)	Benzene	0.01
Chromium(6⁻)	0.05	Total trihalomethane	0.1
Cadmium	0.01	Chloroform	0.06
Arsenic	0.01	Bromoform	0.09
Selenium	0.01	Bromochloromethane	0.03
Fluoride	0.8	Dibromochloromethane	0.1
Nitrate and Nitrite as N	10	Thiram	0.006
Trichloroethylene	0.03	Simazine(CAT)	0.003
Tetrachloroethylene	0.01	Benthiocarb	0.02
Carbon tetrachloride	0.003	1,3-Dichloropropane(D-D)	0.002
1,1,2-Trichloroethane	0.006		

(Health related contaminants)

with the WHO standard and maximum contaminant levels(MCLs) set by U. S. EPA, contaminant levels listed in Table 1 are almost the same. However, the number of parameters related to health effects is about half of the WHO drinking water quality guidelines. And area specific differences also exist. For example, the standard for atrazine is $3\mu g/\ell$ in the U. S. and $0.1\mu g/\ell$ in the countries of the EC; in addition the EC requires that the total concentration of pesticides and related compounds does not exceed $0.5\mu g/\ell$ [3]. Atrazine is not specified in Japan. Instead, the standard for simazine is set at $3\mu g/\ell$.

Regarding current trends in drinking water regulations, it seems that WHO has a plan to revise the drinking water quality guidelines by the end of 1997. More stringent MCLs are also expected in the U. S. Under these circumstances, it has become difficult to meet the standards for components such as trihalomethane, chlorinated solvents, lead and arsenic with conventional technologies. Many municipalities have added membrane separation technology to their plants. In the U. S. RO for brackish water desalination and NF for membrane softening and disinfection by-product(DBP) removal are the major applications. In Europe, microfiltration(MF) and ultrafiltration(UF) have been adopted in several plants to produce potable water from surface water supply.

3. Membrane Roles in Potable Water Treatment

Several membrane technologies exist as shown in Fig. 1. There are four general categories of crossflow membrane filtration : MF, UF, NF, and RO [4]. MF removes particles in the range of approximately 0.1 to 1 micron. In general, suspended particles and large colloids are rejected while macromolecules and dissolved solids pass through the MF membrane. Applications include removal of bacteria, flocculated materials, or TSS (total suspended solids). UF provides macromolecular separation for substances in the 20 to 1000 Angstrom range (up

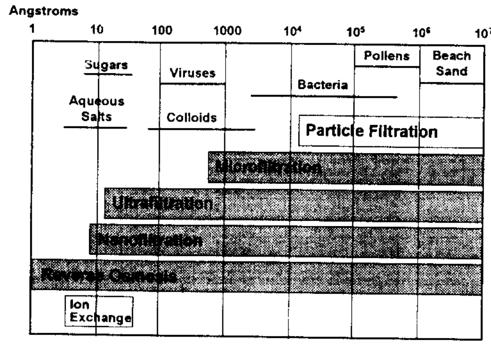

Fig. 1. Filtration spectrum.

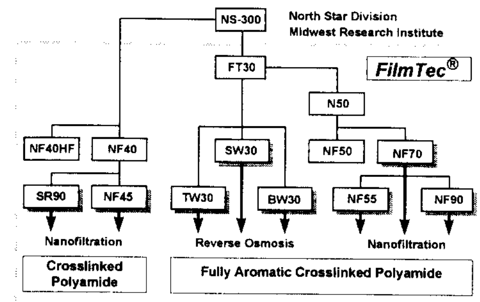

Fig. 2. Filmtec® RO/NF elements.

to 0.1 micron). All dissolved salts and smaller molecules pass through the membrane. Most UF membranes have molecular weight cut-off values between 1,000 and 100,000. RO is the finest level of filtration currently available. The RO membrane acts as a barrier to all dissolved salts and organic molecules with a molecular weight greater than approximately 100. NF is a pressure-driven membrane process with a wide range of performance characteristics between RO and UF. NF membranes offer high rejection of salts of divalent anions as well as organics having a molecular weight above 200.

FilmTec Corporation, a wholly subsidiary of The Dow Chemical Company, has offered a wide variety of spiral wound RO and NF elements to the markets. Typical RO/NF elements are shown in Fig. 2 with some chronological highlights. The FILMTEC® FT30 membrane is made of a thin-film composite which consists of three layers : an ultra-thin poly-

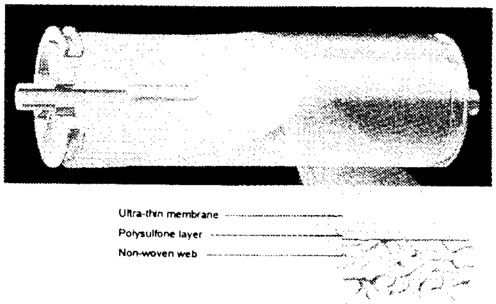

Fig. 3. Filmtec* spiral wound RO/NF elements.

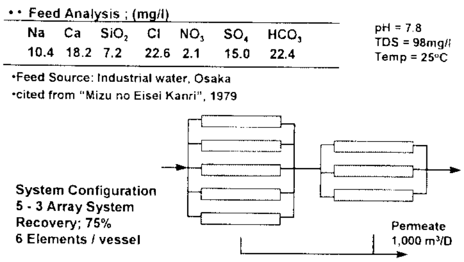

Fig. 4. 1,000m³/D capacity model system for ROSA calculation.

amide barrier layer on top, a microporous polysulfone interlayer, and a non-woven polyester web (Fig. 3). FILMTEC R FT30 membrane is classified in different types of elements, each selected and optimized with respect to the application and the needed conditions for it. Basically four types RO and four types NF elements are currently available :

- TW30-typically used for tap water
- BW30-typically used for brackish water
- SW30-typically used for sea water
- SW30HR-typically used for sea water with higher rejection
- NF55, 70, 90-typically used for municipal water application
- NF45-typically used for food and pharmaceutical application

Depending on the product water requirements, an appropriate element can be selected. It might be also possible to combine these elements to produce the desired TDS water. To better illustrate the di

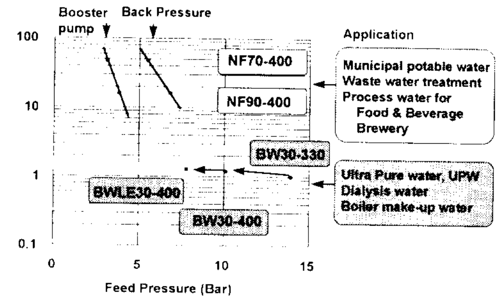

Fig. 5. RO/NF performance prediction by FlimTec ROSA.

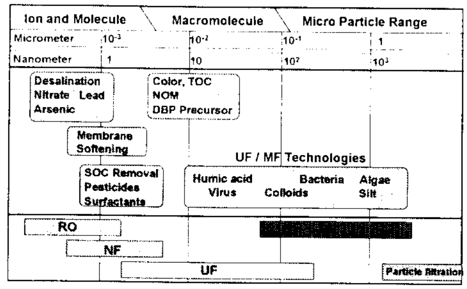

Fig. 6. Membrane role in municipal water treatment.

fference between RO and NF, a model system treating relatively low TDS water (ca. 100mg/ℓ) will be evaluated. Feed water quality and a system configuration having a 5-3 array is shown in Fig. 4. In calculating system performance, FILMTEC RO System Analysis (ROSA) was used. As can be seen in Fig. 5, the BW elements give the better TDS rejection and are considered to be suitable for ultra pure water production in the semiconductor industry and also brackish water desalination in municipal application. For NF elements, the required operating pressure is much lower than that of RO and the elements are typically applied to applications where high salt rejection is not required such as municipal water supply and process water in food & beverage.

Membrane roles in municipal water supply is summarised in Fig. 6. Feed water supply contains a wide variety of contaminants which have to be removed. MF/UF can remove macromolecules and micro particles which include humic substances and

Table 2. Inorganic Removal by Point-of-Use RO

Chemical Contaminant	Influent Concentration mg/L	Rejection %	Chemical Contaminant	Influent Concentration mg/L	Rejection %
Be	0.043	>97.7	Cu	4.81	>98.0
Hg(I)	0.017	>97.1	As^{3+}	0.101	73.3
Se^{6+}	0.083	>94.0	Zn^{2+}	5.42	>99.0
Se^{4+}	0.075	>99.3	Ni	0.239	>95.0
Pb	0.28	>98.3	U(total)	69.2μg/L	>99.0
F	5.95	98.3	U(total)	182.5μg/L	>99.0
Cd	0.045	>95.6			
Cr^{6+}	0.202	>97.6			
Cr^{3+}	0.19	>97.4			

Point-of-use unit : AquaClear H-82, Culligan International Co., Pressure : 42±2psig(289±14kPa)
K. R. Fox and T. J. Sorg. J. AWWA 79(10) 81 (1987)

harmful ions such as pesticides, nitrate, arsenic, and lead. Recently NF has attracted attention of municipalities due to its broad spectrum of separation capability. NF involves :

- Natural organic matter(NOM) removal
  - Color, TOC, disinfection by-product(DBP) precursor -
- Membrane softening
- Synthetic organic chemicals(SOC) removal

There are many NF plants in the U. S., mainly Florida, as indicated in Table 4. Also, a large drinking water supply company in France has been conducting a large scale pilot trial to install 140,000m^3/D NF capacity in Mery-sur-Oise[5]. In Japan the Water Purification Process Association conducted the national project, so called "MAC21", from Fiscal Year(FY) 1991 through 1993 under the direction of the Ministry of Health and Welfare. As a result of the project, guidelines for the introduction of a membrane filtration facility in a small-scale water supply were generated. The second phase of the project started from FY 1994 in Japan. In this project NF has been playing an important role.

4. RO Roles in Potable Water Treatment

In the U. S. many brackish and seawater desalination plants are installed and operated by Municipalities. It was reported in 1992 that the installed and operated by Municipalities. It was reported in 1992 that the installed capacity of brackish water and seawater desalination was 80 million gallon per day(MGD) and 20MGD, respectively[6]. Thus RO can be considered to be a well established technology. For several inorganic contaminants EPA determined that RO is a Best Available Technologies (BATs)[7].

4. 1. Home Tap Water Purification Systems

The Demand for home tap drinking water system (point-of-use, POU) will continue to grow significantly in many countries throughout Pacific. Many types of tap water purification systems exist, which include activated carbon(AC) alone, AC with RO, AC with MF/UF, and etc. There are advantages and disadvantages for each system. Customers should select an appropriate system based upon their concerned contaminant removal potential such as hardness, heavy metals, trihalomethane(THM), chlorine, and odor. Among those, an RO system can be considered to be the finest filter and can remove many contaminants from tap water. Inorganic removal capabilities of POU RO system are shown in Table 2[8]. Very high rejections were obtained. There have been also many research works regar-

Table 3. City of Tustin Nitrate Removal RO Plant Design Basis

	Flow Rate (GPM)	TDS mg/l	Silica Mg/l	Sulfate mg/l	NItrate mg/l	pH
1. Well water	2456.5	1510	29.0	220	94	7.5
2. RO feed	1642.6	1393.7	29.0	333.9	94	6.31
3. Feed Train	821.3	1393.7	29.0	333.9	94	6.31
4. RO perm.	694.0	41.0	1.0	5.1	10.8	4.7
5. Blended product	2202	584.0	11.35	84.5	41.6	6.3
6. pH adjusted	2202	590.2	11.35	84.5	41.6	8.1
7. RO conc.	127.3	8972	181.7	2117.6	548.3	7.1
8. Blend water	814	1510	20.0	220	94	7.5

Temperature : 22～23℃

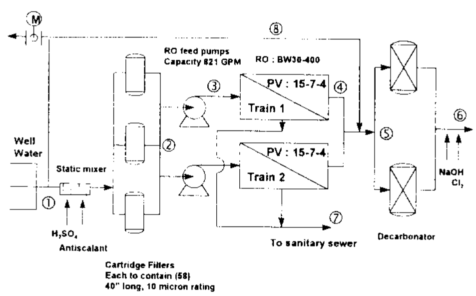

Fig. 7. City of tustin nitrate removal RO plant.

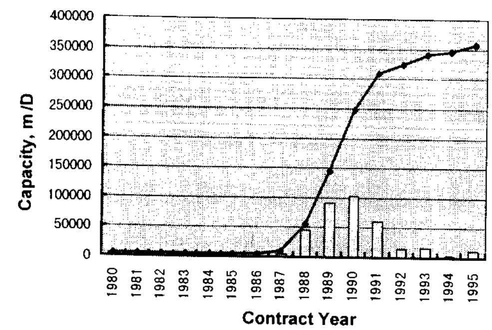

Fig. 8. Membrane softening plants in the U.S.

ding organic and pesticide removal by RO.

4. 2. Nitrate Removal -BW30-400

The much higher nitrate concentrations that have recently been found in ground water is mainly due to the extensive use of artificial fertilizers. Current regulation in the U. S. Safe Drinking Water Act sets the Maximum Contaminant Level(MCL) of 45mg/ℓ as nitrate(10mg/ℓ as nitrogen)[9]. Several techniques to remove nitrate have been evaluated including ion exchange, biological denitrification, and RO.

Recently an actual waterworks plant in the city of Tustin, California, has started in operation based on FilmTec BW30-400 RO elements. Fig. 7 shows the schematic flow diagram of the plant and Table 3 shows the design basis. The plant is capable to produce 7600m^3/D(2 MGD) of RO permeate and 12,000m^3/D(3.2 MGD) of blended product.

5. NF Roles in Potable Water Treatment

Nanofiltration is sometimes referred to as membrane softening. NF membranes can be used for hardness reduction or softening in water sources where the sulfate levels are medium to high. It was said that the idea of membrane softing was first proposed by a Florida based OEM in 1976. However, this membrane technology was not wide spread till 1984 when a three month pilot study proved the effectiveness of NF membrane, designated as N-50. In 1985, this membrane was redesignated NF-50 and labelled as a nanofilm membrane by FilmTec [11]. After flow rates and $MgSo_4$ refection have been improved, it was designated NF-70. Since then, NF-70 has been a typical element in this field. After the extensive research works and pilot tests, the number of municipal water treatment facilities

Table 4. FilmTec NF70/90 Reference List for Use in Potable water Application

Installation	Elemtent	Start-up	Capacity MGD	Capacity m^3/D
Palm Beach Park of Commerce Florida, USA	NF70	1987	0.2	760
City of Sully, Iowa, USA	NF70	1988	0.2	760
City of Wachula, Florida, USA	NF70	1990	0.45	1700
Palm Coast Utilities, Florida	NF70	1992	2.0	7600
City of Chloride, Arkansas, USA	NF70	1993	0.14	530
City of Boynton Beach, Florida	NF70	1993	4.0	15000
Expansion	FN70	1997	4.0	15000
City of Royal Palm Beach, Florida	NF70	1993	1.5	5700
Corkscrew Florida, USA	NF70	1990	0.5	1900
Expansion	NF90	1995	0.5	1900
Expansion	NF90	1996	0.8	3040
City of Miramar, Florida, USA	NF70	1995	4.5	17000
Volusia County, Florida, USA	NF90	1995	0.5	1900
Jarny, France	NF70	1995	0.79	3000
Soiron, France	NF70	1995	0.79	3000
Baja Almanzora, Spain	NF70	1995	3.43	13000
Cooper City, Florida, USA	NF90	1997	3.0	11400

Table 5. RO, NF, UF Membrane Performance : Groundwater Near West Palm Beach, FL

Membrane	Pressure PSIS	Recovery %	THM Precursor		Rejection, % DOC*		Color		TH**	
			AID+	VOG++	AID	VOG	AID	VOG	AID	VOG
BW30	190	60	97		96	98	97	99	96	92
NF70	80	65	96		90	93	97	98	70	67
UF(2000)***	100	80	56		40	57	60	65	13	5

*DOC = Dissolied organic carbon **TH = Total hardness as ppm as $CaCO_3$

***UF = Ultrafileation membrane with nominal MW cutoff 2000(GIO DSI)

+AID = Water Town ACME Improvement District ++VOG = Water Town Village of Golf

Feed water data :

	Temp. ℃	TDS mg/L	THM Precursor mg/L	DOC mg/L	Color CPU	TH ppm as $CaCO_3$
AID	25	490	.961	15	35	332
VOG	25	490	–	14.7	52	246

From Taylor et al. 1987

based on the NF have dramatically increased as shown in Fig. 8. Table 4 shows a partial list of NF70/90 installation in municipal water application. It should be noted that NF70 has been adopted in Europe recently. It is expected that nanofiltration membranes will be used globally for high quality potable water supply.

Another major focus of NF technology is for NOM and SOC removal. NF has proven effective in color, TOC, THM precursor and pesticide removal.

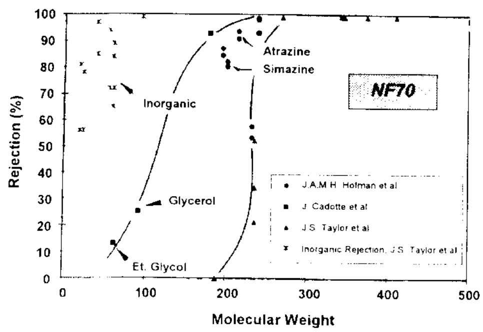

Fig. 9. SOC rejection of NF70.

Such organic removal is critically important in the state of Florida and Europe. Examples of performance of NF70 on Florida groundwater are shown in Table 5. NF70 shows the higher THM precursor rejection with lower operating pressure of 60 psig. As mentioned before, MCLs of pesticide is very low in Europe. Several researchers have evaluated the separation characteristics of NF membranes for these components. In Fig. 9, the rejection of various SOCs are plotted against their molecular weights. It has been proven that NF70 is capable of removing organic substances having a molecular weight of more than 250.

6. Conclusions

In this paper several advantages of RO/NF technologies have been described. However, it should be noted that membrane technology does not solve all the water treatment problems encountered in municipalities. Membranes can provide effective and highly optimized solutions when integrated with conventional technologies such as coagulation, sand filtration, and activated carbon treatments.

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