New High Recovery Membrane Modules for Desalination

Nobuya Fujiwara

TOYOBO Co., Ltd.

2-8, Dojima Hama 2 chome, Kita-ku, Osaka, 530-8230, Japan

ABSTRACT

Desalination by reverse osmosis (RO), which first entered commercial use in the 1970s, was initially mainly used for treating brackish water. Technological progress led to the development of an RO membrane enabling single-pass seawater desalination

Toyobo succeeded in developing a single-pass seawater desalination RO module composed of hollow fiber type membranes made of cellulose triacetate in 1978, and then in 1979 began production of the first commercially available double-element module. This double-element module has many advantages suitable for seawater desalination. It has high chlorine tolerance and high salt rejection, derived from the properties of the membrane material, and it is highly resistant to fouling and scaling matters due to the unique flow pattern and fiber bundle configuration. These advantages help to explain why the Toyobo double-element module has been used so successfully at the many seawater desalination plants around the world.

Since the 1980s, large plants capable of desalinating several tens of thousands of cubic meters a day have sprung up around the Mediterranean and in the Middle East. The Jeddah RO Phase I Plant, which has a capacity of 56,800m^3/day, went into operation in 1989. In 1994, the same sized Phase II Plant came on stream, giving the plant a huge total capacity of 113,600m^3/day. The plant constructor Mitsubishi Heavy Industries, Ltd. (MHI), and the RO membrane manufacturer Toyobo Co., Ltd. In 1998, the world's largest RO seawater desalination plant in operation, which has a capacity of 128,000m^3/day and is run by Saudi Arabia's Saline Water Conversion Corporation (SWCC), went into operation at Yanbu. RO seawater desalination technology has thus already reached the stage of full-scale commercial use. In order to encourage its wider use, however, RO desalination needs to be made more economical by lowering construction and water treatment costs.

Toyobo has therefore developed a new economical RO desalination system by a recovery ratio of 60% using a high-pressure module with a high product flow rate. In 2000, Toyobo high recovery membrane module was selected for the largest seawater desalination plant in Japan, which has a capacity of 50,000m^3/day.

INTRODUCTION

Membrane Material

The hollow fiber membrane in a double-element module is made of cellulose triacetate (CTA). The main advantage of the CTA membrane over polyamide-based membranes is its superior resistance to chlorine. This feature makes it possible to disinfect, intermittently or continuously, the entire seawater desalination plant system and RO modules with a powerful agent. This prevents formation of slime and biofouling in the modules. Because seawater contains generally many micro-organisms and organic substances, being able to use chlorine to disinfect the modules makes plant operation and maintenance much easier and reliable.

Fiber bundle confguration

Fig. 1 is a microscopic photograph of the hollow fiber. The hollow fibers are arranged in a cross style as shown in Fig. 2, making it possible to give a large space between the hollow fibers. This large space produces lower pressure loss and provides superior resistance to fouling mattes.

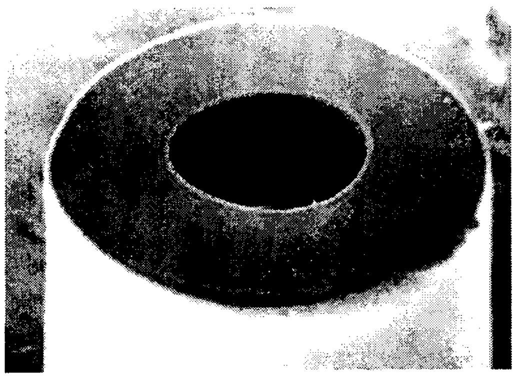


Fig.1 Hollow fiber

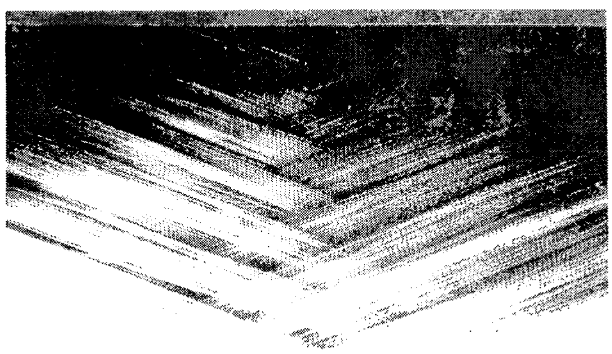


Fig.2 Cross arranged hollow fibers

OPERATION RESULT OF LARGE SCALE SEAWATER RO PLANT

Jeddah 1 Phase II plant

Phase II Plant came into operation in 1994 with a product flow rate of 15MGPD (56,800m^3/day). The flow sheet is shown in Fig. 3. The filters are fine sand and anthracite single-pass dual media filters. Sodium bisulfite (SBS) is injected intermittently in the wake of the micro cartridge filters, accordingly chlorine is injected into the modules intermittently.

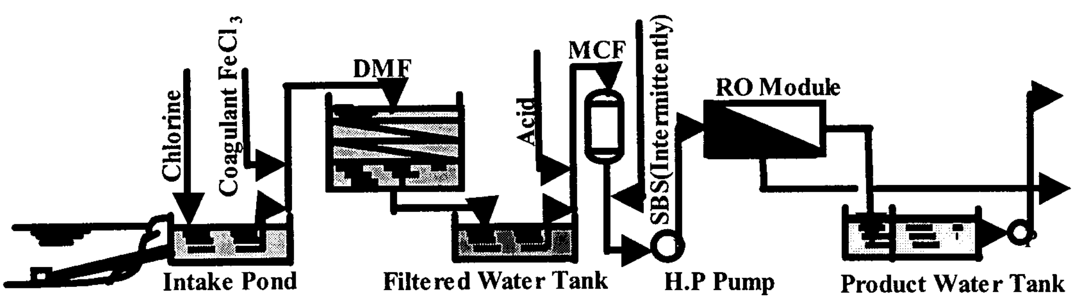


Fig 3 Flow Sheet

This plant is of crucial importance to Jeddah, which is prone to water shortages, and, barring times when the feed seawater is polluted and SDI exceeds 4.5, it operates continuously at 99% capacity. It is important to note that the membrane has not been replaced at all in the five years since the plant went into operation.

Operating conditions

Feed seawater TDS is 43,300mg/l and recovery ratio is 35%. Operating pressure and temperature are shown in Fig.4. Temperature varied between a minimum of 24°C and a maximum of 34°C. Maximum pressure during the winter when temperature was lowest was in the region of 64kg/cm^{2}G which was substantially below the maximum operating pressure of 70kg/cm^{2}G.

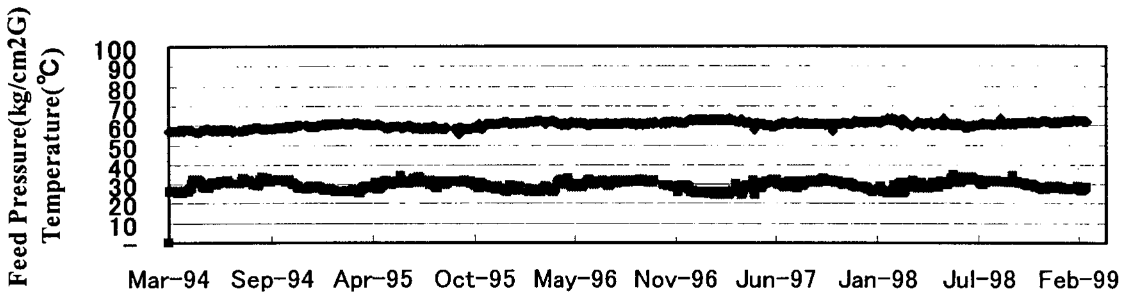


Fig.4 Operating pressure and temperature

Changes in differential pressure

Differential pressure was stable at Phase II Plant (Fig.5), and it was found that periodic cleaning with citric acid once a year reduced differential pressure to almost what it was to start with. It was confirmed that biofouling did not occur.

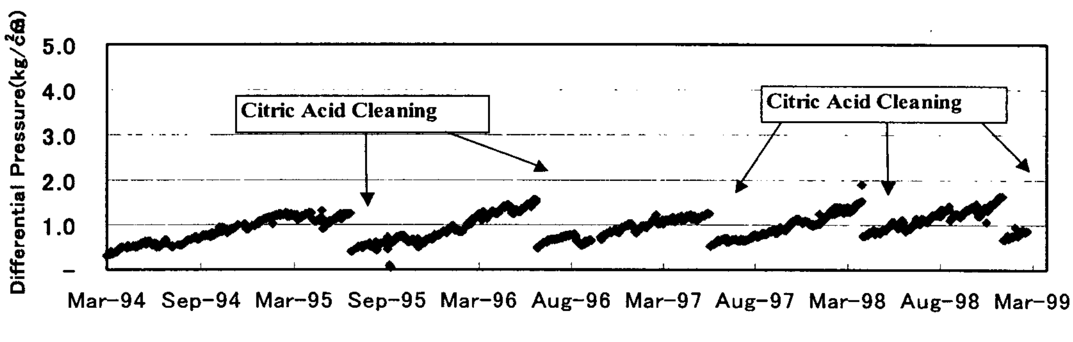


Fig. 5 Differential pressure

Product flow rate

Changes in the product flow rate are shown in Fig.6. The product flow rate remained stable at the rated 56,800m^3/day throughout the entire period. As is evident from the diagram, all 10 trains at the plant were in virtually continuous operation.

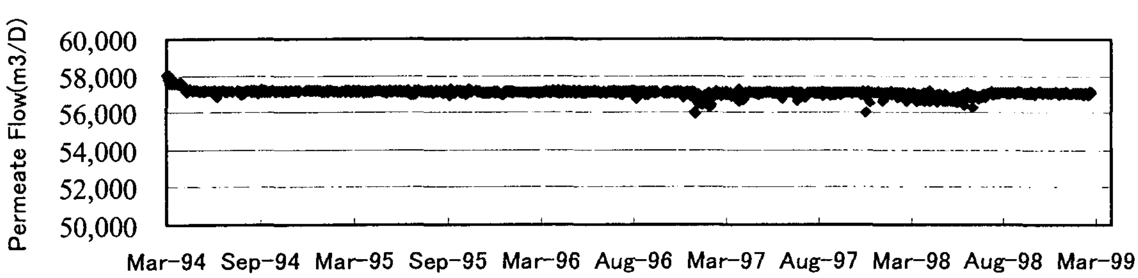


Fig.6 Product Flow Rate

Product quality

Product TDS is shown in Fig. 7. Product TDS stayed below 500mg/l without the membrane being replaced at all in five years, which is highly satisfactory.

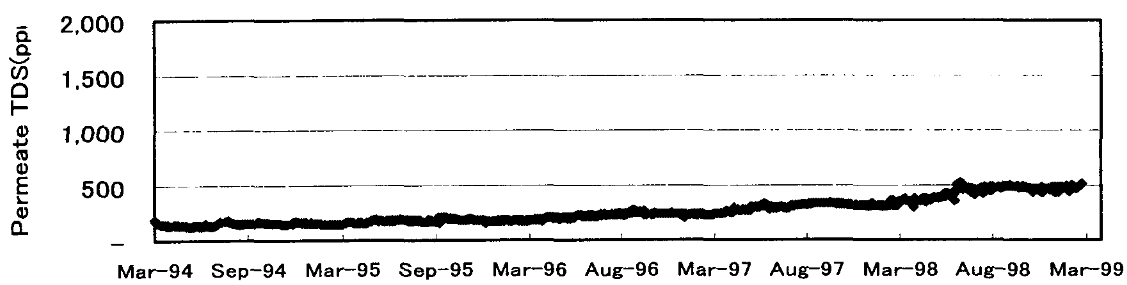


Fig.7 Product TDS

HIGH-EFFICIENCY TECHNOLOGY

High-efficiency operation

The RO seawater desalination plants in commercial use are normally set to run with a recovery ratio (i.e. product water flow rate as a proportion of the feed seawater flow rate) of 40~45%. In areas such as the Middle East where seawater is highly concentrated, the recovery ratio is around 35%. Feed seawater is generally pretreated by sterilizing, reducing turbidity and controlling pH; discharging the 60~65% that is not recovered thus represents a waste of cost.

High-efficiency seawater desalination technology provides a means of reducing the feed seawater flow rate and brine flow rate by raising the recovery ratio. This as a result improves economical efficiency by reducing the need for pretreatment facilities, power sources and chemicals.

Osmotic pressure in the case of ordinary seawater is approximately 2.6MPa. If the recovery ratio is 40%, the osmotic pressure is around 3.4MPa on the average in the module. This figure reaches 4.3MPa in brine. As the osmotic pressure increases to around 4.4MPa on the average, and about 6.2MPa in brine, if the recovery ratio is raised to 60%, a higher feed pressure than in the past is required in order to obtain product water efficiently (Fig. 8). High-efficiency operation therefore necessitates use of a high-pressure RO module.
What is therefore required is a pressure-resistant module comprising a membrane material and elements that are highly resistant to fouling, which is what causes scaling.

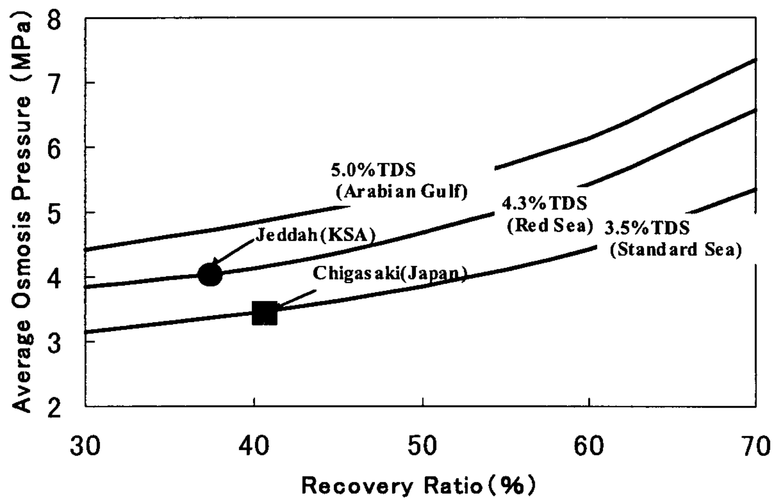


Fig.8 Average osmotic pressure as a function of recovery ratio

DEVELOPMENT OF HIGH-PRESSURE AND HIGH PRODUCT FLOW MODULE

Toyobo's highly reliable hollow fiber RO modules are widely used throughout the world. The high-pressure high-flux HB-series module it has developed is an improved version of a highly reliable, conventional type of module made using the same materials, and preserves the conventional development concept and optimum design. The hollow fiber RO membrane module's hollow fiber membrane itself has outstanding pressure resistance retention, and the fine hollow fiber design and selection of suitable dimensions provide high pressure resistance. In addition, optimization of manufacturing conditions (hollow-fiber spinning technology using high concentrations of polymers, micro-pore control technology for manufacturing membranes, and after-treatment by high-temperature heat treatment) has made it possible to increase the water permeability of the hollow fiber membrane itself.

The new high-pressure high product flow rate module is as durable as a conventional module and has better pressure resistance and water permeability (Table 1).

Table 1 Specification of new module

		New Model		Conventional
Model		HB9155	HB10255	HM10255
Flow Rate	(m^3/D)	16	65	45
Salt Rejection*1	(%)	99.4	99.4	99.4
Number of Elements		1	2	2
Test Conditions				
NaCl Solution	(mg/L)	35,000		35,000
Pressure	(MPa)	5.5		5.5
Temperature	(℃)	25		25
Recovery Ratio	(%)	30		30
Operating Conditions				
Pressure	(MPa)	8.4		7.0
Max Fouling Index	(−)	4		4
Temperature	(℃)	40		40
Residual Chlorine*2	(mg/L)	1.0		1.0

*1:Salt Rejection=(1 −salt concentration in product water/salt concentration in feed water)x100)
*2:Residual Chlorine is limited by the feed water quality

HIGH EFFICIENCY SEAWATER DESALINATION PROCESS

High-pressure single-pass method

As use of a high-pressure high-flux module permits high-pressure operation, a high recovery ratio can be adopted. Toyobo conducted technical studies of high-pressure single-pass desalination with a 60% recovery ratio and 8.4MPa feed pressure in basis of around 3.5% seawater. The single-pass method is a simple, process with a proven track record offering easy and reliable control of operation. A feed pressure of 8.4MPa was used, this being a tried and tested pressure. As shown in Fig.9, high recovery ratio operation can reduce feed flow rate around 30% compared to the conventional system. It makes it possible to reduce construction and running cost of pretreatment system. In addition, energy of high pressure brine is recovered efficiently by energy recovery turbine, therefore, energy consumption will be saved compared to conventional system.

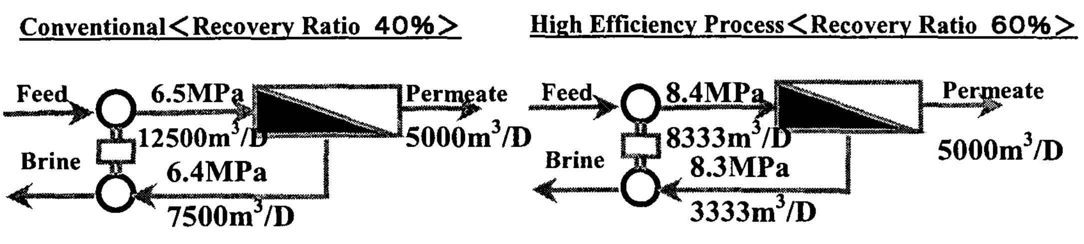


Fig.9 Comparison between conventional and high efficiency process (in case of 5000m^3/day)

Due to the large membrane area per module and the low water permeability per membrane area, there is no particularly heavy burden on the surface of the module's membrane even when the high-pressure single-pass method is used with a high recovery ratio. This was confirmed by simulation calculations for analyzing module performance.

Simulation results of one plus one reject series for a large plant are show in Fig.10. It can be found that concentration polarization factor(ϕ) is similar to the conventional system. Consequently, it is confirmed that seawater is not concentrated abnormally on the membrane surface at the recovery ratio of 60%.

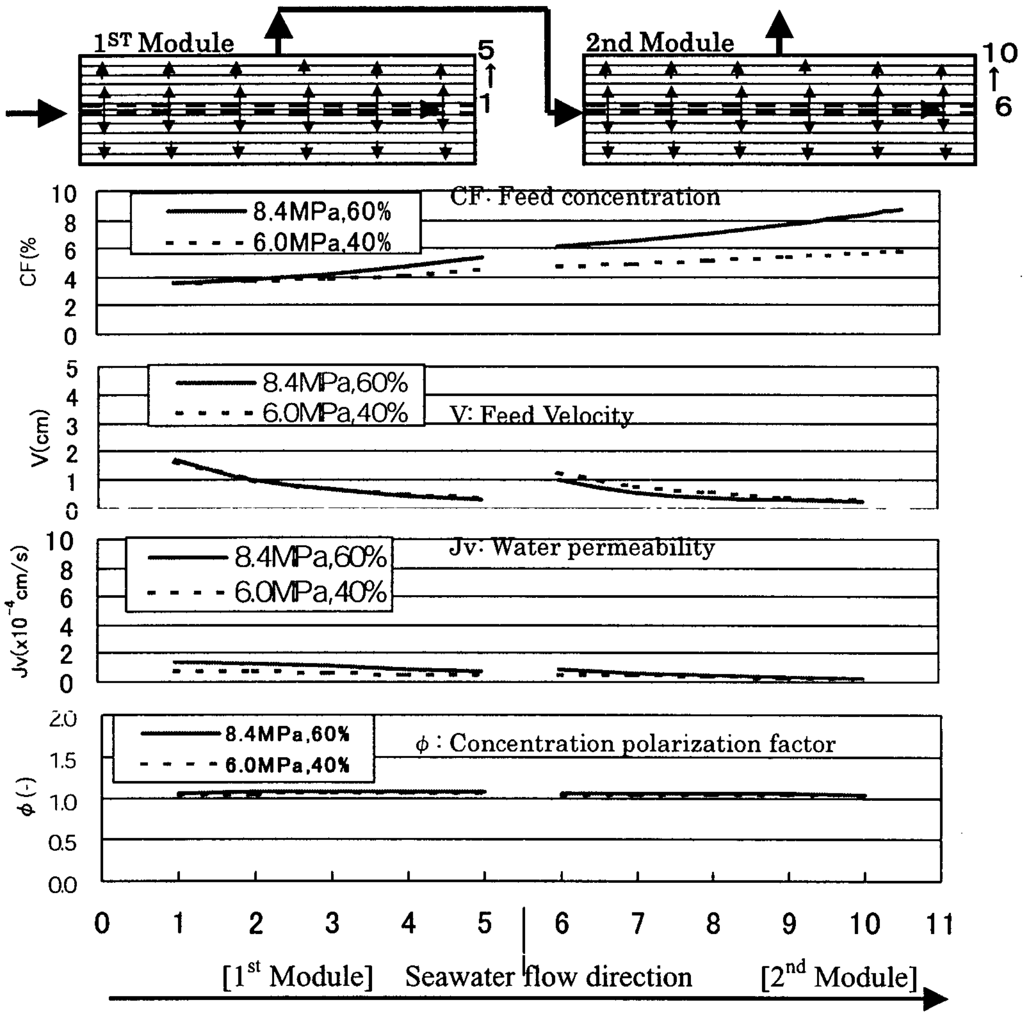
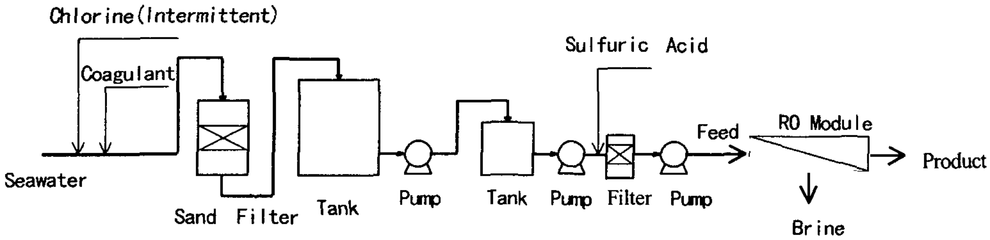
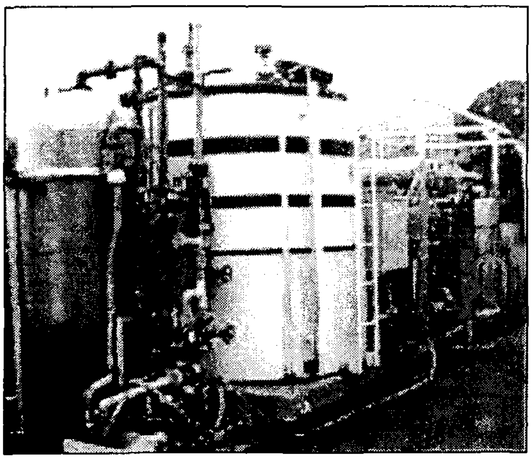


Fig.10 Profile in the modules

LONG TERM TEST OF THE HIGH-EFFICIENCY DESALINATION RO PROCESS

Long-term test of the high-efficiency seawater desalination RO process using a high-pressure high-flux module was conducted at Toyobo's coastal Iwakuni Membrane Plant (Fig. 11). Operating conditions were as follows:





Specification	
RO Module	: HB9155 × 1 Element
Capacity	: $20m^3/D$
Pressure	: 8.4MPa
Recovery Ratio	: 60%
Product quality	(mg/l)
TDS	: 116
Chloride ion	: 67
Boron	: 1.38
THM	
$CHCl_3$	: <0.001
$CHCl_2Br$	: <0.001
$CHClBr_2$	: <0.001
$CH Br_3$	: <0.001
Total THM	: <0.001
THM-FP	: <0.001

Fig.11 Test plant of new economical process(Iakuni $20m^3$/day)

Fig. 12 shows the changes in feed pressure, recovery ratio and temperature. During operation, feed pressure and recovery ratio remained steady at the level at which they were set. Fig. 13 shows the product flow rate, product quality. The stable flow rate confirmed that the membrane's pressure resistance was sufficient for actual use. Product TDS was also satisfactory and stable, and it was confirmed that even with a 60% recovery ratio, the salt rejection remained good enough to produce drinking water

Differential pressure was also low and stable during the test period without chemical cleaning. It was thus confirmed that the scaling did not occur at the recovery ratio of 60%, and it was demonstrated that no drift occurred in the module and there were no abnormal concentrations of seawater in the module. As differential pressure did not rise, no biofouling occurred, and it was thus confirmed that intermittent injection of chlorine 30 minutes per day provided sufficient sterilizing power.

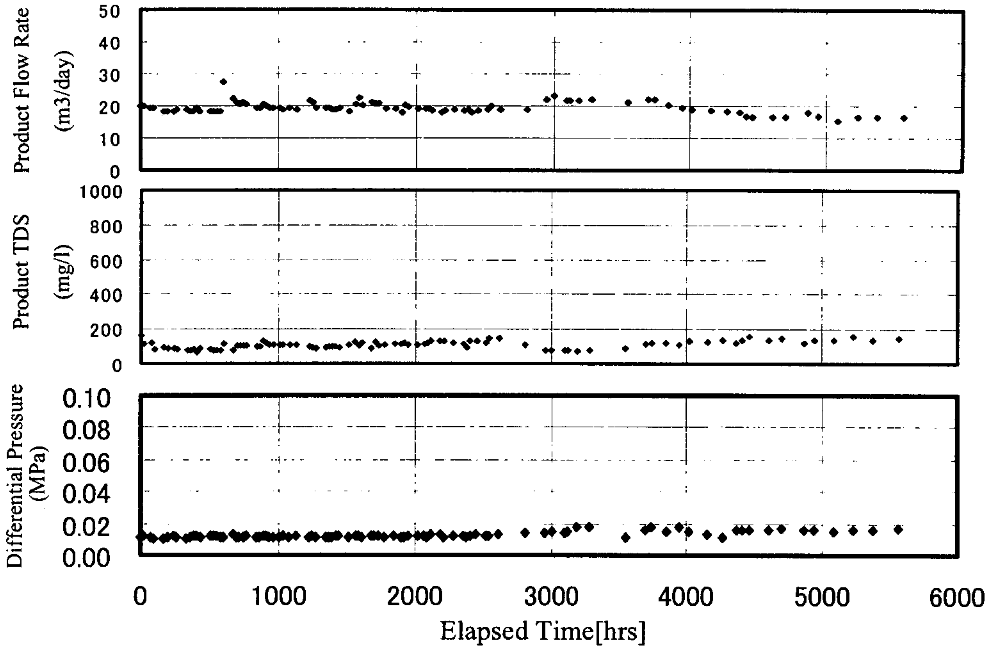


Fig.12 Operating conditions of test plant

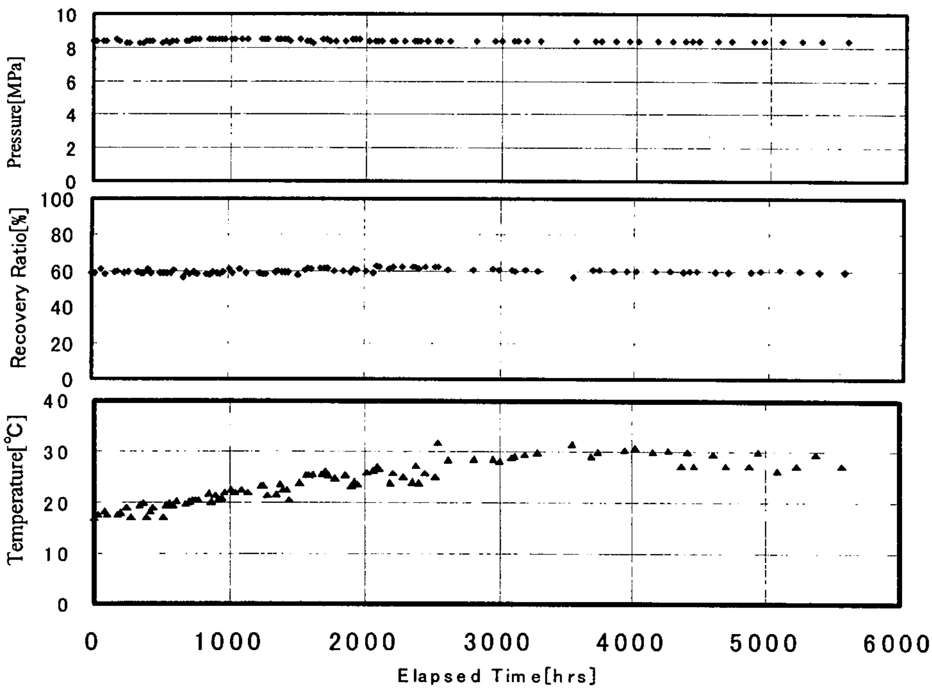


Fig.13 Performance results of test plant

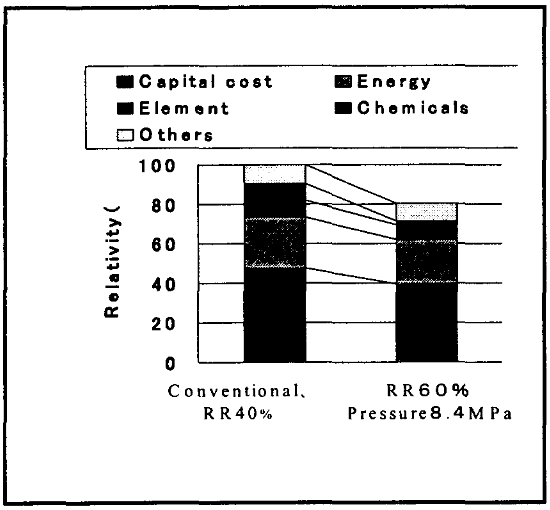
CONCLUSION

(1) Single-pass desalination with a recovery ratio of 60% using Toyobo's pressure, fouling and biofouling resistant RO module was found to be simple and reliable. The method's superiority was proved in tests.

(2) Direct sterilization of the module by Intermittent Chlorine Injection (ICI) prevented biofouling. Generation of toxic by-products such as trihalomethane was also reduced and sea pollution prevented.

(3) As Fig. 14 shows, the high recovery RO method cut the cost of treating water by 20%.

(4) Toyobo high recovery membrane module was selected for the largest seawater desalination plant in Japan, which has a capacity of 50,000m^3/day.



Precondition

Availability	:90%
Period	:20years
Interest	:4.8%
Annual Replacement	:20%
Energy Recovery	

Chemical Cost(US$/kg)

$FeCl_3$(38%)	:0.18
H_2SO_4(98%)	:0.36
SBS (35%)	:0.40
Lime	:0.22
NaClO(10%)	:0.25

Fig. 14 Cost Comparison

REFERENCE

[1] Fujiwara, N. et al.: Desalination,96, p441(1994)

[1] Fujiwara, N. et al.: IDA Conference, San Diego, Vol.3, p89(1999)

[2] Fujiwara, N. et al.: IDA Conference, San Diego, Vol.3, p101(1999)