Recent Development Trends in High Efficiency RO Desalination Systems

Masahiko Nagai
Chemical Laboratory, Nagasaki Research & Development Center
Mitsubishi Heavy Industries, Ltd.
5-717-1, Fukahori-machi, Nagasaki 851-0392, Japan
Tel. 81-985-834-2160, Fax. 81-95-834-2165
E-Mail; mnagai@ngsrdc.mhi.co.jp

1. Introduction

For usual reverse osmosis seawater desalination system, the input pressure of 5.5-6.5 MPa and the recovery ratio of 35-40% used to be adopted from the viewpoint of pressure resistance of membrane and prevention of scale deposition. For example, this level was applied to the demonstration test performed from 1979 by Water Reuse & Promotion Center (1) and the desalination plant constructed in Okinawa with 40,000 m^3/d of the largest capacity in Japan (2).

Recently, however, making it high-pressure & high-recovery has been studied and proposed, aiming at saving energy, by Ohya and other people with the advance of recovery technology for concentrated seawater energy, the improvement in pressure resistance of membrane and the investigation of scale deposition mechanism (3). In correspondence to this, every Japanese RO membrane maker is proceeding with development of high-pressure-resistant membrane and its demonstration test (4)(5)(6). Kamishima introduces these items as topics in the Bulletin of the Society of Sea Water Science, Japan (7). Meanwhile, a plan has been made to introduce the highest recovery of 60% into a 50,000m^3/d plant in Fukuoka district.

A high recovery plant by high pressure, however, has just a little experience, so there are many subjects to further study in the future as well. One of them is to compare and evaluate the systems diversified due to high-recovery tendency. For example, some new systems not having existed before such as concentrated seawater two-stage pressurizing system and energy recovery system by turbocharger (8) have been developed and are progressing toward practice from the energy-saving viewpoint. Every engineering firm is required to evaluate these systems and select the best one in response to the customer needs. From this viewpoint, this article introduces the high recovery desalination systems under current consideration and describes the evaluation technique and the subjects to solve. And the information of high recovery and high efficiency plants and the energy recovery system will be also described.

2. High Recovery Seawater Desalination System

The usual system with a recovery ratio of 35-40% can be grouped into the following 3 systems from energy recovery type: Fig 1 (a) shows a single-stage system without energy recovery; Fig 1 (b) shows a single-stage single-shaft system with single-shaft connection of energy recovery turbine, pump and motor; and Fig 1 (c) shows a single-stage two-shaft system of two-stage pressuring method with single-shaft connection of energy recovery turbine and second-stage pump only.

For energy recovery turbine there is used, for example, a brand name "Turbo" put on the market by American firm PEI. Besides the Turbo, there have been developed various types such as Pelton wheel type and piston driven type. These single-stage systems can recover the energy of brine, but cannot recover the pressure loss due to membrane permeation, which results in energy loss as it is. The amount of this loss becomes as large as to unable to neglect in case of high pressure. To reduce this energy loss of permeated water a concentrated water two-stage pressurizing system has been proposed [*4]. This system, as shown in Fig 2 (a), obtains the permeated water under low pressure at the first stage and further recovers the permeated water by pressurizing the volume-decreased concentrated water by pump so as to achieve a high recovery ratio.

There are two types in this system, one is a type of recovering energy by the first-stage low pressure pump shown in Fig 2 (a), and the other is a type of recovering energy by the second-stage high pressure pump shown in Fig 2 (b). Meanwhile, in many large-scale plants there are arranged several pumps in a row from the actual results of pump capacity; in the world-largest plant there are arranged 15 sets of pumps in a row. As plant formation there are a system with recovery turbine, RO modules and other components installed as an independent unit for every pump (Fig 3 (a)) and a system with some pumps and RO modules connected as a common block by common piping (Fig 3 (b)).

3. Evaluation Method of Each System

In selecting a system suitable for the plant conditions from various high recovery systems, it is required to set and study several evaluation items. Among them the construction cost including pretreatment and the installation area of the whole plant are dependent on the total recovery ratio itself and do not largely vary with the system. Accordingly, qualitative evaluation has been performed for several items directly related to the system such as energy consumption (power unit requirement), operation cost including membrane replacement cost and controllability and reliability corresponding to seawater temperature change.

3.1 Energy consumption (power unit requirement)

Energy necessary for reverse osmosis desalination is the sum of the following 3 items, namely a. mechanical loss, b. flow loss and c. permeated water loss. Mechanical loss is the loss of pump, turbine and motor, and depends on the efficiency of each equipment. Flow loss is the loss caused inside piping, valves and modules; among them control valve loss gets considerably large dependent on margin of each equipment such as pump. Permeated water loss is the loss of energy held by the pressurized seawater of equivalent quantity to permeated water quantity, which can be said to be the loss specific to the reverse osmosis system. Fig 4 shows the calculation example of these losses. Case 1 is an example at a large-scale plant with a recovery ratio of 35% and the maximum RO inlet pressure of 7.0 MPa; flow loss necessary for control is large due to a certain margin having been given to pumps and other equipment in view of the membrane reliability. Case 2 and Case 3 show the calculation results for single-stage pressurizing system and two-stage pressurizing system with a high recovery ratio of 60% respectively. In both Cases mechanical loss lowers with improvement of the recovery ratio; flow loss largely lowers with the optimum design. Permeated water loss is roughly proportional to the RO inlet pressure in per unit volume of the permeated water, but has no relation to the recovery ratio. The mean inlet pressure in two-stage system found under the Fig 4 conditions amounts to 7.17 MPa, which has resulted in saving by the difference between 7.8 MPa. However, in two-stage system the pressure loss of piping and module amounts to almost double compared with single-stage and increases the control loss, so the advantage decreases by this portion. Thus, there is merely a slight difference in power unit requirement between Case 2 and Case 3; there will be rather a large influence by efficiency of the equipment such as pumps.

3.2 Membrane area and replacement cost

When the average pressure at RO inlet lowers, energy consumption decreases, but to the contrary necessary membrane area increases. Fig 5 qualitatively shows the relation between operation cost and RO inlet pressure per unit permeated water quantity keeping the recovery ratio constant. In Fig 5 the power cost increases in proportion to the pressure, but to the contrary the membrane replacement cost decreases almost in inverse proportion to the pressure, so there will be the optimum value in the sum of these two costs.

3.3 Adaptability to temperature change

In the high recovery ratio, the mean salinity in module increases, so the quality of the permeated water deteriorates. Especially in summer, with water temperature rise the salt permeation quantity through the membrane increases, but the total quantity of product water is kept almost constant dependent on the supply capacity of the raw seawater and the like, so the salinity increases and sometimes exceeds the limit. When the temperature rises, the permeated water quantity increases under the same pressure as well, so a problem can be avoided by decreasing the membrane area so as to obtain the permeated water quantity corresponding to the permeated salt quantity per unit membrane area. Therefore, in addition to usual pressure and flow control, membrane control has become a primary control factor in quality assurance; the degree of difficulty in membrane area control has become a factor of the system evaluation. As shown in Fig 3 (b), the system commonly connected as a block by common piping can increase and decrease the membrane area even during operation and so is more advantageous at this point than other systems.

3.4 Reliability

In high recovery system the pressure rises from usual 7.0 MPa to 8-9 MPa, which stays at such a level as to cause no problem in hardware such as pump; the most important point of reliability is a long-term deterioration of the membrane. As the primary factors thereof, there are acceleration of membrane compaction due to operation pressure increase, fouling increase due to high flux (especially lead element), scale deposition such as gypsum due to high concentration and the like. From this viewpoint, the two-stage pressurizing system is composed of the same components as those of the usual system at the first stage and of an unverified part only at the second stage, so it can be said that there is a smaller scope to demonstrate compared with the single-stage high recovery system. The problem except for scale deposition can be addressed by a forecast on the short-term operation results, washing frequency and so on. Meanwhile, it has been proved that no gypsum deposition is caused when the system is operated under the pressure below the osmotic pressure corresponding to deposition limit concentration at each temperature, as the limit concentration shows in Fig 6. To the contrary, above this pressure, there is the possibility of scale deposition not only around the outlet of high concentration, but also at the inlet part if there is stagnation in the flow and the like. Since the stagnation around the membrane surface cannot be avoided completely, it is required to pay full attention to selection of operating conditions.

4. Subjects in High Recovery System

Thus far the high recovery system and its evaluation have been described. This technology is a proposition from Japan toward the world. The lead has already been taken in the technological development, but there has been still left a lot of outstanding subjects, so even greater efforts are required for development in the future. The future subjects will be simply touched on.

4.1 Calculation technique of membrane performance

If the usual arithmetical mean of the salinity is used for calculation of the necessary membrane area, analysis of the operation results and the like, there will cause an error due to high recovery ratio. The concentration polarization or other phenomena have a great influence under a high concentration, so a simple and accurate calculation technique is required [9].

4.2 Investigation of scale deposition concentration limit such as gypsum

The high pressure shall be inevitably applied in order to obtain the high recovery ratio, however, it is safe unless such pressure exceeds the pressure corresponding to the above scale deposition limit concentration. As for a practical pressure limit, there is the possibility that much higher value can be adopted due to super saturation phenomenon of gypsum scale; however, this point shall be verified in the future.

4.3 Verification of long-term stable operation of membrane

The largest technical subject in RO system consists in the stable operation of the membrane, namely the stability of membrane replacement rate, which shall be verified over a long time.

5. Example of High Recovery and High Efficiency Plants

50,000m^3/day seawater desalination Plant is under construction in Fukuoka Area. The Flow Sheet of this plant is shown in Fig.7 The recovery ratio of this plant is 60%. In this plant, TOYOBO hollow fiber membrane is used for the first high-pressure stage and Nitto-Denko spiral membrane for second low-pressure stage. This plant will start in 2005.

A lot of plants which recovery ratio are more than 40% are operating in the world now. The first plant with high recovery ratio started in 1996 by Toray in their factory. Toray's system, BCS (Brine Conversion Two-Stages RO Seawater Desalination System) is the brine pressurized system with hydraulic turbocharger. And their system can be applied to the conventional system. (10),(11)

Nitto-denko also has been tested on high recovery SWRO system in Okinawa Island. Flow Sheet is show in Fig.8.(12) UF filtration system is used as pretreatment in this system.

Redondo (13) shows other type of high efficiency process. The concept of this system is based upon two RO passes, the first one through a regular SWRO system (i.e., not high rejection) to produce a permeate with 700 to 1100 ppm, which will be entirely used as feed to second pass, which uses "low-energy" brackish water membranes and is able to produce a second pass permeate with a TDS in the order of 50 ppm, operating at high recovery ratio. Comparing with conventional two-pass process, power consumption decreased about 20%.

6. Energy Recovery Systems

Moch and Harris calculated the power consumption of high efficiency RO system with different type of energy recovery devices in six operation conditions. (14) The devices are Francis turbine, impulse turbine (Pelton Wheel), two types of hydraulic turbocharger, pressure exchanger and Work exchanger. From the calculation result, the power consumption will be expected to be lower than 2.5kWh/m^3.

7. Closing Remarks

This article has introduced the outline and the evaluation technique for each high recovery reverse osmosis system for seawater desalination being now in progress of practical use. This technology is expected to be the main current of the future RO system from its advantages such as economics.

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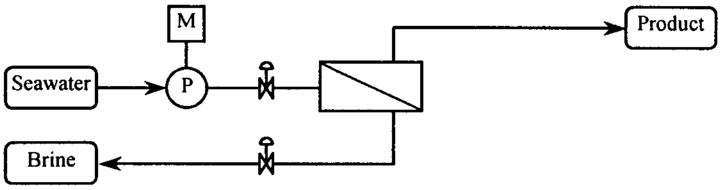
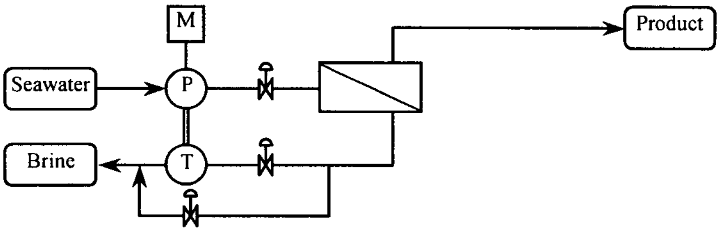
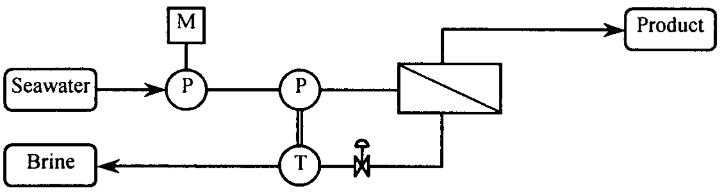


(a) Without Energy Recover

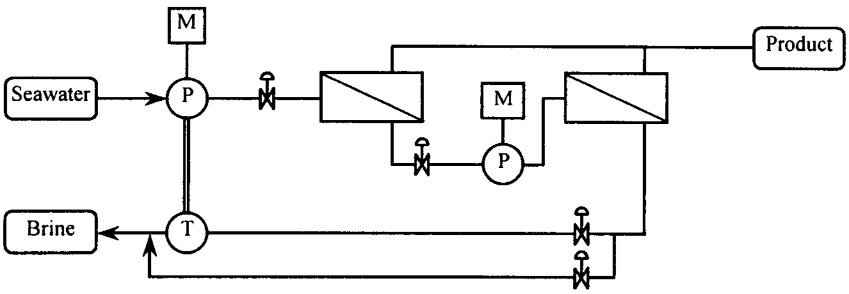


(b) Single-stage Single-shaft Energy Recover

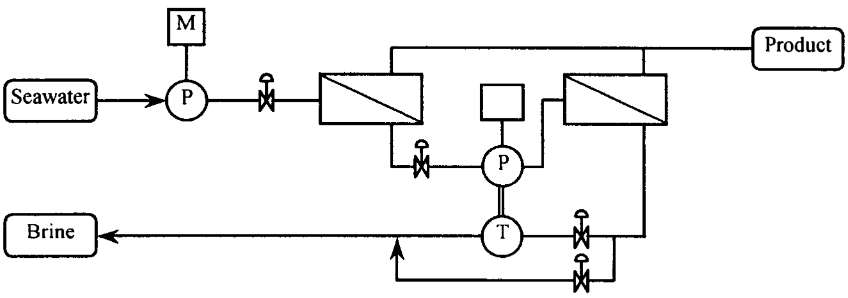


(c) Single-stage Two-shaft Energy Recover

Fig. 1. Single Stage Systems



(a) Energy Recovery by Low Pressure Pump



(b) Energy Recovery by High Pressure Pump

Fig. 2. Brine Pressurizing Two-stage Systems

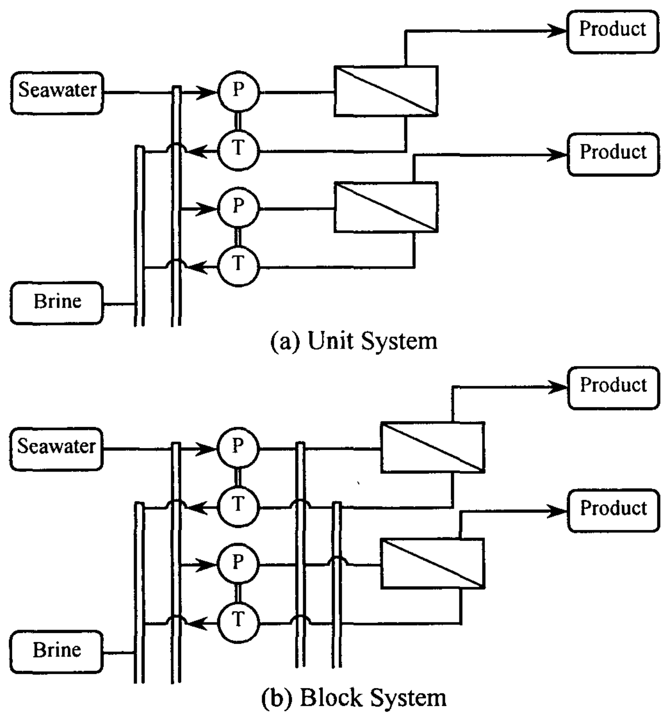
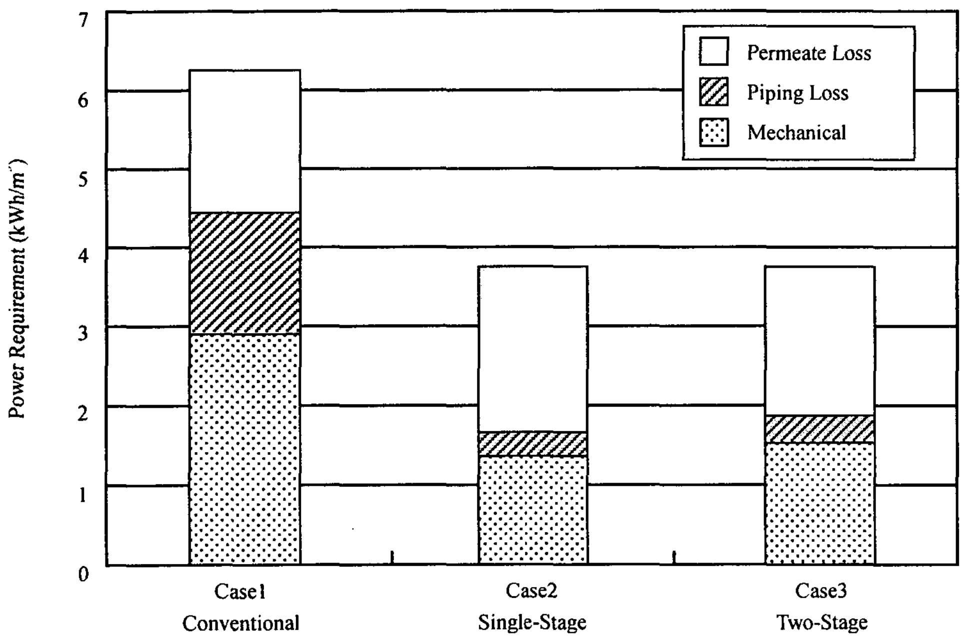


Fig. 3. Unit System and Block System



	Conventional	Single-Stage Pressurizing	Two-Stage Pressurizing	
			1st Stage	2nd Stage
Recovery Ratio (%)	35	60	40	60
Feed Pressure (MPa)	6.5	7.8	6.5	8.5

Fig. 4. Comparison of Power Requirement

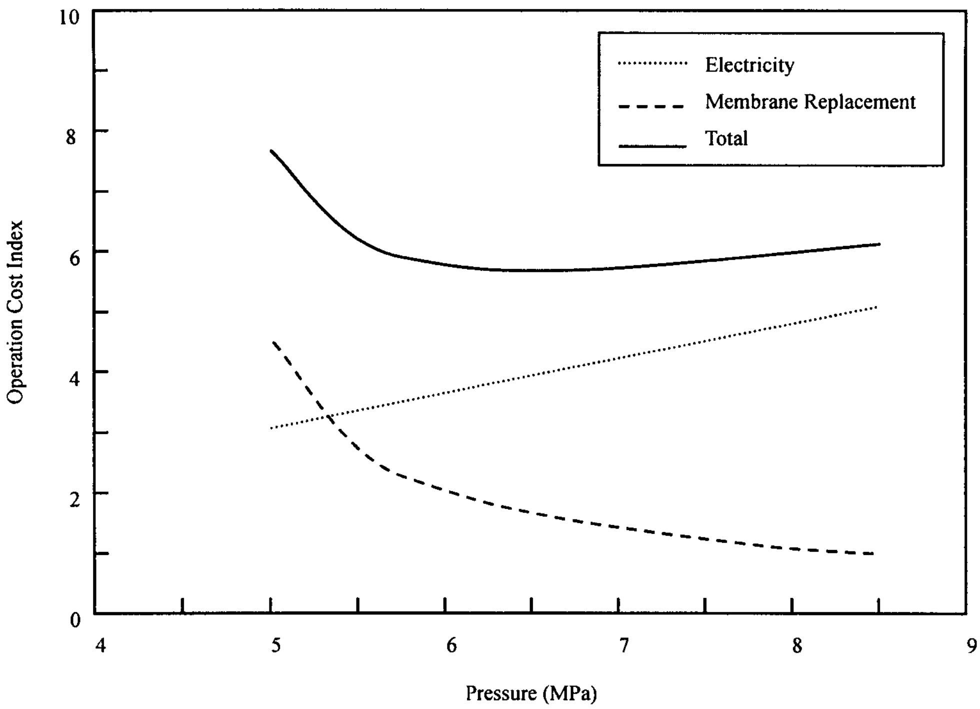


Fig. 5. Comparison of Operation Cost

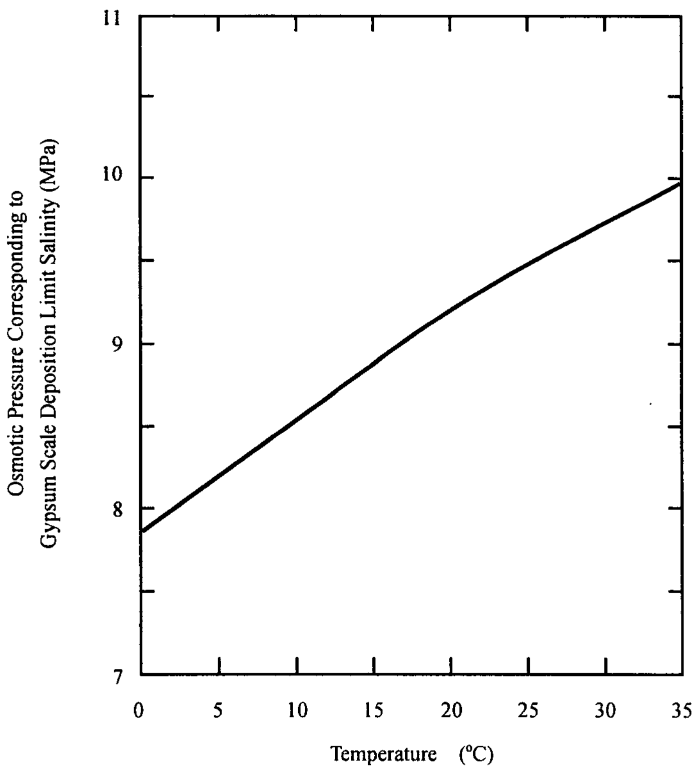


Fig. 6. Dependence on Temperature of Osmotic Pressure Corresponding to Gypsum Scale Deposition Limit Salinity

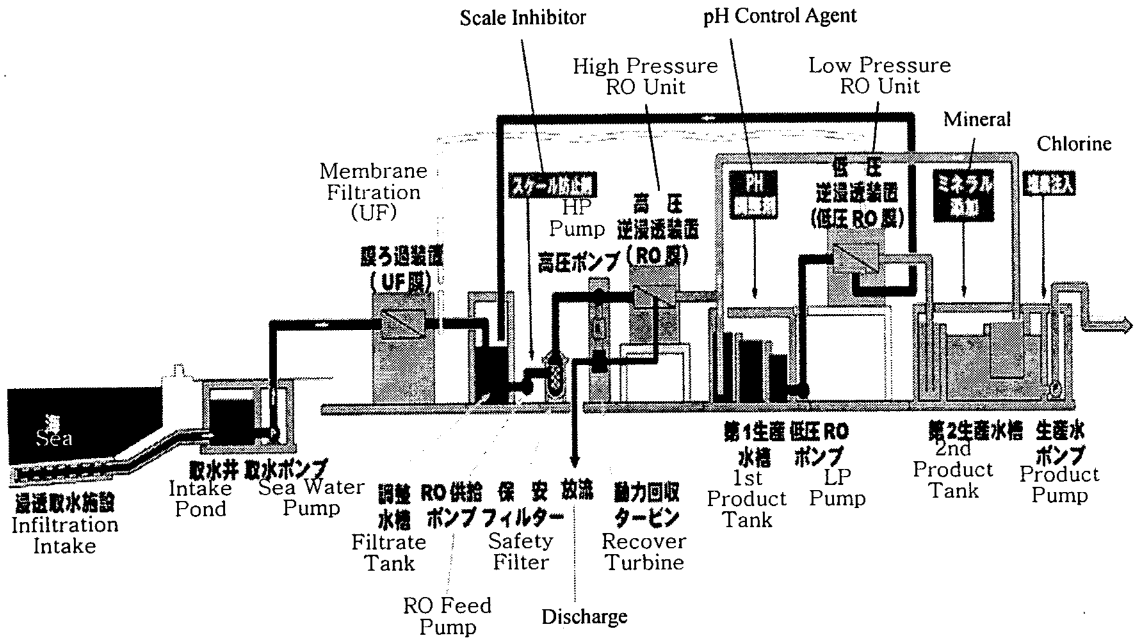


Fig. 7. Flow Sheet of 50,000m³/day RO Sea Water Desalination Plant at Fukuoka

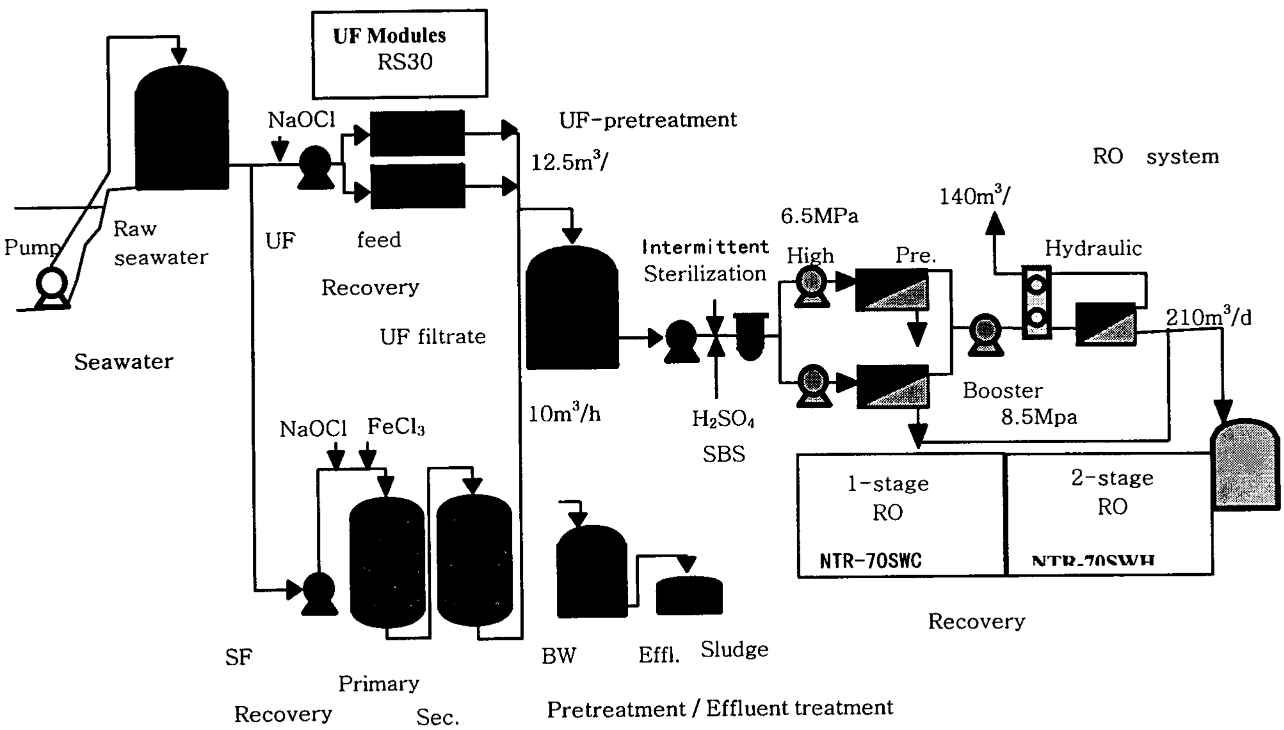


Fig. 8. Flow Sheet of High Recovery Operation Demonstration Plant