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Desalination of seawater using nuclear heat

M.S. Hanra

Bhabha Atomic Research Centre, Mumbai 400 085, India
Tel. +91 (22) 550-5050, ext. 4756; Fax +91 (22) 550-5150; e-mail: mshanra@magnum.barc.ernet.in

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Abstract

The Nuclear Desalination Demonstration Project (NDDP), Kalpakkam, envisages setting up a 6300 m^3/d capacity hybrid MSF–RO plant based on an indigenous design. The plant will meet the process water requirements of MAPS and will augment the drinking water sources of the nearby complex. This paper describes the basic process flow sheet of the SWRO plant, part of the hybrid MSF–RO desalination plant. The SWRO plant consists of a pretreatment system, high-pressure pumping system with energy recovery turbine, RO modules and membrane cleaning system. The product water from the SWRO plant with a TDS of about 400ppm will be mixed with product water of the MSF plant containing 10 ppm TDS. The projection of the permeate output and TDS for a few SWRO commercial modules at different seawater temperatures were carried out to select the optimum conditions of the SWRO plant. The role of energy recovery from RO reject stream is also investigated. As the seawater TDS at our site is around 35,000 ppm, it was proposed to study the feasibility of using reject stream from the RO plant as feed for the MSF plant in future.

Keywords: Hybrid MSF–RO; SWRO

1. Introduction

The Nuclear Desalination Demonstration (NDDP) Project at Kalpakkam consists of a 1800 m^3/d (0.4 mgd) seawater reverse osmosis (SWRO) plant and a 4500 m^3/d (1 mgd) multi-stage flash (MSF) plant making a total production of 6300 m^3/d (1.4 mgd) water. The plant has been designed from the experience gained from MSF and SWRO pilot plants at Trombay. The steam required for the brine heater of the MSF plant was drawn from a 170 MWe pressurized heavy water reactor (PHWR), Madras Atomic Power Station (MAPS).

An MSF pilot plant of 425 m^3/d capacity had been previously designed, constructed and operated. Similarly a small RO plant was designed, constructed and commissioned. From the operation of these MSF and RO pilot plants, considerable experience was gained and has been used for the design of the 1.4 mgd plant. The MSF plant at Kalpakkam needs about 21 t/h of

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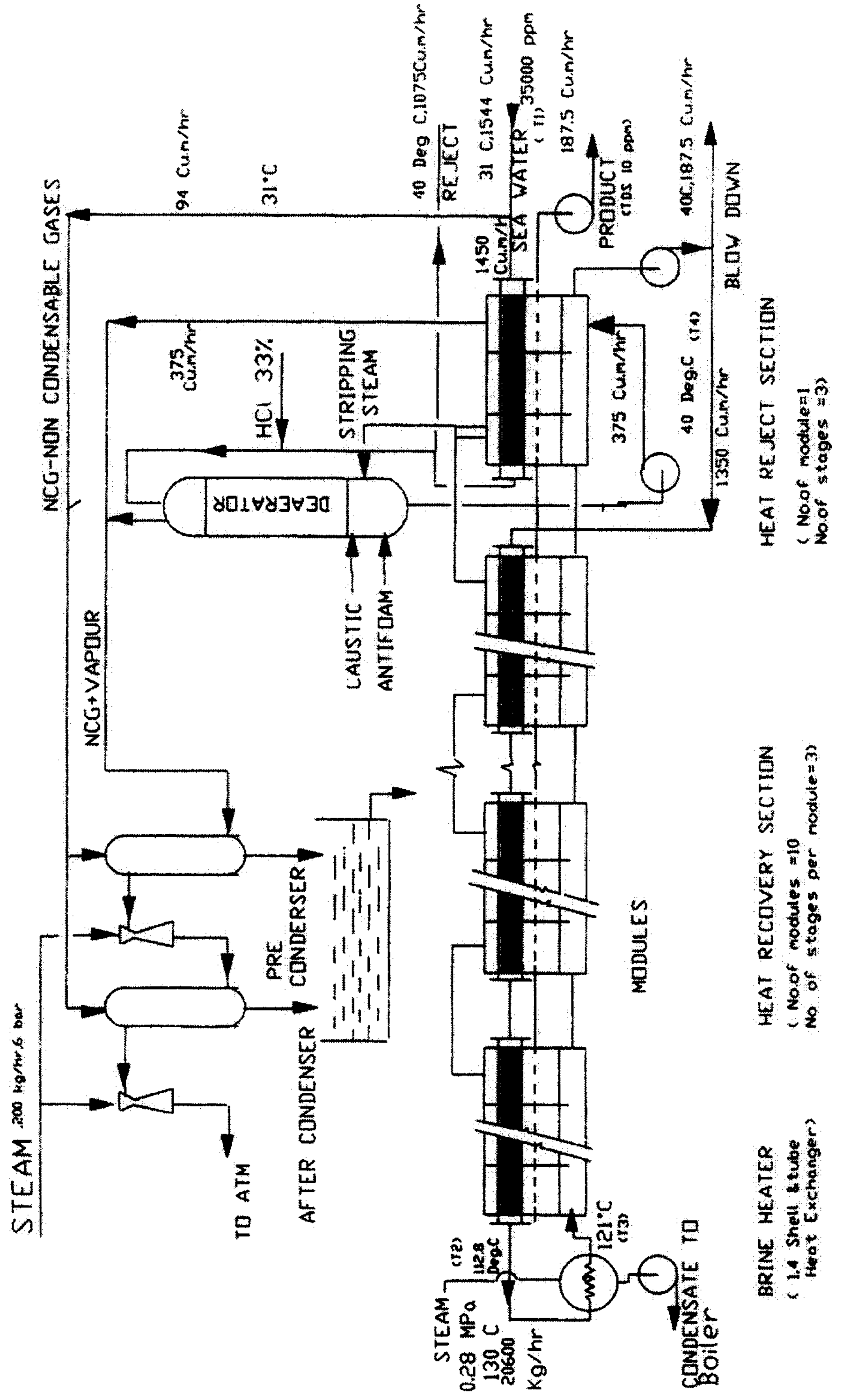

Fig. 1. 4500 m^3/d MSF desalination plant, Kalpakkam.

saturated steam at 3 bar pressure. Seawater supply was from the outlet streams of MAPS at a slightly higher temp (32–34°C). Higher seawater temperature is advantageous for the SWRO plant since water flux of the membrane is about 2.5% higher per degree temperature rise at a fixed pressure. The hybrid MSF–RO plant aims in reducing operation and maintenance (O&M) costs of the product water. A part (1000 m^3/d) of the high purity water (TDS=10–20 ppm) from the MSF plant was utilized as process water after minor polishing and the remaining water from MSF plant was mixed with 400 ppm of water of the SWRO plant to produce drinking water (TDS, 150 ppm) with minimum post-treatment of water produced from either the MSF or SWRO plant. Both the plants have common seawater intake and outfall facilities. It is also possible to use cooling seawater from the reject stage of the MSF plant as feed to RO plant. This will give a high throughput as its temperature is 6–8°C higher than ambient.

2. Salient features of NDDP

The flowsheet of the 4500 m^3/d MSF desalination plant is given in Fig. 1. Steam for the MSF plant (21 t/h) and electrical power for both MSF (0.6 MWe) and SWRO plant (0.5 MWe) are drawn from MAPS.

3. SWRO plant

The process flowsheet of the 1800 m^3/d SWRO plant is shown in the Fig. 2. It consists of a pretreatment system, high-pressure pumping and module system, and a post-treatment and auxiliary system. In the SWRO plant, pretreatment of seawater is an important step to have optimum membrane life.

Seawater composition at MAPS is given in Table 1. It consists of disinfection using chlorine,

Table 1
Seawater composition at Kalpakkam

pH	8.1
TDS by wt	35,600
Total solids by wt, ppm	36,012
Suspended solids, ppm	410
Total hardness (CaO_3), ppm	6,300
Sodium, ppm	10,556
Calcium, ppm	400
Magnesium, ppm	1,272
Potassium, ppm	380
Total alkalinity ($CaCO_3$), ppm	138
Chloride, ppm	18,981
Sulfate, ppm	2,650
Fluoride, ppm	1.3
Iron, ppm	0.1
Silica, ppm	0.8

Table 2
Technical specifications of 1800 m^3/d SWRO plant

Water produced per train, m^3/h	37.5
No. of trains	2
Water produced from both trains, m^3/h	75
Seawater flow per train, m^3/h	110
Seawater TDS, ppm	35,000
Feed water pH	6.5
No. of modules/train	14
No. of elements/module	6
Total no. of modules in plant	28
Total no. of elements in plant	168
Membrane characteristics:	
Type	TFC spiral wound
Model (8040 type)	8" dia.× 40" length
Element capacity, m^3/d/element	22
Solute rejection of membrane, %	99.6 at standard test conditions
Flux decline coefficient/y, %	7
Solute passage increase factor/y, %	10

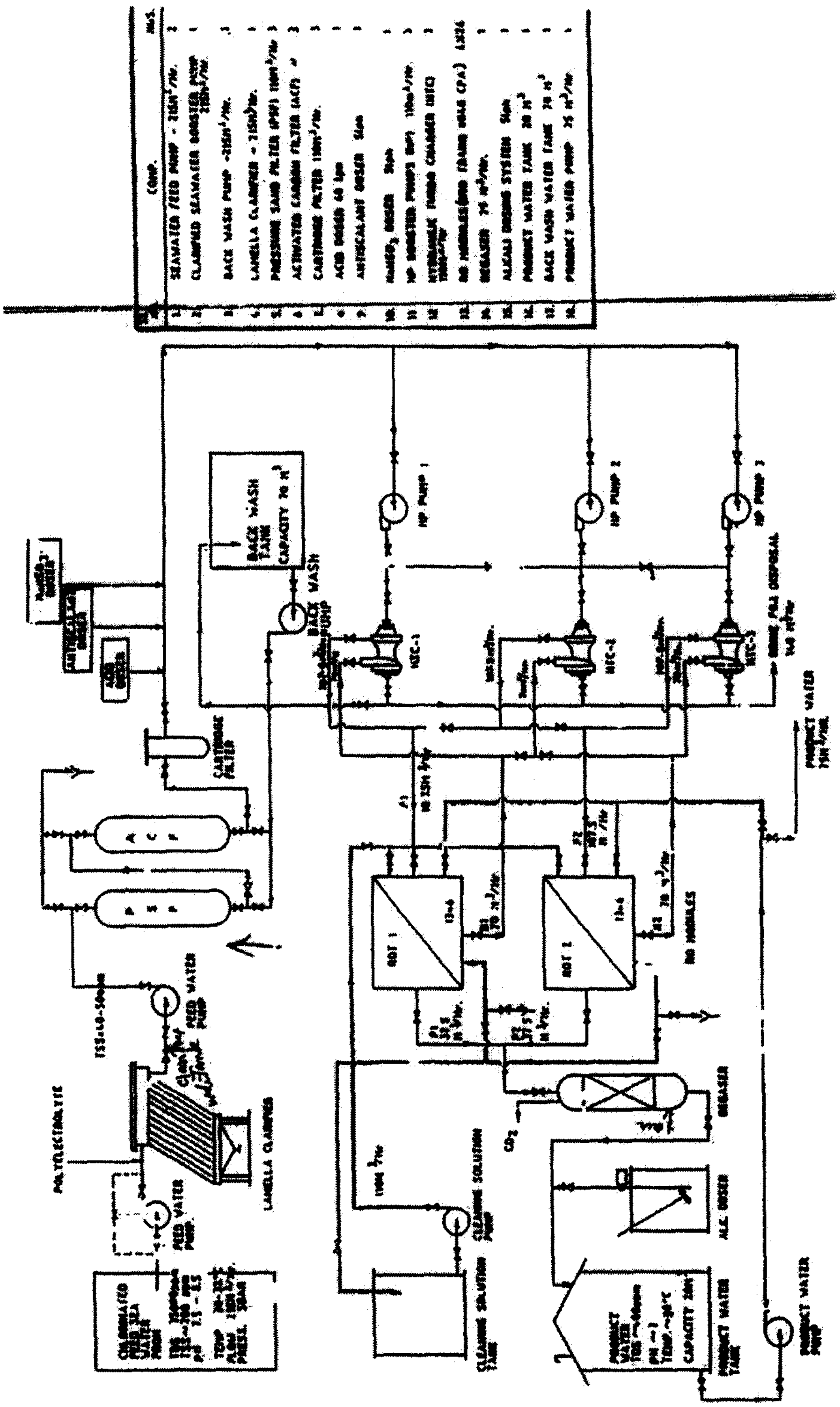

Fig. 2. 1800 m^3/d SWRO plant.

clarification (coagulation, flocculation and sedimentation) to remove major suspended load, media filtration to further reduce the suspended impurities, activated carbon filtration to reduce organic load and to remove chlorine, reduction of alkalinity by pH adjustment, addition of a scale inhibitor, complete removal of chlorine by the addition of sodium bisulfite and microcartridge filtration for removal of very fine particles. To minimize the scaling on the membrane, anti-scalant, SHMP is also added.

The RO modules were arranged in two parallel trains, each train producing 37.5 m/h product. Each train was fed with pretreated seawater of 110 m^3/h at a pressure of 55 kg/cm^2. The membrane elements consist of a TFC spiral-wound polyamide membrane. (Element type is 8040, i.e., 8" diameter and 40" length with an element capacity of 22 m^3/d). Total product recovery is 35%. Each train has 14 pressure vessels with six elements in each. Thus there are a total of 28 pressure vessels and 168 elements in the plant. The technical specifications of the membrane and modules are given in Table 2. Both the trains of RO modules together will produce 75 m^3/h product water of 400 ppm average TDS.

Each train is fed with seawater by a high-pressure centrifugal pump coupled with an energy recovery turbine (ERT) and motor on the same shaft. There are a total of three pump sets, two operating and one stand-by. Each pump set has a capacity of 110 m^3/h at 55 kg/cm^2 pressure. About 33% of the energy can be saved by the use of the ERT. Both the pump and the ERT are made of second-generation duplex stainless steel alloy 2205. The inflow to the ERT is 70 m^3/h at 53 kg/cm^2.

4. Cost

The investment for the 1800 m^3/d SWRO plant and the cost of water are given in Table 3. The basis of calculation is shown in Table 4.

Table 3
Calculation of investment and water cost of the SWRO plant

Plant capacity, m^3/d	1800
Investment, $	2,941,176
Plant factor	90
Power cost, $/kWh	0.58
Power consumption, kWh/m^3	6.10
Maintenance (as % of investment)	3
Fixed cost, $/$m^3$	0.62
Power cost, $/$m^3$	0.35
Chemical cost, $/$m^3$	0.03
Membrane replacement cost, $/$m^3$	0.14
Maintenance, $/$m^3$	0.15
Water cost, $/$m^3$	1.29

Table 4
Basis of calculation

Plant life, y	25
Interest rate, %	12
Membrane life, y	3
Membrane cost, $/element	1500
Membrane elements	168
Inhibitor cost, $/kg	0.58
Inhibitor dosing, ppm	3
Acid cost, $/kg	0.09
Acid dosing, ppm	103

5. Water composition

The composition of permeate water produced at the SWRO plant without post-treatment is given in Table 5, and the composition of water meant for drinking after addition of dosing chemicals is given in Table 6.

6. Reduction of energy consumption (future plan)

SWRO has become more economical after commercialization of the energy recovery units (ERUs). At present commercial ERUs are based

Table 5
Projected permeate water composition without post-treatment

TDS, ppm	336
Calcium, ppm	0.95
Magnesium, ppm	3.03
Sodium, ppm	120.43
Potassium, ppm	5.42
Strontium, ppm	0.03
Bicarbonate, HCO_3^-, ppm	1.52
Sulfate, SO_4^-, ppm	6.81
Chloride, C^-	195.13
Fluoride, F^-	0.03
Carbon dioxide	42.08
pH	4.9
Langelier Saturation Index	6.4
Ryzner Index	17.6

Table 6
Water composition after post-treatment

Dosing chemicals, $Ca(OH)_2$, ppm	36
pH after dosing $Ca(OH)_2$	8.43
Ca, ppm	20.4
Mg, ppm	3
Na, ppm	120
K, ppm	5.4
Sr, ppm	0.03
CO_3^-, ppm	.8
HCO_3^-, ppm	58.3
SO_4^-, ppm	6.8
Cl^-, ppm	195.1
Total TDS	410
Langelier Saturation Index	0.1
Ryzner Index	8.2

on the conversion of power through a shaft and energy consumption is approximately 6–6.5 kWh/m^3 of product water. The introduction of the work exchanger energy recovery unit can bring down energy consumption below 4 kWh/m^3 of water. In principle, the work exchanger transfers the fluid pressure in the reject stream to the fluid pressure in the feed stream across a piston. NF followed y RO can be used for an overall increase in recovery and hence will reduce the energy consumption.