DESALINATION DEMONSTRATION PLANT USING NUCLEAR HEAT

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Abstract

Most of the desalination plants which are operating throughout the world utilize the energy from thermal power station which has the main disadvantage of polluting the environment due to combustion of fossil fuel and with the inevitable rise in prices of fossil fuel, nuclear driven desalination plants will become more economical. So it is proposed to set up nuclear desalination demonstration plant at the location of Madras Atomic Power Station (MAPS), Kalpakkam. The desalination plant will be of a capacity 6300 m^3/day and based on both Multi Stage Flash (MSF) and Sea Water Reverse Osmosis (SWRO) processes. The MSF plant with performance ratio of 9 will produce water (total dissolved solids (TDS-25 ppm) at a rate of 4500 m^3 /day from seawater of 35000 ppm. A part of this water namely 1000 m^3/day will be used as Demineralised (DM) water after passing it through a mixed bed polishing unit. The remaining 3500 m^3/day water will be mixed with 1800 m^3/day water produced from the SWRO plant of TDS of 400 ppm and the same be supplied to industrial/municipal use. The sea water required for MSF & SWRO plants will be drawn from the intake/outfall system of MAPS which will also supply the required electric power pumping. There will be net 4 MW loss of power of MAPS namely 3 MW for MSF and 1 MW for SWRO desalination plants. The salient features of the project as well as the technical details of the both MSF & SWRO processes and its present status are given in this paper. It also contains comparative cost parameters of water produced by both processes.

Introduction

In India nearly three-fourth of the water out of total rain fall of 4000 km^3 runs off to the sea and one-fourth is stored as surface as well as ground water for use. The annual water availability and the consumption can be seen from Table I. Various schemes have been launched by State and Central Government and Municipal Corporations for collecting, storing and distributing rain water specially in water scarce areas for industrial, agricultural and domestic uses. Some of these schemes with capacity & cost are mentioned in Table II. These schemes need large investment and have longer period of construction and cost overruns. Also there is serious environmental concern due to submergence of vast land and displacement of people from the areas. For coastal water scarce region and areas affected by brackishness, desalination plants based on membrane as well as thermal processes can suitably be deployed. Also to augment the water resource, effluent treatment plants using membrane technology have been used worldwide at comparatively low cost. A few desalination plants and effluent treatment plants have already been installed and are operating in India and some plants are under construction for augmenting water as given in Table III. Table IV gives capital & water cost of MSF & Effluent Treatment Plant in India & Table V gives water tariff in Mumbai & Chennai. Mostly these plants are based on membrane processes. One desalination plant based on thermal MED process is operating at Chennai.

MSF desalination plants need steam for heating sea water in brine heater and it is normally drawn from thermal power station. The cost of the steam is generally estimated based on the power loss due to steam supply for desalination plant. A 6300 m^3/d (1.4 MGD) combined MSF and Reverse Osmosis (RO) desalination plant is being set up at Kalpakkam. It would draw steam from Madras Atomic Power Station (MAPS) and use sea water from its outfall system. The reasons for coupling the desalination plant with nuclear power plant are given in the next paragraph.

Table I : Annual water consumption and availability in India (Km^3)

a. Consumption :

Sl. No.	Needs	1985	2000	2025
1	Irrigation	470	630	770
2	Domestic	16.7	24.2	40
3	Industries	10	30	120
4	Power	4.3	5.8	15
5	Miscellaneous	39	60	105
	Total	540	750	1050

b. Water Availability (Km^3)

Total rainfall (Km^3)	Utilizable water (Km^3)	
	Surface water	Ground water
4000	700	350

Table II : Conventional water supply schemes & cost

Sl. No.	Water supply scheme	Capacity (MGD)	US million $
1	Indira Gandhi Canal	--	1000
2	Sardar Sarovar Scheme	500	1715
3	Telegu Ganga Scheme	200	640
4	Krishna Vally Corporation	3000	2040
5	Mumbai Municipal Corporation	100	215
6	RO Sewage Treatment Scheme at Chennai	30	163

Table III : Desalination & RO Plants in India

Sl. No.	Process	Capacity	Location	Supplier	End use
1	RO	225 m^3/h	Madras refinery	Hindustan Dorr Oliver	Test sweage treatment
2	RO	360 m^3/h	Madras refinary	Nuchem weir	-do-
3	RO	360 m^3/h	National Fertilizer, Guna	Ion Exchange	Effluent treatment
4	SWRO	2650 m^3/d	Porbandar	Nu Chem Weir	Sea water desalination
5	SWRO	360 m^3/d	GSFC, Sikka	Thermax	Sea water desalination
6	MED	1650 m^3/d	EID Parry, Chennai	IDE, Israel	Sea water desalination
7	MSF	425 m^3/d	Mumbai	BARC	Sea water desalination
8	128 RO Plants	300 m^3/d	In village of different states	Drinking Water Mission	Drinking
9	SWRO	4500 m^3/d	GEB, Sikka	Ion Exchange	Industrial
10	100 Nos. of RO/NF/UF Plants	10 - 100 m^3/d	Industries	Indian Cos.	Industrial
11	SWRO	4500 m^3/d	Ramanathapuram	BHEL	Drinking
12	MSF-RO	6300 m^3/d	Kalpakkam (under construction)	BARC	Drinking and process water

Table IV: Capital cost and water cost of large MSF desalination and effluent treatment plant in India

Sl. No.	Plant capacity (MGD)	Capital cost million US $	Specific Capital cost million $/MGD
1	1	5.14	5.14
2	5	21.43	4.28
3	20	57.14	2.85
4	30*	163.43	5.43
5	Sea water desalination cost (MSF)		1.48 $ / m^3
6	Sea water desalination cost (RO		1.28 $ / m^3
7	Brcakish water desalination (RO)		0.71 $ / m^3
8	Effluent water tertiary treatment cost		0.57 $ / m^3

*Effluent Treatment Plant

Table V : Water tariffs in Mumbai and Chennai

Mumbai		
Domestic	:	US \$ 0.10 / m^3
BARC (R & D)	:	US \$ 0.3/ m^3
Industries	:	US \$ 1.0/ m^3 + 50 % Sewerage charge
Chennai		
Domestic	:	US \$ 0.30 / m^3
Industries	:	US \$ 0.80 / m^3

Nuclear Power Plant & Desalination Plant

Nuclear power plants produce large quantities of heat (in the form of steam/hot water) at relatively low cost. Cost of fuel oil on the other hand is high and gaseous emissions from fossil fuel burning pollute the atmosphere. Operational expenses of nuclear power desalination plant are lower than the conventional thermal power desalination plant. High degree of safety & reliability in operation of nuclear power plants have been now achieved. India has nine operating nuclear reactors with a total generating capacity of about 2000 MW. These are mostly pressurized heavy water reactor (PHWR) each of cpacity 220 MW operating in various parts of India near sea shore using natural uranium (UO_2) as fuel and heavy water as moderator and primary coolant. The secondary coolant is water/steam at pressure & temperature of 40 bar and 250^0C respectively. Dual purpose nuclear power & demonstration plants can be installed to produce both electricity and fresh water from sea water using low pressure steam extraction from IP/LP turbine. Also the hot sea water from the reject system can conveniently used as feed to sea water Reverse Osmosis plant.

The Process and Salient Features of the Project

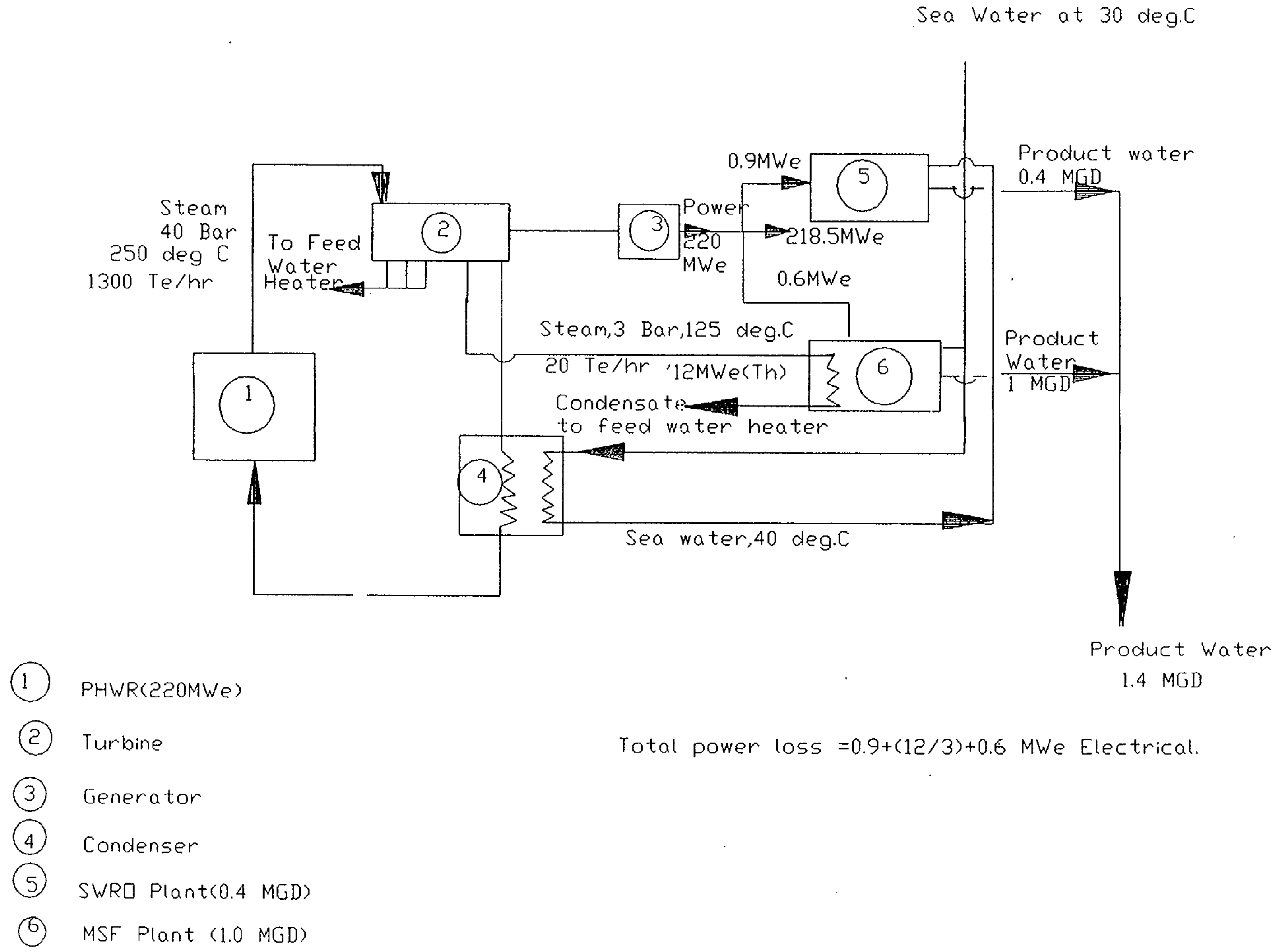
The flowsheet of the 1.4 MGD desalination plant is given in Fig. 1. Steam and the power are drawn from Pressurised Heavy Water Reactor (PHWR) 200 MW at MAPS. Steam at a pressure of 3 bar at 125^0C is drawn from turbine. The product water from MSF plant will be at a rate of 1 MGD. The electrical power loss for MSF plant will be 3.0 MWe including the loss due to withdrawal of steam. The electrical power requirement by SWRO plant will be 1.0 MWe. So the total power loss from MAPS will be 4.0 MWe which will produce 6300 m^3/d of water per day.

MSF Plant

The MSF plant consists of 9 recovery modules each of 4 flash stages and one reject module of 3 stages. Maximum brine temperature is limited to 121°C to prevent calcium sulfate scaling on cupronickel heat transfer tables. Pumps are made of SS 316. The MSF plant will draw sea water at a rate of 1544 m^3/hr from the outfall system and the stream (130 °C, 3 bar pessure) from MAPS at a rate of 20.6 Te/hr and produce product water of 187.5 m^3/hr with less than 25 ppm.

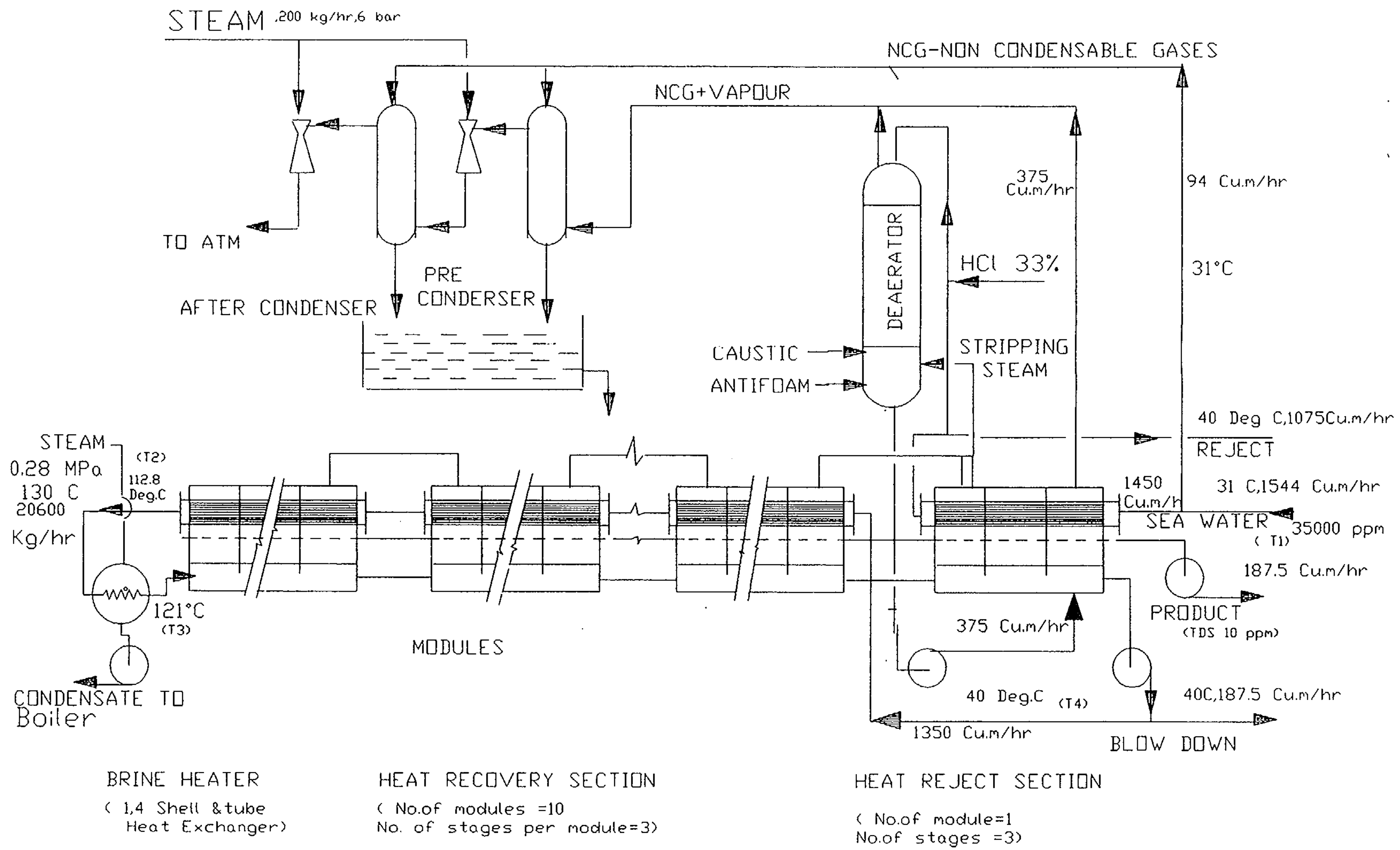
The MSF plant has a performance ratio of 9. The pumping power requirement is 3 kWh/m^3 of water produced. The water produced from MSF plant will be of high quality with TDS of 10 ppm. The part of this water (1000 m^3/day) will be after passing it through a polishing mixed bed unit used as boiler make up water. At present MAPS is producing 940 Te/d of DM water at a cost of \$4.2 per m^3. If high purity water from MSF plant is used for making DM water, about 80% of cost can be easily saved.

The remaining 3500 m^3/day of product water from MSF plant will be mixed with 1800 m^3/day product water from the SWRO plant and the mixed stream containing around 250 ppm TDS will be supplied to industrial/municipal use in Kalpakkam. Layout of the desalination plant project is given in Fig. 2. Table VI gives the sea water composition at MAPS, Kalpakkam.



FLOW DIAGRAM OF 1.4 MGD MSF-SWRO DESALINATION PLANT COUPLED TO 220 MWe COASTAL NUCLEAR POWER STATION

Figure 1



4500 Cu.M/Day MSF Desalination Plant,Kalpakkam

Figure 2

Table VI : Sea water composition at MAPS Kalpakkam

pH	8.1
Total dissilved solids by weight	35600
Total solids (ppm) by wt.	36012
Suspended solids (ppm) (by difference)	410
Total hardness (ppm $CaCO_3$)	6300
Sodium (ppm)	10556
Calcium (ppm)	400
Magnesium (ppm)	1272
Potassium (ppm)	380
Total alkalinity (ppm $CaCO_3$)	138
Chloride (ppm)	18981
Sulphate (ppm)	2650
Fluoride (ppm)	1.3
Iron (pph)	100
Silica (ppm)	0.8

Process

The cold sea water from the outfall system of MAPS is pumped at a rate of 1450 m^3/hr through the tube bundle of the heat reject section (3 heat reject stages). Before it passes through the tube bundle of reject stages, part of the seawater (94 m^3/hr) is used in pre- & inter-condensers. 375 m^3/hr of warm sea water (40^{0}C) from the reject module is subjected to chemical dosing and is sent to the vacuum deaerator. The remaining part of warm sea water (1075 M^3/hr, 40^{0}C) is sent back to the sea (Fig. 3).

The chemical dosing consists of addition of hydrochloric acid to decompose bicarbonates so as to prevent alkaline scale formation on heat transfer surfaces. In vacuum deaerator, the dissolved CO_2 and O_2 are removed to bring it to the level of 1 ppm and 20 ppb respectively. The deaerated feed is then mixed with caustic soda to neutralise excess acid to pH of 6.8 to 7 and a small quantity of antifoaming is injected to avoid foaming during flashing of brine. The deaerated feed is then mixed with recycle brine. It is then passed through the tube bundle of recovery module (9 nos) where it is heated externally by condensation of flashed water vapour. The temperature of recycle brine rised to 112^{0}C which is further heated to 121^{0}C in brine heater. This brine is then gradually passed through all the 36 nos. of stages where it gets flashed & vapours are produced which is then condensed on outside of the tubes and form the product water. Recovery modules are rectangular in shape, long tube design and are arranged in the form of a train. There are total 9 recovery modules and each module has got 4 brine stages. It is made up of carbon steel with sufficient corrosion allowance. The tubes are made of 90/10 cupronickel, 19 mm o.d. and monel demisters are used to separate the brine droplets from the water vapour produced due to flashing. The pumps are made of 316 stainless steel; tubesheets are made of 50 mm thick 90/10 cupronickel.

Noncondensable gases are removed from evaporators by evacuation system. A series of venting is utilized to remove all the gases and to maintain pressure differential in stages. The product water is pumped from last stage and is passed through lime column (calcite bed) before it is distributed. Here it will be mixed with product water from SWRO plant & then will be sent as drinking water.

SWRO Plant

The Sea water Reverse Osmosis (SWRO) plant will receive hot sea water (36-38°C) of 35000 ppm from the condenser outlet of Madras Atomic Power Station (MAPS) at a rate of 215 m^3/hr and it is passed through clarifloceulater, pressure sand filter, activated carbon filter and cartridge filter in order to

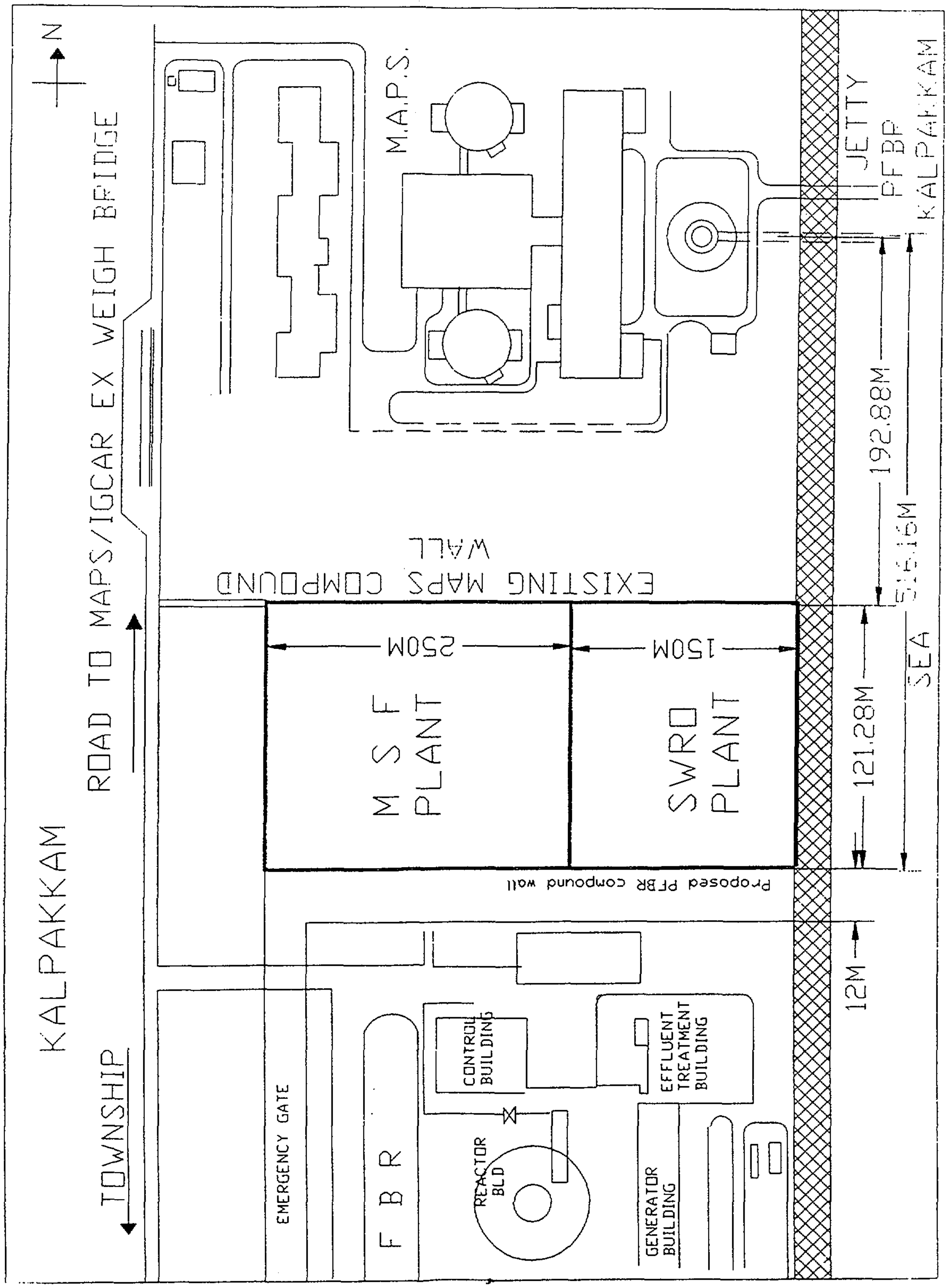

N
KALPAKKAM
TOWNSHIP
ROAD TO MAPS/IGCAR EX WEIGH BRIDGE
M.A.P.S.
JETTY
PFBR
KALPAKKAM
EXISTING MAPS COMPOUND WALL
250M
150M
M S F PLANT
SWRO PLANT
192.88M
516.16M
121.28M
SEA
12M
Proposed PFBR compound wall
EMERGENCY GATE
CONTROL BUILDING
EFFLUENT TREATMENT BUILDING
REACTOR BLD
F B R
GENERATOR BUILDING

Figure 3

remove suspended and colloidal solids and organics. Since the membrane are polyamides, dechlorination of the feed is carried out by addition of sodium sulfite and to minimize carbonate scaling on the membrane, acid dosing is carried out followed by antiscalant dosing to prevent sulfate scaling. The pretreated seawater is then pumped into two parallel sections through the RO modules at a rate of 110 m^3/hr at a pressure of 55 kg/cm^2 by use of high pressure pumps which is fitted with Energy Recovery Hydraulic Turbocharger (HTC). Use of HTC saves about 30% of energy. Membrane modules are 8040 HSY SWC with TFC spiral wound having solute rejection of 99.6%. There are a total of 26 modules having 156 membrane elements. Each pressure tube has 6 elements and the pressure tube are made of FRP. The product water (75 m^3/hr) has a TDS 50 ppm.

The SWRO plant will receive the hot sea water of 35000 ppm from the condenser outlet of Madras Atomic Power Station (MAPS) and produce potable water of about 500 ppm. Provision is kept to mix the SWRO product water with highly pure MSF water to have drinking water of 200-300 ppm. The SWRO plant will use hot sea water at a temperature of about 36 - 38°C as feed. High temperature feed will increase the membrane flux considerably which will in turn will reduce the membrane cost for a particular plant capacity.

Process Description

The hot chlorinated sea water at a temperature of 36-38^{0}C from the outfall of Madras Atomic Power Station (MAPS) is pumped through the clarifier and pressure sand filter. Large size particles upto 25 micron are removed from sea water at this stage at a rate of 215 m^3/hr. It is then passed through activated carbon filters for removal of organics. It is then passed through 5 micron cartridge filter to ensure the removal of particles below 5 micron in size. Since the membranes are polyamide, dechlorination of sea water is carried out by addition of $NaHSO_3$. To minimize the carbonate scaling, acid dosing is carried out followed by addition of antiscalant or SHMP for removal of sulfate scale.

Table VII : Technical specifications of 4500 M^3/day (1 MGD) MSF plant

(i)	Plant capacity	187.5 m^3/hr
(ii)	Product quality	< 25 ppm of salt
(iii)	Top brine temperature	121^{0}C
(iv)	Blow down temperature	40^{0}C
(v)	Performance ratio	9
(vi)	Steam consumption	20.6 Te/hr
(vii)	Pumping power consumption	600 KWe
(viii)	Power loss to power station due to steam withdrawal for desalination plant	2.4 MW(e)
(ix)	Scale control	Acid treatment
(x)	Flash evaporator	Rectangular, long tube design
(xi) (a)	No. of recovery modules	9
(b)	No. of flash stages/module	4
(c)	No. of reject module	1
(d)	No. of stages	3
(e)	Total no. of flash stages	39
(x)	Tubes	Cupronickel 90/10
(xi)	Pumps	SS 316 make centrifugal pump

Table VIII : Technical specifications of 1800 M^3/day SWRO plant

(i)	Product out	75 m^3/hr
(ii)	Product quality	500ppm
(iii)	Feed sea water flow	215 m^3/hr
(iv)	Feed sea water TDS	35000 ppm
(v)	Membrane element (a) Type (b) Model (c) Element capacity	 TFC spiral wound 8040 HSY SWC/TFC 2822 SS 22 m^3/day/ element
(vi)	Product recovery	35%
(vii)	Design pressure	55 Kg/cm^2
(viii)	Solute rejection	99.6% at standard sea water test condition (32800 ppm NaCl, pH = 7.5, 25^{0}C)
(ix)	No. of elements required	156 nos
(x)	No. of elements per module	6
(xi)	Total no. of modules	26

Table IX. Flux characteristics of the membrane with temperature

Temperature (^{0}C)	Membrane flux litre/m^2/day (lmd)
30	709
35	815
40	922

This pretreated sea water is then pumped in two parallel sections through the modules at a rate of 110 m^3/hr each at a pressure of 40 bar. Each pump is fitted with Energy Recovery Hydraulic Turbocharger (HTC). Maximum pressure of the feed is 55 kg/cm^2. About 30% of the energy is saved due to the use of HTC. The sea water membrane module is 8040 HSY SWC with TFC spiral wound with solute rejection of 99.6%. There are a total of 26 module having 156 membrane elements. Each pressure tube has 6 elements. Shells are made of FRP. The product water of TDS 450 ppm after degassing to effect CO_2 removal, is dosed with lime or soda ash to adjust pH or mixed with product water from MSF plant whose dissolved salts are as low as 250 ppm.

Table VII and VIII describe the speficiation of the MSF and RO plants. Table IX indicates the performance improvement of RO plants. Table IX indicates the performance improvement of RO plant with rise in feed water temperature.