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TRANSIENT BEHAVIOUR AND COUPLING ASPECTS OF A HYBRID MSF-RO NUCLEAR DESALINATION PLANT

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Abstract

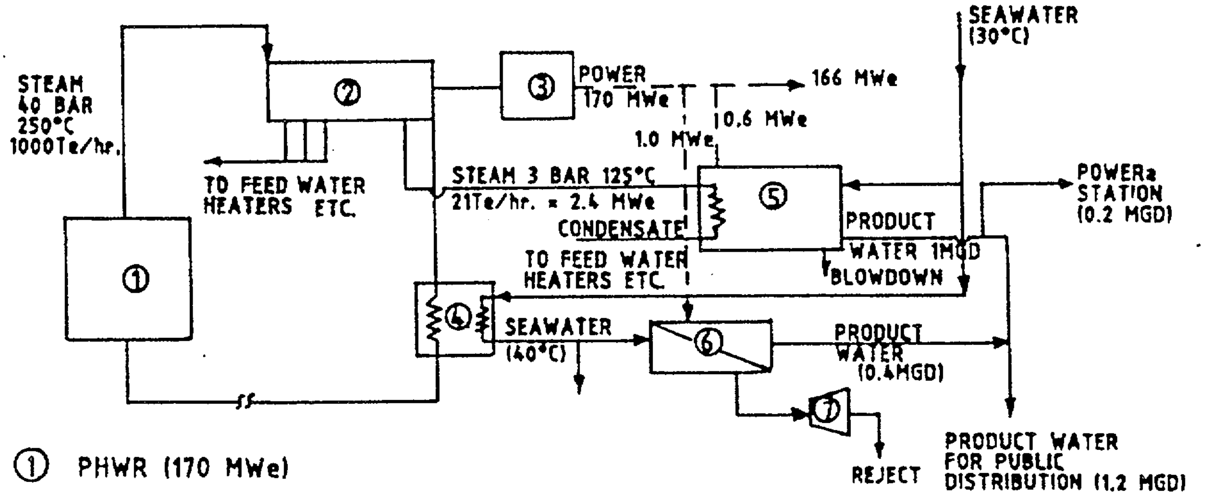
BARC is setting up a 6300 M^3/day (1.4 MGD) hybrid MSF-RO nuclear desalination plant for sea water desalination at Madras Atomic Power Station (MAPS) coupled to a 170 MWe Pressurised Heavy Water Reactor (PHWR). The transient behaviour and coupling aspects of this dual purpose plant has been discussed. A hybrid desalination plant appears to offer high availability factor.

1. INTRODUCTION

Desalination Division at Bhabha Atomic Research Centre (BARC) has been engaged in R&D work on desalination since last several years. It has a fairly advanced ongoing R&D programme on both thermal and membrane desalination. Desalination technologies based on membrane and thermal processes for brackish and seawater desalination have been successfully developed. Multistage Flash (MSF) desalination technology developed by us uses low pressure steam for seawater evaporation. It has been designed keeping in view the higher fuel costs in India. This requires achieving a high gained output ratio (GOR), more number of stages and a higher top brine temperature. It uses less costly material of construction resulting into lower capital investment and water cost compared to international costs. The Reverse Osmosis technology developed at the Centre has been used for providing drinking water in the rural areas of the country. It has also been demonstrated for the effluent treatment and water reuse including production of process water in conjunction with demineralizer.

2. HYBRID DESALINATION

Utilizing design and operation experience of pilot plants, BARC is setting up a 6300 M^3/day (1.4 MGD) hybrid MSF-RO nuclear desalination plant for seawater desalination at Madras Atomic Power Station (MAPS) coupled to a 170 MWe Pressurised Heavy Water Reactor (PHWR) (Fig. 1). The steam required for the 4500 M^3/d MSF is extracted from a tapping point in the low pressure turbine of a power station. A small part of the power generated in the power station is used for operating the 1800 M3/d RO plant and for pumping requirements of MSF plant. The hybrid MSF-RO plant set up at same location aims towards reducing the operation & maintenance (O & M) cost of desalted water by taking the advantage of producing both process and drinking quality water, utilization of water for different applications, having a common sea water intake and outfall systems, common pretreatment to a considerable extent and possibility of using reject streams from one plant to the other. A part of the desalted water (20 ppm TDS) from MSF is used for the makeup requirement. The remaining is blended with the product water of RO plant (500 ppm TDS) and transported for domestic use. The RO plant uses cooling water from the condenser as feed which is at about 6-8^{0}C higher than the ambient temperature. The high temperature operation of RO gives high throughput. It is also possible to use cooling sea water from the reject stage of the MSF plant as feed to RO plant.



① PHWR (170 MWe)

② TURBINE

③ GENERATOR

④ CONDENSER

⑤ MSF PLANT (1.0 MGD)

⑥ SWRO PLANT (0.4 MGD)

⑦ ENERGY RECOVERY DEVICE (ERD)

NOTE:
1. TOTAL ELECTRICAL POWER LOSS INCLUDING POWER LOSS DUE TO THERMAL ENERGY i.e. 3 BAR STEAM DUE TO 1.4 MGD MSF-SWRO WILL BE 4.0 MWe ONLY.
2. SEAWATER REQUIREMENT FOR DESALINATION PLANT IS ABOUT 1 - 2% OF POWER PLANT.

FIG. 1 SCHEMATIC FLOW DIAGRAM OF A 1.4 MGD (6300M^3/DAY) MSF-SWRO HYBRID DESALINATION PLANT COUPLED TO A COASTAL 170 MWe NUCLEAR POWER STATION

TABLE I SALIENT FEATURES OF PHWR

Fuel	Uranium dioxide (UO_2)
Refuelling	Onload
Moderator	
Type	Heavy water (D_2O)
Pressure (MPa)	0.75
Inlet temperature (^{0}C)	44
Outlet temperature (^{0}C)	65
Primary system	
Type	Heavy water (D_2O)
Pressure (MPa)	8.7
Inlet temperature (^{0}C)	249
Outlet temperature (^{0}C)	293
Secondary system	
Coolant	Water/steam
Pressure (MPa)	4.0
Temperature (^{0}C)	250
Heat rejection system	
Coolant	Sea water
Pressure (MPa)	0.00863
Inlet temperature (^{0}C)	30
Outlet temperature (^{0}C)	40

3. COUPLING ASPECTS

When a nuclear reactor is to be used to supply steam for the desalination, the method of coupling has a profound technoeconomic impact. The selection of particular method of coupling depends on the size & type of the nuclear reactor, the characteristics of desalination process and the local factors such as water and power demand.

Where the steam producing capacity of the nuclear reactor is large compared to desalting capacity or when the steam demand is less, a dual purpose plant using extraction steam for desalination and generating power is an ideal choice.

PHWR provides a safer steam generation due to an additional barrier. It uses heavy water (D_2O) as primary coolant and demineralised (DM) water as the secondary coolant. The steam required for MSF is extracted by coupling to the low pressure turbine. The steam is tapped from a suitable point on the low pressure turbine for heating the brine in the MSF plant. The selection of tapping point depends on the maximum brine temperature selected. The arrangement is also made to tap the steam from both the reactor systems for MSF to ensure the continuous operation of the desalination plant. In case of shutdown of a reactor, the steam requirement is met from the other one. Steam line from both the reactors will be connected to a header. Provision is made to regulate the steam supply as well as to isolate the system as and when required. The condensate from the nuclear power station is returned back to MAPS at an appropriate point. A part of the power generated in the nuclear power station is used for operating seawater RO plant by coupling it thermally and electrically with the power plant. The thermal coupling gives higher throughput due to higher feed sea water temperature upto 40^0C.. The remaining power is used for distribution. The pressure of the brine in the brineheater of MSF is maintained higher than the heating system pressure thereby reducing the contamination of brine by radioactive carryover. The quality of condensate is continuously monitored at the outlet from the brineheater. The probability of radioactive contamination of desalted water is extremely low.

The total electrical loss including power loss due to thermal energy i.e. 3 bar steam for 6300 M^3/d hybrid MSF-RO plant is around 4.0 MWe only. Rest of the 166 MWe electrical power is released for distribution. Sea water requirement for desalination is about 1-2% of the power plant.

4. TRANSIENT BEHAVIOUR

A dual purpose nuclear desalination plant consists of three interacting systems - nuclear steam supply system, the turbine generator system and the desalination unit.

The transients are caused due to daily and seasonal load variation. The extent of variation differs from place to place. The potential difficulty in the operation of a dual purpose thermal desalination plant is the dependence of steam flow and thereby desalted water production on the electricity demand. The easiest solution of the problem is achieved by operating the dual purpose plant at full load for most of the time supplying electricity to power grid and water to water grid. In many cases, this solution is feasible, if not, a certain flexibility is required by arranging a steam bypass around the turbine with a pressure regulating valve and a desuperheater. The bypass valve is opened when the turbine steam flow is not sufficient for the stable operation of MSF plant. The MSF does not respond very well to sudden load changes. The main difficulty by sudden load changes in MSF is in the control of brine level in the flash stages by regulating the brine flow and change of area of interstage orifices. There is no difficulty in ensuring the stable operation of desalination plant between 70-110% of full rated capacity with slow change in load. It is difficult to operate MSF plant if there is sudden large reduction of steam flow rate because the brine flow to the flash stages and tubeside brine velocity decreases below the admissible limit. In large MSF plants, this difficulty may be overcome by adopting an operating system in which MSF plant consists of several parallel trains of flash evaporators. In case of sudden large reduction of steam flow rate, some of the trains are switched off to have stable operation of MSF plant.

With the lowering of extraction pressure of the steam at constant steam flow rate, the top brine temperature in MSF comes down giving reduced GOR leading to lower production rate. A steam bypass around the turbine is provided which is opened in order to achieve the top brine temperature. A sea water bypass line around the evaporator is provided to use the brine heater of the MSF plant as a dump condenser for the turbine steam when the MSF plant is temporarily shut down.

In case of a desalination plant using only electricity such as RO, the coupling of the energy source with desalination plant is simple. There is not much of mutual influences due to transients in the nuclear power plant. If the coupling has low availability factor, a RO system coupled to a nuclear power plant has a high availability. On the other hand, a thermal desalination system coupled nuclear power plant gives high overall availability if the coupling has a high availability factor. A hybrid MSF-RO desalination plant coupled to a nuclear power plant appears to give high availability factor in general.

5. CONCLUSION

Transient behaviour and coupling aspects may have some technical fallout but they are like any other technical problems in a plant and solution exists. For the tropical countries as India, the prime need is the power generation at present. Small and medium size desalination plants are required in land and coastal arid zones for process water and safe drinking water requirement unlike Gulf countries where the desalted water demand is high and more important than power requiring high desalting capacity.