TECHNOLOGICAL INNOVATIONS IN DESALINATION

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Introduction

The cost of desalted water depends on three factors, namely, energy input, depreciation and interest, and operation and maintenance cost. Each of the three components contributes roughly one third to the total water cost. The cost of desalted water is coming down due to continued R&D and technological innovations in both thermal and membrane desalination. In the field of thermal desalination, efforts are directed towards utilizing the low grade heat and the waste heat as energy input for desalination, lesser chemical treatment and the advantage of scale up to higher capacity as a cost reduction strategy. In membrane desalination, work is being carried out on newer pretreatment methods like use of ultrafiltration, energy reduction using energy recovery devices and higher membrane life from better quality membranes. Work is pursued on hybrid desalination for producing different quality of product water for process industries and for potable use at lower cost. Table 1 gives the specific capital cost and desalted water cost for seawater desalination for the year 1980-2000. A projection for the year 2010 is also given. It is expected that the specific capital cost of seawater desalination plant will come down in the range of US $ 500-700 / daily m³ and water cost in the range of US$ 0.5-0.7/m³ by the year 2010. The cost for brackish water and effluent treatment by membrane processes are known to be even lower.
### Table 1: Seawater desalination cost

<table>
<thead>
<tr>
<th>Year</th>
<th>Capital cost (US$/ daily m³)</th>
<th>Water cost (US$/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1500</td>
<td>1.25</td>
</tr>
<tr>
<td>1990</td>
<td>1000-1200</td>
<td>1.0-1.2</td>
</tr>
<tr>
<td>2000</td>
<td>800-1000</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>2010</td>
<td>500-700</td>
<td>0.5-0.7</td>
</tr>
</tbody>
</table>

#### Milestones Covered So Far

Desalination Division has been engaged in R & D on desalination since 1970s. The desalination activities were part of a programme of setting up a number of demonstration plants for the energy intensive processes such as desalination of sea water, electrolytic production of hydrogen, and electro-thermal production of phosphorus. These activities are presently termed by IAEA as “Non Electrical Application of Nuclear Energy”. The activities on desalination in the beginning were based on thermal processes. Later the programme of membrane processes was also included in the 1980s when this process showed commercial viability. Table 2 gives the list of the pilot plants installed and operated/operating. These plants provided useful design data for larger capacity plants and for bringing in further technological innovations.

### Table 2: Pilot plants installed and operated so far

<table>
<thead>
<tr>
<th>Date of Commissioning</th>
<th>I. Thermal</th>
<th>Date of Commissioning</th>
<th>II. Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>1. 15 m³/d MSF experimental facility</td>
<td>1984</td>
<td>1. 3 x 30 m³/d brackish water RO plants providing drinking water in villages of Andhra Pradesh, Gujarat and Rajasthan (1998 Jodhpur)</td>
</tr>
<tr>
<td>1985</td>
<td>2. 30 m³/d low temperature evaporation unit</td>
<td>1986</td>
<td>2. 50 m³/d RO industrial effluent treatment plant at RCF</td>
</tr>
<tr>
<td>1990</td>
<td>3. 425 m³/d MSF plant</td>
<td>1994</td>
<td>3. 15 m³/d RO-DM plant at VECC for production of low conductivity water</td>
</tr>
<tr>
<td>1997</td>
<td>4. 1 m³/d thermo-compression desalination unit</td>
<td>1990</td>
<td>4. 2 x 10 m³/d RO units for treatment of radioactive liquid effluents</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. 24 m³/d NF plant for a pharmaceutical industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6. 40 m³/d SWRO plant at Trombay being upgraded to 100 m³/d capacity</td>
</tr>
</tbody>
</table>
Nuclear Desalination

**Coupling of 6300 m³/d hybrid MSF-RO plant with PHWR (MAPS, Kalpakkam)**

In order to gainfully employ the years of experience and expertise in various aspects of desalination activity on laboratory scale/pilot scale and to bring down the cost of water by scaling up, Desalination Division has undertaken installation of a hybrid desalination plant as a demonstration project coupled to 170 MW(e) PHWR station at Kalpakkam under IXth plan, which would be good enough to meet the dual needs of process water for nuclear power plant and drinking water for the neighbouring people.

Nuclear Desalination Demonstration Project (NDDP) at Kalpakkam aims for demonstrating the safe and economic production of good quality water by nuclear desalination of seawater comprising of 4500 m³/d Multistage Flash (MSF) and 1800 m³/d Reverse Osmosis (RO) plant (Fig.1). MSF plant uses low pressure steam from Madras Atomic Power Station (MAPS), Kalpakkam.

The objectives of the NDDP (Kalpakkam) are as follows:

1. to establish the indigenous capability for the design, manufacture, installation and operation of nuclear desalination plants.
2. to demonstrate the safe and economic production of water.
3. to generate necessary design inputs and optimum process parameters for large size nuclear desalination plant (10 MGD).

![Fig.1 6,300 m³/d hybrid MSF-RO desalination plant coupled to 170 MWe PHWR](image)
The hybrid plant is envisaged to have a number of advantages:

1. A part of high purity desalted water produced from MSF plant will be used for the makeup demineralised water requirement (after necessary polishing) for the power station.
2. Blending of the product water from RO and MSF plants would provide requisite quality drinking water.
3. The RO plant will continue to be operated to provide the water for drinking purposes during the shutdown of the power station.

The 6300 m$^3$/d combined MSF-RO nuclear desalination project is located in between the existing 170 MW(e) PHWR MAPS and proposed 500 MW(e) FBR at Kalpakkam. The MSF plant uses the required quantity of low pressure (LP) steam for seawater desalination. In order to avoid any chance of ingress of radioactivity (tritium) to MSF process and product water, it has been decided to incorporate an isolation heat exchanger between MAPS steam supply and the brine heater of MSF. The LP steam is tapped from the manholes in the cold reheat lines after HP turbine exhaust from both the nuclear reactors (MAPS I and II). The moisture content is removed through a moisture separator. The steam is sent to intermediate isolation heat exchanger to produce process steam for brine heater of the MSF plant. It is designed to keep the steam temperature in brine heater below 130°C to avoid scaling on the tube side. The condensate from the isolation heat exchanger is returned back to the deaerator section of the power station. Adequate provisions for monitoring and control have been incorporated for isolation of the steam supply in case of shutdown of the power station or desalination plant.

NDDP requires around 2000 m$^3$/hr of seawater. After detailed study, it has been decided to use process cooling water from MAPS outfall as a source of seawater supply for NDDP. Normally, the cooling water discharge has no debris since the intake water passes through the trash rack and travelling water screens. It is reported to have less biofouling potential.

Considerable progress has been achieved in the implementation of the project. Fig.2 indicates the progress of civil work at the site. Indents for all the major equipment and materials for NDDP have been released and are in various stages of procurement and fabrication at the site. Useful design data are expected from the plant on the coupling of SMR based on PHWR with a hybrid desalination plant. This will also help in scaling up and taking the advantage of the economy of scale to larger size (10 MGD) commercial plants. India will share the O&M experience of NDDP to member states of IAEA when the plant is commissioned as per schedule.

Low temperature evaporation plant utilizing waste heat from research reactor (CIRUS)

As the energy cost contributes about one third of the total water cost, efforts are directed towards the utilization of waste heat which is available free of cost. Desalination Division has an active programme to study the possibility of use of large amount of
waste heat of nuclear research reactor and PHWR for seawater desalination using low temperature evaporation technology. The know-how for the desalination plant based on low temperature evaporation (LTE) utilizing low-grade waste heat (as low as 53°C) for producing pure water from seawater was developed. A 30 m³/d pilot plant was installed and operated for endurance test. This unit is eco-friendly because it does not require exhaustive chemical pretreatment.

Mainstay of Indian nuclear reactors is the PHWR type using natural uranium oxide as fuel and heavy water as moderator and coolant. About 40 MW(th) and 100 MW(th) of waste heat are available in the moderator system of 220 MW(e) and 500 MW(e) PHWR respectively. A significant part of this waste heat can be utilized for seawater desalination. The 30 m³/d LTE plant earlier established at Desalination Division is being shifted to the CIRUS research reactor for its coupling to the reactor (Fig. 3). The plant will be commissioned in the current year. It will demonstrate the coupling of LTE desalination plant to nuclear research reactor and the feasibility of using low quality nuclear waste heat for seawater desalination. The plant eliminates the elaborate chemical pretreatment of feed water for producing demineralised water. The data from this plant will be useful for design of larger size LTE seawater desalination plant for the production of demineralised water and process water.

Fig.3 Schematic diagram of the LTE desalination plant coupled to nuclear reactor (CIRUS)
Such plants would be ideal for industries where waste heat is available in the form of fuel gas and process heat. It is an attractive alternative for producing pure water from high salinity or sea water for the rural areas where waste heat from DG sets/solar energy is available. Consultancy services were provided to the Union Territory of Lakshadweep in utilizing the waste heat of the DG sets for LTE desalination. A 10 m³/d LTE desalination plant utilizing the waste heat of 400 KVA generator has been operating in Kavaratti for producing pure water from seawater.

The total water requirement for the LTE desalination plant is quite high. Work has been initiated to bring down the total water requirement by 20-30 times by coupling a cooling tower and recycling the condenser water. It will be a totally indigenous, reliable and rugged desalination system. Energy requirement can be further brought down by employing more number of effects. The design of such plants of larger capacity for Advanced Heavy Water Reactor (AHWR) program has also been taken up. Studies are undertaken towards utilizing low quality waste heat from the steam and feed water system of AHWR for producing demineralised (DM) water from high salinity water or sea water.

Innovative Developments Undertaken

Improved heat transfer for MED

Basic studies carried out earlier on a horizontal tube thin film (HTTF) boiling indicate that the bubble nucleation in the thin film on the tube takes place with rapid bubble growth. The application of forced convection due to liquid spray on the tube increases the convective contribution and results in early removal of bubble adhering to the surface which increases bubble frequency. The overall heat transfer coefficient in the range of 3-4 kW/m²K was obtained which is about three times the heat transfer coefficient as compared to submerged tube evaporator. High heat transfer coefficient implies low heat transfer area requirement and in turn low capital cost. The data collected on the fluid flow and heat transfer aspect of the boiling in a thin film were used in the design and installation of 1 m³/d HTTF desalination unit for MED (Fig. 4). Low temperature vapour compression desalination plants of 50-200 m³/d capacities are suitable for providing drinking water in the rural/ water scarcity areas and process water/boiler feed water for industries. MED with mechanical vapour compression is ideal for areas where only electrical energy is available and sufficient cooling water is not available. MED with thermocompression are suitable for the regions where high pressure (5-10 bar) steam is available.

Fig. 4 HTTF desalination unit for MED

It produces low conductivity water directly from the high salinity water. It is planned to carryout high temperature MED studies using nanofiltration (NF) in the upstream for the makeup feed pretreatment. Laboratory data on NF indicate substantial reduction of the scale causing constituents in seawater when it is passed through it. The use of NF permeate as makeup feed to MED will provide high Gain Output Ratio (GOR) by operating it at higher top brine temperature. NF helps in removing the total hardness thus reducing the energy and chemical consumption.

Improvements in reverse osmosis for desalination

The RO desalting industry is looking for continued reduction of the cost of desalted water. This calls for the development of better quality membranes offering higher output while maintaining the optimum
salt rejection, reduced chemical pretreatment, longer membrane life and low energy requirement.

Fig. 5 SWRO pilot plant at Trombay

R&D work on indigenous development of advanced polyamide based thin film composite (TFC) membranes has been undertaken at the Division to meet these objectives. After successful development of brackish water RO desalination plants to demonstrate the utility of RO desalination systems in meeting the drinking water needs of brackishness affected villages, a 40 m$^3$/d seawater RO plant has been setup in Trombay for producing drinking quality water (Fig. 5). The plant is being upgraded to 100 m$^3$/d capacity. The conventional pretreatment system has been setup, which includes chlorination, clarification, media filtration, chemical dosing and cartridge filtration. It is planned to introduce membrane based pretreatment system using ultrafiltration (UF) and nanofiltration (NF). The adoption of UF and NF is envisaged to reduce the elaborate feed treatment for removal of scaling constituents, suspended impurities, organics and microbial load. UF installed upstream of RO is very effective as a pretreatment setup. Preliminary investigations have been carried out by using NF as a means to improve the performance of desalination plant. NF reduces the hardness ions of calcium, magnesium and sulfate to a great extent. It also partially reduces the TDS of seawater. This results in reduced seawater treatment and higher recovery.

A brackish water RO plant is setup in Rajasthan in cooperation with Defence Laboratory, Jodhpur, for providing drinking water to the villagers from high salinity brackish water sources. Another RO plant is to be set up at village Chadi (Barmer) for removal of excess fluoride and nitrate apart from brackishness.

**Effluent treatment and zero discharge**

Due to an increasing demand for good quality water, attempts have been directed to treat the waste water for reuse and recycle. The approach is further reinforced by the need to preserve the environment and to follow a zero discharge concept wherever possible. R&D work in the field of thermal and membrane processes has been pursued for the treatment of waste water and removing pollutants from the effluent stream for safe discharge into environment and recovery of significant fraction of the water for reuse. Selection of a process for treatment of a particular waste water is based on product requirements, influent water characteristics and cost. Industrial waste water often is the combined product of a number of different manufacturing processes in the complex. The membrane processes that are useful for waste water treatment include: microfiltration, ultrafiltration, nanofiltration and reverse osmosis. The suspended solids in waste water are successfully removed by microfiltration. Ultrafiltration is useful in separating macromolecules and the submicron particles including oil emulsion and very large molecules such as polymeric compound having a polymeric weight of 1000 and above. Nanofiltration is capable of separating molecules in the range of 300-1000 molecular weight. It also helps in selective separation of low molecular weight organics from salt solution. Reverse osmosis has very small pore size (5-10 Å) suitable for removing ions and molecules. Laboratory scale studies are continuing on development of such membranes and their performance evaluation. As no two waste waters are exactly alike, it is necessary to carryout laboratory evaluations to determine the flux rate under different temperatures and pressures for individual waste water samples. LTE and VC desalination is ideal for treating high salinity effluent and producing pure water for reuse.
**Barge mounted desalination unit**

Barge mounted desalination plant offers a suitable choice for remote locations and small islands or coastal communities where the necessary manpower and infrastructure to support desalination plants are not available. It can be installed anywhere anytime depending on the need in coastal regions. It can supply potable water to remote coastal regions or islands where both good quality water and the energy sources are severely lacking. It does not require intake or outfall infrastructure. It is planned to setup a barge mounted 50 m$^3$/d seawater RO plant. The preliminary details have been worked out. The design considerations of a barge mounted plant are different from those of land based plant. The limitations due to marine environment including conditions of sea and wind, space availability, weight limitations and technical considerations including pump cavitation and vibration are considered in the design stage.

**Participation in the IAEA activities on nuclear desalination**

Guidebook on 'Introduction of Nuclear Desalination': Contributions were made in the preparation of a guidebook on 'Introduction to Nuclear Desalination' and a number of TECDOCs related to nonelectrical applications.

Optimization of the coupling of nuclear reactors and desalination systems: Desalination Division has undertaken a Coordinated Research Project (CRP) entitled 'Performance Improvement of Hybrid Desalination Systems for Coupling to Nuclear Reactors' (IAEA Research Contract No. 10245/RO) for optimization of the coupling of nuclear reactors and desalination systems. The objective of the applied research project is to study the behaviour of MSF, RO and LTE plants under different operating conditions utilising data for improving the performance of hybrid MSF-RO plant coupled to PHWR, and LTE plant coupled to nuclear research reactor.

Economic research on, and assessment of, selected nuclear desalination projects and case studies: It is proposed to take up another CRP entitled 'Economic Assessment of Hybrid Nuclear Desalination Project' for the economic research and assessment. The study would involve evaluation of the economic aspects of hybrid nuclear desalination project. The competitiveness of the hybrid nuclear desalination under specific conditions would be studied. Emphasis will be laid on aspects of cost reduction strategies through technological innovations in both thermal and membrane processes. Economic assessment will be useful in establishing the hybrid nuclear desalination plants for the ultimate benefit of the society.

**Conclusions**

The development work has generated capability in the country to design, fabricate, commission and operate small and large size desalination plants. Efforts are now directed towards reducing the cost of desalted water through technological innovations. In the case of thermal processes, this calls for capital cost reduction through heat transfer enhancement and use of cheaper materials, low grade or waste heat utilization and least chemical pretreatment. Today, production of boiler quality water and high quality process water from sea water desalination is cheaper than that produced from conventional DM plant using raw water where the raw water contains 500 ppm or more salinity. In the case of membrane processes, attempts are continued towards the development of better membranes, least pretreatment, longer membrane life and reduced energy consumption. Effluent treatment and water reuse through desalination route, as a step towards zero discharge, appears promising. The development of barge mounted desalination units will go a long way as a means of pure water supply to remote coastal areas anywhere and at anytime. The technological innovations in desalination would lead to its large scale application and provide opportunities for the socioeconomic development of water scarcity areas and large coastal arid zones of the country.