Advances in Nuclear Desalination in BARC (India)

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Abstract. As a part of our national programme to improve the quality of life of our large population by systematic induction of nuclear energy, Bhabha Atomic Research Centre (BARC) has been engaged in research and development activities 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 seawater, electrolytic production of hydrogen and electrothermal production of phosphorus. These activities are presently termed by IAEA as 'Non-electrical Application of Nuclear Energy'. The development work done at BARC has generated capability to design, fabricate, commission and operate large and small size desalination plants indigenously for large scale deployment and providing opportunities for the socio-economic development of water scarcity areas and large coastal arid zones in the country.

1. Introduction

The founders of Atomic Energy Programme of India have envisioned the critical role of Nuclear Energy in our national development. With compact fuel and stringent operational & safety requirements, large unit capacities were considered appropriate to meet the demand for power. Further to ensure the overall growth of the country, a visionary programme of Nuclear Agro-industrial Complex (NUPLEX) was conceived (Fig.1) for the simultaneous development of energy intensive technologies such as desalination to meet the growing requirements of fresh water.

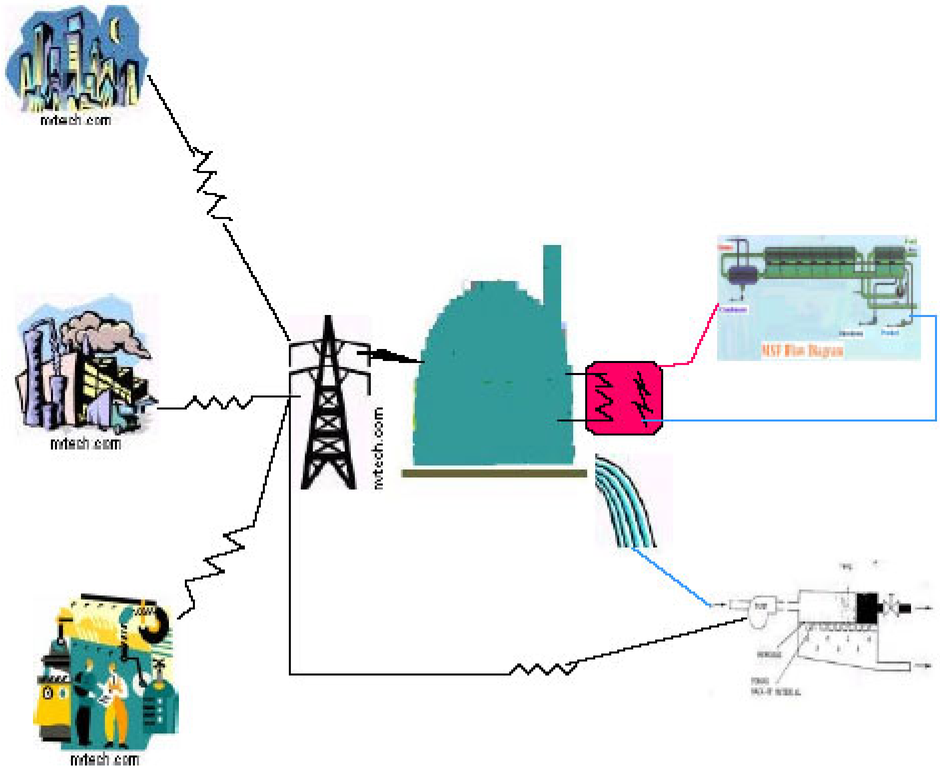

FIG. 1. Nuclear Agro Industrial Complex as envisioned by the founders

Over a period of time, BARC has successfully developed desalination technologies based on multi-stage flash (MSF) evaporation, reverse osmosis (RO) and low temperature evaporation (LTE) and transferred the know-how to several parties for commercial use. In the field of thermal desalination, efforts are directed towards utilizing the low grade heat and the waste heat as energy input for desalination. In membrane desalination, work is being carried out on newer pretreatment methods such as use of ultrafiltration, energy reduction and higher membrane life. Based on these technologies, a number of desalination and water reuse plants have been successfully demonstrated. These include desalination plants for conversion of sea water into fresh potable water, providing safe drinking water in areas affected with brackishness and for process applications including industrial and radioactive waste treatment as given in Table I.

Table I. Some of the Pilot Plants set up by BARC

	Description	Date of commissioning
I.	Thermal	
1.	15,000 litres/day MSF experimental facility for sea water desalination	1975
2.	30,000 litres/day Low Temperature Evaporation (LTE) desalination unit using waste heat	1985
3.	4,25,000 litres /day MSF desalination plant	1990
4.	1,000 litres/day Thermocompression (TC) desalination unit	1997
5.	10,000 litres/day LTE desalination plant using waste heat for sea water desalination at Lakshadweep	1997
6.	1,000 litres/day Horizontal Tube Thin Film (HTTF) desalination unit	2002
7.	30,000 litres/day Low Temperature Evaporation (LTE) desalination unit using waste heat of nuclear reactor (CIRUS) for sea water desalination.	2004
II.	Membrane	
1.	2 x 30,000 litres/day brackish water RO plants providing drinking water in villages of Andhra Pradesh & Gujarat	1984
2.	50,000 litres/day RO unit for industrial effluent treatment for a fertilizer complex	1986
3.	2 x 10,000 litres/day RO units for treatment of radioactive liquid effluents	1990
4.	15,000 litres/day RO-DM plant at Variable Energy Cyclotron (VEC) for production of low conductivity water	1994
5.	24,000 litres/day Nanofiltration (NF) plant for a pharmaceutical industry	1998
6.	30,000 litres/day brackish water RO plant providing drinking water in a village in Rajasthan	1998
7.	1,00,000 litres/day Sea Water RO plant at Trombay	1999
8.	30,000 litres/day RO plant providing drinking water for a village in Rajasthan	2003

2. Nuclear Desalination Demonstration Project (NDDP)

Based on decades of operational experience of MSF (Fig. 2) and RO plants (Fig. 3) at Trombay, BARC has undertaken setting up of the Nuclear Desalination Demonstration Project (NDDP) at Kalpakkam. NDDP consists of a hybrid MSF-RO desalination plant of 6.3 million litres per day (MLD) capacity (4.5 MLD MSF and 1.8 MLD RO) coupled to 2 x 170 MWe Madras Atomic Power Station (MAPS), Kalpakkam (Fig. 4). The requirements of seawater, steam and electrical power for the desalination plants are met from MAPS I & II. The hybrid plant has provision for redundancy, utilization of streams from one to another and production of two qualities of products for their best utilization [1]. The RO plant may use the cooling sea water of the MSF plant as feed which is about 8C higher than the ambient temperature. The higher temperature operation of RO gives high throughput. It is also possible to use reject sea water from RO plant as feed for MSF plant. It saves the chemical pretreatment for the MSF feed.

FIG. 2. MSF desalination plant at Trombay (capacity : 4,25,000 litres/day)

FIG. 3. SWRO plant, Trombay (capacity : 1,00,000 litres/day)

The SWRO plant (Fig. 5), which is already commissioned in 2002, draws sea water from the outfall of Madras Atomic Power Station, whose temperature is about 2-3 deg.C higher than that of the normal sea water, which is an added advantage for the RO plant. The plant incorporates necessary pretreatment and an energy recovery system and produces potable water of about 500 ppm total dissolved solids (TDS) resulting in lower water cost. The plant operates at relatively lower pressure to save energy, employs lesser pre-treatment chemicals (because of relatively clean feed water from MAPS outflow) and aims for longer membrane life. It is expected that these membranes will last for five years. The potable water produced is supplied to nearby areas. The MSF plant which is in advanced stage of construction (Fig. 6) is designed for higher top brine temperature with Gain to Output Ratio (GOR) of 9:1 and utilizes less pumping power (being long tube design). The desalination plant can meet the fresh water needs of around 45,000 persons @ 140 lpcd. There is a provision for augmentation of product water capacity by blending the low TDS product water of MSF plant with brackish ground water/ moderate salinity permeate from SWRO plant. This will then serve the need of larger population. The scheme has been appreciated by International Atomic Energy Agency (IAEA). BARC (India) is a front runner in nuclear desalination as per IAEA.

A part of high purity desalted water produced from MSF plant will be used as the make up demineralised (DM) water after necessary polishing for the power station. Blending of the product water from RO and MSF plants would provide high quality drinking water (about 200 ppm TDS). The RO plant operation can continue to provide water for drinking purposes even during the shut down of the power station.

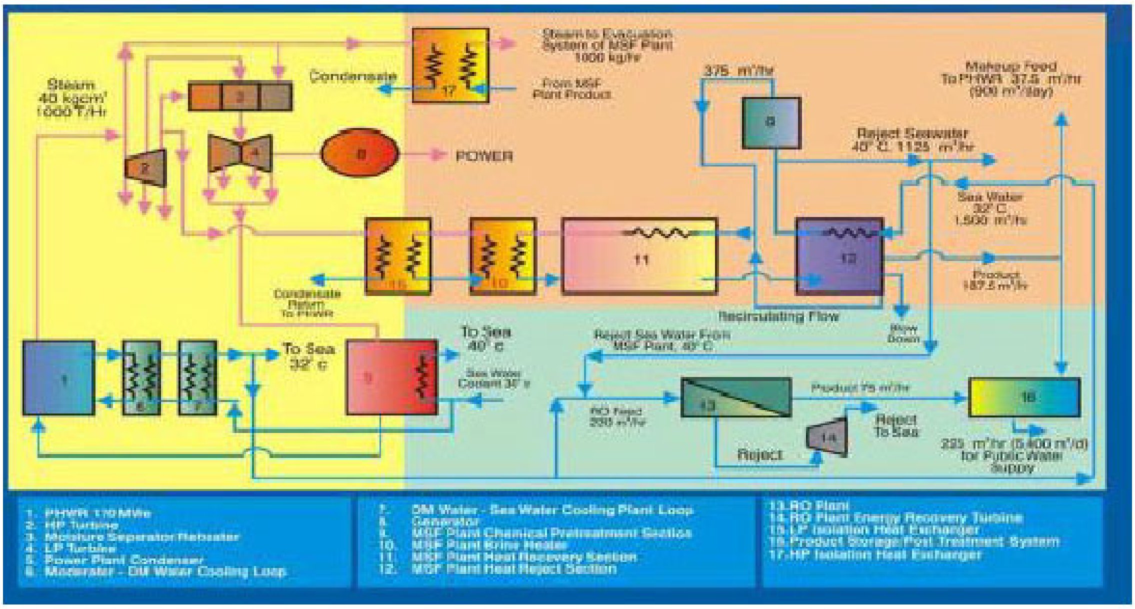

FIG. 4. MSF-RO desalination plant (capacity: 6.3 MLD) coupled to 170 MW(e) PHWR (MAPS, Kalpakkam)

FIG. 5. View of SWRO plant building and membrane modules at NDDP (Kalpakkam)

FIG. 6. MSF plant under construction at NDDP, Kalpakkam

3. Multi-Stage Flash (MSF)

Studies were initiated on Multi-Stage Flash (MSF) desalination process in 1973. A pilot plant of 15,000 litres/day capacity was indigenously designed, fabricated, erected and commissioned in 1975 for the first time in India, to gain first hand experience on the engineering & operational aspects. The unit consisted of three stage cylindrical flash module, brine heater, de-aerator and other accessories. Valuable data was collected for different operating conditions. Based on these data a 4,25,000 litres/day MSF desalination plant with 33 stages was designed, installed and operated producing very pure water from sea water. It incorporated far-reaching design considerations such as long tubes rather than cross tubes and rectangular flash chambers instead of circular ones to reduce capital and operating cost. The plant efficiency was improved by employing a top brine temperature of 121°C with acid dosing rather than the then universally prevalent top brine temperature of 88°C, resulting in lower operating cost. The operation of this plant gave enough confidence in the design and pioneer further growth of thermal desalination in India.

4. Low Temperature Evaporation (LTE)

As the energy cost contributes about one third of the total water cost, efforts were directed towards developing low temperature evaporation (LTE) process, which could be useful in the utilization of waste heat available free of cost. A 30,000 litres/day LTE desalination plant (Fig.7) utilizing waste heat for sea water desalination was designed and installed at Trombay based on the design and operating experience gained from 1,000 litres/day LTE desalination unit earlier. It was successfully operated as per design intent for endurance test without any chemical pretreatment producing very pure water from sea water. Such plants are ideal for industries where waste heat is available. These plants can also produce pure water from high salinity water or seawater for the rural areas where waste heat from DG sets / solar energy is available. A 10,000 litres/day LTE desalination plant, utilizing the waste heat of 500 KVA generator at Kavaratti, Lakshadweep island (Fig. 8) in the south west part of the country was installed in 1997 under our consultancy and guidance for producing pure water from seawater. Nuclear research reactors produce significant quantities of waste heat. A scheme was developed to integrate a desalination unit such that the technology of utilizing reactor waste heat for desalination of sea water by a LTE process can be demonstrated. For conducting a practical demonstration of LTE technology a 30,000 litres/day LTE desalination plant (Fig. 9) was designed to utilise the waste heat of nuclear reactor to produce high quality process water [2]. The desalination plant has been integrated with CIRUS reactor and successfully commissioned recently for demonstration of coupling to nuclear research reactor. The product water from this plant meets the make up water requirement of research reactor. The nuclear research reactor (CIRUS) has a capacity of 40 MW(th) using metallic natural uranium fuel, heavy water (D_2O) moderator, demineralized light water coolant and seawater as the secondary coolant. An intermediate heat exchanger has been incorporated between the nuclear reactor (CIRUS) and the desalination plant to ensure no radioactive contamination and high protection of desalted water. The data from this plant will be useful for the design of larger size LTE seawater desalination plants for the production of demineralized water and process water.

Mainstay of Indian nuclear reactor is the PHWR type using natural uranium oxide as fuel and heavy water (D_2O) as moderator and coolant. About 40 MW(th) and 100 MW(th) low temperature waste heat is available in the moderator systems of the 220 MW(e) and 500 MW(e) PHWRs, respectively. A significant part of this waste heat can be utilized for producing DM water from seawater using LTE technology for seawater desalination .

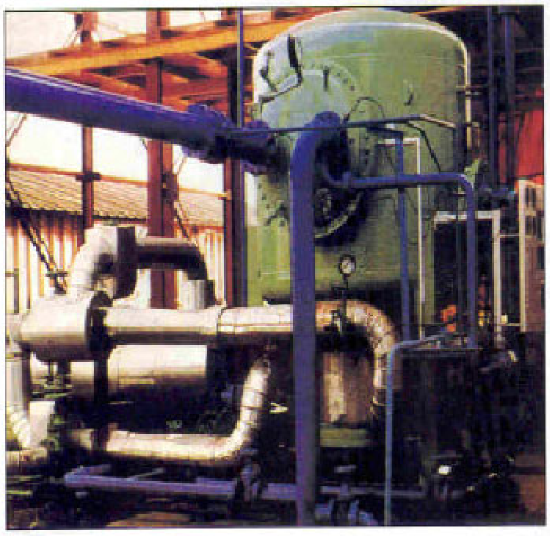

FIG.7. LTE desalination plant (capacity : 30,000 litres/day

FIG. 8. LTE sea water desalination plant using waste heat at Kavarati, Lakshadweep (capacity : 10,000 litres/day)

This concept resulting in utilizing, the otherwise irrecoverable waste heat, has not only resulted in the savings of water demineralization costs due to high purity of desalted water but also in the conservation of the municipal water which is otherwise a valuable resource. The work on further developments has been undertaken to reduce cooling water make up requirements and use of multi-effect desalination systems to improve efficiency. A pilot plant of 50,000 litres/day low temperature evaporator using waste heat (hot water at around 65°C) is being set up as a part of ongoing activities. A cooling tower will be coupled to bring down the large cooling water requirements. Based on the data obtained from 1,000 litres/day Horizontal Tube Thin Film (HTTF) desalination unit (Fig. 10), a Low Temperature Multi Effect Distillation – Vapour Compression (MED-VC) type desalination plant has been designed and developed which would be ready by 2005 end. Due to low operating temperature, this plant does not require any chemical pretreatment of the feed water. It would produce demineralised (DM) quality product water. Such units can be installed in rural inland areas having high brackish water sources and coastal areas.

FIG. 9. Low temperature evaporation desalination plant at CIRUS (capacity : 30,000 litres/day)

FIG. 10. HTTF desalination plant (capacity : 1,000 litres/day)

An MED seawater desalination plant is proposed to be integrated with the Advanced Heavy Water Reactor (AHWR) for producing 500 m^3 /day demineralised (DM) water for inhouse requirement (Fig.11). AHWR is a 300 MWe, vertical, pressure tube type, boiling light water cooled and heavy water moderated reactor. A small fraction of low pressure (LP) steam from LP turbine will be used for sea water desalination in MED plant.

5. Reverse Osmosis (RO)

The utility of semi-permeable membranes for desalination of saline water was discovered in mid sixties and the demonstration of its desalination potential was carried out in a tubular configuration by late sixties. Having visualized the vast potential of the membrane technology, research & development activities in BARC was initiated in 1973. The first set of membranes based on cellulose 2.5 acetate, were cast in our laboratory in 1975. Initially small sheet membranes were cast for developmental studies but for process use tubular membranes were made in porous aluminium tubes. In 1976, a unit capable of yielding 4 lpm fresh water from 5000 ppm feed at 30 bar pressure with tubular membranes supported by porous aluminium tubes was demonstrated (Fig. 12). Later a pilot plant of 10,000 litres/day was operated to gain an insight into the operating problems.

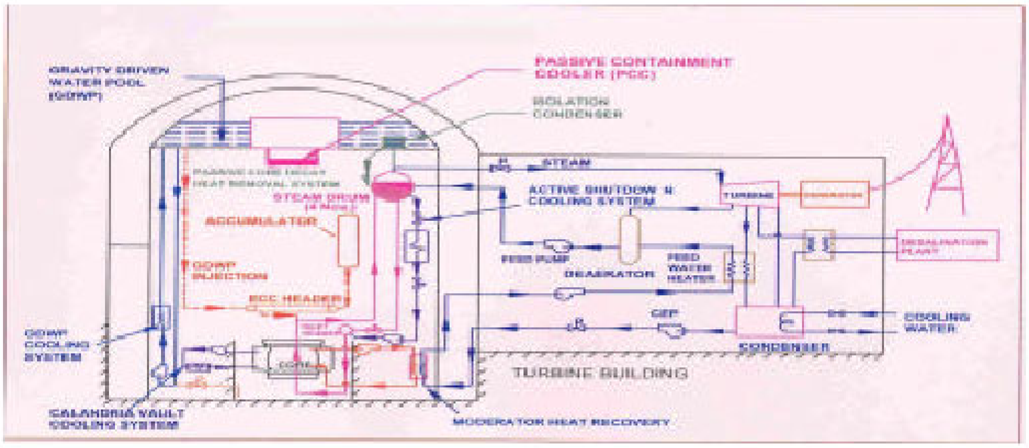

FIG. 11. Seawater desalination plant (500 m3/day capacity) coupled to Advanced Heavy Water Reactor (AHWR)

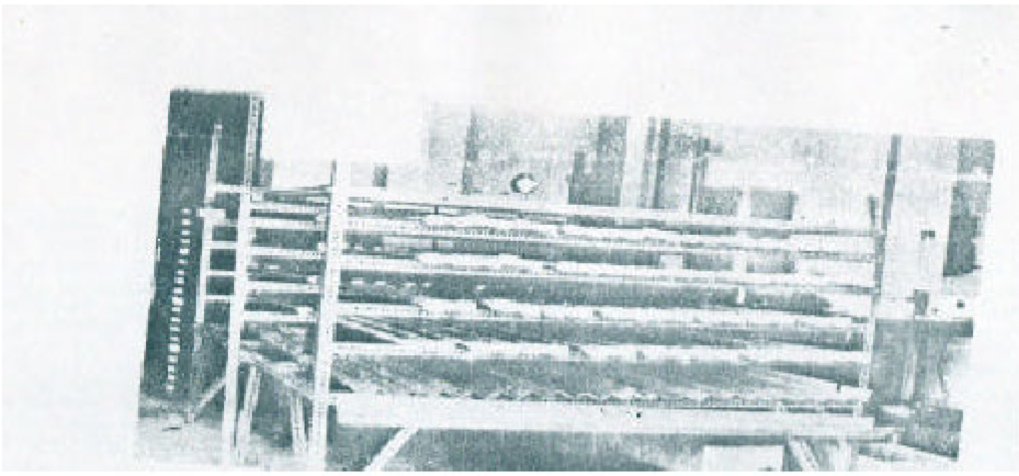

FIG. 12. First RO plant installed at Desalination Division (1975) based oncellulose acetate membranes supported by porous aluminium tubes.

In 1984, Government of India decided to assess the utility of RO technology for desalination of brackish water in remote villages to mitigate the drinking water problem through the then Ministry of Works and Housing. Two 30,000 litres/ day plants were designed and installed at the remote villages of Kattuvapalli at Nellore, Andhra Pradesh (Fig. 13) in the southern part and Malika, Surendranagar, Gujarat in the western part of the country. The plants commissioned in 1985 were operated with local people gaining valuable experience with reference to operation of these plants in remote locations. The BARC developed RO technology was transferred to several parties on nonexclusive basis. BARC has provided active support to the water mission in the water quality monitoring and analyzed large number of water samples for the presence of brackishness, nitrate, fluoride, iron etc. from various affected districts of India.

FIG. 13. Brackish water desalination plant (capacity 30,000 litres/day) for the supply of drinking water to remote villages (Katuvapalli, Nellore, Andhra Pradesh 1985)

A 50,000 litres/day RO plant was set up in a fertilizer complex in 1986 based on plate module to demonstrate the recovery of water from effluents for recycle in the process (Fig. 14). The application was extended to radioactive effluent treatment and a pilot plant was set up to achieve a decontamination factor of more than 10 with a volume reduction factor of 10. Successful demonstration led to the design of a 100,000 litres/day plant for low level radwaste decontamination and the plant is now a part of the recently commissioned WIP at Trombay. In another development, around 1993-94 a reverse osmosis plant was set up at uranium metal plant to demonstrate its ability to separate the radioactive species (uranium & its daughter products) from the dissolved ammonium nitrate species with a volume reduction factor of 50 and a decontamination factor of 50. To meet the inhouse needs of demineralised water a 15,000 litres/day RO plant was commissioned at Variable Energy Cyclotron (VEC), Kolkatta in 1994. In 1996, a plant was established in an industry for the concentration of calcium lacto-bionate based on cellulose acetate blend membrane.

FIG. 14. Inauguration of 50,000 litres /day water recycling plant based on plate module RO installed at RCF, Mumbai (1986)

By this time the first spiral element was developed (Fig.15) and the in house requirements of sterile water could be met using our own membranes and configurations.

FIG.15. Spiral elements developed in-house (1988)

A 40,000 litres per day plant was installed at Trombay for seawater desalination. The pilot plant experience has been used in the design of SWRO plant for Nuclear Desalination Demonstration Project at Kalpakkam. At present the sea water desalination plant has been upgraded to 100,000 litres/day capacity and is used for testing new concepts on pretreatment and design evaluation of subsystems. Based on the expertise gained, consultancy services were provided to install RO plants for desalination and water recycling. In order to meet the fresh water requirements in isolated coastal areas, during natural calamities and emergency, the development of a barge mounted RO unit of 50,000 litres/day is underway which will be ready in December 2005. The RO unit is installed on a barge. The high pressure pumps of RO unit is diesel operated instead of electrically driven.

The research and development work on advanced membrane is underway for widening the scope of membrane technology to include effluent treatment, water reuse and various industrial applications. As there were a number of limitations with cellulose acetate membranes, being susceptible to biodegardation, hydrolysis etc. four types of polyamides "poly m-phenylene isophthalamide", "polyamide hydrazide", "polyetheramide hydrazide" and "polysulfonamide" polymers, were successfully synthesized and membranes were prepared. Laboratory developed membranes have already shown solute rejection upwards of 95%. Casting machine for the production of macroporous polysulphone substrate and a coating machine for the preparation of TFC membranes have been designed and installed. BARC has actively participated in the National Drinking Water Mission and setup a number of small reverse osmosis (RO) plants in the villages during eighties. In recent years, a RO plant has been installed by BARC in village Sheelgan, Barmer District (Rajasthan) in western part of India. Another plant has been installed in Satlana village, Jodhpur in west India in Jan. 2003 (Fig. 16). Table II gives the operating data of the 30,000 litres/day (30 m^3/d) RO plant at Satlana village producing drinking water from brackish water. Performance of RO for fluoride removal is given in Table III.

FIG. 16. RO plant installed at Satlana Village, Rajasthan, for providing drinking water to villagers (2003)

Table II. Operating data of 30 m^3/d RO plant, Satlana village, Jodhpur Dist. (Rajasthan)

Feed Pressure : 160 psig (11 bar) Recovery : 45%

Date	Feed TDS (ppm)	Permeate Flow (lpm)	Permeate TDS
23.05.03	9810	21	376
20.04.03	9560	21	364
20.03.03	8940	21	269
24.02.03	8190	21	247
01.02.03	7540	21	208

Table III. Performance of RO Membrane for Fluoride Removal

Membrane Type : TFCP(BW30) Operating Pressure : 10 bar

Feed TDS ppm	Fluoride in feed (ppm)	% Recovery	Permeate TDS (ppm)	Fluoride in permeate (ppm)
1200	4	50	52	0.15
1200	4	75	66	0.25

Recently, based on the request received from Lakshadweep administration, BARC has completed the detailed project report for a 0.6 MLD (600 m^3/d) Sea Water Reverse Osmosis (SWRO) plant at Kavaratti (Lakshadweep) for producing drinking water from sea water. Similarly, on the request from Diu administration, the detailed project report for 3.0 MLD (3000 m^3/d) and 4.5 MLD (4500 m^3/d) SWRO plant at Diu island has been completed for producing drinking water from sea water.

6. On Line Domestic Water Purifier

Ultrafiltration process, where porous polymeric or ceramic membranes are used under relatively low pressure is capable of separating colloidal impurities, dissolved macromolecular solutes and bacteria from water systems. It is a single step continuous separation process wherein a host of undesirable contaminants are removed simultaneously. Ultrafiltration is increasingly adopted as an efficient surface water treatment and pretreatment technique. Several polymeric ultrafiltration membrane systems such as polysulfone, polyethersulfone, cellulose acetate butyrate and cellulose propionate polymers have been developed in BARC. As an offshoot of this development, BARC came out with a membrane based On-line Domestic Water Purifier.

On line domestic water purifier based on polysulfone ultrafiltration membrane is a unique cylindrical configuration, capable of removing bacteria, turbidity and produces crystal clear water. The device does not need electricity or addition of any chemical. It works under hydrostatic head of 1.5 to 3.5 bar and can produce about 40 litres of safe drinking water per day. It is maintenance free except cleaning the deposits over the membrane surface periodically. The device as shown in Fig.17 is mechanically and chemically stable and is expected to be functionally useful for a minimum period of 5 years. During the last one year, the know-how of this technology has been transferred to ten private parties for commercialization on non-exclusive basis. The product has already been brought out in the market by several BARC licensees (Fig. 18).

FIG.17 : Domestic Water Filter developed by Desalination Division to produce bacteria and safe free water

FIG. 18. The product (Domestic Water Filter) brought out in the market by BARC Licensees

7. International Co-ordination

BARC is a member of International Nuclear Desalination Advisory Group (INDAG) of International Atomic Energy Agency (IAEA) to assist Member States in the process of preparatory actions for nuclear desalination demonstration projects and providing advice and guidance on IAEA activities in nuclear desalination. BARC has been participating in Coordinated Research Projects (CRPs) of IAEA and sharing the expertise with other Member States in different aspects of nuclear desalination.

8. Consultancy Services

Consultancy services have been provided to several private parties and public sectors on desalination and water reuse. BARC is providing its expert services to a petrochemical complex for seawater cooling system and revamping of their RO plant for effluent treatment and water recycle. BARC has been interacting with the Government of Rajasthan, Union Territory of Lakshadweep, Diu administration and will further expand this contact with the Government of Gujarat, Maharastra, Andhra Pradesh etc. Enough expertise is available for the design of large size MSF and RO plants for seawater desalination. Expertise is also available on utilization of low grade and waste heat for producing pure water from saline water. There is a serious interest in the country to put up a number of large size plants of million litres per day (MLD) capacity for brackish and sea water desalination, treatment of effluent for water reuse as well as process stream concentrations.

9. Road Map

In the area of desalination of water, BARC has been working on a number of challenging and innovative concepts. The road map for BARC includes:

- To gain operational experience of 6300 m^3/day MSF-RO nuclear desalination plant at Kalpakkam.
- To utilize the data for detailed design of 100,000 – 300,000 m^3/d (100 – 300 MLD). desalination plants coupled to nuclear power station for deployment in water scarce coastal areas.
- To interact with different companies & Public Sector Units interested in adoption of desalination for manufacture of commercial scale plants.
- To provide consultancy to various parties interested in desalination & water reuse.
- To continue R&D for indigenous development of new thermal & membrane technologies for cost effective desalination, water purification, effluent treatment & recycling.

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