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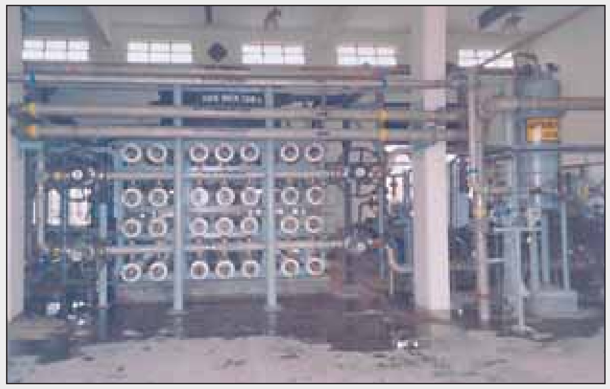

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Chapter 8

Management of Water Resources - Desalination Technologies

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Department of Atomic Energy
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Captions for Photo-Collage

1. *Artist's view of a multistage flash plant*
2. *Sea Water Reverse Osmosis (SWRO) plant building and membrane modules at Kalpakkam*
3. *Reverse osmosis plant at Saltana village, Jodhpur, Rajasthan*
4. *Reverse osmosis plant (capacity : 30 cubic metre per day) set up at Sheelgan village, district Barmer, Rajasthan*

Desalination Technologies

India receives abundant rains. The average annual precipitation is estimated to be about 4000 billion m^3. Only 1000 billion m^3/year is available as usable surface water and ground water. At present the water consumption in India is about 750 billion m^3/year for all the applications viz., agricultural, industrial, domestic and commercial. Assuming a conservative figure of per capita water consumption of 1000 m^3/year, the water availability in the country is likely to get fully stretched by the year 2010 unless augmentation is planned right now. The consumption norm of 1000 m^3/year is only 10-20% of the per capita consumption in industrialised countries. Moreover the geographical distribution and seasonal variation of rainfall are not uniform. There are pockets like Saurashtra and Kutch, the coastal areas of Tamil Nadu and land locked areas of Western Rajasthan and Marathwada in Maharashtra with scanty rainfall and perennial water scarcity. A holistic approach is therefore called for to cope with the fresh water needs of the country in the coming decades.

Government of India and the concerned State Governments have launched a number of water supply schemes. Desalination technology is one of the proven options to augment water resources in the water scarce areas. BARC has been engaged in R&D on desalination to develop indigenous technologies for providing fresh water from sea water in water scarce coastal areas and safe drinking water in salinity affected inland areas.

Also, to ensure overall growth of the country it was felt that the needs of agriculture should be satisfied. Thus, a visionary programme of Nuclear Agro-industrial Complex (NUPLEX) was conceived for simultaneous development of energy intensive technologies such as desalination to meet growing requirements of fresh drinking water, agro-chemicals like phosphorus and electrolytic hydrogen. Thus, the Desalination and Effluent Engineering Division was born at BARC with a mandate to develop the technologies on desalination, electro thermal phosphorous and hydrogen.

Desalination Technologies Developed

The R&D activities on desalination were initiated in the 1970s and were based mainly on thermal processes initially. Pilot plant projects were started on 15000 liters per day multi-stage flash (MSF) plant called Desalination Experimental Facility (DEF). During this period the potential of reverse osmosis as desalination process was just emerging and was showing signs of commercial viability. Later in the 1980s R&D effots towards development of membrane processes for reverse osmosis (RO) were also undertaken.

Thermal desalination serves as a part of dual-purpose power plant that can lead to economic production of both power and water. On the other hand, membrane technology can be a stand-

Desalination Pilot Plants set up by BARC

Description	Date of Commissioning
A. Thermal	
1 15,000 liters/day MSF experimental facility for sea water desalination	1975
2 30,000 liters/day Low Temperature Evaporation (LTE) desalination unit using waste heat	1985
3 4.25 lakh litres /day MSF desalination plant	1990
4 1000 litres/day Thermo Compression (TC) desalination unit	1997
5 10,000 litres/day LTE desalination plant using waste heat for sea water desalination at Lakshadweep	1997
6 1000 litres/day Horizontal Tube Thin Film (HTTF) desalination unit for MED	2002
7 30,000 litres/day LTE desalination unit using waste heat of nuclear reactor (CIRUS) for seawater desalination.	2003

Description	Date of Commissioning
B. 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 plant at RCF	1986
3 2 x 10,000 liters/day RO units for treatment of radioactive liquid effluents	1990
4 15,000 litres/day RO-DM plant at VECC for production of low conductivity water	1994
5 24,000 litres/day NF plant for a pharmaceutical industry	1998
6 30,000 litres/day brackish water RO plant providing drinking water in village Sheelgan, Barmer, Rajasthan	1998
7 1 lakh litres/day SWRO plant at Trombay	1999
8 30,000 litres/day RO plant providing drinking water in village Satlana, Jodhpur, Rajasthan	2003

alone desalination system besides having many spin off applications including treatment of radioactive effluents. Over a period of time, BARC has successfully developed desalination technologies based on MSF evaporation, RO and Low Temperature Evaporation (LTE). In the field of thermal desalination, efforts are directed towards utilising low grade heat and waste heat as energy input for desalination. In membrane desalination, work is being carried out on newer pre-treatment methods such as use of ultrafiltration, energy reduction and higher membrane life.

Based on these technologies, a number of desalination plants have been successfully demonstrated during the last few years. These include desalination plants for conversion of seawater into fresh potable water, providing safe drinking water in areas affected with brackishness and for process applications including radioactive waste treatment.

Thermal Desalination

Multistage Flash Desalination

Studies were initiated on Multistage Flash (MSF) desalination process in 1973. A pilot plant of 15000 litres / day capacity was indigenously designed, fabricated, erected and commissioned in 1975, for the first time in India, to gain hands-on experience on the engineering and operational aspects. The unit consisted of three stage cylindrical flash modules, brine heater, de-aerator and other accessories. Valuable data was collected for different operating conditions. Based on these data a 4.25 lakh litres / day MSF desalination plant with 33 stages was designed, installed and operated producing very pure water from seawater. 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 394 K with acid dosing rather than the then universally prevalent top brine temperature of 361 K, 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.

Artist's view of a multistage flash plant

Low Temperature Evaporation (LTE) Unit

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 one tonne per day desalination unit suitable for use in ships, using the engine cooling water at 343 K was developed. The plant could produce pure water from seawater at an operating temperature of 326 K. Later a 30000 litres/day pilot plant utilising waste heat for sea water desalination was designed, installed and operated without any chemical pretreatment. It produces very pure water from seawater. 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 rural areas where waste heat from DG sets / solar energy is available. A 10000 litres/day LTE desalination plant, utilizing the waste heat of 500 kVA generator at Kavaratti, Lakshadweep island has been installed with DAE cooperation for producing pure water In-keeping with the adage that charity begins at home, a 30,000 litres/day LTE desalination plant was designed to utilise the waste heat (328 K) in CIRUS to produce high quality process water. The desalination plant has been integrated with CIRUS for demonstration of coupling to nuclear research reactor. The product water from this plant meets the requirement of research reactor.

Multi-Effect Distillation (MED)

Basic studies conducted on heat transfer on a Horizontal Tube Thin Film (HTTF) boiling indicated an increase of overall heat transfer coefficient to about three times as compared to submerged tube evaporator implying lower heat transfer area and low capital cost. The information on thin film boiling studies were used in the design of a 1000 litres/day HTTF desalination unit for MED which is operating successfully producing de-mineralized quality water from sea water. MED coupled to vapour compression both mechanical and thermo-compression has been found quite attractive in bringing down the water costs.

Membrane Processes

Research & development activities on membrane technology were initiated in 1973. The first set of membranes based on cellulose 2.5 acetate, were cast in 1975. A unit capable of yielding 5760 litres / day lpm fresh water from 5000 ppm feed at 30 bar pressure with tubular membranes supported by porous aluminium tubes was demonstrated. Later a pilot plant of 10000 litres / day was operated to gain an insight into the operating problems.

The corrosion of aluminium tubes and subsequent blocking of the pores prompted the search for non-metallic supports such as FRP. With the collaboration of NAL, Bangalore, porous FRP tubes were developed and thus was started brackish water desalination based on tubular module in India. By this time the cellulose acetate based membrane casting technology was perfected. In 1984 the Government of India decided to assess 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 with the full complement of pretreatment system and installed at the remote villages of Kattuvapalli at Nellore, Andhra Pradesh and Malika, Surendranagar, Gujarat. The plants commissioned in 1985 were operated with local people for more than three years gaining valuable operating experience with reference to operation of these plants in remote locations.

During the interim period, R&D efforts resulted in indigenous development of pressure plates based on polycarbonates and thus the plate module configuration was launched, which is compact and can accommodate a membrane area about 8 times that of an equivalent volume tubular module. Towards the third year of operation of the village plants, some of the tubular modules were substituted with plate modules and the relative performance was assessed. A 50,000 litres / day RO plant was set up at M/s. Rashtriya Chemicals & Fertilizers Mumbai in 1986 based on plate module to demonstrate the recovery of water from effluents for recycle in the process.

Having got a good feel of the technology, 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 in-house needs of demineralised water a 15000 litres / day RO Demineralization plant was commissioned at Variable Energy Cyclotron (VECC) Kolkatta in 1994. In 1996 a plant was established at M/s Sandoz for the concentration of calcium lacto-bionate based on cellulose acetate blend membrane. The first spiral element was developed and the in-house requirements of sterile water could be met using our own membranes and configurations.

Sea Water Reverse Osmosis (SWRO) plant building and membrane modules at Kalpakkam (Top and Bottom)

A 40,000 litres per day plant was also established at Trombay for seawater desalination during this period. 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 establish a number of reverse osmosis plants for desalination and water recycling.

Efforts were also directed towards membrane development, as there were a number of limitations with cellulose acetate membranes, being susceptible to biodegradation, hydrolysis etc. Four types of polyamides “poly m-phenylene isophthalamide”, “polyamide hydrazide”, “polyetheramide hydrazide” and “polysulfonamide” polymers, were successfully synthesized and membranes were prepared. These asymmetric membranes gave very good solute rejection but the water flux was not sufficient to warrant commercial deployment. In order to improve flux without sacrificing solute rejection, attempts were made for preparing thin film composite membranes popularly known as TFC membranes. TFCs consist of a thin semi-permeable barrier layer of polyamide deposited over a preformed macro porous polysulfone substrate. The membrane layer being only a few tenths of a micron provides sufficient flux with high rejection. 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.

Nuclear Desalination Demonstration Project (NDDP)

Based on decades of operational experience of MSF and RO plants at Trombay, BARC has undertaken establishment of the Nuclear Desalination Demonstration Project (NDDP) at Kalpakkam. NDDP consists of a hybrid MSF-RO desalination plant of 63 lakh litres per day capacity (45 lakh litres per day MSF and 18 lakh litres per day SWRO) coupled to 2 x 170 MWe PHWRs at MAPS, Kalpakkam. The requirements of seawater, steam and electrical power for the desalination plants are met from MAPS I & II which are around 1.5%, 1.0% and 0.5% respectively of the available resources at MAPS. 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. The objectives of the programme were to establish and demonstrate safe production of desalted water from sea water at affordable cost, its economic soundness due to sharing of resources with the nuclear power plant, concept of hybrid desalination and demonstration of technological capabilities developed in-house.

The SWRO plant, which has already been commissioned, draws seawater from the outfall of Madras Atomic Power Station, whose temperature is about 2-3 deg C higher than that of the normal seawater which is an added advantage for the RO plant. The plant incorporates necessary pretreatment and an energy recovery system and produces potable water with about 500ppm Total Dissolved Solids (TDS) resulting in lower water cost. The plant operates at relatively lower pressure (51.5 bar during 1st year and 54 bar during 3rd year) to save energy, employs lesser pre-treatment chemicals (because of relatively clean feed water from MAPS outflow) and aims for longer membrane life. The MSF plant which is in an advanced stage of construction 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 at 140 litres/day consumption rate. There is a provision for augmentation of product water capacity by blending the low TDS product of MSF plant with brackish ground water/ moderate salinity permeate from SWRO plant. This will then serve the need of larger population. The overall water production cost for this plant is estimated to be 5 paise/litre and is expected to come down to 4 paise/litre for larger size plants.

A hybrid plant has several advantages. A part of high purity desalted water produced from MSF plant will be used for the make up Demineralised Water (DM) requirement after necessary polishing, for the power station. Blending of the product water from RO and MSF plants would provide high quality drinking water. The RO plant can continue to be operated to provide water for drinking purposes even during the shut down of the power station.

NPCIL has recently put up two trains of SWRO plant, each of capacity 25 m^3/h (total capacity : 1200 m^3/d) at Kudankulam. The product water is primarily being utilised for construction and other water requirements at Kudankulam site. The SWRO plant includes pre-treatment section, RO system along with energy recovery turbo unit.

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. As an offshoot of this development, a membrane based on-line domestic water purifier has been realised.

Domestic water purifier

This device based on polysulfone ultrafiltration as well as membrane has an 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 5 psig to 35 psig and can produce about 40 litres of pure water per day. It is maintenance free except cleaning the deposits over the membrane surface periodically. The device is mechanically and chemically stable and is expected to be functionally useful for a minimum period of 5 years.

Technologies Under Development

The desalination industry is witnessing numerous technological innovations so that these are available to the population in the water scarce areas. In an attempt to keep pace with the developments, BARC has initiated activities on, centrifugal reverse osmosis, LTE desalination plant with cooling tower, continuous Thin Film Composite (TFC) membrane casting assembly, barge mounted reverse osmosis unit, etc. The successful completion of these projects would lead to effective solutions for meeting the fresh water needs in the coastal as well as inland areas of the country.

Consultancy Services and Technology Transfer

BARC has actively participated in the Rajiv Gandhi National Drinking Water Mission and setup a number of small reverse osmosis (RO) plants in villages during the eighties. In recent years, a RO plant was installed in Sheelgan, Barmer District (Rajasthan) and in Satlana village, Jodhpur in Jan. 2003. The cost of such plants which provide drinking water to habitation of about 1000 people is only around Rs. 7 lakhs. The water cost is only about 3 paise/litre.

Reverse osmosis plant (capacity : 30 cubic metre per day) set up at Sheelgan village, district Barmer, Rajasthan

Reverse osmosis plant at Saltana village, Jodhpur, Rajasthan

The knowhow of the RO technology has been transferred to a number of parties and they are manufacturing and supplying RO plants for various applications. The technology for on-line domestic water purifier has been transferred to several parties. The technology for indigenous production of spiral membrane elements using sheet membranes has been developed. Commercial equivalents of elements have already been made. Efforts are in progress for standardising and subsequent transfer of the technology for commercial exploitation. The mobile/ transportable desalination units based on RO and VC are in an advanced stage of development. Standardised modules both for RO (5-50 m^3/d) and small thermal desalination units (5-50 m^3/d) using waste heat (diesel or solar) specific to individual needs have been developed.

Considerable expertise is available in DAE for the design of large size MSF and RO plants for sea water desalination. Expertise is also available on utilisation of low grade and waste heat for producing pure water from saline water. There is a considerable interest in the country to put up a number of large size plants of million gallons per day capacity for brackish and sea water desalination, treatment of industrial effluents for water reuse as well as process stream concentrations.

The development work carried out at Trombay has resulted in technological capabilities for designing, fabricating, commissioning and for operation of small and large size desalination plants indigenously. The technological innovations in desalination would lead to large scale application and provide opportunities for the socio-economic development of water scarcity areas and large coastal arid zones of the country.