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Technological Innovation in the Area of Drinking Water for Treatment of Saline Water

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Abstract: The research paper reviews different types of desalination technologies for drinking water and the innovation in conventional drinking water purification systems for inland and sea water salinity. It also provides the updated status of salinity problem in India and attempts to document field experiences in tackling desalination problem for the benefit of the people with scientific approach.

Key words: Salinity, reverse osmosis, habitations, LTTD plants.

Introduction

Research/Review papers on status of salinity in ground water in India is very limited in numbers. There are a few research papers indicating status of salinity at some locations (Misra et al., 2007). Salinity is the saltiness or dissolved salt content in water. As a result of consumption of saline water, physiological functions of the human beings are affected. Bureau of Indian Standards (BIS) has specified maximum desirable limit of 500 mg/L and maximum permissible limit of 2000 mg/L for Total Dissolved Solids (TDS) in drinking water (BIS, 2012). World Health Organization (WHO) has suggested a guideline value of 1000 mg/L for salinity in drinking water (WHO, 2011). Depending upon Total Dissolved Solids (TDS) in water, water can be categorized as below:

Fresh water	Less than 500 mg/L TDS
Moderate brackish water	500 to 1000 mg/L TDS
Brackish water	1,000 to 5,000 mg/L TDS
Highly brackish water	5,000 to 15,000 mg/L TDS
Saline water	15,000 to 30,000 ppm mg/L
Sea water	30,000 to 40,000 mg/L TDS
Brine	40,000 mg/L and above

Salinity can be measured either by physical or chemical methods. Physical methods use conductivity, density, or refractivity measurement. The physical methods are rapid and more convenient than the chemical methods. The chemical methods determine chlorinity (the chloride concentration), which is closely related to salinity and TDS.

Status of Salinity Affected Habitations in India

As reported by the States on online Integrated Management Information System (IMIS) of Ministry of Drinking Water & Sanitation (MDWS), as on 01/04/2015, there are 66,761 quality affected rural habitations in India of which 15,617 habitations are salinity affected habitations (MDWS, 2015). Statewise salinity affected rural habitations is shown in Table 1. First five States with highest salinity affected habitations are Rajasthan (13,814), Odisha (586), Andhra Pradesh (610), Uttar Pradesh (203) and Karnataka (201). Since the data is exclusively for rural habitations, total number of people facing salinity problem including those who are living in urban areas, could be very high.

Table 1. Status of Quality affected rural habitations and salinity affected habitations as reported by the States on IMIS of the Ministry as on 01/04/2015

S.No.	*State*	*Contamination wise number of habitations and population*	
		Total number of water quality affected habitation	*Salinity affected habitations*
1	Andaman and Nicobar	0	0
2	Andhra Pradesh	593	164
3	Arunachal Pradesh	82	0
4	Assam	8977	0
5	Bihar	3519	0
6	Chandigarh	0	0
7	Chattisgarh	1841	21
8	Dadra & Nagar Haveli	0	0
9	Daman & Diu	0	0
10	Goa	0	0
11	Gujarat	21	2
12	Haryana	13	2
13	Himachal Pradesh	0	0
14	Jammu & Kashmir	6	0
15	Jharkhand	33	0
16	Karnataka	2365	201
17	Kerala	751	108
18	Lakshadweep	0	0
19	Madhya Pradesh	653	27
20	Maharashtra	609	162
21	Manipur	0	0
22	Meghalaya	31	0
23	Mizoram	0	0
24	Nagaland	66	0
25	Odisha	4979	586
26	Puducherry	0	0
27	Punjab	1850	18
28	Rajasthan	22254	13814
29	Sikkim	0	0
30	Tamil Nadu	352	50
31	Telangana	1342	192
32	Tripura	4550	0
33	Uttar Pradesh	418	203
34	Uttarakhand	27	0
35	West Bengal	11429	67
	Total	66761	15617

Technologies for Desalination

Membrane Processes

A membrane is defined as a interphase between two adjacent phases acting as a selective barrier, regulating the transport of substances between the two compartments. There are two factors that determine the effectiveness of a membrane filtration process: selectivity (% rejection) and productivity (flux). Choice of type of membrane technology depends upon desired objectives (Figure 1).

Reverse Osmosis

The quality of permeate depends upon the pressure applied across the membrane, the concentration of salts in the feed water and salt permeation constant of the membranes. The feed water should be pretreated to remove bio-fouling and scaling. Permeate quality can be improved by adding arrays of membranes.

Electrodialysis

Electrodialysis is an electro-membrane process in which transport of ions present in contaminated or blackish is accelerated due to an electric potential difference applied externally. An electrodialysis cell consists of a large number of narrow compartments through which the feed water for desalination is pumped. These compartments are separated by alternative placed cation and anion selective membranes in a parallel fashion across the current path to form an ED cell. Using a DC electrical field, cations and anions migrate through the appropriate membranes, forming compartments of electrolyte enriched waste water and electrolyte depleted product water. Non-ionic particulates, bacteria and residual turbidity may also pass through the cells with the product water and therefore, this may require further treatment to achieve the desired product water standards. ED plants have been put to use in India at only isolated places (Figure 2) as RO plants are more commonly used.

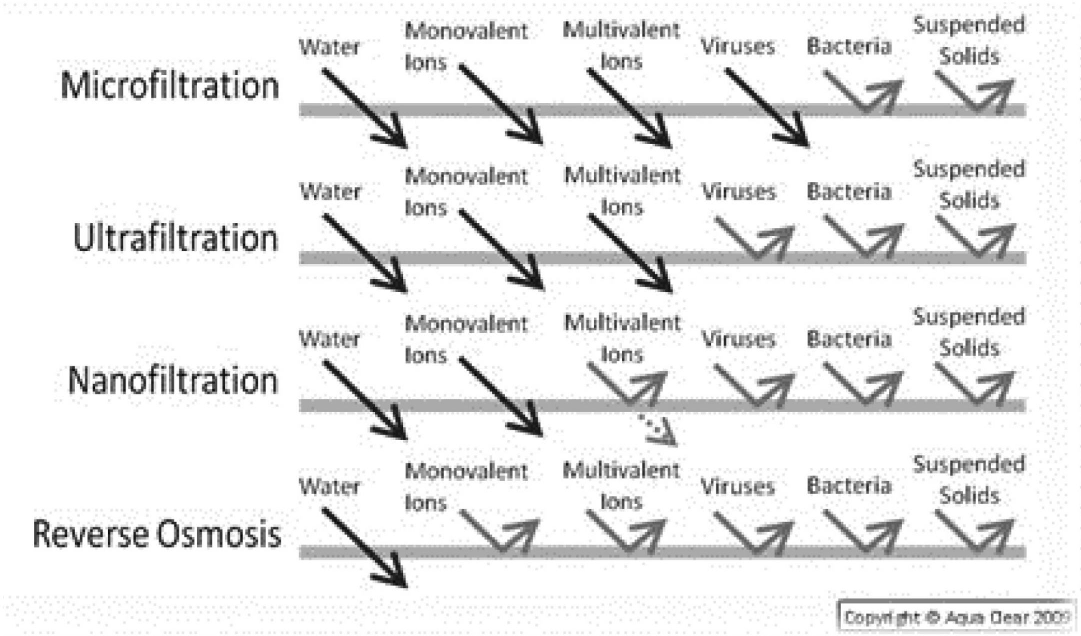

Figure 1: Application of different types of membranes for water quality parameters.

Figure 2: ED-ROM hybrid system high recovery desalination.

Distillation Processes

Distillation is basically a phase separation method whereby saline water is heated to produce water vapour which is then condensed to produce potable or fresh water.

Single/Multi-Stage Flash Distillation (SSF/MSF)
Multistage flash distillation is still one of the most commonly used technique, particularly where energy is still not an issue or inexpensive. In MSF plant, a stream of heated brine flows through a vessel consisting of various chambers, or stages, each operating at a slightly lower pressure than the previous one. As the brine enters each chamber or stage, a portion of it "flashes" into steam and is then condensed to produce a pure distillate. The concentrated brine remaining at the end of the process is rejected as blow down. MSF operating temperatures range from 100 to 110°C and they produce 6.0 to 11.0 kilograms of distillate per kilogram of steam applied. Depending upon the number of flashes, the process could be termed as SSF or MSF. The unit cost of production varies between 3.5 paise per litre and 8.3 paise per litre of water/distillate produced.

Multi-Effect Evaporation (MEE)/Multi-Effect Distillation (MED)
Multi-effect distillation has a greater potential as an evaporation technique. It is also similar to condensation but requires a heating device like a boiler or waste heat from any other sources like thermal plants etc. Steam extracted from low and medium pressure turbines provides the heat necessary for evaporation. MEE operates with top-brine temperature of 64-70°C. The unit cost of production of MEE systems varies from 3.9 paise to 8.9 paise per litre of water/distillate produced.

Vapour Compression Desalination (VCD)
VCD is a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapour. Since compression of the vapour increases both the pressure and temperature of the vapour, it is possible to use the latent heat rejected during condensation to generate additional vapour. The effect of compressing water vapour can be done by two methods as given below.

Thermal Vapour Compression (TVC)
The process of condensation is similar to other distillation processes except that requirement of steam is a pre-requisite for the system. TVC has been clubbed with MEE system for large scale plants for better economies. The unit cost of production of distillate/water is 5.9 paise per litre, as per information available.

Mechanical Vapour Compression (MVC)
The mechanical vapour compression process uses mechanical energy rather than direct heat as a source of thermal energy. Moreover, it is distinguished from other distillation processes by the presence of a mechanical vapour compressor, which compresses the vapour formed within the evaporator to the desired pressure and temperature. The system also includes plate heat exchangers for pre-heating the feed-water using heat exchangers from the brine blow-down and the distillate product. This system is also based on evaporating effect like MEE. This is a good technology and can be adopted for capacities ranging from 100 m^3/day to about 20,000 m^3/day or more. The cost of production is slightly higher at 22.5 paise per litre of distillate/water produced in case of 100 m^3/day to only 2.07 paise per litre of distillate/water produced in case of 20,000 m^3/day plant. This technology is often used at resorts and industrial sites.

Low Cost Vertical Tube Evaporators (VTE)
VTE technology is MEE technology but synthesized for smaller applications, specifically the rural sector of India. The principle involved is the recycling of latent heat of condensation/vaporizations of water in successive efforts so as to achieve a good performance ratio. An LPG boiler is used for heating the feed water and with a 6-effect VTE, the unit cost of production of distillate/water is found to be 30–40 paise per litre of water produced at the laboratory conditions. The cost is expected to be around 10 paise per litre of water produced, if bio-mass gassifiers are used in the field. This technology again is site specific and depends upon availability of *Pros phisjuliflora* and *Acacia auriculiformis*, which are generally the bio-mass used for heating in the boilers. The 6-effect VTE at the laboratory conditions produced 2000 litres per day of product-water with TDS of 10 mg/L. The cost of the plant was reported to be about Rs. 56,000 only.

Solar Humidification/Solar Stills

Solar still is basically a large scale shallow water pond wherein saline water (about 10 cm deep) is spread over a large surface area and covered with glass over. The natural sunlight is used for evaporating the saline water and the condensed vapour is collected from the glass-case. The operation and maintenance cost of such plants is almost zero and no electricity is required for this system. This type of system is cost effective for rural areas because of the availability of land. In principle, well-managed and maintained solar stills require a solar collection area of about one square metre to produce up to six litres of fresh water per day but on average usually return 3L/m^2/day. Thus, for an 800L/day facility, land area ranging 130–260 m^2 would be required depending on efficiency. The main advantage of this process is its relative simplicity to operate and service and obviously its ability to use renewable energy source such as sunlight makes it an economical option for producing potable (fresh) water from various feedwater sources like sea water, brackish water or treated wastewater.

Freezing Desalination

Freeze desalination theoretically has some advantages over distillation methods such as lower theoretical energy requirement, minimal potential for corrosion, and little scaling or precipitation. This process is based on the fact that dissolved salts are naturally excluded during the formation of ice crystals. In order to desalinate saline water using this method, the non-frozen saline component is removed at the appropriate time in the freezing process, and the frozen (fresh) water is washed and rinsed to remove any of the remaining salts adhering to the ice crystals. The ice is then melted to produce fresh product water. There have been a small number of plants developed and constructed over the past 40 years; however, the process has not been commercially developed in the production of potable water for community drinking water purpose.

Membrane Distillation

Membrane distillation is a relatively new process which has been introduced commercially only in the last few years. It uses a specialized membrane which passes water vapour only but not liquid water. This membrane is placed over a moving stream of warm water, and as the water vapour passes through the membrane, it is condensed on a second surface which is at a lower temperature than that of the feed water.

Low Temperature Thermal Desalination (LTTD)

Low Temperature Thermal Desalination (LTTD) process utilizes the temperature gradient (generally 10-15°C temperature) between two water bodies in sea water to evaporate the warmer water at low pressures and condense the resultant fresh using the colder water to obtain high quality fresh water. Capital (direct and indirect costs) include well construction, brine disposal, land, process equipments, building, membranes, freight and insurance, construction overheads and Contingency. Annual operating costs include electricity, labour, maintenance and spares, membrane replacement, insurance, chemicals, amortization.

Advantages/Disadvantages of Membrane and Distillation based Technologies

Advantages of RO plants over distillation include:

(a) feed-water generally does not require heating
(b) lower capital cost
(c) no thermal impacts of brine disposal
(d) fewer corrosion problems, if feed-water is pre-conditioned
(e) lower energy requirements
(f) very high recovery rates
(g) removes unwanted contaminants like trihalomethane present in sea water.
(h) lesser surface area
(i) re-mineralization would be required as TDS levels are very low in the product water.

Disadvantages of RO plants over distillation include:

(a) comparatively lesser potential for economies of scale
(b) RO membranes are very sensitive to turbidity, algae and pH
(c) biofouling
(d) higher O&M costs
(e) availability of membranes and chemicals
(f) RO membranes must be cleaned once in a quarter of a year and must be replaced after 3-5 years
(g) brine disposal could be detrimental to eco-sensitive zones.

Innovation in Desalination Technology

Nano-Filtration (NF) based treatment technology is a very promising technology in the purification process of water and industrial effluents, because of energy efficiency and low cost. Although Reverse Osmosis (RO) membranes are widely used in present desalination units, NF membranes are considered as "future membranes" for desalination, because of the low operating pressure (Mukesh et al., 2011).

Performance of the membrane is determined in terms of Hydraulic Permeability Coefficient (HPC), Molecular Weight Cutoff (MWCO) and percentage rejection of salt and brackish water. Recent studies on membrane technology lay emphasis on chemical modification of polymers to improve the properties like hydro-philicity, solubility and charge, synthesis of metal oxide nanoparticles and preparation of nano filtration composite membranes, surface modification of some nano filtration composite membranes by UV-light, surface morphology studies and determination of membrane surface charge by measurement of ion exchange capacity (IEC) and diffusion potential. Following innovations have taken place in the area of treatment of brackish water/saline water:

- Development of hollow fibre Ultra Filtration (UF), Micro Filtration (MF) and Nano Filtration (NF) membranes in RO technologies.
- Development of Thin Film Composite (TFC) RO membrane and modules.
- Development of multibarrier desalination process for more reliable water quality with comparatively low energy consumption as compared to conventional single barrier sea water desalination which involves pushing of sea water through a single barrier .
- *Development of Solar energy based thermal desalination plants:* Large capacity desalination plants and small scale plants, both have been developed using solar energy. Many institutions such as CSIR-CSMCRI, BARC-Mumbai and IITs have developed/modified solar energy based desalination plants (Figure 3). Solar energy based RO ATMwater purification systems work on card sensing system and coin insertion basis. The water purification is done using a series of quartz sand filter, activated carbon filter, micron filter, RO cartride, UV, ozonation and collection of clear water. The capacity of the ATM based drinking water vending machines depends upon the population. However, the general capacity vary between 2000 litre/day and 3000 litre/day. Those who are desirous to take drinking water frequently can get the card and recharge it with Rs 100 or with higher amount. Solar energy is provided through various arrays/ panels of four SPV cells each providing ranging from 50W-200 W capacity. For a capacity of 2800 litre/day, solar panel of 200 W has been found sufficient. This could further be improved by solar energy based pumping from borewell which has not been done so far. Infact, pumping of drinking water using solar power should also be an integral part of the solar panel based systems.
- *Development of Electrodialysis Reversal (EDR) process to improve efficiency of electrodialysis cell:* The scaling and fouling problem in basic electrodialysis unit has been overcome by recent advancements to the ED technology in the form of Electrodialysis Reversal (EDR). The EDR process involves a reversal of the water flow in order to break up and flush out scales, slimes and other foulants deposited in the cells before they can build up and create major fouling problems. This flushing also allows the electrodialysis unit to operate with fewer pretreatment chemicals, hence minimizing costs. The ED/EDR process is usually only suitable for brackish feed waters with a salinity of up to 12,000 mg/L TDS. With higher salinities, the process rapidly becomes more costly than other desalination processes. This is because the consumption of power is directly proportional

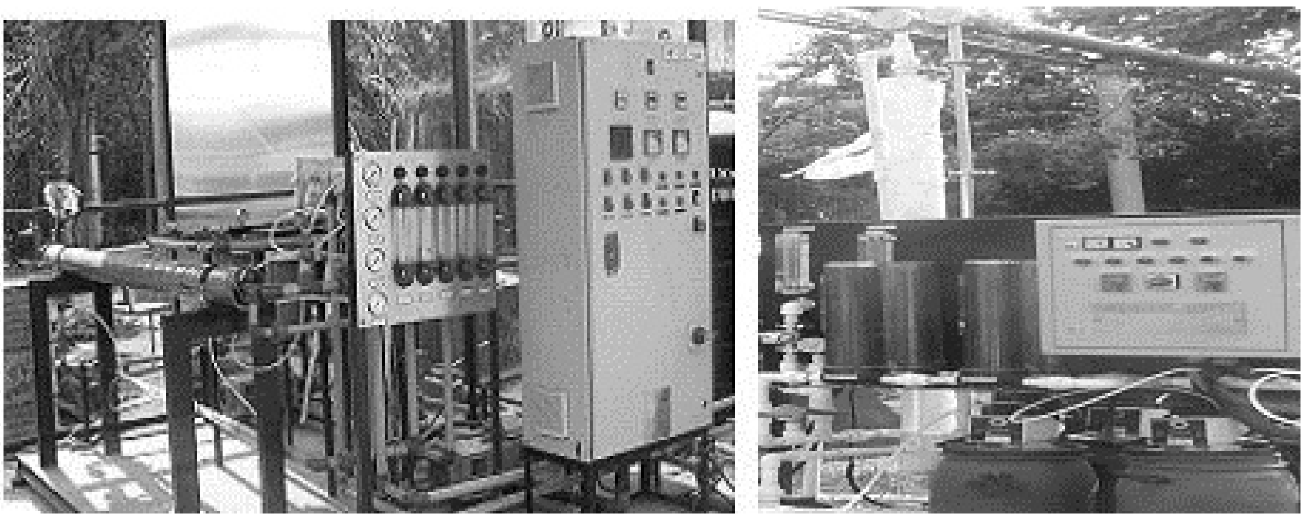

Figure 3: Solar energy driven community level brackish water desalination plant (BARC).

to the salinity of the water to be treated. Generally, approximately 1 kWH is required to extract 1 kg additional salt using ED/EDR.

- *Capacitive deionization (CDI) process:* In this process, activated carbon modified by nitric acid is used as the electrodes for the desalination of an aqueous electrolytic solution. The experimental results have shown that the modification of activated carbon greatly increases the salt removal from the solution. The desalination efficiency has been found increased to about 15%, and the desalination kinetics are improved in the form of rate constant from 0.09208 to 0.09922. It has been found that the modification greatly increases the oxygen-containing functional groups on the surfaces of activated carbon, leading to the increases of the capacitance and the reduction of the charging resistance, which might be attributed to the improvement of the desalination.

Conclusion and Recommendations

- Membrane based filtration technologies are less energy intensive than thermal processes for reduction of salinity in drinking water. HighInland salinity (TDS of 1500–3000 mg/L) is generally found in groundwaters in many States of India (Haryana, Delhi, Uttar Pradesh, Karnataka, Punjab, Rajasthan, Gujarat and Tamil Nadu). These parts receive 5.5–6 kWh/m^2/day of annual average Global Horizontal Irradiance (GHI) making the photovoltaic (PV) cells the apparent choice for desalination process. Integration of desalination technologies with solarenergy is the most sustainable solution.
- Integration of solar energy could be done with either UF-RO combination or NF-RO combination depending upon salinity and other drinking water quality of raw water. A comparative study of the results obtained by integrating solar panel with various membrane filtration technologies is shown in Table 2.
- Solar energy based small drinking water ATM vending machines can be replicated at few places. During last two years, some companies have set up such ATMs in borewells/handpumps attached water supply schemes. However, it has been observed that solar energy is used only for treatment purpose and not for pumping water from borewells. Solar energy based schemes should be also used for pumping of drinking water from borewells besides treatment system.
- With the help of HGM (Hydro-Geo-Morphological) prepared by National Remote Sensing Centre (NRSC) Hyderabad, attempt should be made to select appropriate sites for construction of sustainable structures. These recharge structures should facilitate replenishing of the groundwater with fresh water and dilute the salinity of aquifer over a period and reduce the dependency of agriculture on surface water resources.
- The abandoned/previously lost paleo channels, if available, should also be diagnosed. These may be also utilized for recharging. The rainfall pattern of last 10 years should be analyzed to assess the runoff availability for artificial recharge in salinity affected habitations. The artificial recharge structures like 1st

Table 2. Plant capacity and water production cost of solar panel integrated desalination plants of different membrane technology

S. No.	*Solar powered desalination techniques*	*Plant capacity (m^3/day)*	*Water production (Rs/m^3)*	*Reference*
1	PV-NF/RO	0.934	99.81	R & D project funded by Ministry of Drinking Water & Sanitation to IIT-Roorkee (PI: Prof. Himanshu Joshi)
2	PV-RO (SWRO)	120-12	480.58-1753.05	(Al Suleimani & Nair 2000; Ahmad & Schmid 2002; Hafez & El-Manharawy 2003; Thomson & Infield 2003)
3	PV-RO (BWRO)	250	438.26	(Al Suleimani & Nair 2000; Ahmad & Schmid 2002; Hafez & El-Manharawy 2003; Thomson & Infield 2003)
4	PV-ED	<100	350.61 - 967.2	(Kuroda et al. 1987; Thomson et al. 1996)
5	Solar-MEH	1-100	157.17-392.93	(Michael et al. 2010)
6	Solar-MD	0.15-10	634.73-1178.78	(Ali et al. 2012)
7	Solar-CSP/MED	>5000	169.26	(Al-Shammiri & Safar 1999)

Source: Prof. Himanshu Joshi, IIT-Roorkee in Ministry of Drinking Water & Sanitation, 2014.

and 2nd order drainage deepening and widening, construction of village tanks and nala bund can be very useful. However, before constructing such artificial recharge structures, it is necessary to study the nature of the aquifer, their spatial geometry and movement of ground water. In order to envisage the basin settings, the structural map prepared by GSI should be critically studied with more ground controls on thickness and nature of sediments and groundwater quality. By understanding the groundwater flow direction, necessary measures could be taken up for arresting the fresh water discharge into the other basin or exploiting the ground water at favourable structural controlled sites for meeting the needs of agriculture and drinking water.

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