Alternate Technologies for Desalination: Pre-Treatment, Environmental Impact and Green Options

Bharat B. Gulyani, B.G. Prakash Kumar, and Arshia Fathima

***Abstract*—**Potable water is a necessity for all human operations. However, pure water resources are limited on Earth and even the water available requires further purification. Desalination is a crucial industrial process that helps to reduce the gap between supply and demand of potable water. Pre-treatment of feed water for desalination is required for high system performance while post-treatment of desalinated water is required to conform to standards of water for the specified purpose. In this paper, current and developing pre-treatment technologies have been reviewed. Decreasing salinity using some common substances as adsorbents has been investigated as an option for pre-treatment. Ecological impact of desalination process has also been assessed.

***Keywords*—**adsorbent, desalination, pre-treatment, salinity

I. Introduction

WATER is an essential need for life on Earth. Water is vital for all human operations from personal to domestic, agricultural to industrial. About three-fourths of earth is covered with water out of which 97% is sea water and rest is fresh water. With rapid industrialization, growing population and dwindling fresh water resources due to pollution, the demand for water is projected to increase by 50% between 2007 and 2025 in developing countries and by 18% in developed countries [1]. The water demands are met either by withdrawing fresh water from underground aquifers or desalination of water resources (brackish or sea-water). As the groundwater levels are falling at alarming rates, there has been a shift towards obtaining water from desalination processes. The desalination processes are broadly classified into three categories as follows [1]:

(a) Phase change/ Thermal desalination: includes Multi-Stage Flash (MSF) distillation, Multi-Effect Distillation (MED), Vapor Compression (VC). Solar still/ distillation also comes under this category. These processes separate water from salts by breaking the chemical bonds.

Bharat B. Gulyani is Associate Professor at the Chemical Engineering Department at BITS Pilani Dubai Campus, Dubai International Academic City, Dubai 345055 (phone: +971553034760, fax: +97144200844; email: gulyani@dubai.bits-pilani.ac.in).

B.G. Prakash Kumar is Assistant Professor at the Chemical Engineering Department at BITS Pilani Dubai Campus, Dubai International Academic City, Dubai 345055 (email: prakash@dubai.bits-pilani.ac.in).

Arshia Fathima is a recent graduate from University of California, Berkeley, USA and BITS Pilani Dubai Campus. (e-mail: arshiafathima92@gmail.com).

(b) Membrane/ Single phase desalination: includes Reverse Osmosis (RO), Electro-dialysis (ED), Electro-dialysis Reversal (EDR), Forward Osmosis (FO). Membrane desalination is based on molecular separation according to the different sizes of water and solute molecules.

(c) Chemical desalination: includes ion exchange, liquid-liquid extraction, and gas hydrate formation.

Among the above mentioned processes for desalination, MSF and RO dominate the commercial production with 44% and 42% water production of worldwide capacity, respectively. Desalination using MSF accounts for more than 93% of thermally desalinated water while RO accounts for 88% of membrane desalination production [2].The definitions of different categories [3] are as follows:

Seawater: 15,000-50,000mg/L TDS
Brackish water: 1,500-15,000mg/L TDS
River water: 500-3,000mg/L TDS
Pure water: less than 500mg/L TDS
Waste water (untreated domestic): 250-1000mg/L TDS
Waste water (treated domestic): 500-700mg/L TDS

Major costs of a desalination plant come from the energy demands and maintenance of the plant for optimum production. In case of reverse osmosis, energy demand in form of pressure greater than the osmotic pressure and costs of replacing the membranes contribute to its costs. Thermal desalination plants demand energy for phase transformation in order to get pure water. These form major costs of the plant besides optimum operation of the distillation columns. Feed pre-treatment is essential for reverse osmosis to obtain high efficiency. Scale inhibition is the minimum pre-treatment required for feed water in thermal desalination plants.

II. Feed Pre-Treatment For Desalination

Sea-water has high TDS content, turbidity, hardness and also microbial content. Due to this composition of sea-water, the productivity of desalination is hindered due to scaling, fouling, and corrosion. Other sources of water also have considerable TDS and microbial content. Table I below lists major elements that occur in sea water [4].

TABLE I
MAJOR CONSTITUENTS OF SEA WATER

Chemical ion contributing to sea water salinity	Concentration in ppt (parts per thousand) In average sea water	Proportion of Total salinity
Chloride	19.345	55.03
Sodium	10.752	30.59
Sulfate	2.701	7.68
Magnesium	1.295	3.68
Calcium	0.416	1.18
Potassium	0.390	1.11
Bicarbonate	0.145	0.41
Bromide	0.066	0.19
Borate	0.027	0.08
Strontium	0.013	0.04
Fluoride	0.001	0.003
Other	Less than 0.001	Less than 0.001
Total	~35 ppt	99.99

Besides these elements, sea water also contains dissolved gases such as oxygen, nitrogen and carbon dioxide, which warrants the need for de-aeration of feed water. Pre-treatment of feed-water is essential in order to increase the production and also reduce the energy requirements. The level and type of pre-treatment required depends on the source and quality of the feed water and the chosen desalination technology. For example, for thermal process, inhibition of scale-forming salts would be sufficient while in membrane desalination fouling factors need to be controlled.

For source water of poor quality, pre-treatment can be a very significant portion of the overall plant infrastructure. Pre-treatment involves removal of suspended particles by filtration followed by chemical treatments to reduce hardness, corrosive elements, immiscible liquids, organic compounds and scaling salts. Effects on public health and environment from pre-treatment is associated with use of chemical such as anti-scalants, coagulants, lime softening (for removal of hardness), and oxidizing agents (chlorine/ sodium hypochlorite) to control fouling.

Pre-treatment processes include sedimentation, coagulation, flocculation, and filtration. These may be followed by degasification/ de-aeration and secondary filtration. Chemicals used for pre-treatments include acids (usually sulphuric acid) to lower pH thereby reducing formation of scales (hydroxides of calcium and magnesium). Sodium- bisulfite is used in MSF to remove traces of residual oxygen and chlorine in brine recirculation [5]. Metal salts such as ferric salts, alum, lime and poly-electrolytes are used for coagulation. Polyphosphates such as sodium hexametaphosphate and poly-electrolytes are used as scale inhibitors [6]. Crystalline EDTA is used to remove carbonate deposits from the facilities. Membrane cleaning also requires chemicals such as citric acid and EDTA [7]. Dissolved air floatation (DAF) is proving to be a cost effective method for treatment of feed water. Following DAF, flux for ultra-filtration could be increased by 70% resulting in substantial reductions in capital costs.

For desalination processes like reverse osmosis, filtration is essential to remove particulate material. Granular media such as silica sand or coal are used after lime softening for primary filtration. Dual-media having different specific gravities with sand and anthracite are widely used filters. Three-media filtration uses garnet besides above mentioned media as the filter bed. Ultra-filtration, cartridge filters, ultra/ micro/ nano-filtration follows primary filtration to ensure high quality feed water especially for reverse osmosis [6].

Disinfection using UV, chlorine, and other oxidants such as ozone prevent bio-fouling of membranes. Degasification is undertaken following filtration by blowing air through a packed tower and sprinkling the water from the top. Water vapors may also be used as the stripping gas. This is to prevent interference of dissolved oxygen and nitrogen in evaporation of water [6].

A typical pre-treatment system includes a dual-media filter followed by fine sand filter and cartridge filter and addition of required chemicals for high quality feed water. Aeration may be performed to decrease the concentration of dissolved gases like carbon-dioxide. Improvements have been made to this system by use of ultra-filtration and micro-filtration techniques. Recently, nano-filtration (NF) has also been incorporated in pre-treatment process. With use of NF, only small quantities of chemical are required as most of the scaling ions and microbial content is filtered by the NF membranes. Pre-treatment with NF for sea-water reverse osmosis (SWRO) has already been incorporated with success [8].

In addition to removal of above mentioned compounds, reducing salt concentration of feed water will greatly affect the performance and costs of a desalination process. Few inexpensive adsorbents (of biological origin) were investigated as a pre-treatment to reduce the feed salinity. Salinity reduction in feed will significantly cut down the costs of desalination as the energy load is reduced. Operating and maintenance costs are also reduced as corrosion due to brine is minimized. With the aim of cost optimization, reducing the salt content of feed may be considered as a pre-treatment. However, environmental impact of using adsorbents for pre-treatment has to be assessed.

III. RESULTS AND DISCUSSION

Sample preparation with desired salinity was prepared based on Knudsen's formula in Mohr-Knudsen titration [12] as given below in equation (1):

$$Salinity(\%) = 0.03 + 1.805 * Chlorinity(\%) \quad (1)$$

Each test sample was made with 250 ml solution and amount of NaCl equivalent to 1%, 2% and 3% salinity was added respectively for sample solution. Salinity was measured using conductivity meter. A linear correlation between conductivity and salinity was first established so that it could be used as a calibration standard for testing adsorbent activity in reducing salinity.

There were 14 common substances that were tested for adsorbent to reduce salinity. These adsorbents were selected on basis of cost-effectiveness and minimal environmental impact. The adsorbents tested for - in order as given in fig. 1 -

are: silica gel, activated carbon (from date seeds), zeolite, alumina, sawdust, used tea leaves, bentonite, dried orange peel, wood blocks, charcoal, fresh banana peel, desert sand, dried date palm leaves and beach morning glory (weed). All adsorbents except for banana peel and charcoal were tested after being steeped in solution for 2 hours. Fresh banana peel and charcoal were tested overnight for their potential as an adsorbent. Fig. 1-3 and Table II show the comparative results for the adsorbents tested.

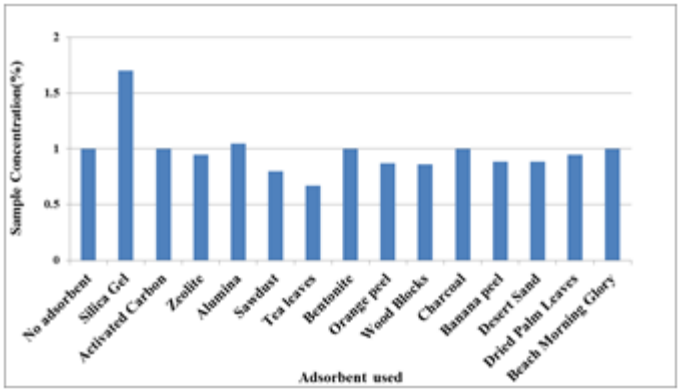

Fig. 1 Sample concentration after adsorbent testing for samples with initial concentration of 1 % salinity

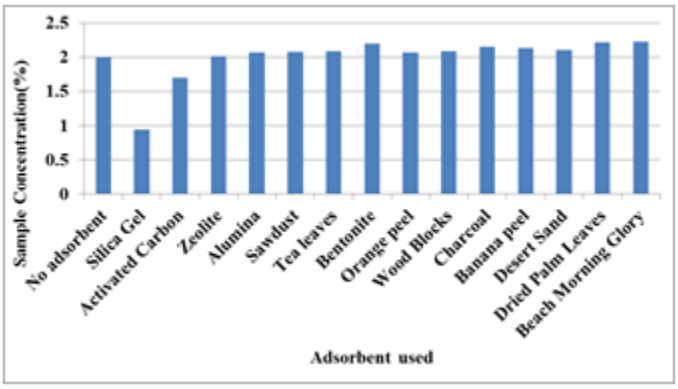

Fig. 2 Sample concentration after adsorbent testing for samples with initial concentration of 2 % salinity

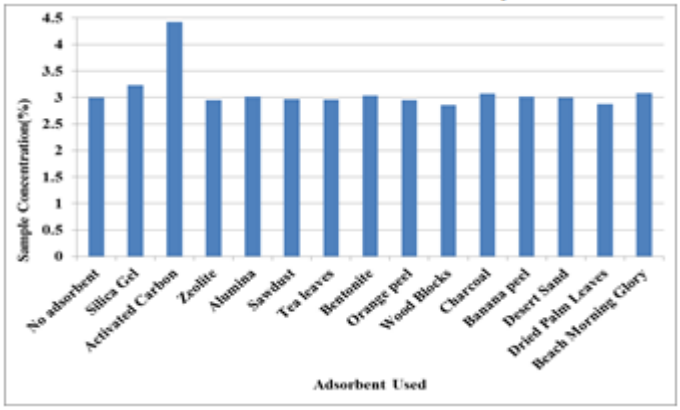

Fig. 3 Sample concentration after adsorbent testing for samples with initial concentration of 3 % salinity

TABLE II
COMPARATIVE TEST RESULTS FOR ADSORBENTS IN REDUCING SAMPLE SALINITY

Adsorbent used	Sample salinity after adsorption for initial sample salinity of 1%	Sample salinity after adsorption for initial sample salinity of 2%	Sample salinity after adsorption for initial sample salinity of 3%
No adsorbent	1	2	3
Silica Gel	1.702	0.936	3.23
Activated Carbon	0.9979	1.6998	4.42
Zeolite	0.945	2.012	2.946
Alumina	1.045	2.0698	3.0192
Sawdust	0.797	2.072	2.973
Tea leaves	0.672	2.082	2.96
Bentonite	1.001	2.198	3.0384
Dried orange peel	0.873	2.0625	2.95
Wood blocks	0.862	2.08	2.86
Charcoal	0.999	2.146	3.0768
Fresh banana peel	0.885	2.135	3.02
Desert sand	0.885	2.106	3.002
Dried palm leaves	0.949	2.21	2.88
Beach morning glory	0.998	2.22	3.0832

Among the adsorbents tested, silica gel and activated carbon have shown changes in conductivity for all three salinity concentrations thereby showing good potential as a pre-treatment adsorbent for reducing salinity. Sawdust, dried orange peel and tea leaves have shown potential for salinity reduction for lower salinity concentrations. Some adsorbents like silica gel gave results with salinity higher than initial sample salinity. This is attributed to the fact that water was absorbed by these adsorbents thereby giving higher salinity readings.

IV. ENVIRONMENTAL IMPACT OF DESALINATION AS A PROCESS

Each step of desalination process may have a minimum impact on the environment. The chemicals used in pre-treatments need to be disposed off in suitable manner. Similarly chemicals used for post-treatment of product and effluents need to be disposed. The brine produced during the desalination is also a cause of concern. These concerns have been expedited in the following discussion.

Concentration and temperature of brine produced from desalination are factors that may affect the environment if not discharged in to appropriate locations. Often the effluent is discharged into oceans at surface or at a depth of 20m. Some plants inject the brine in deep wells on land [9]. The salinity of brine is believed to have an impact on the marine life as it has potential to kill and damage their population disturbing the marine ecology in long term [7]. Areas that support saline tolerant species such as wetlands and estuaries are good disposal sites. However the temperature of the discharge must be equal to that of ambient temperature to ensure there are no changes in the living environment of the species around [11].

Alternative to disposal of brine to landfills, the brine can be used in construction of solar ponds where taking advantage of concentration gradients, solar energy can be stored. This energy can then be harvested using Rankine cycle [11]. The

brine can also be sold to industries for sodium chloride production by evaporation and chlorine production by electrolysis or reused for regeneration of resins used for water softening. Brine can be further processed to remove chemicals used during pre-treatment and then be used for food preservation. It can also be used for heat transport provided the pipes carrying it must be corrosion-proof.

Energy demands of desalination also affect the environment. Especially in the Middle East where there is an abundance of fossil fuels and natural gas, these demands are met by combustion of the fuels. A well-known fact is that this fuel combustion is a major source of carbon dioxide and smoke that is responsible for the air pollution and global warming. Besides this, as fossil fuels are non-renewable sources of energy, dwindling resources have caused a hike in their prices thereby inflating the cost of desalination also. Incorporation of renewable sources of energy for desalination including solar, wind and geothermal are active research areas. Solar collectors are used to heat the water for thermal desalination plants around the world. A few test plants have been established that meet their energy requirements from the temperature gradient present in oceans and are called low temperature thermal desalination (LTTD) plants. Co-generation desalination plants are being built where potable water and electricity is produced simultaneously for efficient energy consumption. Hybrid plants are constructed where two desalination processes such as reverse osmosis and MSF are used for energy efficient and economic production.

V. Focus On Environmental Effects Of Pre-Treatments

Pre-treatments involve chemical treatments besides mechanical separation as mentioned in earlier sections. Scale inhibitors, coagulants, anti-foulants and disinfectants add to the sludge generated during the pre-treatments. Besides these, the solutions used to clean membranes in case of reverse osmosis have toxic effect. The sludge produced is dewatered using operations such as filtration, centrifugation or evaporation using solar beds. The solid wastes are then sent to landfills [11]. Recovery of chemicals used in pre-treatment from effluent depends on the economy of the process. The effluent may also contain traces of metal from the equipment due to corrosion that can be categorized as toxic waste. Chlorine used for disinfection during pre-treatment affects the ecology of the water body where effluent is discharged.

Use of ultrafiltration (UF) or microfiltration (MF) may help in removal of suspended matter and organic compounds thereby reducing use of coagulants and anti-foulants. However the trade-off involves use of suitable membranes and operating and maintenance costs for the same. An innovative chemical product that can help solve this issue of suspended matter is HaloKlear by HaloSource, which is a natural based polymer that binds suspended particles to itself and settles down. The effectiveness of this product has been demonstrated on large scale with results being visibly presented from few seconds to minutes [13]. Another suggestion would be use of suitable adsorbents used for pre-treatments to reduce the amount of chemicals being used. The adsorbents may have a dual effect by reducing the salinity of feed water hence reducing the concentration of brine by-product. However, use of adsorbents generates solid wastes that have to been disposed in eco-friendly manner. In case of regeneration of adsorbent, chemicals may have to be used or energy must be provided, both having indirect impacts on the environment.

VI. Alternatives For "Green" Desalination

To reduce the environmental impact of desalination plants, research is required to find energy-efficient alternatives to meet energy demands for thermal desalination, complete conversion of plants to renewable energy based ones and better alternatives for effluent from pre-treatments and brine disposal.

Meeting energy demands of desalination using renewable sources of energy is the first initiative for "green" desalination. Many desalinations plants in Middle East have started using solar energy for desalination either using parabolic troughs or solar collectors for thermal desalination or using photovoltaic cells for providing the required energy. Wind energy, geothermal energy and Ocean thermal energy conversion (OTEC) as also being considered for alternative sources of energy. Eco-friendly, cost-effective and efficient pre-treatments need to be developed to increase the overall efficiency of the current desalination plants. Bio-sorbents such as yeast and algae may be considered besides the adsorbents tested for this paper. Investigations are required to find effective solutions involving processes besides adsorption to serve the purpose. Disposal of wastes generated is another cause of concern. Solutions including use of waste as by-products or raw materials for other industries have to be explored. A recent innovation was that "Switchable Water" by Forward Water Technologies at Green Centre Canada, where by using an additive in forward osmosis process, a mix of desalinated water and additive is collected. This mixture is then easily separated via bubbling of air through the mixture to separate in pure liquid water and reusable gaseous additive [14]. Similar innovations are needed to be explored for sustainable solutions to obtain potable water.

VII. Conclusions

Desalination is a solution available to produce potable water from the resources around us. However this process is energy intensive and hence requires various methods to lower the energy demands. Due to the nature of treatments producing a suitable feed for the process and the brine produced as a by-product, desalination affects the environment as discussed in the paper. Reducing the salinity as a pre-treatment of the process has been considered as a method to reduce the energy requirement with adsorption process tested with common waste substances. Future research on improving adsorptive capacity of these common wastes is proposed while research for innovative chemicals like "Switchable Water" needs to be further explored.

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