

## A REVIEW ON SEAWATER & SEA ICE DESALINATION TECHNOLOGIES

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### ABSTRACT

Life on our planet requires fresh water. According to WHO, water scarcity affects roughly one-third of the world's population, and approximately 2.3 billion people. The World Water Council states that this water crisis will become more acute over the next fifty years as the world population increases. Yet, water covers nearly three quarters of our planet -- 97.5% of this water is saltwater. Therefore, a practical, economically viable desalination process is crucial to overcoming this crisis. A number of seawater desalination technologies have been developed during the last several decades to augment the supply of water in arid regions of the world. Due to the constraints of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. However, the steady increasing usage of seawater desalination has demonstrated that seawater desalination is a feasible water resource free from the variations in rainfall. A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. The process requires some form of energy to desalinate, and utilizes several different technologies for separation. Two of the most commercially important technologies are based on the multi-stage flash (MSF) distillation and reverse osmosis (RO) processes. Although the desalination technologies are mature enough to be a reliable source for fresh water from the sea, a significant amount of research and development (R&D) has been carried out in order to constantly improve the technologies and reduce the cost of desalination.

### INTRODUCTION

World water resources are mainly salty (97.5%) and fresh water (2.5%). Salty water is found in oceans, seas and some lakes while fresh water is either stored underground (30%) or in the form of ice / snow covering mountainous regions, Antarctic and Arctic (70%) but only 0.3% is usable by humans . With this limited amount of usable fresh water, desalination offers the means to meet the increasing demand for Fresh water. Desalination technologies are divided into three major groups, namely: (i) thermally activated Systems in which evaporation and condensation are the main processes used to separate salts from water, (ii) pressure-activated systems where a pressure is applied on the salty water that forces it through a membrane, leaving salts behind and (iii) chemically-activated desalination methods. Thermally activated systems include: multi-stage flash distillation (MSF), multiple-effect distillation (MED), vapor compression distillation (MVC), humidification - dehumidification desalination (HDH), solar distillation (SD) and freezing (Frz). In these systems, heat transfer is used either to boil or freeze the seawater or brackish water to convert it to vapor or ice so the salts are separated from the water. Pressure- activated systems use permeable membranes to create two zones where water can pass through leaving salt behind.

These technologies consist of reverse osmosis (RO), forward osmosis (FO), electro-dialysis (ED) and Nano filtration (NF). Chemically-activated desalination systems include ion-exchange desalination (I.Ex), liquid-liquid extraction (LLE) and gas hydrate (G.Hyd) or other precipitation schemes. Recently, Adsorption technology (Ads) has been investigated for desalination application. In this technology an Adsorbent material with high affinity to water like silica gel can be used to separate the water from the salts. This work aims to critically assess the performance of all available desalination systems in terms of energy required, cost, Quality of feed and produced fresh water and environmental impact.

**Konstantinos Zotalis, Emmanuel G. Dialynas, Nikolaos Mamassis and Andreas N. Angelakis** Have reviewed desalination technologies in Greece Data on the cost of desalination shows a decrease in the future and the potential of water desalination in Greece. The work summarizes the current status in southeastern Greece (e.g., Aegean islands and Crete), and investigates the possibility of production of desalinated water from brackish water.

**Akili D. Khawajia\*, Ibrahim K. Kutubkhanaha, Jong-Mihn Wieb** has reviewed the current status, practices, advances, R&D activities, and future prospects of the state-of-the-art seawater desalination technologies. In view of the two most commercially successful processes in extensive use, this review has been made with special emphasis on MSF distillation and RO technologies.

**P. G. Youssefa, R.K. AL-Dadaha\*, S. M. Mahmouda** focused on current desalination technologies and compares their performance in terms of input and output water quality, amount of energy required, environmental impact and cost. It was found that adsorption desalination technology is a promising method for desalinating seawater due to its low running cost and low environmental impact as it uses waste energy resources.

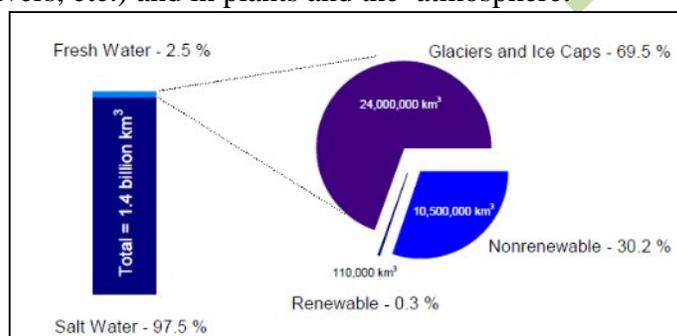
**Lixin Xiea, Jia Maa, Fang Chengb\*, Pingli Lia, Jie Liua, Weibin Chenc, Shichang Wanga,** studied different desalination methods including sea ice solid-state desalination and sea ice melt-water desalination were compared. In a centrifugal desalination experiment, rotation speed was one of the major controlling parameters. The best desalination result in terms of salinity was obtained at a rotational speed of 2000 rpm for a duration of 2–3 min. When sea ice was desalinated by slight-melting, environment temperature and time were the dominant factors. By using the reverse osmosis process, the total dissolved solids of sea ice melt-water could reach about 100 mg/L. The results indicate that methods of sea ice desalination could decrease sea ice salinity from 3‰–8‰ to 0.2‰–2‰ at a reasonable cost

**Umer Shafique, Jamil Anwar b, Munawar Ali Munawar , Waheed-uz Zaman ,Rabia Rehman b, Amara Dar a, Muhammad Salman b, Maria Saleem b,**

**Naeema Shahid b, Mehwish Akram b, Arooj Naseer a, Nadia Jamil c** studied Chemistry of ice: Migration of ions and gases by directional freezing of water & found that redistribution of anions and cations creates an electrical imbalance in ice grown from electrolyte solutions. Movement of acidic and basic ions in cooling solutions can permanently change the pH of frozen and unfrozen parts of the system, largely. The extent of pH change associated with freezing is determined by solute concentration and the extent of cooling. In the present work, redistribution of hydrogen, hydroxyl, carbonate, and bicarbonate ions was studied during directional freezing in batch aqueous systems. Controlled freezing was employed vertically as well as radially in acidic and basic solutions. In each case, the ions substantially migrated along with moving freezing front. Conductometry and pH-metry were employed to monitor the moving ions.

The global capacity of desalination plants, including renewable desalination, is expected to grow at an annual rate of more than 9% between 2010 and 2016. The market is set to grow in both developed and emerging countries such as the United States, China, Saudi Arabia (SA) and the United Arab Emirates (UAE). A very significant potential also exists in rural and remote areas, as well as in islands (Figure 2, rest of world (ROW)), where grid electricity or fossil fuels to generate energy may not be available at affordable costs. About 54% of the global growth is expected to occur in the Middle East and North Africa (MENA) region, where the 21 million m<sup>3</sup>/d of desalinated water in 2007 is expected to reach 110 million m<sup>3</sup>/d by 2030, of which 70% is in SA, the UAE, Kuwait, Algeria and Libya

There is an almost unfathomable amount of water on earth: about 1.4 billion km<sup>3</sup> (330 million cubic miles) [3]. Of this total, less than 3% is fresh water (about 35,000,000 km<sup>3</sup>), much of which (about 24,000,000 km<sup>3</sup>) is inaccessible due to the fact that it is frozen in ice caps and glaciers (Figure 1). It is estimated that just 0.77% (about 11,000,000 km<sup>3</sup>) of all the earth's water is held as groundwater, surface water (in lakes, swamps, rivers, etc.) and in plants and the atmosphere.



## SEA ICE DESALINATION TECHNOLOGY

Ice is formed when the temperature is below the freezing point, but most salt ionic species contained in seawater are so large that it is difficult to incorporate them into the ice crystal lattice. So the salts contained in seawater are transferred into the underlying ocean and only parts of them are retained in the volume of newly grown ice in the form of a so-called brine pocket. Further desalination may occur when the sea ice grows and melts, which can reduce the salinity to a lower level [9]. Thus, sea ice is composed of ice crystals, brine pockets, air pockets and a bit of solid impurities, which is different from fresh water ice.

The salt from sea ice mainly exists in the brine pocket; the salinity of sea ice is usually about 3‰–8‰, which is much lower than seawater (about 3.5%). It is seen that the sea ice formation process is actually a natural desalination process, which can save lots of investment and reduce the cost when the sea ice is used as a desalination material.

Sea ice desalination includes solid-state desalination and liquid-state desalination were studied in different scales in detail. Centrifugal desalination and slight-melting desalination are the typical methods of solid-state desalination while RO is the main method of liquid-state desalination.

## CRYODESALINATION

Norbert Buschbaum developed pilot unit for desalination of sea water by using a different technique called Cryodesalination, Desalination by freezing processes is based on the fact that, ice crystals formed are made up of essentially pure water when the temperature of saline water is lowered to its

freezing point and further heat is removed leaving behind brine solution. When in contact with a liquid, these crystals become slush. Brine adheres to the crystals and becomes trapped. Complete removal of brine from slush is difficult to achieve. As a result, when the ice melts becoming water, the residual brine in the slush makes the water salty. This is the reason freeze desalination failed in the past.

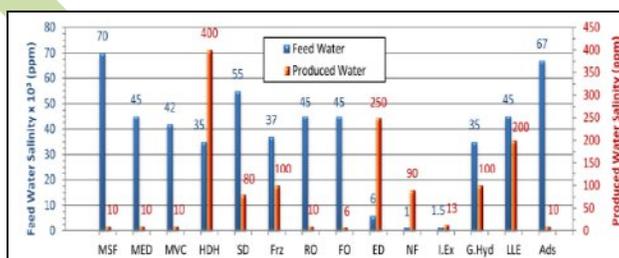
The problem of separating ice from brine is solved by a method never previously used in freeze desalination: floatation.

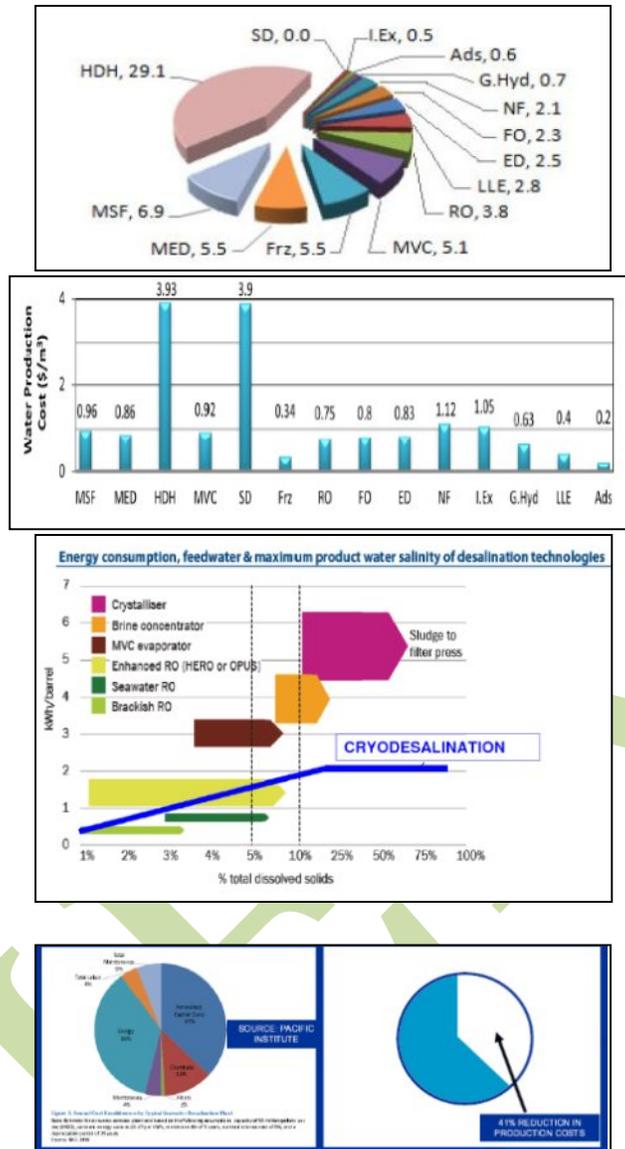
Simply stated, the method works as follows: ice floats on water. Many fluids also float on water. By selecting a fluid that floats in-between ice and brine we can effectively separate the ice from the brine. Harvesting this separated ice produces fresh water.

The approach overcomes this problem and successfully achieves ice-brine separation by interaction of oil, brine, and ice in a separation column. Cryo Desalination is highly energy efficient. The efficiency approaches the thermodynamic minimum. This efficiency is achieved by using the “cold energy” in the ice to condense the refrigerant vapors, thereby recapturing a substantial portion of the energy expended to make the ice.

### COMPARISON OF DIFFERENT TECHNOLOGIES

Several parameters affect the selection of desalination systems including; quality of salty water to be desalinated, salinity level of produced potable water, input energy, environmental impact and cost. According to salinity of water, it could be categorized into brackish or seawater. Brackish water contains total dissolved solids (TDS) higher than potable water and lower than seawater. Potable water should have TDS lower than 1000 ppm (or mg/l) and brackish water in the range of 1,000 to 25,000 ppm while seawater has an average of 35,000 ppm TDS concentration. Figure 2 shows the variation of feed water and produced water salinity for the listed technologies. It is clear from this figure that MSF and Ads desalination technologies can handle feed water with the highest salinity and produce water with the lowest salinity. Figure 3 shows the amount of thermal and/or electrical energy required by each technology. It is clear from this figure that SD, I.Ex, G.Hyd and Ads require the least amount of energy (below 2kW.hr/m3). Figure 4 shows the environmental impact of each technology in terms of the amount of CO2 emissions, where all the calculations were based on; emission factor for burning of natural gas of  $6.42 \times 10^{-5}$  tCO<sub>2</sub>/MJ (thermal energy) and on CO<sub>2</sub> emission factor for electricity generation of 0.4612 tCO<sub>2</sub>/MWh [1]. It is clear from this figure that SD, I.Ex, Ads and G.Hyd produce the least amount of CO<sub>2</sub> below 0.7 kg/m<sup>3</sup>. Figure 5 shows the running cost of the listed technologies where Ads, Frz and LLE have the lowest cost of below 0.5\$/m<sup>3</sup>.





RO plant cost Vs Cryodesalination plant cost

## CONCLUSION

All the techniques which are available have their own advantages & disadvantages, Cryodesalination is better when implemented in large scales & when used for sea ice desalination rather than sea water desalination, this cost reduction is the result of eliminating the costs of chemicals, membranes, and filters (17%) plus lowering by one half the capital, labor, and maintenance costs of RO ( $\frac{1}{2} * (10\% + 37\%)$ ). Their sum represents a 41% reduction in total cost of production when using CryoDesalination rather than Reverse Osmosis. Adsorption technology is also proving to be competent, because of its lower environmental impact, less energy consumption, less CO<sub>2</sub> emissions, Slight-melting desalination has own special advantages; for example, no complex equipment, easy to be realized, lower cost, easy operation, etc. Therefore, it is suited for situations which do not require very high water quality but do need lower investment.

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