Freeze Desalination Process- An Overview

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Abstract— Desalination is a water treatment process used for removing total dissolved salts from water. The selection of desalination process for a certain purpose depends on factors such as energy costs, final water quality, temperature and overall process cost. Various thermal and membrane technologies are used for desalination. In this paper, freeze desalination process is reviewed considering its several advantages over other process such as lower energy consumption, environment friendly. Experimental setup of Ice Plant is used to analyze the Freeze desalination process. Separation of ice and brine can be tried by using an intermediate fluid.

Key words: Desalination Process, Freezing Desalination, Fluid Separation

I. Introduction

Water is important for existence of life on earth. Out of the total available water 97.5% is salty, whereas only 2.5% is freshwater. Water shortage is becoming a major issue as the existing water resources are unable to meet the water supply demand, due to increase in human population. Due to increasing shortage of fresh water, sea water becomes an alternative, where desalination becomes essential. In order to solve the water scarcity problem, we need to find better and more economic ways of desalting salt water. Desalting techniques have increased the rate of water resources available for use by a community.

Desalination generally treats seawater to produce a stream of freshwater and separate saltier stream of water. It can create a new source of freshwater from otherwise unusable waters and this source may be more dependable than freshwater sources that relies on runoff, annual precipitation, recharge rates. Desalination can be developed to produce fresh water for industrial, agricultural and human consumption. In desalination, various technologies are used to remove excess salt concentrations from sea water and supply potable water. Hence, energy efficient desalination methods are of very much importance to solve these problems. Reducing energy requirements of desalination would decrease its cost uncertainties. Most of the cost for seawater desalination is for energy required to operate the plant.

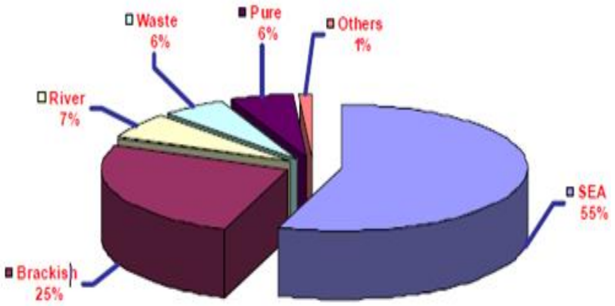

Fig. 1: World desalination capacity by raw water quantity [8]

Freeze desalination failed in the past due to several reasons, main being the separation of ice and brine. This paper aimed at understanding this problem and trying to separate the ice and brine by introducing an intermediate fluid.

II. Various Desalination Technologies

Water desalination process has become a sustainable and non-conventional water resource in the world. All are operated either by a conventional energy or renewable energy to produce fresh water. The best desalination system should work when it is installed and continue to work and deliver suitable amount of fresh water at the expected quantity, quality and cost for life of a project. Desalting techniques have increased the range of water resources available for use by a community. A desalting system essentially separates saline water into two streams: one with lower concentration of dissolved salts and other containing remaining dissolved salts. The device requires certain energy to operate and can use number of technologies for separation. The processes are many and generally classified according to technology used and mainly classified to thermal and membrane.

Initially, thermal technologies were the only option. But with the growth of membrane science, reverse osmosis took over. The search for new improved technology led to the use of freeze concentration method. The selection of desalination process for a certain purpose depends on various factors such as energy cost, final water quality, fouling propensity, temperature, overall process cost. Due to the potential advantage such as low energy requirements, less environmental impact, no pre-treatment and immunity of fouling and scaling or corrosion of freeze desalination process, it is given consideration.

A. *Classification of Desalination Process*

Thermal	Membrane	Other minor Process
Multistage Flash system	Reverse Osmosis	Ion Exchange
Multi effect distillation	Forward Osmosis	Humidification-Dehumidification
Vapour compression System	Electro-Dialysis	
Solar Distillation		
Freezing Desalination		

Table 1: Classification of Desalination

Selection of Desalination process suitable for particular application depends on several factors:

1) Amount of fresh water required in particular application in combination with range of applicability of various desalination process.
2) Effectiveness of process with respect to energy consumption.

3) Suitability of process for solar energy application.
4) Seawater treatment requirements.
5) Capital Cost of equipments.
6) Land area required or could be made available for installation of equipment.
7) Robustness criteria and simplicity of operation.
8) Low maintainence, compact size and simplicity to transport to site.

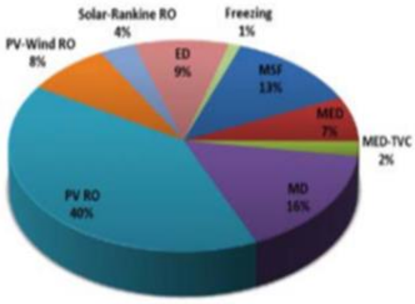

Fig. 2: Water desalination technologies coupled with solar power sources installed worldwide [9]

Some of the desalination technologies can be explained below:

1) Multi Effect Distillation: In this process, feed water passes through the evaporator placed in series. In each effect the pressure is lesser than the precedent. This allows the water to be boiled without any requirement of additional heat.
2) Multi Stage Flash system: It is a method to distil seawater by flushing a portion of water into steam in multiple stages, taking advantage of the fact that water boils at successively lower temperature when pressure decreases. Hot water entering from one stage to another under lower pressure boils vaporising seawater. Afterwards vapour circulates in condenser to produce pure water.
3) Vapour Compression System: Also known as Mechanical Vapour Compression System. In this, Saline water is evaporated to be compressed afterwards in order to use the energy produced in compression to evaporate new saline water.
4) Reverse Osmosis: It is a process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of osmotic pressure. Thus, the water flows in reverse direction to the natural flow across the membrane leaving behind the dissolved salts with an increase in salt concentration.
5) Humidification-Dehumidification process: Based on the fact that if a flux of air passes over a mass of saline water, air can get a quantity of water as vapour. After the vapour's condensation, almost salt-free fresh water is obtained.
6) Nano-filtration: It operates mainly on divalent ions such as calcium or magnesium. It works under a pressure of 2.75-17.24 bar. It is used to soften the water mainly domestic water supply purposes, pesticides and other organic substances.
7) Electro-dialysis: It consists of electrochemical separation process in which electrically charged membranes and electrical potential difference are used to separate ionic species from aqueous solution and other uncharged components.

III. PRIOR WORK RELATED TO FREEZE DESALINATION

Freezing Desalination is a thermal process of obtaining freshwater from contaminated fluid without the addition of chemicals. The basic principle is that the structure of ice crystals does not accommodate salts. During freezing, salts are rejected by growing ice crystals. In solid-liquid phase change, solute impurities are rejected readily from the crystal structure. When freezing the brine, the ice crystal will reject the solute and will continuously freeze the water. Thus, concentration of solute will increase steadily in water. Heat is extracted through saline water until it becomes crystallized into pure water ice crystals, which is then separated through residual brine and melted into fresh product water. Some of heat extracted in freezing cycle, may be recovered and utilized in melting stage.

Freeze Desalination was very well known in the years 1950s to 1980s. The reason it failed earlier is, in seawater, ice crystals form irregular crystals. When in contact with the liquid ice becomes slush, brine adheres to the crystals and gets trapped. So, complete removal of brine from slush is difficult to achieve. The key process which needs some research and development is the separation of ice from salt water mixture.

Farah Hanim Ab. Hamid [1] studied the use of progressive freeze crystallization to produce pure water in the form of ice crystal block leaving behind a salt solution. The effect of coolant temperature and efficiency of system was reviewed based on value of effective partition constant. Efficiency and salinity reduction were calculated in order to determine system performance. He concluded that progressive freeze concentration system has splendid potential to be applied for desalination process.

Avinash Shaligram [2] proposed a novel system for desalination of sea water using solar energy. He suggested the use of Ammonia Absorption Refrigerant plant which will be operated by steam generator either from a concentrating solar system or biomass fired boiler. The brine solution will be used to freeze seawater into ice in a separate cold store. Since only water can freeze only while salt cannot, there will be a mixture of ice with salt solution. Some of salt may stick to ice in the form of crystals. Next step would be to separate ice from salt solution. For this a cost-effective and efficient technique would be needed.

T Mtombeni et al [3] found the use of hybrid technology as an alternative for brine treatment. In this, a primary refrigerant R404a is recycled between refrigeration unit and heat exchanger to cool brine and produce ice crystal from fresh water. Heat exchanger provides indirect heat transfer surface between brine and refrigerant. Slurry is thus generated and ice filter separates ice from brine without addition of fresh water to wash ice crystals in a continuous process.

M.V. Rane, Y.S. Padiya [4] discussed a patented layer freezing technology which has competitive initial and operating cost and eliminates operational difficulties of conventional freezing system. It is scalable and coupled with a heat pump which selectively freezes water from seawater in an evaporator and melts ice in subsequent phase when it serves as a condenser. They studied the use of vented tube-tube double wall heat exchanger which enables refrigerant and seawater to exchange heat without use of intermediate fluids. It avoids the need of separation mechanism.

Paul M.Williams [5] discussed the basic principles of freeze concentration and found the reason for its limited use due to dominance of thermal and membrane technologies. It studied application for freeze concentration and discussed the possibility of application to high saline brine waste in hybrid technology.

Gao Penghui et al [6] studied that seawater can be frozen driven by humidity difference between air and liquid surface at 0°C. It utilizes the latent heat of vaporization to freeze seawater and thereafter produce fresh water. Based on heat and mass balance equations, they developed theoretical model and verified through experimental results.

Cong-shuang Luo et al [7] studied the factors affecting quality of ice crystal during freezing concentration for brackish water. Desalination rate was positively co-related with freezing temperature and amount of seed ice, while negatively co-related with freezing rate, solid fraction, solution concentration and surface area of freezing container. It was found that initial temperature of solution has no effect on quality of ice.

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IV. Freeze Desalination Process

Desalination Process is mainly classified on the basis of technology used, generally as thermal and membrane desalination. Principle of the thermal desalination depends on the difference between boiling or freezing temperature of salt and water. It is usually used where high salinity feed waters are used i.e. seawater, high recoveries are required, high feed water temperature, and low energy cost, main drawback is extensive energy consumption. Some of thermal desalination technologies are multi-stage flash distillation, multi-effect distillation etc. Membrane desalination uses a relatively permeable membrane to move either water or salt to induce two zones of differing concentrations to produce fresh water. It includes several processes but the principal difference between them lies in the size of the entities, ions, molecules and suspended particles that are retained or allowed to pass through the membranes. There is a need to develop more environmental friendly, energy efficient and operational viable technologies for brine treatment.

Freeze desalination has been proven to be a viable technique to handle brines of elevated salinities. The process is based on the process is based on the principle that due to small dimensions of ice crystal lattice, inclusion of compounds in crystal lattice is not possible except for ammonia. The basic freeze desalination includes three discrete steps to obtain fresh water from saline water. Those are: Ice formation by heat removal of saline water, Separation of ice from brine, melting of ice.

The desalination of water by freezing is a well-known process and relies on the principle that structure of an individual ice crystal does not accommodate salts. In freezing process, salts can be rejected by growing of ice crystals. Crystals can be separated from the concentrated solution, which is rejected as brine and melted to yield pure water. Its several advantages over other process include lower theoretical energy requirement, reduced potential for scaling, corrosion, and few precipitation problems due to lower operating temperatures. It is insensitive to salinity and composition of feed water. A low salinity water can be obtained and large proportion of feed water can be recovered as clean water. Some obstacles for success of this method includes control and optimization of crystallization process, process complexity due to the need to grow the individual ice crystals, handling and transportation of ice slurry and separation of ice from mother liquor.

V. Separation Technique

The purpose of my work is to find out a separation technique of ice from brine and obtain fresh water. There are several methods for separation of ice crystals from liquid. Chosen methods depend upon the characteristics of crystals. Two things of concern are crystal size and specific gravity. The more efficient the separation process, the less carryover of salt into separated ice stream and more economical the overall process will be. One probable method would be tried out by using a floatation liquid. The fluid needs to be chosen such that it has specific gravity between ice and brine and is water immiscible and has low viscosity.

In order to separate the ice and brine effectively, an intermediate fluid can be introduced with the sea water while freezing. The most important characteristics of the separating medium are: It is immiscible with water, its specific gravity is within the range of 0.9 to 0.98 and has low viscosity. One such fluid (oil) can be considered as a separating medium between the ice and salt. Some of such oils are identified and details are as given below:

A. Possible Alternatives for Separating Fluid

Oil	Freezing point (°C)	Specific gravity
Castor oil	-18	0.961
Corn oil	-20	0.924
Sunflower oil	-17	0.92
Soyabean oil	-16	0.94
Linseed oil	-24	0.929

Table 2: Possible alternatives for separating fluid

Castor oil is a colourless to pale yellow liquid with a distinct taste and order once injected. It is used in manufacturing soaps, hydraulic and braking fluids, waxes, polishes etc. Corn oil is also used as a feedstock in biodiesel, used for rustproofing of metal surfaces, in insecticides and inks. Corn oil is comparatively less costlier than others.

Sunflower oil is the non-volatile oil compressed from sunflower seeds. It is commonly used in food as a frying oil, and in cosmetic formulations as an emollient. Soyabean oil is most widely used cooking oil. As a drying oil also used as a base for printing inks and oil paints. Linseed oil is superior to soyabean for drying applications. It is a colourless to yellowish oil used as plastisizer and hardener in putty.

The basic desalination process aims at reducing the salinity of water. Process is carried out and salinity reductions can be achieved after the freeze desalination process.

VI. Conclusion

Freezing desalination process is studied due to its several advantages over other process such as a lower theoretical energy requirement, a reduced potential for corrosion, and few scaling or precipitation problems and less environmental effect. It has the potential to concentrate waste streams to higher concentration than other process and energy requirements are comparable to reverse osmosis. The only disadvantage is that it involves handling ice and water mixture that are mechanically complex to move and process. Seawater can be used for freezing purpose. Ice purity is favoured by low ice fractions that are attainable at higher freezing temperature and low flow rate. Thus by the use of freeze desalination process, separation of ice and salt can be carried out and reduction in salinity of the water can be achieved.

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