INTEGRATED METHOD FOR DESALINATION OF SEAWATER

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ABSTRACT

Desalination has been adopted on a large scale over the last few years to overcome water shortages in many areas around the world. Due to increasing scarcity of potable water there is a necessity to find alternative source of potable water.The main objective is to desalinate sea water using Reverse osmosis and membrane distillation as an integrated method for the production of potable water. Sea water as abundantly available can be very promising source after proper treatment. Reverse Osmosis (RO) is the leading technology for desalination of sea water because of their strong capabilities in removing dissolved salts. Membrane Distillation (MD) is an emerging technology for effective desalination process of sea water due to its potential lower energy consumption and simplicity. Both RO and MD have a great potential for treatment of water worldwide due to its availability, low cost and high efficiency.

Keywords: Desalination, Membrane Distillation (MD), Reverse Osmosis (RO), Water Quality.

I. INTRODUCTION

Water is the most common element in the world, however, 97% is seawater and only 3% is fresh water. The availability of water for human consumption is decreasing due to increasing the environmental pollution. According to the World Health Organization (WHO), about 2.4 billion people do not have access to basic sanitation facilities, and more than one billion people do not have access to safe drinking water. Moreover, the world's population is expected to rise to nine billion from the current six billion in the next 50 years. The US geological survey found that 96.5% of earth's water is located in sea sand oceans and 1.7% of earth's water is located in the icecaps. The remaining percentage is made up of brackish water, salty water found as surface water in estuaries and as groundwater in salty aquifers [1]. Chronic water pollution and growing economies are driving municipalities and companies to consider the desalination as a solution to their water supply problems. Generally, desalination processes can be categorized into two major types: 1) phase change/thermal and 2) membrane process separation. Some of the phase-change processes include multi-stage flash, multiple effect boiling, vapour compression, freezing and solar stills. The pressure driven membrane processes, such as reverse osmosis (RO), Nano filtration (NF), ultrafiltration (UF) and microfiltration (MF), have found a wide application in water treatment [2].Although India occupies only3.29 million km geographical area, which forms 2.4% of the world's land area, it supports over 15% of world's population. The population of India as of March 31, 2011was 1,210,193,422 persons (Census, 2011)[3]. Desalination uses a large amount of energy to remove a portion of pure water from a salt water source. So it is necessary to do the process efficiency, flux performance and energy consumption for desalination of sea water to meet the water crisis problem and global economic challenges. RO and MD when used as an integrated process, provides more efficient results as compared to other pressure driven processes. Challenges, however still exists to produce desalination water for relatively large communities for the continuous growth, development and health, and for modern efficient agriculture, at moderate costs [4].

II. PROCESSES FOR DESALINATION

Desalination is a process of removing dissolved salts from water. It is also called as desalting. Various methods can be used for desalination of seawater.

2.1 Thermal Processes

2.1.1 Multi-stage flash (MSF):

The by far most frequently used process for desalting of seawater is the Multi Stage Flash (MSF) distillation. It is a process that comprises of evaporation and condensation of water, where pressurized feed water is heated in the brine heater before entering a chamber under partial vacuum. The latent heat of evaporation is recovered for reuse by preheating the incoming water. To increase water recovery in each stage of an MSF unit operates at a successively lower pressure.

2.1.2 Multiple effect distillation (MED):

Multiple Effect Distillation (MED) employs the principle of distillation that incorporates boiling of the feed water. Therefore, this method comes across problems with scaling and has in general a more complex installation and control as compared to MSF. MED also uses different pressure vessels or effects, and the feed water is evaporated in the first vessel at its boiling point [5].

2.1.3 Mechanical vapor compression (MVC):

The MVC process is symbolized by being driven exclusively by electric current, which is used to drive the mechanical vapour compressor. External heating steam is required for initialization of MVC process. Vapour compression (VC) is similar to the MED principle. Feed water introduced into the column is evaporated and the produced vapour leaves by passing through a moisture separator. Instead of condensing in the next subsequent effect as the case MED, the feed water is compressed and hence its condensing temperature is elevated [6].

2.2 Membrane Technologies

2.2.1 Reverse osmosis (RO):

Although the overall capacity of reverse osmosis is comparatively small desalination plants based on this process is one of the most popular types installed now-a-days. Reverse osmosis being a membrane process; the salt is separated from the water by means of a selective membrane. Energy is required solely to pump the feed water at a pressure above the osmotic pressure. However, higher pressures must be used, typically 50-80 bar, in order to have a adequate amount of water pass through a unit area of membrane [7].

2.2.2 Electro dialysis (ED):

As the name implies, this technology utilizes an electrochemical separation process in which charged membranes are applied to separate ionic species from a mixed aqueous solution of varied components and water through ion exchange membranes, which cause the concentration variations of solute in dilute and concentrated compartment [8].

2.2.3 Membrane distillation (MD):

Membrane distillation (MD) is a thermally driven process that utilizes a hydrophobic micro-porous membrane to support a vapour-liquid interface. Vapour pressure difference arises if a temperature difference is maintained across the membrane. As a result, water gets evaporated at the hot interface, crossing the membrane in the vapour phase and condenses at the cold side, which gives rise to a net trans-membrane water flux [9,10,11].

III. INTEGRATED PROCESS OF DESALINATION OF WATER

The integrated process of desalination consists of reverse osmosis followed by membrane distillation

3.1 Reverse osmosis

Reverse osmosis is a process in which pressure is applied greater than the osmotic pressure through a semi permeable membrane so that the solute is removed from the feed solution.

Principle: RO is a physical process based on osmosis phenomenon. It is a pressure driven process wherein feed stream is fed into a chamber having semipermeable membrane resulting in the separation of two streams, one consisting of high concentration salt and other with less concentration. Pressure applied is higher than the osmotic pressure and the salt is retained in the feed side.

In this method there are various stages in RO mainly as follows:-

- Pre-treatment.
- High pressure pumps (if required).
- Membrane assembly.
- PH adjustment.
- Disinfection.(if required)

Pre-treatment:

It is a process in which the water is pre-treated in such a way that all the macromolecules are filtered out from the feed water solution, so that thereis no deposition of solid macromolecules on the semipermeable membrane. This leads to lesser damage to the membrane and there is availability of more surface area for the process.

High pressure pump:

High pressure is required when the applied pressure is less than osmotic pressure which is required for the RO. High pressure pump is generally not used when an energy recovery is combined with the RO set-up as it leads to minimum consumption of energy.

Membrane assembly:

The membrane assembly consists of a pressure vessel with a membrane that allows pre-treated feed water to be pressed against it. The membrane must be strong enough to withstand whatever pressure is applied against it. Reverse osmosis membranes are made in a variety of configurations, with the two most common configurations being spiral-wound and hollow-fibre. A part of the saline feed water pumped into the membrane assembly passes through the membrane and the salt gets removed. The remaining "concentrate" flow passes along the saline side of the membrane to flush away the concentrated salt solution. The recovery ratio varies with the variations in the salinity in the pre-treated feed water and the design parameters of the system.

pH adjustment:

Sometimes it is necessary to adjust the pH value of the pre-treated water so that there is no effect on the membrane of the system. Generally liming is done to maintain the pH value of the pre-treated water to be as close to the pH value 7.

Disinfection:

It is a post treatment process in which the bacteria and the viruses are being destroyed using UV lamps or chlorination to make it disinfected potable water [12].

IV. FACTORS AFFECTING REVERSE OSMOSIS

4.1Pressure

When the effective pressure of the feed water is increased, the dissolved solids content of permeate will decrease, while the permeate flux increases.

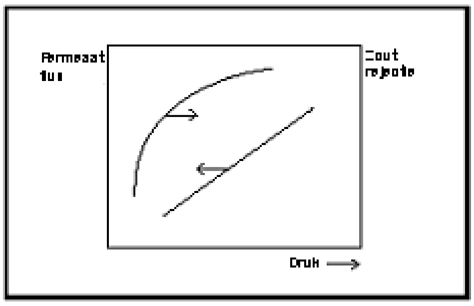
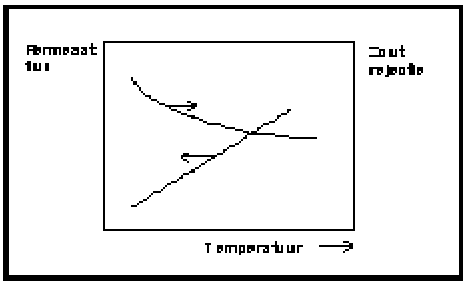


Figure 1 Performance and pressure RO

4.2 Temperature

When temperatures increase and other parameters are constant, the permeate flux and the salt flow will increase.



\Figure 2 Performance and temperature of RO

4.3 Recovery

The recovery means the relation between the permeate flow and the feed water flow. When recovery increases, the permeate flux will decrease and stagnate, when salt concentrations are of a value where osmotic pressure equals feed pressure.When recovery increases, the salt retention will decrease.

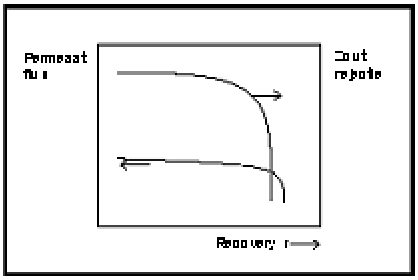


Figure 3 Performance and recovery of RO

4.4 Salt concentration of the feed water

The effects of the salt concentration of the feed water on the permeate flux and salt retention are shown here.

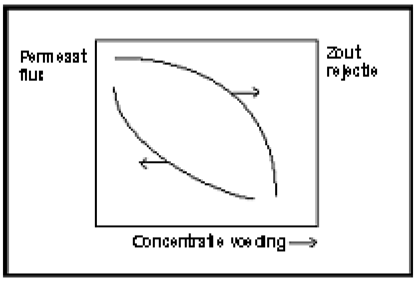


Figure 4 Permeate Flux, Rejected O/P and Concentration

V. MEMBRANE DISTILLATION

Principle

MD is a thermal, vapour driven transportation process through hydrophobic membranes. It is a non-isothermal membrane process in which the driving force is partial pressure gradient across the membrane. Sea water is heated, its vapour pressure is increased which creates the difference between the partial pressure at both sides of membrane. Hot water evaporates through the non-wetted pores of hydrophobic membranes and only non-condensable gases are present within the membrane pores. The vapour coming out of the membrane is then condensed and fresh water is produced.

The output of the reverse osmosis process is used as a feed to the membrane distillation. In membrane distillation unit further of the water occurs. The membrane distillation process is carried out as follows.

There are various methods to carry out the membrane distillation process as mentioned as follows [13,14,15]:

- Direct contact membrane distillation
- Air gap membrane distillation
- Vacuum membrane distillation
- Sweeping gas distillation

- Vacuum multi effect membrane distillation

Out of these, generally DCMD process is used due to its easy construction and better comparative efficiency than the other methods. In DCMD basically there are two chambers for the flow of the fluids with membrane at the centre of the container. The fluids flow in counter current fashion. Hot fluid flows through the one side of the chamber whereas the cold fluid flows through other side of chamber. The output of the RO process is used as input to MD process. The input to the MD is first preheated and then passed through the chamber of the MD apparatus. The vapours are formed due to the preheating; these vapours then diffuse through the membrane.

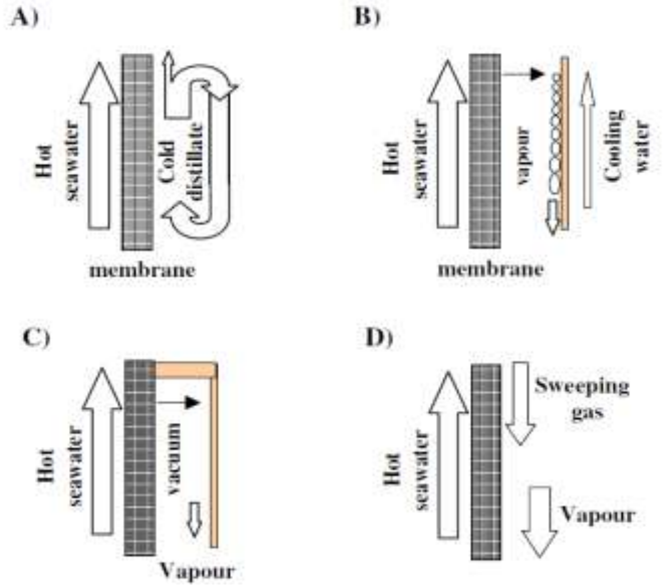


Figure.5 Schematic Diagram of MD

The membrane is hydrophobic in nature. The diffused vapours are then condensed on the other side chamber and thus potable water is achieved as product.

VI. EFFECTS OF OPERATING PARAMETERS

Feed temperature

The effect of the feed temperature on permeate flux has been widely analysed. The feed temperature typically ranges between 60’C and 90’C.Generally, there is exponential increase in flux with feed temperature. Thedriving force for membrane distillation is the difference in vapour pressure across the membrane.As the feed temperature is increased, thevapour pressure in thefeed solution channel also increases which results in the increment in the trans-membrane vapour pressure. it is better to work under high feed temperature,according to several researchers, as the evaporation efficiency and the total heat from the feed to the permeate/cooling side is high. The temperature polarization effect increases with the increase in feed temperature. However, if the operation is carried out at very high temperatures i.e. 90’C it may lead toreduction of membrane selectivity and severe scaling problems. [13, 14, 15]

Coolant temperature

Due to the exponential increase of the vapourpressure with feed temperature, the general effect of increasing the coolant temperature is less influential than the feed temperature.[13,15,16]

Feed concentration

Feed concentration cause trans-membrane flux to decrease. This is due to several reasonsas follows

i) Vapour pressure reduction due to the salt concentration, ii) Formation of concentration boundary layer at the membrane surface and iii) Increased temperature polarization. [14,15,17]

Feed flow rate

In most of the studies, the effect of the feed flow rate results in the increase of permeate flux. This is due to decrease in temperature and concentration polarization effects by the mixing effect caused due to higher turbulence inside the feed channel. Such turbulence brings the temperature at the membrane surface closer to the bulk feed temperature. The effect of flow rate on yield is less than half of the influence of feed temperature; and its significance is obvious at higher temperatures especially associated with highertrans-membrane temperature drop. In general, the relationship between the trans-membrane flux and feed flow rate is linear to a certain limit, after which it has no effect on the trans membrane flux.[15,16]

Coolant flow rate

In the case of DCMD configurations, an increase of the permeate flow velocity increases the heat transfer in the permeate side of the membrane module by reducing the temperature and concentration polarization effect. This will tend to increase the permeate flux as the temperature difference increases. [15,16]

Trans-membrane temperature difference

The driving force in MD is the trans-membrane vapour pressure, as a result of temperature difference between the feed and permeate/cooling side of the membrane module. Flux increases linearly with hot to cold side temperature difference and increases slightly when coupled with a rise in feed concentration, as the boundary layer increases and contribute to the temperature polarization effect. Moreover, the slope at which flux increases with temperature drop tends to decrease at higher values. Such tendencies are related to temperature and concentration polarization effects which are affected by feed flow rates [15, 18, 19].

Effect of non-condensable gases

Non-condensable gases evolve with the vapour, including dissolved. These gases get trapped in the membrane pores resulting in additional mass transfer resistance which leads to decline in the flux. When feed and permeate are degassed, the partial pressure of air within the pores becomes lower, hence, the molecular diffusion resistance decreases. De-aeration could significantly increase the permeate flux when large pore size membrane is used.[13,16,19,20]

VII. TEMPERATURE POLARIZATION IN MEMBRANE DISTILLATION (MD)

The thermal boundary layer at feed side of the membrane imposes a resistance to heat transfer and creates a temperature difference between the membrane surface and the bulk liquid which creates heat transfer. The influence of this thermal layer in the feed channel (and cooling channel) is known as temperature polarization effect. Temperature polarization coefficient

(TPC) is used to quantify these phenomena by following equation:

$$TPC = \frac{T_{ms} - T_{cf}}{T_h - T_c}$$

Where,

T_{me} is temperature at the membrane,

T_{cf} is temperature at condensation film,

$T_h$is temperature at hot/feed bulk solutionand

T_c is the temperature at the cooling bulk liquid.

Lower the TPC value, higher the temperature polarization effect, and vice versa. The temperature polarization effect increases with increase in feed temperature The thermal boundary layers depend on fluid properties, operation condition and hydrodynamic conditions[14,15,21].

VIII. ADVANTAGES AND DISADVANTAGES OF INTEGRATED METHOD

Advantages:

- The degree of purity of the product obtained by this integrated method is very high.
- The energy can be easily recovered in this process.
- Low space requirement as the equipment is compact.
- Fouling of hydrophobic membrane used in MD is less when used as an integrated method.

Disadvantages:

- The commercial membrane modules are expensive.
- This method requires higher power consumption.
- Pre-treatment of water is must for free of pathogens and suspended particles for feed water.
- Non-condensable gases evolve impose additional mass transfer resistance during the process.

IX. CONCLUSION

Desalination technologies create new sources of fresh water from seawater or brackish water.This paper focuses on the fundamental aspects of combined RO and MD units for desalination process. This novel technology of coupling of Reverse Osmosis with membrane distillation (DCMD) shows a greater scope for the feasibility ofDCMD for good quality of product flow, high rejection of salts, low energy consumption and efficiency in desalination of water. The field of RO membrane desalination has become the primary choice for water purification over the past 40 years. MD is known since 1963 and is still being developed at laboratory stage for different purposes and not fully implemented in industry. Due to the low energy requirement, compactness and ease of operation in reverse osmosis process and low pressure and temperature requirements in membrane distillation process, forms a very effective method for desalination/purification of seawater and /or brackish water.It reduces dependency on conventional and depleting energy sources.This integrated process provides easy access ofdrinking water for the people in rural and remote areas hence this integrated method will be a boon for long run operation with less energy consumption, easy maintenance and one time capital investment, which is more economical.

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