Desalination Using Membrane Distillation: A Review

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Abstract:-
As the water demand increases continuously, large capacities of desalination plant are added every year to meet freshwater demand. The higher carbon footprint of desalinate- ton raises concern on global climate change. The integration of desalination and renewable energy source could mitigate this water-energy nexus. Due to lack of rain-fall and seawater intrusion, conversion of underground water to salt water is inevitable. Hence, a large capacity of desalination plants has to be installed in various places to convert the saline water in to potable water. Membrane distillation (MD) is a non- isothermal desalination process in which the low-grade heat is used as the driving force. Many researchers have tried to integrate solar energy and MD for sustainable water desalination. Moreover, an alternative source of energy which is from the heat stored in the lower zone of the solar pond was investigated by using the combination of MD and salinity gradient solar pond (SGSP). Solar powered MD systems have been investigated for last few decades. However, its commercialization is very limited due to low flux, high specific energy consumption and large collector area requirement. A Concentrated Photovoltaic (CPV) and Direct Contact Membrane Distillation (DCMD) hybrid system is available solution to address water shortage in arid and rural areas. We see the recent developments in MD membrane, innovative MD modules and the importance of optimization, which was able to improve the performance of solar MD.

Keywords: Membrane distillations, solar desalination, Salt gradient solar pond, Multi- effect membrane distillation, Heat recover.

INTRODUCTION

MD is a thermally driven process, in which water vapor transport occurs through a non-wetted porous hydrophobic membrane. The term MD comes from the similarity between conventional distillation process and its membrane variant as both technologies are based on the vapor-liquid equilibrium for separation and both of them require the latent heat of evaporation for the phase change from liquid to vapor which is achieved by heating the feed solution. The driving force for MD process is given by the vapor pressure gradient which is generated by a temperature difference across the membrane.as the driving force is not a pure thermal driving force, membrane distillation can be held at a much lower temperature than conventional thermal distillation. The hydrophobic nature of the membrane prevents penetration of the pores by aqueous solutions due to surface tensions, unless a trans-membrane pressure higher than the membrane liquid entry pressure (LEP) is applied. Therefore, liquid/vapor interfaces are formed at the entrances of each pore. The transport through the membrane can be summarized in three steps:

(1) Formation of a vapor gap at the hot feed solution–membrane interface;

(2) transport of the vapor phase through the micro porous system;

(3) Condensation of the vapor at the cold side membrane–permeate solution interface.

Murugesan et al. (1985) investigated the Membrane distillation is a relatively new membrane separation process which might overcome some limitations of the more traditional membrane technologies. In particular high solute concentrations can be reached and ultrapure water can be produced in a single step. When micro- porous hydrophobic membrane separates two aqueous solutions at different temperatures, selective mass transfer across the membrane occurs: this process takes place at atmospheric pressure and at temperatures which may be much lower than the boiling point of the solutions. The hydro-plasticity of the membrane prevents the transport of the liquid phase across the pores of the partition while water vapor can be transported across them from the warm side, condensing at the cold surface. The driving-force is the vapor pressure difference at the two solution membranes interfaces. Because the process can take place at normal pressure and low temperature, Membrane distillation could be used to solve various waste water problems.

DESCRIPTION

MEMBRANE DISTILLATION PROCESS:

Smith et al. (1987) studied the essence of membrane distillation is temperature difference-induced vapor transport through a non- wetting hydrophobic, porous membrane, where the driving force is the vapor pressure difference across the membrane pores; more exactly the chemical potential difference across the membrane. The capillary force hinders the aqueous liquid from entering the hydrophobic membrane pores. Simultaneous heat and mass transfer takes place during the membrane distillation process. The feeding liquid is brought into direct contact with the porous, hydrophobic membrane layer. The so-called breakthrough pressure difference can be given by the Laplace (Cantor) equation.

The membrane distillation process consists of three steps:

- The hot feed vaporizes from the liquid/gas interface.
- The vapor is transported by the vapor pressure difference and diffuses/flows from the hot surface to the cold interface through the pores.
- The vapor condenses onto the cold surface entering the cold stream.

TYPES:

- DCDA (Direct Contact Membrane Distillation)
- AGMD (Air Gap Membrane Distillation)
- SGMD (Sweeping Gas Membrane Distillation)
- VMD (Vacuum Membrane Distillation)

K. Zhao et al (2003) studied the fundamental simplicity of traditional distillation is compromised by various factors such as the need for complete removal of all non-condensable gases. The use of vacuum pumps, high pressure vessels, de-aeration devices, etc. are required for removing the effects of the non-condensable gases, with a significant energy consumption. The term MD comes from its similarity is conventional distillation. Both MD and conventional distillation technologies are based on vapor/liquid equilibrium for salt separation from water and both require latent heat of evaporation to be supplied to the aqueous feed solution of salt.

The driving force in MD is the difference in partial vapor pressure of water across a membrane that must fulfill the following characteristics:

a) Porous with high void volume fraction or porosity
b) Pore size range may be from several nanometers to few micrometers
c) Totally hydrophobic or at least the layer facing the salt aqueous solution is hydrophobic
d) Not welted by the aqueous solution of salt with sufficiently high liquid entry pressure (LEP)
e) Membrane material of excellent chemical resistance permitting cleaning with case acid and base components is necessary.

PROCESS CONDITIONS FOR MEMBRANE DISTILLATION:

Khayet et al (2003) studied the effects of various operational parameters on MD performance must be controlled to achieve the best results. Some of these parameters are:

a) Feed temperature:
The feed temperature has a powerful effect on the permeate flux. Based on the Antoine equation, by increasing the temperature, the vapor pressure increases exponentially. So, the permeate flux will increase exponentially by increasing of the temperature.

b) Feed concentration:
When the feed concentration increases, the permeate flux will decrease considerably due to the reduction of vapor pressure and increment of temperature polarization.
c) Feed flow rate.
Increasing of feed flow rate leads to permeate flux increment. This is due to the improved mixing and the reduction of temperature boundary layer thickness on the feed side of the membrane.

d) Membrane type.
MD membranes should have porous surface with high mean pore size. The distillate flux is proportional to the surface pore size and porosity and inversely proportional to the thickness of the membrane.

REVIEW OF LITERATURE

Bodell et al. (2002) concluded the idea of MD and its feasibility, Findley investigated the feasibility of distillation by using a porous membrane. Typical polymer materials such as poly-tetra fluoro-ethylene (PTFE), polypropylene (PP) and poly-vinyl difluoride (PVDF) are used for synthesizing MD membrane. The hydrophobic membrane employed in this process creates a surface tension force that forms a water-vapor interface at the surface of the membrane. If the water vapor pressure at feed membrane interface is higher than the cold permeate interface, evaporation occurs at the hot surface and diffuse through the membrane to a cold surface, where they will condense.

J. Koschikowski et al. (2011) stated that a solar membrane distillation coupled to a water collector and PV module was installed, fabricated and experimentally tested during daytime for sunny days (summer time) at the climatic conditions of the City of Kairouan, Tunisia. The various temperatures like inlet and outlet evaporator temperature, the inlet and outlet condenser temperature, and the distillate flow rate of the unit were recorded by using thermocouples and the data was plotted. Thermocouples sensor were placed in different places of the solar unit distillation and the water solar collector.

Francesca et al. (2014) stated that the scale formation at the membrane surface has been observed in the studies addressing the MD applied to solutions containing salts. Greta has investigated the membrane distillation performance in treating the spent solution from heparin production. The rapid flux declined was reported due to the fouling and scaling. The presence of salt deposits on distillate side confirm the occurrence of wetting as well. The permeate quality and the operation stability were dependent upon the nature of the feedstock. In a study, Gryta has analyzed the performance of MD against several different types of feed solutions including brine, bilge water and water containing protein. The strength and nature of fouling were dependent upon the feed and operating conditions used. The formation of protein-based deposits on the membrane surface was detected. The scale formation in MD was pointed out as one of the major responsible factors for wetting, flux reduction and damage to the membrane structure.

Bourawi et al. (2006) concluded that membranes with pore size between 100 nm to 1 μm are usually used in MD systems. The permeate flux increases with increasing membrane pore size. The mechanism of mass transfer can be determined, and the permeate flux calculated, based on the membrane pore size and the mean free path through the membrane pores taken by transferred molecules (water vapor). Generally, the mean pore size is used to determine the vapor flux. A large pore size is required for high permeate flux, while the pore size should be small to avoid liquid penetration. As a result, the optimum pore size should be determined for each feed solution and operating condition. There are several investigations examine the importance of pore size distribution in MD flux. It was reported that, care must be taken when mean pore size is utilized to calculate vapour transfer coefficient instead of pore size distribution. Better understanding of membrane morphology such as pore size, pore size distribution, porosity, and thickness directs to have an accurate mass and heat transfer modelling.

Phattaranawik et al. (2003) concluded the thermal conductivity of the membrane is calculated based on the thermal conductivity of both polymer k_s and gas kg (usually air) and porosity(ε). The thermal conductivity of the polymer depends on temperature, the degree of crystalline, and the shape of the crystal. The thermal conductivities of most hydrophobic polymers are close to each other. Scientist suggested some ways to reduce the heat loss by conduction through the membrane; using membrane materials with low thermal conductivities, using a high porosity membrane, using thicker membrane, and minimizing heat losses. It is also suggested that the permeability can be enhanced by using a composite porous hydrophobic/hydrophilic membrane.

Banat, et al (1994), There is a significant fall in the flux product when feed concentration increases due to decreasing vapour pressure and increasing temperature polarization. It was found that there is a reduction in the permeate when the acid concentration increase.

CONCLUSION

Membrane distillation is a most effective separation process than any other processes in certain areas because it gives high concentration at low pressure and temperature, has integration with other membrane operations implies more efficiency, good and excellent mechanical properties and chemical resistance and 100%(theoretical) rejection of ions, macromolecules, colloids and non-volatiles.

As a promising alternative to replace other separation processes, MD has gained much interest for its lower energy requirement in comparison with conventional distillation, lower operating pressures and higher rejection factors than in pressure driven processes such as NF (Nano Filtration), and RO (Reverse Osmosis). In recent years, some pilot plant studies have been proposed for desalination. However long- term evaluations of pilot plant applications for the concentration and recovery of aqueous solutions containing volatile solutes especially in the food industry are still scarce. On the other hand, there is a lack of commercially available MD units; practically all membrane modules are designed for other membrane operations (i.e. microfiltration) rather than MD. More attention should be paid to the possibility of integrating MD to other separation techniques in order to improve the efficiency of the overall system and to make the process economically viable for industrial applications. For fruit juice concentration, coupled operation of MD and OD (optical distillation) seems promising to overcome high temperature related problems (i.e. aroma and color loss) encountered in MD.

The ability to effectively operate at low temperatures makes MD process possible to utilize low- grade waste and/or alternative energy sources. In recent years, coupling MD with solar, geothermal and waste energy systems has been proposed to decrease energy consumption in desalination systems. Such an approach may be crucial for food processing systems. For example, in the case of fruit juice concentration, much lower temperatures should be applied in order to obtain stable products able to retain as much possible the uniqueness of the fresh fruit, its original color, aroma, nutritional value and structural characteristics.

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