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Sustainable seawater desalination by permeate gap membrane distillation technology

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Abstract

Membrane distillation (MD) as a novel thermally-driven process with moderate operating temperatures, is an effective technology for salt water desalination, by this process, it becomes achievable to directly utilize low-temperature waste heat or solar energy. This research is aimed to design a lab scale plate-and-frame permeate gap membrane distillation (PGMD) module, with internal heat recovery characteristic which could significantly reduce the energy consumption of the process. In this paper, the PGMD module performance is experimentally investigated for fresh and saline water feed, in terms of permeate water flux, specific thermal energy consumption (STEC) and gained output ratio (GOR). The experimental results show, by increasing the saline feed flow rate in a range of (0.4-1) lit/min, the fresh water flux increase from 3 to 11 $kg/m^2.hr$, however, the thermal energy demand of process also increased by nearly 20 %. As a result, optimization of the MD module performance is achievable, by adjusting the effective membrane surface area and feed flow rate, to improve internal heat recovery and also produce higher fresh water rate.

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Keywords: Sustainable desalination; Membrane distillation; Flat module design; Specific thermal energy consumption; Permeate flux

1. Introduction

The need for fresh water is considered as a critical international problem, according to the World Water Council, 17% of the world population will be living in short of the fresh water supply by 2020 [1].

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Nomenclature

C_p	specific heat capacity (J/kgK)
E_i	total energy input (J/s)
GOR	gained output ratio (-)
ΔH_v	specific heat of vaporization (J/kg)
J_p	permeate flux (kg/m^2.s)
$\dot{m}_f$	feed flow rate (kg/s)
ΔP	pressure drop (Pa)
q_{STEC}	specific thermal energy consumption (kWh/m^3)
S	salinity (g/Kg)
TEi	temperature at evaporator inlet (ºC)
TEo	temperature at evaporator outlet (ºC)
TCi	temperature at condenser inlet (ºC)
TCo	temperature at condenser outlet (ºC)
$\dot{V}_f$	feed flow rate (m^3/s)
$\dot{V}_p$	permeate flow rate (m^3/s)

The demand for alternative sustainable water sources including ground water, desalinated water and recycled water is increased, in recent years. As a result, the implementation of desalination plants is growing on a large scale. Fresh water can be derived from sea water by evaporation processes (e.g., multi-stage flash) or by membrane based processes, such as reverse osmosis, electro dialysis and membrane distillation. The commercially developed RO technology for desalination requires large amounts of energy in the form of electricity or shaft power to drive the pump, which the electricity is presently being generated from non-renewable and polluting fossil fuels [2].

In contrast, MD use lower top temperature with respect to the traditional distillation processes, making it suitable for using waste heat or solar heat, besides, aqueous solutions of salts with higher concentrations than seawater can be treated by MD. Reducing discharge volumes and increasing the water recovery factor up to 95% which considerably diminish the environmental impact of the brine disposal are advantages of the MD process [3]. However, the MD process is still under evaluation, the lack of experimental data has indicated that there is a need for more intensive research in this field, both experimentally and mathematically. The central issues are the external energy source in MD units, lack of MD membranes and fabrication of modules to suit each MD configuration, difficulties with long term operations with risk of membrane pores wetting and fouling. Thus, the optimization of different MD installations and systems is still to be done in order increase MD performance and decrease energy consumption [4-6].

2. Experimental work

2.1. Description of setup

A novel optimized experimental approach was followed up by a lab scale plate-and-frame PGMD module with two transparent poly acrylic sheets with 25 mm thickness for evaporator and condenser sides and the permeate water sheet with 6 mm thickness (Fig. 1). As it is clear from this figure, two main cylindrical channels with 10 mm hole diameter is milled in each evaporator and condenser plate for the flow inlet and outlet manifold. To have a more optimized flow distribution from the inlet and outlet, a set of 11*3 mm distributor holes, was drilled in each flow channel. The hydrophobic PTFE membrane with 0.22 µm nominal pore size, (140-200) µm thickness and polypropylene (PP) as support, with an effective surface area (760*160) mm^2 was applied, the permeate channel was separated from condenser channel by an impermeable 100 µm clear PP film, which filled by two similar plastic net spacer either as a mechanical support between membrane and condensing polymeric film and turbulence promoter.

The schematic diagram of the lab scale experimental setup is shown in Fig. 2. The feed water is pumped from storage tank using a 12 V small DC water pump. A mechanical filter with 0.2 mm pore size have used before the