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Membrane operations for treatment of produced water

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Abstract
Growing energy demand associated with improved living standards and rising population has intensified the consumption of petroleum based energy sources. To bridge the gap between demand and supply of petroleum-based energy resources, the concept of enhanced oil recovery and exploration of new non-conventional resources including shale gas, coal bed methane gas and tight gas have gained popularity. These new techniques, however, use relatively fresh water and produce huge volumes of highly contaminated produced water. Membrane operations might significantly contribute to minimize the environmental problems and to facilitate the produced water reuse.
In this study investigations carried out with direct contact membrane distillation (DCMD) process to treat oil produced water are discussed. Polymeric membranes were used and, in particular, lab made polyvinylidene fluoride membranes (PVDF1 and PVDF2) and commercial polypropylene membranes (PP1). The carried out experimental tests showed that the treatment of produced water with membrane distillation (MD) allows to obtain salt rejection greater than 99% and total carbon rejection higher than 90%. Moreover, an economical analysis was carried out to assess the feasibility of the process.

1. Introduction

The rapidly increasing world's population and the scarcity or shortage of water, material resources and energy have forced the process industry to bring revolutionary changes in processes and equipments. Process intensification strategy has been introduced to cope with these challenges. The process intensification strategy puts emphasis on the application of innovative principles with the aim to minimize energy and raw material consumption, to improve product quality and to achieve higher production rates. In this regard, membrane based processes have exhibited their superiority over state-of-the-art processes implemented in industry [1].
Membrane distillation (MD) is a membrane process which is interestingly aligned with the objectives of process intensification strategy thanks to its advantages (i.e., theoretically

complete rejection of non-volatile solutes, lower temperatures and pressures with respect to those usually used in conventional distillation column and in pressure driven membrane operations, the possibility of using plastic equipments which reduces or avoids corrosion problems, etc.). Membrane distillation is a temperature gradient based process in which two phases with different partial pressure are separated through a hydrophobic membrane. The vapors from the feed (or retentate) side (with higher partial pressure) diffuse through the membrane and are collected on the distillate (or permeate) side.
In the present work the potentialities of direct contact membrane distillation (DCMD) for the purification and reuse of de-oiled highly concentrated saline water are presented. The effect of feed temperature and flow rate, and of membrane characteristics on the separation achieved have been investigated. Moreover, an economical evaluation was carried out to assess the feasibility of the MD process in desalting produced water.

2. Materials and methods

The set-up utilized for the DCMD tests has been described elsewhere [2]. Two different lab made polyvinylidene fluoride membranes (PVDF1 and PVDF2) and commercial polypropylene membranes (PP1) were used in the experimentation. The experimental tests have been carried out at different feed flow rate and temperature. Samples of the produced water used as feed and the obtained DCMD permeate and retentate have been characterized in term of total suspended solids, total dissolved solids, ionic composition, carbon content, conductivity and pH.

3. Results and discussion

The achieved results showed that PVDF2 is the membrane with the higher trans-membrane flux thanks to its higher porosity and mean pore size, and lower thickness with respect to the other tested membranes. Moreover, trans-membrane flux increases with the increasing of feed flow rate (due to the improved transport coefficients-Figure 1) and feed inlet temperature (owing to the proportionality in DCMD between the flux and the vapor pressure gradient across the membrane-Figure 2).

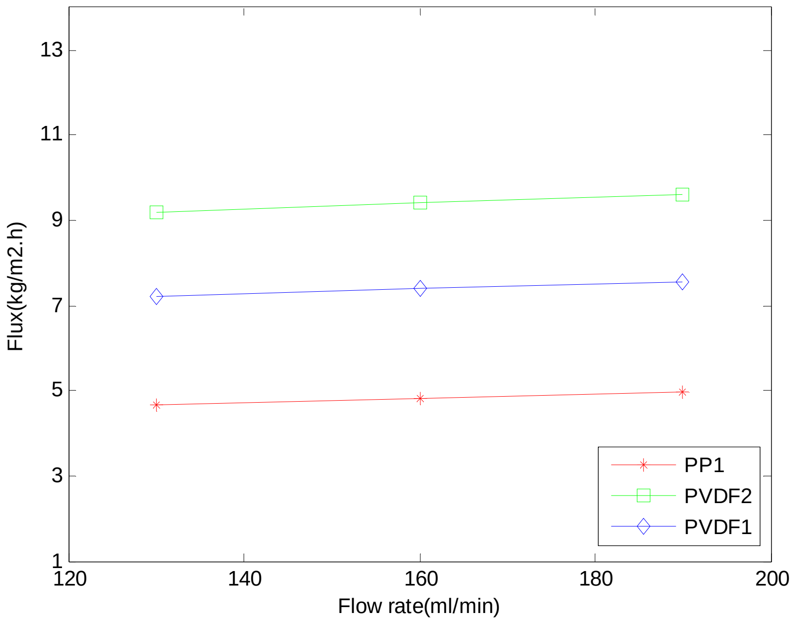

Figure 1. Effect of feed flow rates on flux

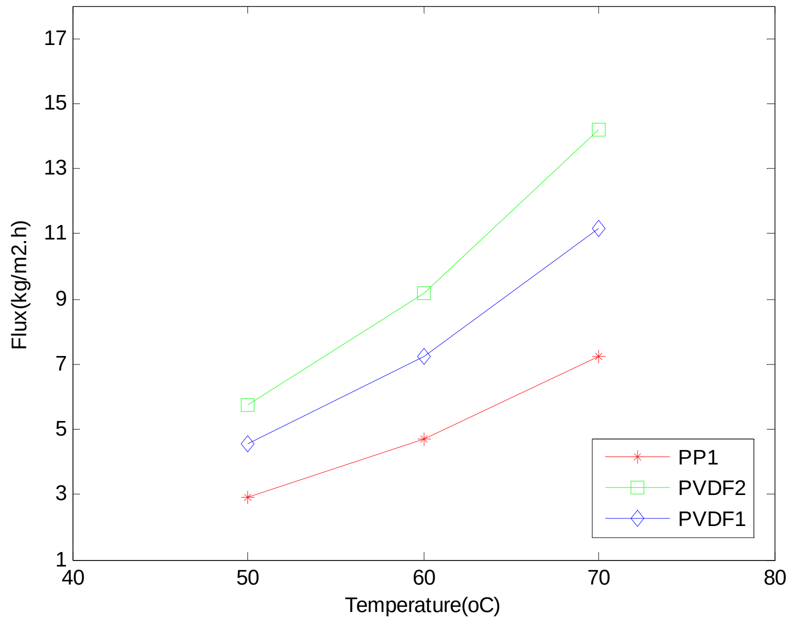

Figure 2. Effect of feed temperature on flux for different membranes

The properties of the obtained permeate show that rejection factors higher than 99% with respect to total dissolved solids and higher than 90% with respect to total carbon have been achieved in all the lab made membrane modules.
For what concerns the estimation of the costs in desalting produced water through DCMD, the economical evaluation has been made including annual operating costs, direct and indirect capital costs (details can be found in [2]). Data from cost analysis indicate that, considering 5 years as membrane life-time and 70% as MD recovery, water cost is equal to 1.28$/m^3 when the temperature of the produced water fed to the system is 20°C whereas water cost is equal to 0.72$/m^3 when the temperature of the produced water fed to the plant is 50°C (T=25°C and temperature of the DCMD feed inlet =50°C) .

4. Conclusions

A study was performed to test the potentiality of using DCMD for desalting high saline oilfield produced water. Both PVDF and PP membranes were utilized. DCMD showed an excellent rejection both of the total solids and of the carbon present in the saline feed solution. Membrane modules with PVDF membranes characterized by the higher pore size and the lower membrane thickness showed the higher trans-membrane flux. Moreover, data from cost analysis indicate that for MD operating at 50°C and with a recovery of 70%, desalted water cost is 0.72$/m^3 when the temperature of the produced water fed to the plant is 50°C and 1.28$/m^3 when the temperature of the produced water fed to the plant is 20°C.

Acknowledgments

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