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Dual-stage forward osmosis/pressure retarded osmosis process for hypersaline solutions and fracking wastewater treatment

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HIGHLIGHTS

- Dual-stage FO/PRO is proposed for hypersaline water treatment and power generation.
- Two designs were suggested: PRO–FO and FO–PRO systems.
- PRO–FO system generates higher power than the FO–PRO system.
- Increasing draw solution flow rates increased the permeate flow rate and TDS.
- Treated hypersaline water is suitable for RO treatment or discharge to sea.

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ABSTRACT

Hypersaline solution with high TDS is not suitable for direct treatment by the conventional membrane and thermal processes. The current study proposes a dual-stage FO/PRO process for hypersaline solution treatment and power generation. The treatment process reduces the concentration of saline wastewater and hence renders it suitable for disposal directly to sea or treatment by the conventional membrane and thermal processes. The draw and feed solutions in the FO process were the hypersaline solutions and wastewater effluent, respectively. Five concentrations were evaluated for the process treatment with different concentrations ranging from 53 g/L to 157 g/L. The performance of FO membrane was estimated using pre-developed computer software. The results showed that a higher power can be generated from the PRO-FO system than from the FO-PRO system without compromising the concentration of hypersaline solution after dilution. The study also showed that although increasing the flow rate of draw solution resulted in an increase in the permeate flow rate, it caused a reduction in the dilution of draw solution. On the other hand, the study showed a negligible improvement in the performance of FO membrane upon increasing the feed solution flow rate. Finally, the simulation results showed that the concentration of diluted draw solution was suitable for the conventional membrane and thermal treatments or discharge to seawater after the dual-stage FO membrane treatment.

1. Introduction

Hypersaline solution is a wastewater generated from industrial activities such as oil and gas industries. It is characterized by the high-concentration of Total Dissolved Solids (TDS) which is normally more than seawater concentration of 35 g/L. Such wastewater is difficult to treat by the conventional water treatment technologies such as Reverse Osmosis (RO) and Bioreactors [1–5]. Shale gas industry is one of the activities which largely contribute to hypersaline wastewater generation. Typically, water and additives are injected at high pressure into the gas well so as to open fractures in the shale and develop a flow path for the gas to escape. Despite the rapid growth in shale gas industries over the last few years, the capacity for treating and handling of the fracking wastewater has remained underdeveloped [1,2]. The characteristics and composition of fracking wastewater vary from place-to-place and time-to-time throughout the production cycle. Drilling water, for instance, contains rock cuttings which are carried back to the land surface while flowback water contains high concentrations of additives. The volume of the flowback has been reported to vary from 1500 m^3 to 4500 m^3 per well per week, but decreases with time upon the completion of fracking operation [6]. In addition, there is a large volume of production water which is collected during the production life of the gas well. Practically, production water is retained in the gas well and exposed to the shale formation for long period of time [6]. Fracking wastewater, in general, contains large amounts of suspended solids, high salinity (TDS), fluid additives, and other naturally occurring metal ions [1,3,5]. TDS is of particular importance because of its

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negative impact on the biological treatment, aquatic life, freshwater salinity and water composition. Flowback wastewater, therefore, has a particular importance because of its high TDS which makes it unaffected by the conventional processes for water and wastewater treatment. The typical flowback TDS varies from 5000 mg/L to 250,000 mg/L with an average salinity about 125,000 mg/L [2,8]. However, TDS over 300,000 mg/L was reported in some fracking water samples.

The current options for hypersaline and fracking water management vary from a simple dilution treatment to a complicated evaporation and crystallization processes [7]. Some of the proposed technologies have a limited efficiency in hypersaline wastewater treatment [6,7]. For example, dilution is an inexpensive treatment option but it has a limited capacity for decreasing the salinity of wastewater [7]. The new regulations for wastewater discharge recommend that the TDS of effluent should not exceed 500 mg/L which renders the conventional dilution treatment insufficient. Evaporation and crystallization processes were also proposed for hypersaline wastewater treatment. The technology has the advantage of reducing the wastewater TDS and the treated water can be reused but it is very expensive (about 0.25 USD per gallon) and energy-intensive [8]. Reusing of hypersaline water is often performed to reduce the generation of wastewater as in the shale gas industry. For example, the flowback water from the shale gas industry can be reused so many times but it has to be treated when the salinity reaches 100,000 mg/L [1]. However, the disadvantage of flowback water reuse is the high level of contaminants which may plug the gas wells [7]. Natural evaporation is also performed in the United States for the treatment of flowback water, but the process is slow and only suitable for dry hot climate [7]. Regardless of the treatment technology, hypersaline wastewater may require a pretreatment for the removal of sediments, suspended solids and hydrocarbon residues.

In this paper, a dual-stage forward osmosis (FO)/pressure retarded osmosis (PRO) process for the treatment of hypersaline wastewater was investigated. The draw and feed solutions in the first FO stage are, respectively, the hypersaline wastewater and the wastewater effluent. Because of its high salinity, the TDS of hypersaline wastewater cannot sufficiently be reduced to the desirable level by the first stage of the FO/PRO treatment. Therefore, the TDS of the diluted hypersaline solution from the first FO/PRO stage would be relatively high and a second FO/PRO stage is required to reduce its salinity to the desirable level (Fig. 1). In the second stage, the diluted hypersaline solution enters an FO membrane for further dilution by wastewater effluent. After leaving the second stage of membrane treatment, the hypersaline solution is either treated by RO/thermal process or discharged to seawater. The dual-stage FO process is able not only to reduce the TDS of the hypersaline solution but also to generate a useful power from the osmotic pressure gradient across the FO membrane using the PRO process. The impact of the hypersaline solution TDS, draw and feed solution flow rates and the position of the turbine system is evaluated in the current work. Different salinities, between 53,000 mg/L and 157,000 mg/L, were evaluated for the dual stage FO/PRO treatment. These salinities are reported for the flowback water in the shale gas industry [8]. The performance of FO membrane was estimated using pre-developed FO software [9]. A hydraulic pressure of 10 bar was assumed to be on the draw solution side of the FO membrane when it is operated on the PRO mode for power generation. Finally, the Van't Hoff equation was applied to calculate the osmotic pressure of the draw solution [9,10].

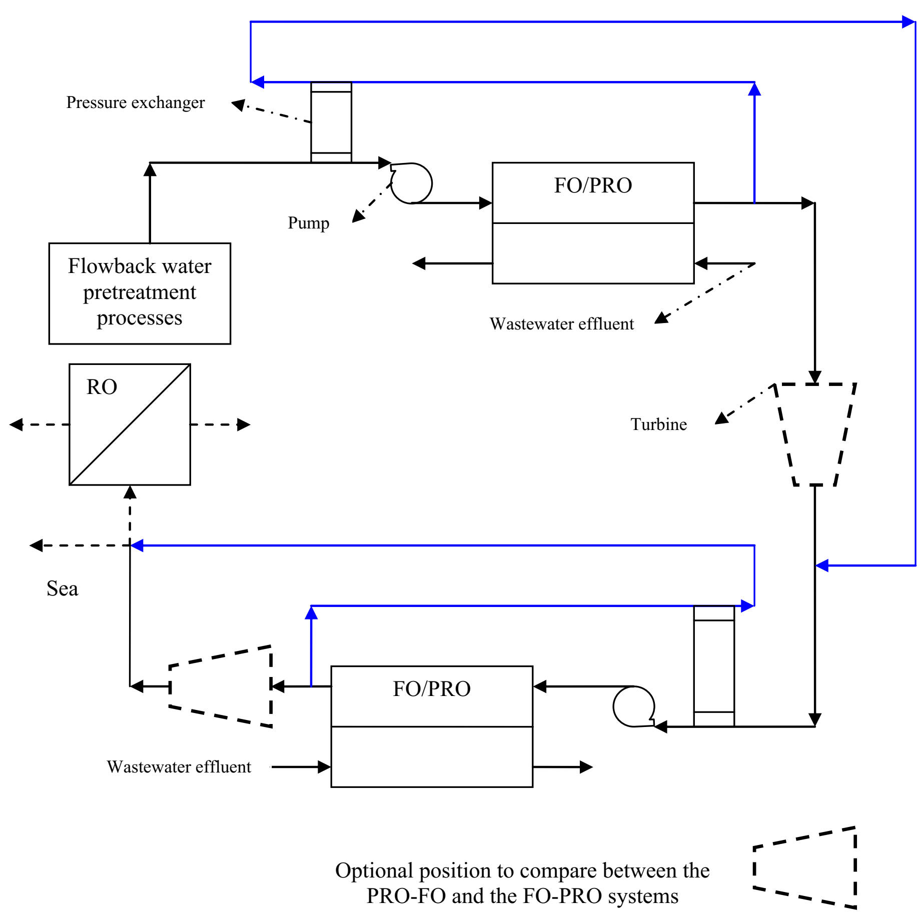

Fig. 1. Schematic diagram of the dual stage FO/PRO system for flowback water treatment.