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Dual stage PRO power generation from brackish water brine and wastewater effluent feeds

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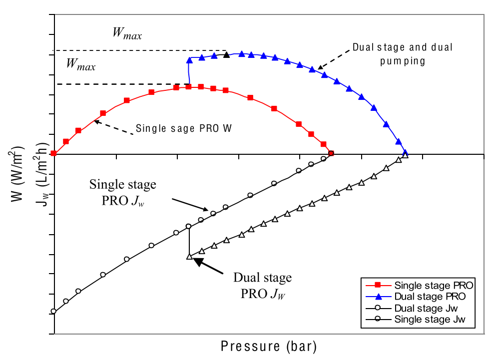
HIGHLIGHTS

- MSDSPRO process is applied for power generation and BW brine concentration.
- Power density was higher in MSDSPRO than in DSPRO and PRO processes.
- RSD increased with increasing draw solution TDS or hydraulic pressure decrease.
- Solute losses per unit of power generated were calculated as the ratio of J_{sr}/W.
- BW brine can be decreased by 18% after the PRO membrane treatment.

GRAPHICAL ABSTRACT



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ABSTRACT

Multi-Stage pumping Dual Stage PRO, MSDSPRO, process was proposed for power generation and brine concentration using brackish water brine and wastewater effluent feeds in stages one and two of the process. MSDSPRO process showed high efficiency for power generation and brackish water brine concentration before disposal. Power density, reverse salt diffusion and brackish water recovery rate were calculated in stages one and two of the DSMSPRO process taking into account the phenomenon of concentration polarization. The results showed that the MSDSPRO process efficiency for power generation was considerable even at relatively low draw solution concentrations. At 73 g/L draw solution concentration, power density was 4 and 6.25 W/m^2 in stages one and two, respectively. Reverse salt diffusion was found to increase with draw solution concentration and it was higher in stage two compared to stage one. The ratio of reverse salt diffusion to power density, $J_{s\text{-}r}$/W (mol/Wh) was calculated to determine draw agent loss per unit of power generation in the MSDSPRO process. The results also showed that volume of brackish water brine decreased by 18% after the PRO membrane treatment. As such, MSDSPRO process can be applied for power generation and reducing the volume of brine waste for disposal which is particularly important in inland desalination.

1. Introduction

Pressure Retarded Osmosis (PRO) has been intensively investigated for power generation from salinity gradient resources such as seawater and freshwater [1–6]. Bench and pilot plant experiments have been carried out to evaluate the performance and cost-effectiveness of the PRO process [4,7]. The impact of operating parameters such as effect of feeds flow rates, feed concentrations, and hydraulic pressure on the process performance is well understood [8–11]. Many studies proposed improving the performance of PRO process through optimizing the

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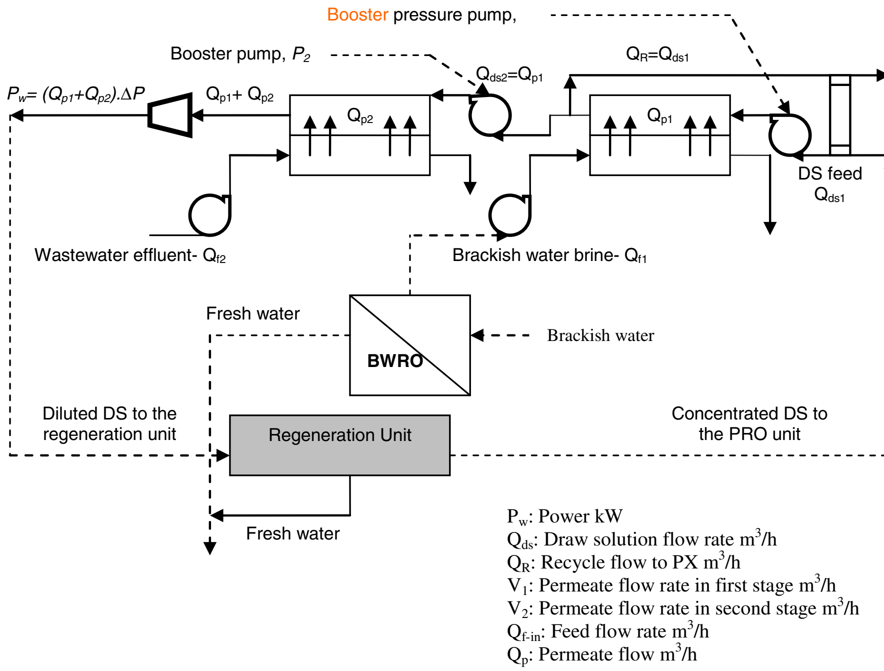

Fig. 1. Dual Stage PRO process schematic diagram.

operating parameters and/or reducing membrane fouling [3,6]. Sufficient pretreatment, however, of feed and draw solutions (if required) can guarantee an uninterrupted PRO process performance [12]. In addition, using newly-developed PRO membranes improved the performance of the PRO process significantly [3,13]. Laboratory-scale studies demonstrated that up to 10 W/m^2 power density was feasible using a tailor-made Thin Film Composite (TFC) membrane [14]. Pilot plant studies, however, demonstrated that a maximum power density of 7.7 W/m^2 can be extracted from seawater brine-wastewater effluent salinity gradient resource [7].

Despite the promising results, underperformance of the PRO process was also reported in a number of pilot and laboratory scale experiments [3]. The underperformance of the PRO process was often attributed to an insufficient membrane performance, low salinity gradient resource, or fouling problems [3]. Most notably, the underperformance of the PRO pilot plant operated by Statkraft in Norway which was attributed to the insufficient osmotic pressure gradient across the membrane in which seawater and fresh water were applied as the salinity gradient resource [15]. Unfortunately, the power density from the osmotic power plant was less than 5 W/m^2 which is the theoretical threshold for an economical PRO process. Additionally, concentration polarization has detrimental impact on the PRO membrane performance [5]. In general, the effect of concentration polarization is more serious at high feed salinities and it often results in an unsatisfactory performance of the PRO process [16,17]. However, it should be noted that internal concentration polarization is more problematic than external concentration polarization in osmotically driven membrane processes [5]. Unlike the external concentration polarization, internal concentration polarization can't be alleviated by increasing the flow rate of feed solution but by reducing the membrane structural parameter, S.

Salinity gradient resource, on the other hand, is an essential parameter in any successful PRO process and requires a careful consideration at the early design stage of the PRO process. Increasing draw solution concentration or flow rate has a positive impact on the membrane flux and process performance but it increases the operation cost [18].

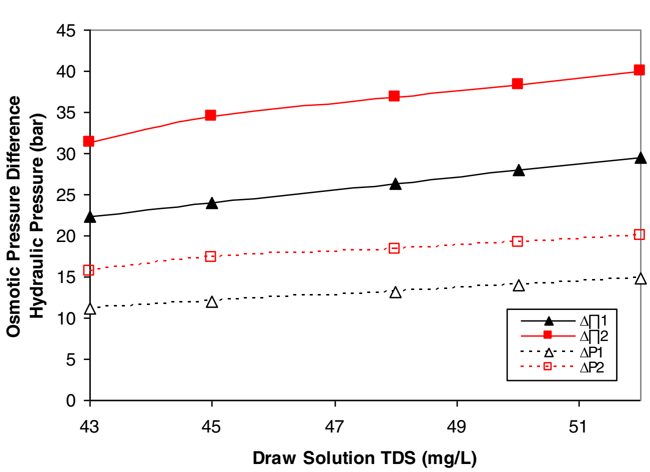

Fig. 2. Osmotic and hydraulic pressure difference across the PRO membrane in the first and second stages of DSPRO, osmotic pressure difference was calculated at zero hydraulic pressure across the membrane, hydraulic pressure is equal to $\Delta P = \Delta\pi/2$.

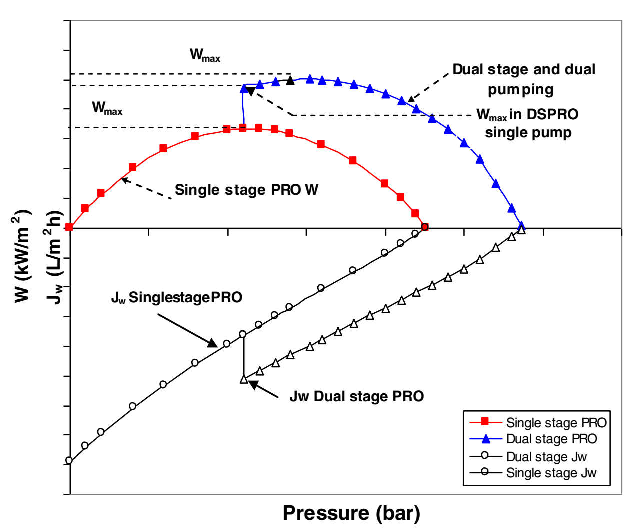

Fig. 3. Power density in PRO, DSPRO and multi-stage pumping DSPRO, draw solution 43 g/L, feed solution is 18 g/L and 0.2 g/L in the first and second stages, respectively.