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Optimization and economic analysis of small scale nanofiltration and reverse osmosis brackish water system powered by photovoltaics

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HIGHLIGHTS

- Use of RSM (CCD) method for optimization input conditions of NF and RO system
- Membrane surface characterization by AFM, contact angle measurement and FTIR
- Comparison between NF–RO hybrid systems in concentrate and permeate staging mode
- Current generated by PV system was found enough for the NF-C-RO hybrid unit.
- Water production cost of NF–RO hybrid system was found lesser than single system.

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ABSTRACT

Integration of renewable energy with desalination technologies is a strongly emerging field in many regions of the world having drinking water and energy crisis. This study presents the results of a techno-economical investigation of a small scale, photovoltaic (PV) powered hybrid nanofiltration (NF) and reverse osmosis (RO) membrane system for the brackish water treatment. Optimization experiments of six commercially available small scale RO and NF membranes were carried out using central composite design (CCD) of response surface methodology (RSM). Experiments employing optimized input conditions validate the developed RSM model. Predictive model, using multiple response optimizations, revealed that CSM RO and NF250 membranes showed the optimal efficiency with 20.24% and 18.98% water recovery, 90.22% and 70.64% salt rejection and 17.87 and 9.35 kWh/m^3 of SEC respectively. Comparison of membranes was also carried out by membrane characterization duly supported by experimental observations. Membrane surface was characterized by AFM, contact angle measurement and FTIR. Hybrid experiments were performed with NF and RO membranes in concentrate and permeate staging configurations. Results also suggested that techno-economic performance of the hybrid PV–NF/RO system was affected by factors like mode of integration of NF and RO membranes, recovery ratio, daily average operating hours and government subsidy.

1. Introduction

Power and fresh water requirement are the two major issues that mankind will have to face and solve in 21st century [1]. Renewable energy is strongly emerging as a viable and more environment-friendly option to supplement and, at times, replace the conventional power generation options, which may observe a continuous decline in coming decades, for example, fossil fuel sources are getting exhausted rapidly and use of nuclear sources is facing intense opposition in many countries [2]. Concurrently, fresh water crisis is affected by many factors including climatic and geographical condition, population growth, rapid urbanization, industrial growth etc. [3].

Inland salinity of groundwater, having total dissolve solids (TDS) of 1500–3000 mg/l, has been found in substantial volumes (over 1.90 lakh km^2) throughout the major parts in India (Haryana, Delhi, Uttar Pradesh, Karnataka, Punjab, Rajasthan, Gujarat and Tamil Nadu) [4]. However, these parts incidentally also receive a 5.5–6 kWh/m^2/day of annual average global horizontal irradiance (GHI), making the photovoltaic (PV) the apparent selection as a renewable energy source [5]. For the removal of salinity in drinking water, pressure driven reverse osmosis (RO), a relatively new and less energy intensive process that was first commercialized in 1970s, has found more favor in comparison to the thermal processes [6,7]. Nanofiltration (NF) and RO membrane process are used for the removal of divalent (calcium, magnesium, sulphate etc.) and monovalent ions (sodium, chloride etc.), respectively [8].

Rural areas in many parts of developing countries suffer from power crisis, due to insufficient resources and heavy installation requirements

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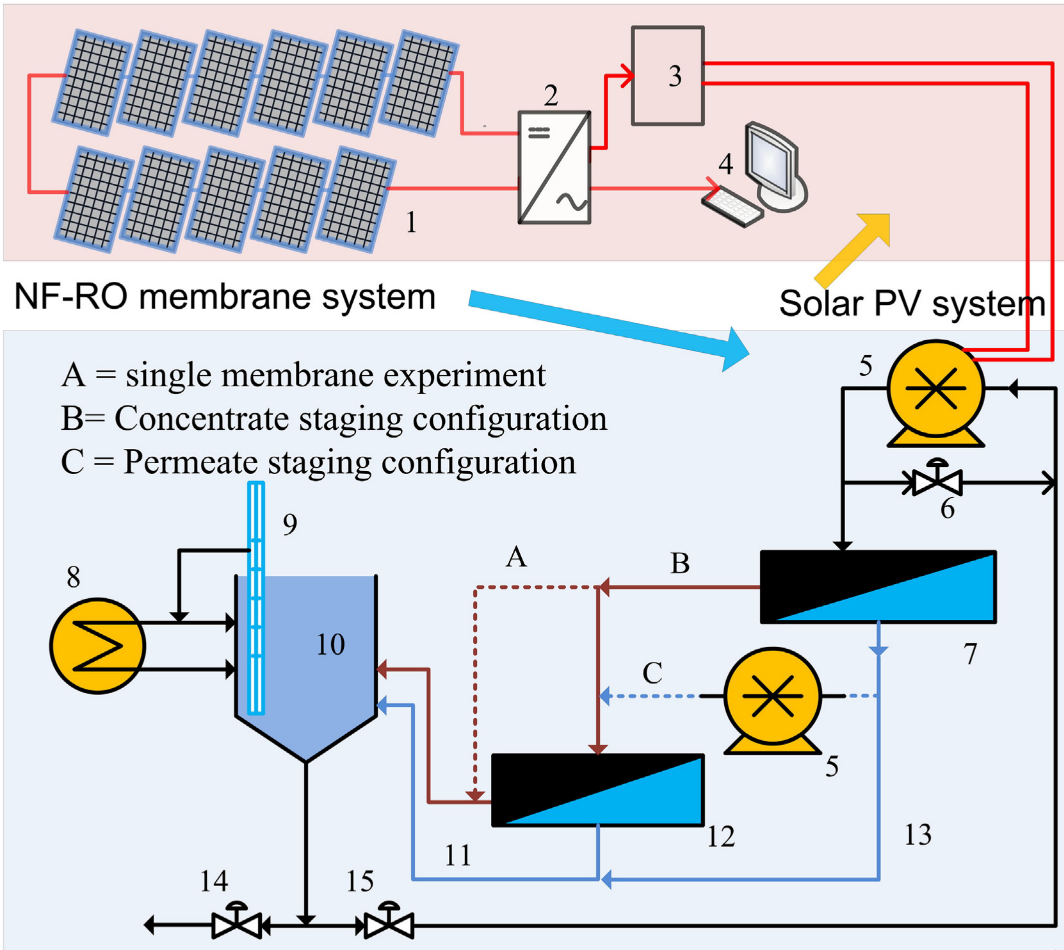

Fig. 1. Different schemes of single and hybrid PV–NF/RO membrane experimental setup; 1 = PV modules, 2 = DC-AC inverter, 3 = AC distribution board, 4 = data logging system, 5 = high pressure pump, 6 = bypass valve, 7 = NF module, 8 = temperature controller, 9 = temperature probe, 10 = feed water tank, 11 = concentrate stream, 12 = RO module, 13 = permeate stream, 14 and 15 = valve.

for electric power generation. Use of solar power can be a boon for these residents, which provides renewable source of energy with comparatively lesser installation prerequisites and almost maintenance free operation. In view of the above, integration of renewable energy (i.e. PV) with membrane filtration based desalination technologies (NF and RO) may be the solution to the drinking water problem in areas suffering from brackish ground water sources as well as non-existent or limited electricity accessibility.

Various configurations of solar powered membrane filtration systems had been investigated earlier [9–19]. The performance and overall cost of such systems have been evaluated on the basis of water productivity, rejection capability and power consumption.

Fig. 2. Experimental setup with membrane filtration unit and PV system.