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Experimental evaluation of a multi-skid reverse osmosis unit operating at fluctuating power input

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HIGHLIGHTS

- High flexibility by the multi-skid configuration
- Efficient performance & good fresh water quality at partial & full load operation
- Compared to a sole RO unit (similar capacity): better performance at wide load range
- Examination of the unit in 3 case studies coupled with PV

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ABSTRACT

A reverse osmosis (RO) desalination unit, composed of three identical skids connected in parallel and using an energy recovery system, has been designed and manufactured for operation at variable conditions. The main goal of the current experimental investigation is the evaluation of such a system for operation at variable power input and the increase of fresh water production as a function of the power input conditions.

An RO desalination unit can be powered by renewable energy sources such as wind and solar energy. However, the power that derives from these sources can strongly fluctuate, since it depends on the weather conditions and/or available solar radiation. As the available power production fluctuates, the water feed and the production of permeate also fluctuate. Therefore, flexibility concerning the RO unit is required, in order to operate efficiently, ensuring the good quality (low salinity) of the produced fresh water. A configuration of three identical sub-systems using an energy recovery unit of axial piston motor – APM type has been chosen, in order to ensure flexibility at variable load operation. The number of the sub-units that operate depends on the available power. The total RO unit capacity is 2.1 m^3/h of fresh water. All the components have been equipped with the appropriate instrumentation for detailed experimental testing.

The laboratory experimental testing uses frequency inverters in order to simulate the variable power input. The power input has been monitored through the control of the high pressure pump frequency. The RO unit has been tested for seawater salinity of 37,500 ppm, and for different seawater temperature. An efficient performance of the RO unit is achieved due to the on/off switching of the three sub-units, keeping an acceptable fresh water quality at both part and full load operation.

The application of such flexible RO unit has been then examined and demonstrated in three different case studies, using local weather data. The power input originated from photovoltaics (PV) of capacity ranging from 10 up to 20 kWp, showing that it is suitable to combine RO with renewable energy sources with strong intermittent power production.

1. Introduction

Reverse osmosis (RO) is gaining worldwide acceptance in both water treatment and desalination applications. It is a pressure-driven process whereby a semi-permeable membrane rejects dissolved constituents present in the feed water by the application of a pressure greater than the osmotic pressure, at the side of the concentrated solution [1,2]. Several research and demonstration studies have been carried out, in order to combine renewable energy sources with RO desalination processes. Renewable sources such as wind energy, solar energy through Photovoltaic, solar thermal energy through solar collectors

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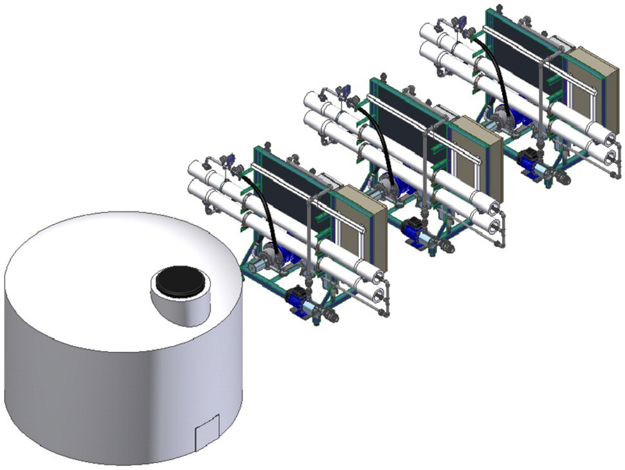

Fig. 1. Configuration of the RO unit, depicting the seawater tank and the three sub-units.

Fig. 3. A single RO sub-unit.

and geothermal energy have been studied and successfully implemented in small RO desalination plants [3–5]. Hybrid systems which combine renewable with conventional energy sources to feed RO desalination units have also been evaluated, resulting in significant reduction in the fuel consumption [6]. The implementation of an Organic Rankine Cycle using solar energy from solar collectors to feed RO desalination units has been studied and evaluated, proving that such technology is very promising in terms of environmental, technological and economical aspect and that further research can improve the efficiency of such a system, while decreasing the cost of the produced fresh water [7–10]. Bilstad et al. [11], have developed two pilot units dedicated to wind-powered RO desalination. Both units showed that a combination of RO desalination and wind power is technologically feasible when the RO system is operated with fluctuating and intermittent loads following the energy supply characteristic of the wind turbine. Depending on the technical design, the systems provide 1.4 and 7.5 m^3/day potable water, which satisfy basic needs for small populations in coastal regions. Moreover, Elasaad et al. [12], have developed a unit in which a PV-RO desalination system has been designed, fabricated and deployed in a remote village in Mexico. The PV-RO system was successful at producing safe, quality drinking water in the remote village of La Mancalona, Mexico. TDS levels were reduced to acceptable levels (approximately 10 ppm) and biological contaminants were eliminated using the system's solar-powered UV disinfection. Davies [13] proposes a new system that uses a Solar-Rankine cycle to drive reverse osmosis (RO). The working fluid such as steam is expanded against a power piston that actuates a pump piston, which in turn pressurizes the saline water thus passing it through RO membranes. The research concludes that a field of linear Fresnel collectors occupying 1000 m^2 of land and raising steam at 200 °C and 15.5 bar could desalinate 350 m^3/day from saline water containing 5000 ppm of sodium chloride with a recovery ratio of 0.7. Finally, Mohamed et al. [14], presented a design of a stand-alone hybrid wind-PV system to power a seawater reverse osmosis desalination unit, with energy recovery. The aim of the study was to size and simulate a system that would supply 100% of the water needs of the population of 60 habitants in the island Crete, Greece, and to minimize the water production cost by recovering the wasted hydraulic energy in the brine.

In the current experimental study, a variable power input simulating any of the aforementioned technologies supplies the RO desalination unit. Since the power input fluctuation is intense, the feed water flow and fresh water production fluctuations are also high. Therefore, a flexibility concerning the RO unit operation is necessary in order to operate efficiently in a large range and also to ensure fresh water production of a sufficient quality (low salinity) even at low load/power input [7]. This necessity has driven the RO design to a multi-skid configuration with three identical sub-units. Each sub-unit has a capacity of 0.7 m^3/h, thus the total water production is spread from 0.5 to 2.1 m^3/h, with

Fig. 2. Installed RO unit in the laboratory.

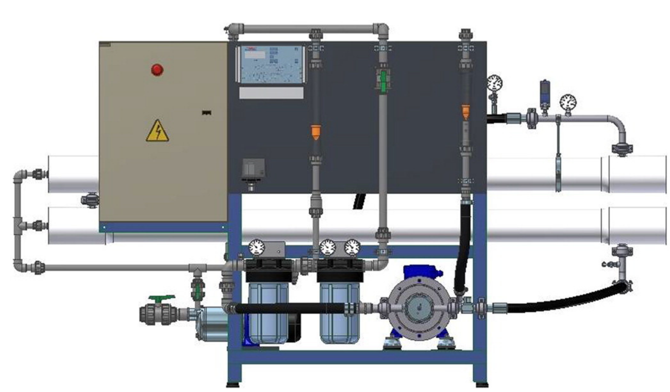

Fig. 4. RO sub-unit, depicting the HP pump, feed pump, control panel, membrane vessels, filters and hydraulic circuit.