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Brackish water desalination by a stand alone reverse osmosis desalination unit powered by photovoltaic solar energy

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Abstract

Desalination of brackish water as a viable option to cope with water scarcity and to overcome water deficit in Jordan is assessed. A stand alone reverse osmosis (RO) desalination unit powered by photovoltaic (PV) solar energy is proposed, and a computer code in C++ was generated in order to simulate the process, and to predict the water production at 10 selected sites based on the available solar radiation data, sunshine hours and salinity of the feed water (TDS of 3000, 5000, 7000, and 10,000 mg/L). It was found that most of the selected sites showed favorable application of the proposed system in Jordan. Tafila, Queira, Ras Muneef, H-4, and H-5 are the most favorable sites. With TDS of 7000 mg/L, the highest annual water production of 1679 m^3/year was observed in Tafila, followed by Queira with production of 1473 m^3/year. Ras Muneef, H-4, and H-5 showed close to each other production of 1363, 1345, and 1340 m^3/year, respectively. Among the most favorable sites (Tafila, Queira, Ras Muneef, H-4, and H-5), Ras Muneef was found to be the best site in terms of the daily amount of water produced during the driest months of the year (May–September). Its production during these months forms about 65% of its total daily water production during a 1-year cycle, while for each of the other most favorable sites namely Tafila, Queira, H-4, and H-5, a 61% of production was observed during the same period.

Keywords: Brackish water; Desalination; Jordan; Reverse osmosis; Photovoltaic solar energy

1. Introduction

Shortage of drinking water is a major problem in Jordan, and precipitations are insufficient to meet the growing demand for water [1]. Therefore, it is necessary to resort to underground resources. However, most of the aquifers have been over-exploited and also suffer serious problems of saline contamination. Therefore, desalination of brackish water is considered as one of the key options to cope with water scarcity and to overcome water deficit in Jordan [2].

In addition to the shortage of fresh water, Jordan is suffering from shortages in fossil fuels such as crude oil and natural gas [3]. However, problems relevant to the use of the limited fossil fuels could be resolved by utilizing the abundant renewable energy resources, such as solar energy [4]. Photovoltaic (PV) solar energy could be exploited to power reverse osmosis (RO) systems even at far remote and isolated areas. Water desalination by the technique of RO powered by PV has proved to be the lowest energy consuming technique. It consumes nearly around half of the energy needed for thermal processes. Furthermore, water desalination by RO units removes not only inorganic ions but also organic matters [5,6]. On the other hand, PV generators are silent, simple, non-polluting, and maintenance-free. The fuel—sunlight—is free, abundant, renewable, and economic power source [7,8].

The objective of this paper is to assess the potential of brackish water desalination as a viable option to cope with water scarcity and to overcome water deficit in 10 different Jordanian sites (Tafila, Queira, H-4, H-5, Ras Muneef, Mafraq, Hasa, Deir Alla, Baqura, and Wadi Yabis). A stand alone RO desalination unit powered by PV solar energy is proposed, and a computer code in C++ was generated in order to simulate the process, and to predict the water production at the selected sites based on available solar radiation data, sunshine hours, and salinity of the feed water (TDS of 3000, 5000, 7000, and 10,000 mg/L).

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Nomenclature

A	PV modules area (m^2)
E	average daily energy production of the PV modules (kWh/day)
E_{req}	required energy production (kWh/day)
E_{SR}	average daily solar irradiation (kWh/m^2 day)
E_{SRS}	solar irradiation under standard operating conditions
h	average hours of daylight in the region
I_{mps}	module's current at the maximum power point under standard operating conditions
P	PV modules output power (kW)
P_D	energy required by the desalination unit (kWh/day)
T_C	actual cell temperature (°C)
T_S	temperature at standard operating conditions (25 °C)
V_{mps}	module's voltage at the maximum power point under standard operating conditions

Greek letters

η	overall efficiency
η_b	battery efficiency
η_{ch}	charging efficiency of the battery
η_{con}	losses due to connections
η_d	total efficiency of dirt
η_{dch}	discharging efficiency of the battery
η_{inv}	inverter efficiency
η_{mp}	maximum power point efficiency of the PV modules
η_{mps}	module efficiency under standard operating conditions
μ_{mp}	temperature coefficient of efficiency at the maximum power point
μ_v	voltage temperature coefficient (V/°C)

2. Solar radiation over Jordan

In terms of solar radiation as well as the variation in the topography and climatology of Jordan, the country is divided into five regions [4].

(1) The southern region (29–30.5°N, 35–38°E) represented by M'aan and Aqaba areas. This region has the highest solar insolation in the country and has the lowest value of diffuse irradiance.
(2) The eastern region (30.5–32.5°N, 36.5–39°E). This region represents the semi-desert (badia) remote areas in the country.
(3) The middle region (30.5–32°N, 35.5–36.5°E). Compared to other regions, this region has the highest annual daily average values of diffuse irradiance.
(4) The northern region (32–33°N, 35.5–36.5°E).
(5) The western region (30.5–33°N, 35–35.5°E). This region represents the Jordan Rift Valley areas. The elevation of these areas is below the sea level (from 170 m at Baqura to 250 m at Ghor Safi).

Table 1 shows the annual daily average values of global and diffuse irradiance for these regions. In general, the abundance of solar energy in Jordan is evident from the annual daily average of global solar irradiance, which ranges between 5 and 7 kWh/m^2 day on horizontal surfaces. This corresponds to a total annual value of 1600–2300 kWh/m^2 year.

3. The stand alone PV- powered RO desalination system

Fig. 1 shows the schematic diagram of the proposed system. It consists of two main subunits—the energy production subunit and the desalination subunit. The membrane separation section of the desalination subunit is fed via a high pressure reciprocating pump (pressurizing the feed stream up to the desirable pressure levels), and which is properly connected to energy production subunit for the recovery of energy by the brine stream leaving the process. The permeate stream leaving the membrane constitutes the lean product of the system. The high-pressure pump operates by means of a three-phase motor which is supplied with electrical power by the energy production subunit, which consists of PV modules, storage batteries, a battery charge controller, and a direct current into alternating current (DC/AC) inverter.

Table 1
Annual daily average values of global and diffuse irradiance for Jordan

Region #	Region name	Annual daily average values of global irradiance (kWh/m^2 day)	Annual daily average values of diffuse irradiance (kWh/m^2 day)
1	Southern	6–7	1.2–1.35
2	Eastern	5	1.5
3	Middle	4.5	1.6–1.9
4	Northern	5.5	1.45–1.55
5	Western	4.5–5	1.6–1.8