

Status of solar thermal-driven reverse osmosis desalination

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Received 11 December 2007; Accepted 27 December 2007

Abstract

Experience in combining solar thermal and seawater or brackish water reverse osmosis (RO) desalination technologies is very limited. Two SOFRETES systems were in operation in the early 1980s for brackish water desalination. Only such two implementations involving a single design can be cited, along with a reduced number of theoretical analyses and design proposals. Nevertheless, since RO is the most cost-effective desalination technology and its energy requirements are low, solar thermal-driven reverse osmosis desalination is promising in comparison to other desalination processes driven by solar energy. In addition the research conducted in other renewable energy-driven RO technologies would be profitable for developing RO technology based on solar thermal systems as special designs of energy recovery systems, direct coupling of wind and photovoltaic systems without batteries or assessment of membranes damage due to change of operational parameters in stand-alone systems.

Keywords: Reverse osmosis; Solar desalination; Organic Rankine cycles

1. Introduction

Experience in combining solar thermal and seawater or brackish water reverse osmosis desalination technologies is very limited. Only two implementations involving a single design can be cited, along with a reduced number of theoretical analyses and design proposals. Because of this scarcity, it is necessary to revisit

systems which share a certain similarity with previous systems, such as those which use solar thermal-driven pumps. The use of solar energy to drive water pumping systems is a technique that has been studied since the 19th century. The process itself consists in transforming solar energy into mechanical energy which is then used to pump water to a certain height. This type of system which converts solar thermal energy into mechanical energy is usually referred to in the literature as a solar heat engine. Pytlinski [1]

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considers a description made by the French engineer Solomon de Caux in 1615 as the first record on the use of a solar heat engine to pump water. The machine was capable of raising the liquid through the expansion of air that had previously been heated with solar energy. Elsewhere, in Butti and Perlin [2], there is a mention of Heron of Alexandria's invention in the first century A.D. of a solar siphon which, when placed in the sun, was capable of displacing water from a container. Air heated by solar energy expanded and expelled the water. This last example, though previous to Solomon de Caux's, will not be considered here as the first practical application of a solar heat engine. Thus, we will accept Pytlinski's example [1] as the first record of a practical application of the system under consideration in this paper.

2. Solar thermal-driven reverse osmosis

With regard to solar thermal-driven reverse osmosis, Bowman et al. [3] presented the preliminary design of a system capable of producing between 7.6 and 26.5 m³ of desalinated water from brackish water with a salinity of 5400 ppm in Saudi Arabia. The system operated independently of the grid but had a fuel oil-fired boiler and a thermal storage backup. Thermal storage consists of a steam accumulator connected to two steam piston engines. One of the engines is directly coupled to the RO unit high-pressure pump, and the other to an electrical generator for producing auxiliary electricity. The steam is generated through the exchange of heat with the heat transfer fluid circulating in a north-south oriented solar field composed of two rows of parabolic trough collectors with an aperture area of 133.4 m² each. The dry saturated vapor is generated in the accumulator, which itself doubles as a thermal storage unit and which must be able to supply the demand from the steam engines for up to half an hour when the system

has no energy input from either the solar field or the boiler. The solar field is designed to produce enough energy to supply the quantity of steam needed by both engines for eight hours on an average sunny day on the best month of the year (May).

As for the RO system, it is made up of two hollow fiber modules in parallel with a total capacity of 79.5 m³ at 2757 kPa with 5400 ppm TDS feedwater and a 75% conversion rate. Using both modules in parallel allows for single- or dual-module operation, depending on the available energy. Simulation results for an average March day show that the system would operate in solar-only mode for 8.5 hours, producing a total of 28.2 m³ of desalinated water [3].

Husseiny and Hamester [4] described the design of a hybrid reverse osmosis-electrodialysis desalination system. The RO system would use the electricity generated by a solar concentration system and a Rankine cycle, while the electrodialysis system would use electricity generated by photovoltaic panels. The specific aspects of each of the subsystems would make the overall system very flexible in its operation.

The system presented by Manolakos et al. [5], intended for both brackish water and seawater, uses evacuated tube collectors. Water circulating inside these tubes is heated to a temperature of 77°C and then sent to a heat exchanger where it generates superheated 1,1,1,2-tetrafluoroethane (HFC-134a) vapor. This superheated vapor is used in expanding devices — design details for these are not given — which generate the mechanical energy necessary for the pumps in the reverse osmosis system, the water circulation loop and the HFC-134a loop. There is no conversion to electrical energy; therefore, the mechanical energy goes directly to the expanding devices. The system uses the RO feedwater as the cooling fluid to condensate the HFC-134a vapor. This also serves to preheat the feedwater in the reverse osmosis unit. The prototype for this system will have a surface area of 240 m² of evacuated tube

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