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Autonomous Membrane Distillation Pilot Plant Unit Driven by Solar Energy: Experiences and Lessons Learned

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Abstract

Through the SMADES EC-funded project a solar driven membrane distillation unit was installed by Fraunhofer Institute for Solar Energy Systems in the Aqaba city of Jordan. The feed was real seawater from the Red Sea without any pretreatment. The unit consists of three subsystems: the solar collector field, the heat exchanger and the membrane distillation module. Batteries to backup the system during cloudy times or blackout hours were used. This paper presents results obtained from the unit over one year of continuous operation.

Keywords: *Membrane Distillation, Solar Energy, Standalone Systems, Desalination*

1. Introduction

Water scarcity in Jordan is one of the major problems facing the economic growth and development. Meanwhile the yearly supply of fresh water per capita in Jordan amounts to 148 cubic meters only [1]. Jordan suffers directly from the shrinking surface water and the deterioration of groundwater reservoirs; the winter precipitation in the country has been only 62% of the long-term average. Therefore, pressure on water resources and the need for water for various purposes should be accompanied by searching for new sources of water supply.

The potential for use of small-scale autonomous desalination units powered by renewable energy in remote coastal communities has received increasing attention in recent years. In Jordan, Desalination of water from the Red Sea/ Aqaba Gulf might be economically and technically feasible by efficient use of renewable energy sources such as solar energy. In using solar energy in desalination, there are two applications involved: thermal and photovoltaic. Solar thermal energy is used for direct applications in water distillation, or for indirect applications such as producing steam for electricity generation. Photovoltaic (PV) cells produce Direct Current (DC) electricity from sunlight. Membrane Distillation (MD) for water desalination is a membrane-based technique in which a microporous hydrophobic membrane separates a warm saline solution from a cooling chamber, which contains either a liquid or a gas. Under conditions of non-wettability vapor migrates through the pores of the membrane due to the vapor pressure difference created by the temperature difference on the membrane sides [2]. The MD technology is currently not used commercially for desalination.

SMADES is the acronym of a project titled "PV and thermally driven small-scale, stand-alone desalination systems with very low maintenance needs". This project was funded by the European Commission and coordinated by Fraunhofer Institute for Solar Energy Systems ISE (Germany). The participating countries in this project were Jordan, Egypt, Morocco, Turkey, and Spain. The overall objective of the SMADES project was the development of stand-alone desalination systems for arid and semi- arid remote regions with a lack of drinkable water but a high solar irradiation. The modular system set-up is based on the highly innovative membrane distillation technology.

Within SMADES project, a two loop solar driven MD pilot plant was installed in Aqaba, Jordan. Comprehensive measurements and experimental investigations were carried out on this pilot unit over more than one year of continuous operation. The authors published some of the results obtained in the early stages of operating the unit [3]. The present study aims to present the operating experience of the system after one year of continuous operation.

2. System Design

The flow sheet of the pilot unit is shown in Fig.1. The design capacity of the system was 700-900 liters per day. Four membrane distillation modules with internal heat recovery function are used. The membranes are made of PTFE with 0.2 µm pore diameters, 35 µm thickness and 80% porosity, the flow channels were made in the membrane spiral wound geometry (Fig. 2). The effective membrane area in each MD module is 10 m². The flat plate solar collector area is 72 m². A heat exchanger from titanium is used to transfer the heat from the collector to the seawater loop. A 3-m³ thermal heat storage

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tank is used so that the system can continue to produce distillate after sunset. It also uses a PV subsystem to achieve a completely self-sufficient energy supply.

To supply electricity for the auxiliary equipments as pumps and magnetic valves in the large system, a PV array consists of 12 PV modules each 120 Wp was installed. The energy produced by the PV array is transferred through the DC/AC charge controller to a battery bank capable of storing enough energy for extra operation hours after sunset, the stored energy is then transferred to the control unit and the pumps through a DC/AC inverter (Fig. 3). A 230V grid supply is connected to the system as emergency backup for the case of a none sufficient dimensioning of the PV supply. Fraunhofer Institute for Solar Energy Systems ISE, Germany put the system together.

The desalination pilot plant was monitored by recording the necessary data through a data acquisition system. Figure 4 shows a picture of the collector field. Figure 5 shows a picture of the heat storage, heat exchanger and the membrane distillation modules.

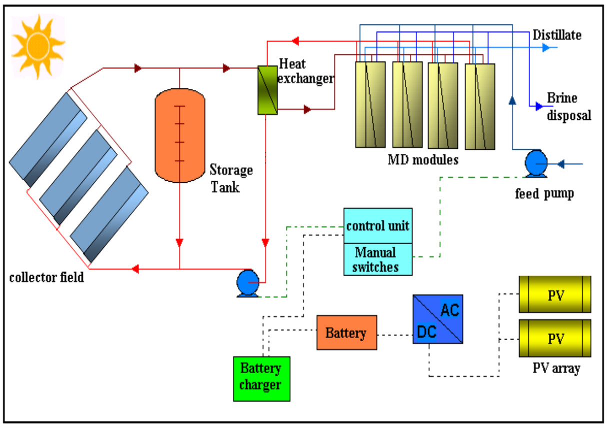

Fig. 1. Flow sheet of the MD unit in Aqaba

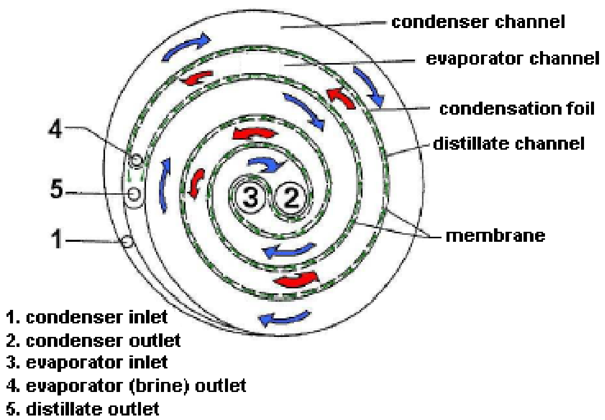

Fig.2. Spiral wound membrane distillation module

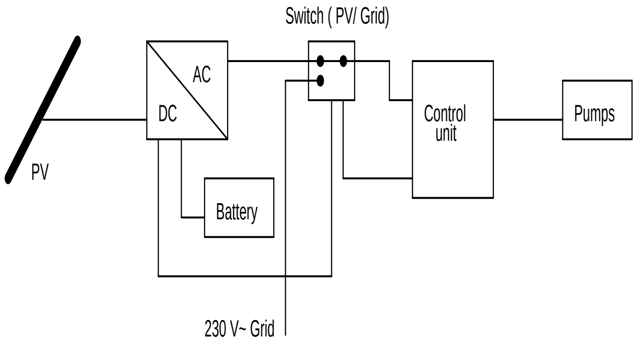

Fig.3. Layout of the electrical supply system

Fig.4. Flat plate solar collectors and PV cells

Fig.5 Picture of the desalination unit

3. Results and Discussion

3.1. Influence of Global Irradiation on Plant Capacity

Figure 6 presents one day of operating the unit in a fine day in April 2006. The distillate production started at 8:00 AM and followed the course of irradiation with a maximum of 1.17 $L/m^2/hr$ at noon. The production continued for 2 hours after sunset using the energy stored in the thermal storage tank. The distillate conductivity started with a peak of 1800 μS/cm due to the stagnation during night, and then decreased to100 μS/cm. The cumulative volume of collected distillate during the operating hours of that day was 350 L with an average conductivity of 180 μS/cm.

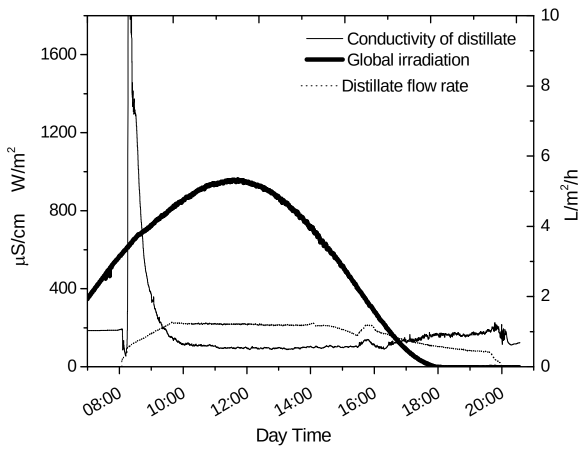

Fig.6. Daily variations of distillate flow rate and conductivity with solar radiation for a sunny day

Fig. 7 is a plot of the system performance for a cloudy day in February 2007. Because of the low global irradiation at that day, the feed pump started at 11:15 AM when the temperature at the heat exchanger inlet exceeded 60°C. The maximum distillate flux reached one $L/m^2/h$ at that day. As such, the total amount of distillate gained was about 20 L per that day. The maximum distillate gain attained during the test period of summer 2006 was about 800 L/day.

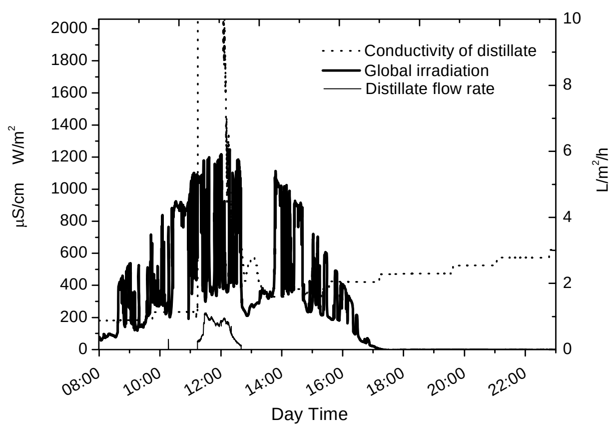

Fig.7. Variations of distillate flow rate and conductivity with solar radiation for a cloudy day

3.2 Monthly Variation of Distillate Flux

To monitor the unit performance, data collected over one year were analyzed in terms of average distillate flux, as shown in Fig. 8. It was found that from 12 to 20 liters per square meter of membrane surface area per day was achieved in good weather summer days. The minimum production rate was in the range of 2-4 L/m^2.d in winter months (November, December and January).

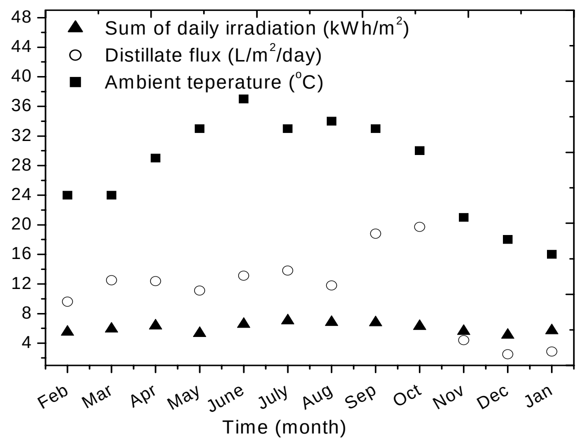

Fig.8. Monthly variation of distillate flux

3.3 Solar Collectors

Fig. 9 illustrates the thermal performance of the solar collectors from February 2006 to January 2007. The figure shows the solar collector efficiency, the average ambient temperature and the average amount of energy delivered to the solar collector (kWh/m^2). As shown in the figure the collector efficiency correlated well with the trend of solar irradiation and temperature. The solar collector efficiency falls sharply in the winter months (November, December and January). This occurred due to specific weather and operation conditions. Under all conditions, the average solar collector efficiency was in the range of 35-50%.

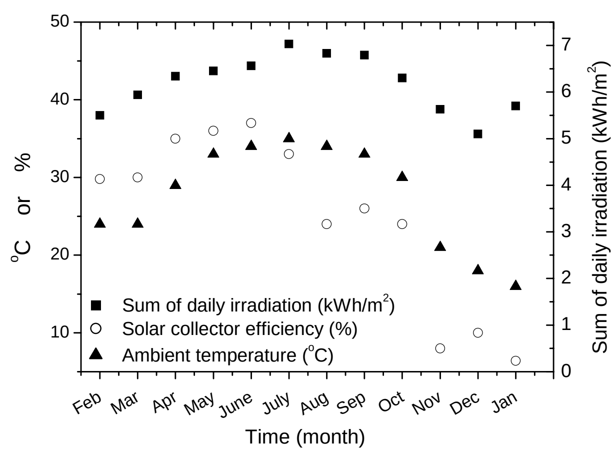

Fig.9. Monthly variation of collector efficiency

3.4 Operation and Maintenance

During the first month of operation (February 2006), the quality of produced distillate was very good with a conductivity of less than 10 µS/cm. In March 2006, an increase in the distillate conductivity was noticed. After a thorough evaluation, it was decided to remove the deteriorated module and to operate the system with three membrane modules instead of four.

In July 2006, the unit performance deteriorated significantly, the conductivity of the feed was very high (about 2000 µS/cm). The three modules were disconnected, drained and cut open to diagnose the problem. A picture of the membrane surface is shown in Fig. 10.

Fig.10. View of the membrane surface after 6 months of operation

Inspection of the inside showed considerable scaling of the membrane. A thick layer of scaling was observed on the membrane surface. Most of the scaling took place on the hot side (80°C) of the membrane. Two new membrane modules were used to replace the three old malfunction modules in September 2006. To reduce the effect of scaling, dilute formic acid was injected with feed seawater once every month to wash any possible scale deposits on the membrane hot side surface. Thereafter, the plant was running well producing distillate with a conductivity less than 150 µS/cm.

3. Conclusion

The experience gathered after one year of seawater desalination using an autonomous solar-powered membrane distillation unit shows that such plant offers an attractive solution to provide remote coastal areas with clean drinking water from untreated seawater. The production rate from this unit shows a seasonal variation; about 800 liters per day of high quality permeate were achieved in good weather summer days. Scaling was a problem that deteriorated the membrane performance and tackled by washing the membrane surface with dilute formic acid solution every month.

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