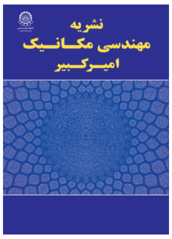

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Experimental Investigation of a System to Produce Fresh Water from the Heat of Photovoltaic Module Using Heat Pipes

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ABSTRACT: In this study, an investigation was performed on a solar hybrid desalination system which was used to desalinate the brine water. Among the aims of this study was the fabrication of a desalination system with the help of both photovoltaic module and thermosyphon heat pipe technologies in a single system. After the fabrication of the desalination system, various parameters such as the amount of produced freshwater by distilled vapor on the glass covering and basin side walls and the surface temperature of the photovoltaic, heat pipe and glass cover were studied. Analysis of the effect of water depth in the basin and also the effect of the presence of a mirror inside the reservoir were also performed and finally the amount of freshwater production was studied in passive state (scenario 1), active state (scenario 2) and active state with mirror (scenario 3). The results indicated that the optimum water depth was 5 cm and the maximum amount of product water was measured to be 0.292 kg/(m^2 h) at 2 p.m. The daily overall efficiency of the passive, active solar still and active solar still with mirror (scenarios 1, 2 and 3) were calculated. Furthermore, results showed that the installation of the mirror led to an average 10.0% and 12% increase in freshwater production and electric power, respectively. Finally, Economical analysis was performed on the proposed system and production cost per a liter of freshwater was calculated.

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1- Introduction

The vast majority of water on the Earth's surface which is observed in the atmosphere, biosphere, and lithosphere equals to 1386 million km^3(1.386 billion m^3) [1], which covers around 75% of the Earth's surface. However, a small number of the available water resources can be used in agricultural and hygienic applications [2]. Approximately 3% of the planet's water supply is related to freshwater, which is stored in Icecaps and glaciers, ground water, surface water, lakes, rivers, the atmosphere under the ground and the like [3]. As ocean and sea waters are salty, it is necessary to refine water if an investment in the construction of desalination facilities are emphasized [4]. Manokar et al. [5] indicated that condensation rate is a function of wind speed and the shape of glass cover and evaporation rate is related to a function of water depth in the basin, the thermal capacity of the system, and the like. Jones et al. [6] analyzed different types of basin cover material such as plain glass, Plexiglass and thin polyethylene sheet and their effect on the rate of freshwater production and reported the best performance and highest efficiency of the plain glass cover for solar still. He et al. [7] fabricated a thermal system for water heating purposes based on Photo Voltaic (PV) module made from aluminum alloy. The system had a daily efficiency of 40% based on the natural water cycle. Zakharchenko et al. [8] focused on the water thermal system in a PV module-collector composition and concluded that the low-temperature portion of the collector should be covered by the PV module in order to operate at low temperatures. El-Sebaii [9] studied passive and active solar stills with various designs through analyzing the effect of wind speed, the surface temperature of the glass cover and water as well as water depth on increasing efficiency.

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2- System Description

Fig. 1 illustrates a schematic diagram of the PV module and Thermosyphon Heat Pipes (THPs). The general system consists of a brine water basin, a PV module, a glass cover, a tray, a copper surface, and nine THPs. The schematic plan of the system is shown in Fig. 2. A tray was placed inside the basin whose dimensions were smaller than those of the basin bottom. Initially, brine water was poured into the tray and vaporized by heat transfer through the THPs. Then, the resulting vapor rose inside the basin and condensed upon contacting the glass cover due to heat transfer with the outside having a lower temperature. In the next stage, the condensed vapor was guided to the bottom of the glass cover and the freshwater reservoir due to the inclination of the glass cover. In addition, the aggregated vapor on the basin's side walls became freshwater similarly.

3- Methodology

All data were collected between 8 a.m. and 5 p.m. in Tehran as the solar irradiance is high in this period [10]. The desalination system used a PV module, which was simultaneously served both as a thermal collector and a producer of electric energy. The current study aimed to evaluate the performance of a solar still with the advantage of recovering the dissipated heat from the PV module by using heat pipes. In all cases, a tray was placed in the middle of the basin. Three scenarios used to compare the active and passive states are following:

1) Passive solar still (scenario 1)
2) Active solar still (scenario 2)
3) Active solar still with mirror (scenario 3)

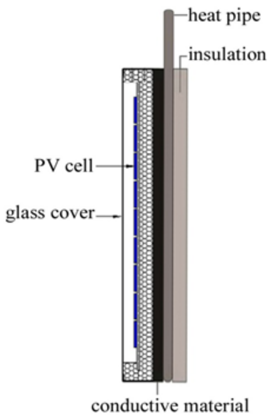

Fig. 1. A schematic diagram of PV module, heat pipes, and an insulating surface

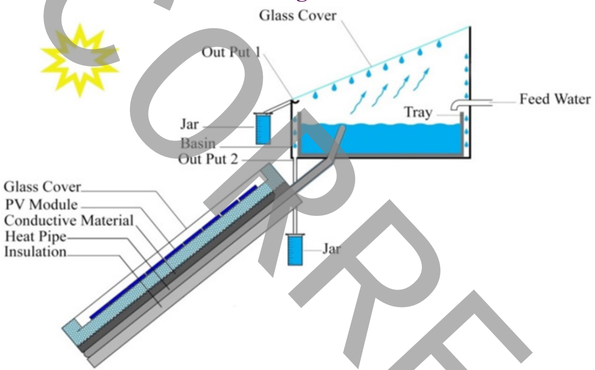

Fig. 2. A schematic plan of the system

4- Results and Discussion

In the present study, the electrical efficiency of transforming solar energy into electric energy by the PV module system is approximately 10.27 - 11.59%. The dissipated energy was recovered in the back of the PV module by the THPs to decrease the PV module surface temperature and increase its electrical efficiency [13]. The tests were conducted in the depths of 3, 5 and 7 cm measured from the bottom of the tray for scenario 1. The maximum freshwater production was obtained at 5 cm depth, which was selected as the optimum depth. Fig.3 illustrates the amount of yield $(kg/m^2.hr)$ at depths of 3, 5 and 7 cm measured from the bottom of the tray. As shown in this figure, an increase in the solar radiation

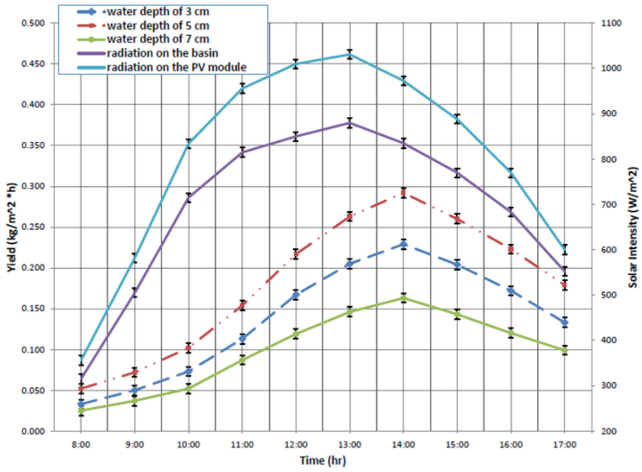

Fig. 3. Solar intensity and the amount of produced freshwater for various water depths in the basin (depths of 3, 5 and 7 cm)

intensity resulted in an increase in the value of hourly yield. As it is evident from Table 1, the daily thermal efficiency of the passive conventional still is about 22.4% (scenario 1) while the thermal efficiency of 14.64% was achieved in the active system without fan (scenario 2). Further, the daily thermal efficiency of the active solar still with the mirror was 14.55% (scenario 3). Therefore, the overall system efficiencies of the active solar stills are much higher than that of the passive solar still.

4- 1- Cost analysis

The cost analysis was performed according to guidelines provided by Fath et al. [14]. The total cost including manufacturing and manpower costs for scenario 1 (Bain+PV module) was estimated to be 268 $\$/\mathbf{m}^2$. The higher CPL obtained in this study is related to the use of a high price PV module to heat the brine water in the basin as well as the lack of consideration for the price of the generated electricity. As it was already mentioned, the cost per liter of freshwater production for scenario 2 was 0.0537 $(\$/\mathbf{l})$, based on the proposed economic analysis. However, 0.898 $\mathbf{kWh}/\mathbf{m}^2\mathbf{.day}$ electric power was generated in scenario 2 which can be sold to the national grid as the proceeds. The selling price of electric power is different around the world. As mentioned before, the CPL of the current system is

Table 1. Daily thermal, electrical, equivalent thermal and overall system efficiencies of solar stills in active and passive states

No Scenario	Present study	System type	Daily thermal efficiency (%)	Daily electrical efficiency (%)	The equivalent thermal daily efficiency (%)	The overall system efficiency (%)
Scenario 1	Passive (without fan)	Conventional still (only ba sin)	22.4	-	-	22.4
Scenario 2	Active (without mirror)	PV module, THPs and basin	14.64	11.00	28.94	43.58
Scenario 3	Active (with mirror, without fan)	PV module, mirror, THPs and basin	14.55	11.21	29.50	44.05

0.0537 $\$/\mathbf{l}$ with average daily an yield of 1.814 $\mathbf{l/m^2.day}$. Thus, the total cost of daily freshwater production becomes 0.0974 $\$/\mathbf{m^2.day}$. Finally, the final cost of production is obtained by subtracting the cost of production and the revenue from the sale of electricity. The final CPL of producing water is 0.0039 $\$/\mathbf{l}$ which is regarded as the lowest, compared to the results of all other previous works.

5- Conclusions

The conclusions obtained are as follows:

- The optimal height of the water in the tray, in terms of the amount of produced water, was found to be equal to the condenser length of the heat pipes.
- Due to the larger irradiated surface (Basin + PV module), the total amount of water produced by the active system (scenario 2, 1.527 kg) was greater than the passive system (scenario 1, 0.604 kg) in one day. This is while, due to its higher thermal resistance and use of heat pipes, the maximum yield ($kg/m^2.hr$) generated by the active system (0.292 $kg/m^2.hr$) was less than the passive one (0.406 $kg/m^2.hr$).

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