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Effects of SSD and SSDHP on convective heat transfer coefficient and yields

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ABSTRACT

The present study is focused on the analysis of a Simple Solar Distiller (SSD) and a Simple Solar Distiller Hybrid with Heat Pump (SSDHP) plants. Experiments have been conducted for 17 h as True Solar Time (TST) for climatic conditions of Gabès (southeast region of Tunisia), during the months of June and July 2006 for four configurations of the above-mentioned plants. Data obtained from experimental conditions are used to determine values of convective and evaporative heat transfer coefficients as well as experimental and theoretical yields. It was found that the SSDHP configuration exhibits better results than the SSD one. In this case, the convective heat transfer coefficient is found equal to 2.373 W/m^2 °C and the experimental yield is equal to 1.8 l/m^2 h.

1. Introduction

The presence of water is an important element in the development of the economy and welfare of any nation. One of the major concerns in the world at present is to find new resources and new processes for providing cheap fresh water, especially for people in remote areas. During the last two decades, processes of getting potable water from saline one using solar energy have been carried out. Tzen and Morris [1] proposed the use of renewable energy sources (RES) coupled with existing technologies as one method, whereby, the need of conventional energy can be reduced, desalination costs can be lowered in the long run and does not result in environmental degradations. Delyannis and Delyannis [2] gave an overview of the existing solar distillation plants in the world, as well as the design geometry of various commercial solar stills at that time. The simplest unit of solar distillation is known as the convectional single slope solar still. The yield of this still is about 2 l/m^2 day of the still area, which is very low. There are, however, several methods to increase this yield, which generally fall into two categories: concentrator and flat-plate collectors. Zaki et al. [3] studied an active system of conventional single slope solar still integrated with a flat-plate collector under thermosyphon mode of operation. They found that the maximum increase in the yield was up to 33% when the water in the still was preheated in the collector.

The heat pump is a useful device for transforming low-grade heat from the air, ground and solar radiation into a usable source. Many experiments were performed by using heat pumps for desalination. Siqueiros and Holland [4] found that the cost to produce potable water for cities is competitive to that of reverse osmosis and electro-dialysis. Slesarenko [5] found that, connecting a heat pump to a thermal desalination plant could increase significantly the economic viability. Hawlader et al. [6] described a novel system of solar assisted heat pump desalination. The performance ratio (PR) and the coefficient of performance (COP) have been evaluated. The (PR) obtained from the experiments ranges from 0.77 to 1.15 and the COP of the system was found to vary between 5.0 and 7.0.

Tiwari et al. [7] studied the convective heat transfer for passive/active solar still by using inner glass cover temperature for limited period of operation. Dunkle [8] proposed a group of complete heat and mass transfer correlations based on a modified Grashof number to express the operating process of basin-type solar stills. Esteban et al. [9] performed the construction of an assisted solar distiller. The new distiller was compared with a common basin-type distiller and a commonplace basin-type distiller coupled with a flat solar collector. Daytime, nocturnal, weekly and hourly measurements showed that the daily production of the new assisted solar distiller always surpassed that of the basin-type distiller by approximately 70%, and that of the basin-type distiller coupled with a flat solar collector by approximately 20%. Thermal performance of a triple-basin solar still based on an analytical solution of the energy-balance equations was studied by El-Sebaii [10]. It was found that for a typical summer day, the daily productivity of the still is equal to 12.635 kg/m^2/day, which agrees well with the results reported in the literature for triple-effect solar stills. Further, the calculated productivity of the lower basin is higher than the productivities of the middle and upper basins during the daytime, this behavior is reversed overnight. Khoukhi and Maruyama [11] presented a rigorous theoretical approach of a flat-plate solar collector with a black absorber considering the glass cover as an absorbing-emitting media. The profile of the efficiency curve obtained was found to be not linear in shape. Indeed, the heat loss from the collector is a combination of convection and radiation and

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highly non linear. The effect of the outside convective heat transfer on the efficiency curve is also studied. In fact, when the convection is the dominant heat transfer mode compared with the radiation one, the profile of the efficiency curve is more or less straight line. Consequently, the heat loss coefficient could be calculated using Klein model. It has been also shown that the effect of the wind speed on the glass cover mean temperature is very important. This effect increases with the increase of the mean absorber temperature.

Other authors, namely, Shawaqfeh and Farid [12] and Calrk [13] studied heat and mass transfer coefficients based on experimental results, they proposed other empirical correlations for these coefficients in solar stills. Papadakis et al. [14] analyzed the nature of the convection mechanisms inside and outside of the greenhouse cover and presented criteria to determine whether pure free, pure forced or mixed convection takes place. Papadakis et al. [14] provided empirical relations for the convective heat transfer coefficient inside and outside of the cover surfaces during the day time (the greenhouse was naturally ventilated) as a function of the air cover temperature difference and the air current speed. They concluded, in agreement with the conclusion of Stanghellini [15] that, when the greenhouse vents are open most of the time, mixed convection is the prevailing mechanism of convective heat transfer inside the greenhouse.

The aim of the present study is to determine the convective and evaporative heat transfer coefficients as well as experimental and theoretical yields, for four configurations based on a Simple Solar Distiller (SSD) and a Simple Solar Distiller Hybrid with Heat Pump (SSDHP) plants. Experiments have been carried out during the months of June and July 2006 in Gabès (south east region of Tunisia).

2. Experimental set up

As mentioned, in our experimental work, two models are used. The first one is called the SSD model, in which the water output is simply obtained by purely solar energy. This model works only on day. The second one is named the SSDHP, in this model; heat pump is used in order to increase the quantity of water output. This model works by using both purely solar energy and heat pump, consequently it can be used on day and night.

For the SSDPH model, it should be noticed that the condenser will contribute to the heating of water and thus its evaporation, especially from the morning to midday to compensate the sun miss. The evaporator will allow while being cooled, a more quantity of condensed water.

2.1. The SSD model

Fig. 1 shows the schematic diagram of the SSD installation. It consists of a basin which is fabricated from fiber forced plastic material that accommodates the brackish water such that the maximum depth was fixed at 30 cm, and is covered by two slopping covers. The height of the lower vertical side of solar still was kept at 60 cm and the area of the basin is equal to 0.4 m^2. The operation of the still is very simple: the incident solar radiation is transmitted through the transparent glass cover to the water. As a result, the water is evaporated, and reached the glass cover, then collected at the distilled water gutter at condensed phase.

2.2. The SSDHP model

In order to produce more output-distilled water, we added a heat pump to the SSD model. Fig. 2 shows this configuration. A condenser is immersed in basin water to increase the water temperature and then evaporated quantity of water will increase. The condenser, which is located near the upper region of the glass cover, enhances the condensation of the water vapor, and the refrigerant (R12) leaving the condenser is introduced in a recuperator filled with fresh water in order to maintain the temperature of the refrigerant. After that, the refrigerant enters the evaporator at low pressure inducing the condensation of water vapor. As a consequence, a more quantity of condensed water will be recuperated at the distilled water gutter. This process has the advantage that is done naturally.

2.3. Experimental parameters

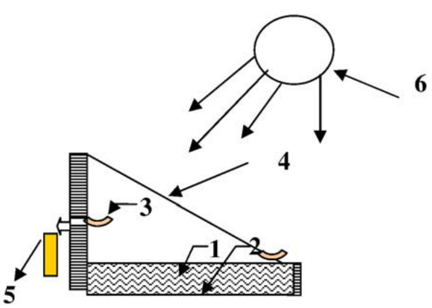
For the installation, we assigned the value (0) for which the SSD and the SSDHP plants are oriented towards the south and the value (1) for which the plants are periodically oriented towards the sun (azimuth consideration).

For the glass cover, the value (0) is given when a single glass cover is used and the value (1) for double glass cover. Similarly, the value (0) is given in absence of heat pump and the value (1) is given when the heat pump is used. Table 1 illustrates different studied configurations.

All temperatures are measured by using sondres, while distiller output water temperature is measured by a mercury thermometer. The distiller output is measured by a graduated test-tube (Table 2).

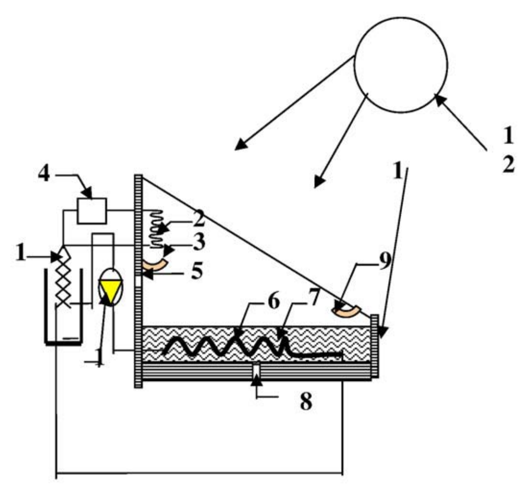
The following parameters are measured every hour for the two studied models as indicated in Figs. 1 and 2:

- Water temperature T_w
- Vapor temperature T_{evp}
- Ambient temperature T_a
- Distiller output $\dot{m}_{ex}$.



1 -brackish water, 2 -basin, 3 -distilled water gutter, 4 -glass cover, 5 -distiller water, 6 -Sun

Fig. 1. Simple Solar Distiller (SSD) plant.



1-compressor, 2-evaporator, 3 -distilled water gutter, 4 -expending valve, 5 -input brackish water, 6 –condenser, 7 -brackish water, 8 - brackish water, 9 -distilled water gutter, 10 –insulator, 11 -recuperator , 12 -Sun

Fig. 2. Simple Solar Distiller Hybrid with Heat Pump (SSDHP) plant.