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Experimental study on the effect of coupling parabolic trough collector with double slope solar still on its performance

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ABSTRACT

The performance of coupling parabolic trough collector (PTC) with double slope solar still is investigated experimentally. The incident solar energy on the PTC is transferred to the solar still by oil pipes connected with finned-piped loop heat exchanger imbedded in the solar still. The experiments are conducted at summer and winter times for three systems; conventional solar still, solar still with fixed PTC and with tracked PTC and for two cases of saline water depth in the basin 20 and 30 mm. The results illustrate that the solar still with PTC has higher sill temperature and productivity compared with conventional solar still. The freshwater productivity of solar still with tracked PTC is higher than that of fixed PTC by about 28.1% and for conventional solar still by about 142.3% at saline water depth 20 mm in summer. Freshwater productivity is about 8.53 kg/m^2/ day and 4.03 kg/m^2/day for solar still coupled with fixed PTC in the summer and winter respectively. The results also illustrate that the performance of solar still in winter is smaller than summer for all studied cases and systems. In summer and at saline water depth 20 mm, the daily efficiency of the conventional solar still, solar still with fixed PTC and solar still with tracked PTC are 36.87, 23.26 and 29.81% respectively.

1. Introduction

Water is the vital for all forms of life on the earth; human, animals and planets. Water is one of the greatest abundant resources on the earth's surface where it covers 71% of its surface. About 97% of the earth's water is present in oceans and seas as salty water, 2% is reserved in Polar Regions as ice and the rest is presented as freshwater in the form of lakes, ground water, and rivers (Singh et al., 2016a,b). The availability of freshwater from the natural resources of water shrinks from day to day because of rapid growth of world population and poor management of water (Tiwari and Sahota, 2017). There are many people living in remote areas in hot climates where lack of electricity and water occurs and it needs highly expensive cost to supply them with their need of freshwater. Due to water related diseases, in the earth, 3.575 million people die each year (Sampathkumar et al., 2010). So, it is important to search for an alternative source to supply these people with their need of freshwater. The solar energy is available everywhere and it is free and renewable source of energy. Therefore, it is valuable to use solar energy in the desalination of salty water to overcome this problem. Many solar desalination systems were developed over the last years. The most simple and conventional solar desalination device is the solar still compared to the other distillation devices (Hassan and Abo-Elfadl, 2017). In general, solar still uses saline water and works on the principle of evaporation–condensation. The saline water inside the basin of the solar still is evaporated in the humid air region by using the solar energy and it condensates on the solar still walls. The condensated vapor on the solar still walls is collected and leaves as freshwater. The solar stills are mainly classified into two types: passive and active solar still. For passive solar still, the incident solar radiation on the solar still is the only parameter which produces the evaporation process. For active solar still, beside the incident solar radiation, the evaporation is also produced by using a supplementary device like fan, pump, solar collectors, system of sun tracking or any other devices (Hassan and Abo-Elfadl, 2017). The main problem encountered the solar still is its low productivity of freshwater, which is within the limit 2.5–5 L/m^2 day. To improve the productivity of the solar still, many researches were carried out up till now. Some of these works concentrated on choosing the best working parameters of the solar still. Singh and Tiwari (2004), Tiwari and Tiwari (2006), Phadatare and Verma (2007), Murugavel et al. (2008, 2010, 2011), Khalifa et al. (2009), Rajamanickam and Ragupathy (2012) and Sushrut and Nataraj (2015) studied the effect of climate conditions and basin

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Nomenclature

C_p	specific heat, J/kg K
D	depth, m
I	incident solar radiation, W/m^2
K	thermal conductivity, W/m K
L	latent heat of evaporation, J/kg
M_p	daily productivity, kg/s
PTC	parabolic trough collector
Q_u	useful energy, W
T	temperature, °C

Greek symbols

ρ	density, kg/m^3
η	efficiency
μ	viscosity, Pa s

Subscripts

a	ambient
g	glass
in	inlet
out	outlet
v	vapor
w	water

water depth of the solar still on its productivity. Their studies showed that the freshwater productivity of the solar still decreases with increasing basin water depth. Other researchers worked on developing the passive solar still design. Ahmed et al. (2014) studied experimentally the effect of different solar still configurations. They found that the solar still productivity is about 3.95 L/day, 3.6 L/day and 4.25 L/day for double slope, single slope and pyramid solar stills respectively. Other passive solar still researchers used different materials or porous media with the saline water in the basin or modified the solar still glass cover to increase its performance. Tiris et al. (1996) enhanced the performance of the solar still by using absorbing materials within it. They tested three types of absorbing materials; charcoal, black-paint, and blackened rock-bed. Their results showed that charcoal has an efficiency of (23–29%) greater than blackened rock-bed and (11–18%) greater than black-paint. The productivity of solar still was improved by using nanofluids with the solar still (Sahota and Tiwari, 2016a,b). Abdel-Rehim and Lasheen (2005) studied the effect of installing packed layer and rotating shaft close to the basin water surface on the solar still productivity. Their results illustrated that the productivity of solar still with a packed layer increases from 5 to 7.5%, while it increases from 2.5 to 5.5% in case of using rotating shaft compared to conventional still. Velmurugan et al. (2006, 2007) integrated a mini solar pond with a single acting solar still to improve its productivity. Their work showed that its productivity increases by about 57.8%. Arunkumar et al. (2013) studied the effect of using phase change material (PCM) on the productivity of the concentrator coupled hemispherical basin solar still. The findings showed that the productivity with PCM is 26% greater than without PCM. Velmurugan et al. (2008a, 2008b) and Ayuthaya et al. (2013) increased the solar radiation absorption and heat transfer in the basin by using plate fins inside the basin. They found that using finned basin increases the daily productivity of freshwater by about 45.5%. Shukla et al. (2014) studied experimentally the performance of passive solar still using horizontal and vertical meshes in the basin. Their results indicated that the horizontal and vertical meshes increase the efficiency by about 6 and 13% respectively, and they increase the average productivity 0.4 and 1 L/day respectively compared to conventional solar still. Hassan and Abo-Elfadl (2017) improved the productivity of the single acting passive solar still by about 31% by using pin finned heat sink as a condenser compared to conventional solar still. They also increased solar still productivity by about 35% by using steel fibers in the basin compared to the conventional one. Some studies aimed at increasing the productivity of the solar still by using an auxiliary device coupled with the passive solar still (active solar still). Singh et al. (1996) developed a simple analytical expression for the water temperature of a solar still with flat plate and concentrator collectors in terms of the system and climatic parameters. They found that the productivity of the solar still coupled with the concentrator is greater than that with the flat plate collector. Also, the evaporative heat transfer coefficient in case of using concentrator with still is greater than the case of using flat plate collector. The performance of solar still combined with flat plate solar collector was presented by Tiris et al. (1998), Badran et al. (2005) and Tiwari et al. (2009). Their findings showed that the production of freshwater of the solar still coupled with flat plate solar collector increased by 52% compared to the conventional one. The performance of solar still including a solar energy concentrator was studied by Abdel-Rehim and Lasheen (2007). Their work indicated that the yield of modified still accelerated to 18% greater than that of conventional still. Dev and Tiwari (2012) studied experimentally the yield of single slope solar still joined with evacuated tubular collector. Their findings showed that the daily production of this still is higher than that of a conventional single slope solar still. Singh et al. (2013a,b) studied numerically the efficiency of solar still coupled with evacuated tube collector. The results indicated that the exergy and the overall efficiencies are located in the range of 0.15–8.25% and 5.1–54.4% respectively at 3 cm saline water depth. A study on the performance of evacuated tubular collectors with solar still was carried out by Singh et al. (2013a,b), Kumar et al. (2014) and Singh and Tiwari (2017b). The results illustrated that the cost of freshwater decreased by about 15% by using numbers of this collector. Eltawil and Omara (2014) studied experimentally the productivity of single slope solar still and photovoltaic joined with flat plate collector. This study revealed that the production of freshwater increased to 51% more than the conventional solar still. Mamouri et al. (2014) experimentally evaluated the performance of single basin solar still with evacuated tube collectors. They found that the system achieved an efficiency of 22.9%. An experimental work was presented by Kabeel et al. (2016) on the performance of a solar still with PCM integrated with double passes solar air collector. Their findings showed that the daily yield of the solar still with PCM coupled with solar air heater is 108% greater than that the conventional still. Tiwari et al. (2015) and Singh et al. (2016a,b) studied solar still coupled with two hybrid flat plate collectors of photovoltaic. Kalbande et al. (2016) theoretically studied a single slope solar still integrated with evacuated tubes collector. The results showed that the maximum daily energy and exergy efficiency are to be 34.39 and 4.04% respectively during the sunshine hours for 3 cm saline water depth. Singh and Tiwari (2016, 2017a) examined the performance of solar still incorporating with number identical compound parabolic collectors. They found that the performance of double slope is better than single slope system at water depth 0.14 m.

In spite of the large number of studies on the solar still, still a work can be presented to improve its performance and productivity. To the author's best knowledge, there is not any study presented the performance of double slope solar still with fixed and tracked PTC. Almost, majority of the solar still experimental works were presented in summer times and few studies were presented during winter days. Also, all previous studies for active solar still didn't consider the economics of