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An experimental study of a single-slope solar still with innovative side-troughs under natural circulation mode

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ABSTRACT

Modifying the conventional solar still with the aim of augmenting its yield has been a long serious concern. Therefore, the main purpose of the present study was to experimentally investigate the effects of some parameters, on top the novel modification of attaching side troughs to side glass walls, on solar still yield. Hence, for each case the modified solar still (TSS) yield, as a decisive factor, was compared with that of a conventional one (CUSS) and the degree of impact was determined. It was observed that, opposed to preliminary assumption, shading the top glass cover as the condensing element significantly reduced the yield while side-attached troughs augmented the still yield remarkably and a significant improvement in fresh water output was achieved. Finally, the daily efficiency, for each modification applied, was calculated and it was observed that except for the modifications including shading, remarkable improvements were gained and TSS could reach a daily efficiency around 81.72% relative to that of CUSS.

1. Introduction

On one hand, it is believed that about 99% of water available on Earth is salty, brackish or frozen and remaining 1% is fresh and potable [1]. On the other hand, stills have shown high potential for providing fresh and healthy water for the growing population of the world. In the meanwhile, removing salt from saline is an energy intensive problem and its operational costs are too high. But, it is discovered by researchers that solar distillation may be the most viable candidate and is one of the more economical systems as opposed to other distillation systems, due to the cost of free energy and reduced operating costs [2,3]. It is also believed that desalination of brackish water by solar-powered systems is a practical and promising technology for producing potable water in the regions which suffer from water scarcity especially located in arid areas usually accompanied by high insolation [4]. These all reasons together prove the high potential for solar stills in providing sustainable pure water, especially for remote areas. But the low productivity of solar stills is of high concern and different attempts have been made to enhance the solar still yield. Moreover, the solar still productivity is strongly reliant on its capability in brackish evaporation inside the still humid-air filled cavity highly affected by buoyancy force. But, to increase the rate of evaporation inside the cavity and consequently augment the productivity of the solar still, different methods have been applied. Mahian et al. [5] studied the effect of heat exchanger using nanofluids on solar still performance. The main objective of their research was to determine how much nonofluid passing through heat exchanger integrated with still basin can be effective on evaporation rate. They reported that role of heat exchanger having nanofluids can be beneficial in case the temperature is higher than 60°C while the effect of nanofluids are positive but marginal compared to water. A parametric study was also theoretically performed for a solar still consisting of a vertical multi-effect and tilted wick units to seek for the optimum conditions for gaining maximum daily yield. It was reported that through optimum conditions, the given solar still daily production can be competitive to that of other multi-effect types. Moreover, they also experimentally tested a 4-effect one while the difference between the experimental and theoretical results was found around 10% [6]. Besides, a double-slope solar still equipped with rubber scrapers was experimentally tested by Al-Sultanni et al. They claimed such a novelty makes use of a small slope of the condensing cover accompanied with higher rate of solar radiation entering the still along with rubber scrapers used to overcome the possible disadvantages. They reported that use of scrapers led to enhanced overall heat transfer coefficient which brought about higher yields. They also mentioned that such a modification led to a productivity improvement of 63% [7]. To analyze the effect of storage material on the

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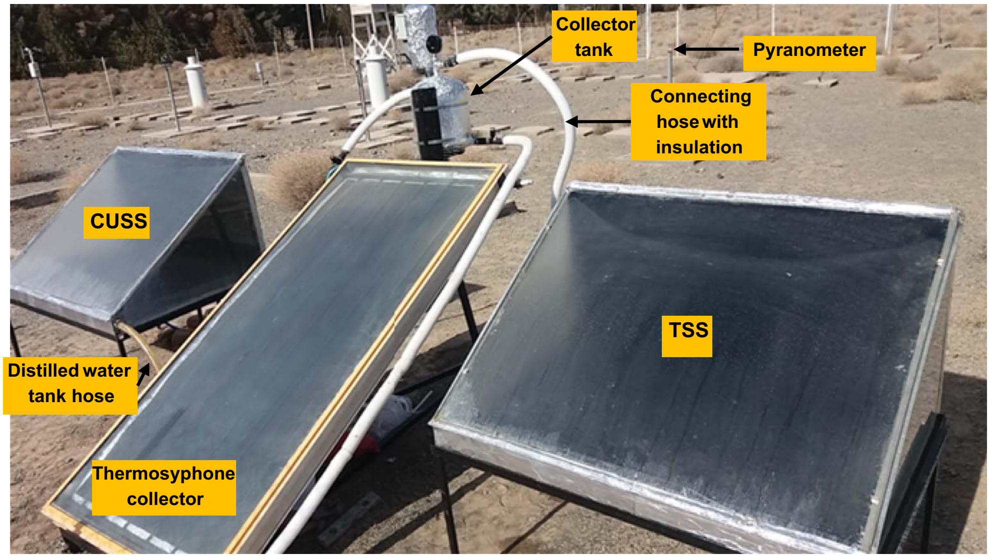

Fig. 1. Front view of solar stills beside solar collector.

performance of solar still, sand and servotherm medium oil were placed beneath the still liner of a single slope single basin still. Through investigation of different storage material depths for a specified amount of water in basin, it was found that lower storage depths were more favorable. They also mentioned the positive effect of passive storage materials on overnight productivity of still while the daylight productivity was found to be lowered [8]. Haddad et al. also aimed to augment the productivity of a conventional solar still through application of a vertical rotating wick believed to work as an additional collector-evaporator area. They reported noticeable improvements in distillate yield i.e. 14.72 and 51.1% in summer and winter, respectively [9]. Rajaseenivasan et al. evaluated the height variation between saline water surface and the glass condensing cover and the best height was selected. They also created turbulences in saline water through application of four stirrers run by solar photovoltaic-powered motors. Moreover, they placed paraffin wax and charcoal in basin to monitor their effects on distillate production rate. They found that fresh water production rate is conversely related to height while the stirrers showed great impact on production of distillate and also the storage material augmented the fresh water production [10]. Through another research, a water fan was integrated with a conventional solar still and put inside. This water fan was also operated by a wind turbine. They reported that water fan integration could increase the daily productivity of solar still in comparison with the one without fan. The authors also mentioned that the maximum productivity of fan-equipped solar still was achieved at water depths of 1 and 3 cm with rotational speeds of fan below 22 and above 33 rpm, respectively [11].As an another novel research, internal and external reflectors were used to study their effects on the performance of a stepped solar still. It was found that such a modification was promising and could bring about increments in still performance [12]. Bhardwaj et al. integrated plastic channels as passive condensers into an inflatable solar still and performed laboratory scale tests. They achieved 0.95 $l \cdot h^{-1}$ yield through application of air flow over the passive condenser or wet tissues on the given condenser to mimic the wind or evaporation cooling conditions, respectively [13]. Abdelal and Taamneh also performed a more chemical experiment with the aim of augmenting the distilled water production of a solar still. Here, they manufactured some solar stills having absorber plates manufactured from carbon fiber/epoxy composites incorporating different percentages of carbon nanotubes and graphene nanoplatelets in the epoxy matrix. It is worth mentioning that through the above mentioned modifications, even a 109% increase in the amount of distilled water was observed compared with the ordinary type absorber plate through adding 5 wt% carbon nanotubes to the epoxy matrix in the carbon fiber/epoxy composites [14]. Kabeel et al. also experimentally investigated the effect of hot air injection on the performance of a still having phase change material. They reported that under the same atmospheric conditions, the target (modified) still could reach 108% higher productivity in comparison with a conventional one [15]. Trying to overcome the low productivity of solar stills, three modifications including flake graphite nanoparticles, phase change material, and film cooling were also used by Sharshir et al. Their report on productivity showed a 73.8% enhancement while a more 13% increase in productivity was achieved through minimizing the water depth from 2 cm to 0.5 cm [16]. Following all those modifications mentioned above, in the present experimental study, six different tests each including specific modifications, were performed to determine the effects of each upon the still yield. Moreover, in the conventional solar stills, the only condensing surface used is the top glass one which has a main collecting trough glued to its lower edge for collecting fresh water while in the present study it was observed that many drops would appear on the inner surface of the side glass walls. Hence, two troughs were formed and glued to side walls while they were tilted downward towards the main collecting trough. It is much worth mentioning that side troughs attached to side glass walls of solar still was of noticeable effect on still productivity and as far as the authors are aware, it can be considered as the novelty of experimental study presented here.

2. Experimental set-up

To study and compare the effect of each modification on solar still yield, it was essential to fabricate two completely the same solar stills, one as the control unit (CUSS) and the other as the target solar still (TSS), shown in Fig. 1. The main components of the systems are as follows:

1. Glass cover which provides a transparent aperture to let the incident solar radiation enter into still cavity for heating up water accumulated on blackened basin liner. Moreover, the inner surface of this transparent cover also works as a condensing surface on which the vapor is condensed;
2. Glass side walls to augment solar radiation flux into still cavity;
3. The completely insulated back and bottom walls of blackened metal sheet;
4. A closed-loop thermosyphone flat-plate collector detachable to fulfill the preheating role;
5. A tank with spiral copper tubes inside to help transfer collector-generated heat to water being later fed to solar still;