Applied Thermal Engineering 113 (2017) 684–693

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study

S.W. Sharshir [a,b,c], Guilong Peng [a,b], Lirong Wu [a,b], Nuo Yang [a,b,*], F.A. Essa [c], A.H. Elsheikh [d], Showgi I.T. Mohamed [e], A.E. Kabeel [f]

[a] Nano Interface Center for Energy (NICE), School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan 430074, China
[c] Mechanical Engineering Department, Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt
[d] Production Engineering and Mechanical Design Department, Faculty of Engineering, Tanta University, Tanta, Egypt
[e] Mechanical Department, Faculty of Engineering and Technical Studies, El Imam El Mahdi University, Kosti, Sudan
[f] Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt

HIGHLIGHTS

- Effects of graphite and copper oxide as new nanoparticle on the still yield.
- The influence of nanoparticle concentration on the still yield.
- The effect of varying the basin water nanofluid depths on the still yield.
- The influence of glass cooling with using nanoparticle on the still productivity.

ARTICLE INFO

Article history:
Received 24 March 2016
Revised 5 November 2016
Accepted 11 November 2016
Available online 12 November 2016

Keywords:
Micro-flakes
Nanofluids
Graphite
Copper oxide
Water depth
Glass cooling

ABSTRACT

The use of graphite and copper oxide micro-flakes with different concentrations, different basin water depths, and different film cooling flow rates is experimentally investigated in an attempt to improve the performance of solar still. The micro-flakes concentrations are ranged from 0.125% to 2%. While, the basin nanofluid depths are ranged from 0.25 to 5 cm. Whereas, the glass cooling flow rates are ranged between 1 and 12 kg/h. The obtained results show that the solar still productivity is enhanced by about 44.91% and 53.95% using the copper oxide and graphite micro-flakes, respectively, compared with the conventional solar still (without micro-flakes). In case of using the water over the glass cover, as a feed water, the output yield is improved by about 47.80% and 57.60% using copper oxide and graphite particles, respectively while the daily efficiency of the conventional still is 30%. Furthermore, the daily efficiencies of 38% and 40% are obtained when using copper oxide and graphite, respectively, without using glass film cooling. Finally, the stills' daily efficiencies when using copper oxide and graphite micro-flakes with glass film cooling are 46% and 49%, respectively.

1. Introduction

Water is the main requirement for life. Because the amount of the available freshwater is limited, and because of population increase and industrial development, the need for freshwater is increased [1]. Water desalination using solar energy is one of the methods to get potable freshwater from saline water. One of the well-known attractive and simple solar distillation techniques is solar stills. So far, too much work had been conducted to increase the still output yield such as solar water purifier [2], regenerative solar desalination unit [3], asymmetric greenhouse type solar still with some mirrors [4], reflectors and absorbers [5], water plat collectors [6–8], wick still [9,10], triple-basin still [11], capillary film [12], solar still with thermal energy recycle [13], solar water collector [14,15], black rubber and black gravel [16,17], sponge cubes [18], double and single slope solar still [19], electrical blower [20], phase change materials [21–23], and suspended absorber [24].

In addition to the aforementioned modifications, there are also some other efficient modifications. The glass - water temperature difference is a main factor affecting the output yield of the solar still. To keep up this temperature difference as a maximum value,

* Corresponding author at: Nano Interface Center for Energy (NICE), School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China.

E-mail address: nuo@hust.edu.cn (N. Yang).

http://dx.doi.org/10.1016/j.applthermaleng.2016.11.085
1359-4311/

several researchers had investigated the mechanisms of flowing water over the glass cover. The condensation rate can be enhanced and hence the yield can be enhanced by increasing the flow rate of glass cooling water and decreasing the inlet cooling water temperature as obtained from the results of [25–31]. The cooling water of the glass cover has many benefits such as continuously self-cleaning of glass and hence high still efficiency. The governing equations representing the heat transfer by convection for the glass cover cooled by water film are obtained by Incropera and Dewitt [32]. The still efficiency was increased up to 20% using the water cooling film, as represented by Sherwood et al. [33], by using water cooling film. The efficiency was increased from 34% to 42% when the temperature of the glass cover has been lowered using the cooling as experimented by Arunkumar et al. [34]. Abu-Hijlew and Mousa [35] achieved, numerically, an enhancement in the efficiency by approximately 20% when using the glass cooling.

Nanofluids has many special properties compared to its base liquid, such as high thermal conductivity [36–44] and high solar intensity absorptivity [45], which will help to enhance the still productivity. Recently, some researchers studied the influence of different types of nanofluids on the yield of solar still. The efficiency of solar still was increased by 29% when the violet dye was used as obtained by Nijmeh et al. [46]. Elango et al. [47] enhanced the output of the still using nanofluids; stills with Aluminum Oxide (Al_2O_3), Tin Oxide (SnO_2) and Zinc Oxide (ZnO) nanofluids have 29.95%, 18.63% and 12.67% higher productivity, respectively, compared with the still without nanofluids.

Kabeel et al. [48,49] studied the influence of aluminum oxide nanomaterial with outside condenser on the still performance [49]. The obtained results showed an increase by 53.2% in the total output when using the external condenser while an increase by 116% was achieved when using aluminum oxide nanomaterial with external condenser. Madani and Zaki [50] investigated the productivity of a still with porous basins. An average productivity of 2.5–4 kg/m^2/day was obtained when carbon powder (40–50/μm size) is used. Sahota and Tiwari [51] conducted an experimental and theoretical study to enhance the productivity of double slope solar still (DSSS) using Al_2O_3 nanoparticles. The output of DSSS with aluminum oxide (Al2O3) nanofluid (0.12% wt of Al_2O_3 nanoparticles) was improved by 12.2% and 8.4% at 35 kg and 80 kg base fluid, respectively.

Based on the aforementioned review, integrating the nanomaterials with solar stills needs more attentions from researchers. For the present experimentations, we choose graphite and copper oxide nanoparticles as our experimental object in consideration of its relative high thermal conductivity and low cost [52–54] compared to the other nanomaterials.

Therefore, the objective of this research work is to enhance the still performance by using different new types of micro-flakes with different weight concentrations. In addition, the present study is conducted with and without different film cooling rates, and also with different water depths. The nanomaterials are the graphite and copper oxide micro-flakes at concentrations ranges from 0.125% to 2%, to get the ideal concentration in which the highest productivity occurs. Also, the glass cooling flow rate is changed from 1 kg/h to 12 kg/h to get the best cooling film rate with micro-flakes. Furthermore, different brine depths from 0.25 cm to 5 cm are investigated to get the optimum depth with micro-flakes. Besides, the thermal performance of the system is also investigated.

2. Experimental setup

The whole system, including solar stills, is manufactured in the School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, China (Latitude 29°58°N and longitude 113°53°E). The experiments are carried out during the period from August to October 2015.

Three basin stills with the same size were used to evaluate the solar desalination system performance. A photograph and a schematic of a solar desalination setup are shown in Figs. 1 and 2, respectively. They consist of a conventional still, a solar still with graphite nanofluid without and with glass film cooling, solar still with copper oxide nanofluid without and with glass film cooling, and film cooling water tank. Basin areas of all stills are 0.25 m^2 (0.5 m length × 0.5 m width). Low-side is 160 mm and the high-side is 450 mm. The stills are made from iron sheets (1.50 mm thick). To enhance the absorptivity of the still and hence increase the evaporation rate, black paint is used to coat all inside basin surfaces. To eliminate heat loss as possible, all external and bottom surfaces are well insulated by fiberglass of 5 cm thickness. The trough inside the basin still is used to collect the distillate output water into an external calibrated flasks through plastic pipes. The drain brine fluid is wasted outside the basin still through another pipe.

The basin is covered with a clear glass sheet of 3.5 mm thickness inclined at nearly 30° horizontally, which is the latitude of Wuhan, China. To receive as much insulation as possible, the tilt angle is selected equal to the latitude of Wuhan city and the setup is kept to face the south direction.

The factors to be investigated in this experimental design are: (a) use of nanofluids, (b) concentration of nanofluids(wt.%), (c) water depth (cm), and (d) cover cooling flow rate (kg/h). Each factor has several experimental levels. For example, levels for factor (a) are (i) graphite and (ii) copper oxide. Levels for factor (b) are (i) 0.25, (ii) 0.5, (iii) 1.0, (iv) 1.5, and (v) 2.0. Levels for factor (c) are (i) 0.25, (ii) 0.5, (iii) 1.0, (iv) 2.0, (v) 3.0, (vi) 4.0, and (vii) 5.0. Levels for factor (d) are (i) 1.0, (ii) 2.0, (iii) 4.0, (iv) 6.0, (v) 8.0, (vi) 10.0, and (vii) 12.0. The modified solar stills have the same conventional still dimensions except using the graphite and copper oxide micro particles with different concentration mixed with the water inside the basin still.

The cold-water flows over the glass (film cooling) is varying from 1 kg/h to 12 kg/h and kept constant and uniform for each value with the help of a constant head tank and a regulator. The dimensions of the cold-water tank are rectangular base of 88 × 42 cm and 42 cm height. The glass cover, from inside direction, condenses the uprising evaporated water. Due to the tilting of the glass and gravity, the condensed water runs down through the small inclined rectangular channel (trough) to be collected into the flasks. Basically, the glass and non potable water temperatures, air temperature, total solar intensity, air velocity, and the amount of distillate are measured. The temperatures have been measured using calibrated copper constantan type thermocouples with range of (−50 to 280 °C) with accuracy of (±1 °C) and uncertainty of (±0.15236) which are connected to a digital temperature indicator (model TES-1310). While, solar meter (model TES-1333) with range of (0–2000 W/m^2) with accuracy of (±10 W/m^2) and uncertainty of (±3.16633) is used to measure the solar intensity. The air velocity is measured using the Vane type digital anemometer (model Benetech GM816) with range of (0–30 m/s) with accuracy of (±1 m/s) and uncertainty of (±0.17541) Finally, a flask of 1.5 l capacity with accuracy of 5 ml and uncertainty of (±0.001) is used to measure the productivity. Both the measuring range and the accuracy of all measuring instruments, i.e., the thermocouples, solar meter, and digital anemometer depend on the specifications of the commercial types we used. Moreover, the uncertainty is calculated from the equation stated in reference [55]. Specifications of graphite and copper oxide micro-flakes are shown in Table 1.

Experiments are conducted at the school of energy and power engineering, Huazhong University of Science and Technology, Wuhan, China during the period from 9 am to 5 pm of August to