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ORIGINAL ARTICLE

Augmentation of a solar still distillate yield via absorber plate coated with black nanoparticles

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Abstract Effects of utilizing nanomaterial on the solar still productivity investigated experimentally. Cuprous oxides (CuO) chosen as a nanoparticles material. The nanoparticles added to the black paint of the solar still walls to enhance the solar still performance. Experiments conducted with cuprous oxide nanoparticles weight concentrations ranged from 10% to 40%. It is found that adding nanoparticles to paint increase heat transfer rate and saline water temperature. Solar still productivity of the proposed system is higher than that for the conventional still. Results acquired that utilizing CuO nanoparticles boosted the distillate by 16% and 25% as compared to the conventional solar still (CSS) at weight fraction concentration of 10% and 40%, respectively. Payback period of the distillation system for the modified still using CuO nanomaterials is about 96 days, at weight fraction 10%, which is considerable as compared by 89 days for CSS.

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1. Introduction

Water drinking availability is decreasing day by day; while the water-drinking requirement is increasing quickly. While most of earth's surface is water, freshwater is very limited in lakes, rivers, and underground. Hence, getting water of drinking is main problems through all universes due to shortage, pollution, and salt concentration. Then, people have to make some treatments for brackish or salt water. Distillation using solar stills is one of the most primitive forms of water treatment that collaborates in solving the water problem. As known well, solar stills have many advantages: simple, cheap, pollution free, and negligible maintenance expenses. However, the productivity of fresh water of CSS is limited as investigated by researchers. In addition, thermal efficiency of CSSs is about 35–40% with a daily productivity about 3–4 l/m^2 d [1]. Much theoretical and experimental works were conducted to enhance the solar still performance [2].

Xiao et al. [3] investigated operating and climate conditions influencing the solar still production. Climate conditions

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include incident solar irradiation, wind velocity and temperature of surrounding. While, the operating conditions include coated material, temperature difference between water and glass cover, water depth, and insulation.

Lomascolo et al. [4] presented a review about the main results available in the scientific survey for heat transfer of nanofluids. Specifically, they dealt with the important results of experimental works acquired in the scientific community for convection, conduction and radiation in nanofluids. What's more, the influences of nanoparticle (material, shape, size and volume concentration) and base fluid (of additives, clustering, and temperature) were discussed.

Syam et al. [5] estimated experimentally ethylene glycol thermal conductivity and mixture of water based Al_2O_3 and CuO nanofluids at various temperatures and volume concentrations. The base fluid was a mixture of 50:50% (by weight) of ethylene glycol and water. In addition, the concentration up to 0.8% and range of temperature from 15 °C–50 °C were tested. They indicated that Al_2O_3 and CuO nanofluids obtained higher thermal conductivity compared to base fluid. In addition, the thermal conductivity of CuO nanofluidis more compare to Al_2O_3 nanofluid, under same temperatures and volume concentrations.

Addition ofsuspended solid-sized nanoparticles to a specific fluid called nanofluid. The heat transfer characteristics of the base fluid changed because of the new additions of nanoparticles. Distillation efficiency rises by about 29% when mixing violet dye with the water in the experimental work by Nijmeh et al. [6]. The solar heater performance with the new additions of SiO_2, CuO, TiO_2 and Al_2O_3 nanofluids studied numerically by Faizal et al. [7]. They estimated that 8625 kg, 10239 kg, 8618 kg and 8857 kg total weight for 1000 units of solar heaters can be saved for SiO_2, CuO, Al_2O_3 and TiO_2 nanofluid, respectively. Koilraj et al. [8] completed an experimental test rig to study the effect of adding carbon nanotubes to the basin water on the yield of a vacuum still. In recent times, Kabeel et al. [9] examined the effect of providing vacuum inside the conventional still with adding an external condenser on fresh water production of the tested still. The authors' investigations also concluded the influence of using nanofluid on the tested still performance. They concluded that providing vacuum increases the water productivity by around 53.2%. While 116% was the enhancement percentage of water productivity because of using nanofluid. In another study for the same authors, Kabeel et al. [10] made experimental comparisons between using the solid nanoparticles of CuO and Al_2O_3 with various concentrations (by weight fraction) to optimize the performance of the solar still. Their results obtained that using CuO nanoparticles, as well as Al_2O_3 nanoparticles, increased the fresh water production by around 125.0%, 88.97%, 133.64%, and 93.87%, without and with operating the vacuum fan, respectively.

External condenser and internal reflectors integrated with a corrugated wick solar still (CrWSS) was examined by Omara et al. [11]. Influence of utilizing various types of nano materials on CrWSS performance also investigated and compared with the conventional still. Their results indicated that adding of both an external condenser and reflectors to CrWSS improve its productivity. In addition, the distillate of CrWSS with reflectors using providing a vacuum improved by around 180% higher than the conventional still. The productivity of the system enhanced using Al_2O_3 and CuO nanoparticles by approximate percentages of about 254.88% and 285.10%, respectively.

The aim of this study is to improve the freshwater yield of the conventional still by utilized black paint mixed with nanomaterials for the basin walls. Where, nanomaterials increase the heat transfer rate between the basin water and walls of still.

2. Experimentation

Fig. 1 shows a schematic graph of the experimental test rig. The test rig consists of a tank of saline water, a modified solar still (MSS) and conventional solar still (CSS). They are identical in specification, dimensions and the fabricated material of galvanized iron sheets. The two fabricated solar stills have a single basin with an effective area of 0.5 m^2 (0.5 m width × 1 m length) for each. For each still, the height of high side and the low-side walls is 44 cm and 15 cm, respectively. The stills were made of galvanized sheets with 1.5 mm thick. The surfaces of conventional solar still coated with black paint from inside to improve their absorptivity, while those of modified basin coated with black paint mixed with the nanomaterial (copper oxide) nanoparticles. In addition, the two stills well insulated with wool to decrease the heat losses. The two basins covered with 3 mm thick glass sheet inclined with 30° on horizontal (Latitude of Kafrelsheikh, Egypt). Silicon used to prevent any leakage of water vapor anywhere to outside of basins.

The main saline water tank was utilized to feed the saline water through the main line which was branched into two lines of feed water to the basin stills as shown in Fig. 1. The condensate distilled water was collected in a graded container as shown in the figure.

Experiments under weather condition of Kafrelsheikh, Egypt conducted for 3 days for each concentration (10, 20, 30, and 40%) and the average value taken during September 2014 to test the performance of the stills. Wind velocity, temperatures and solar radiation measured using the instruments of digital air flow/volume meter, thermocouples (K-type) and solarimeter, respectively. Solar radiation measured on tilted glass cover.

Specifications of the used nanomaterial tabulated in Table 1. The performance of MSS with the new addition compared with CSS. Experiments were done on MSS utilizing CuO nanoparticles mixed with the black paint at concentration (weight fraction) ranged from10% (100 g of nanomaterials to one kg of black paint) to 40%.

3. Error analysis

System performance depends on several parameters measured during experimentations. Brine, glass cover, surrounding temperatures, wind velocity, total incident solar irradiation and amount of freshwater are the parameters evaluate the performance of stills. All temperatures measured utilizing the calibrated thermocouples (copper constantan type) with an accuracy of ±0.5 K. The total insolation was measured by the solar power meter ranged from 0 to 5000 W/m^2 (±1 W/m^2 Accuracy). The accuracy of the van type anemometer measuring the wind speed was ±0.11 m/s. A regulated flask of 2 l capacity (5 ml accuracy) utilized to measure the hourly fresh water production.

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