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Effect of using nanofluids and providing vacuum on the yield of corrugated wick solar still

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ABSTRACT

Purifying water using solar energy is a suitable green technique for rejecting salts from saline water. Solar stills are famous and simple devices for sea water desalination but their productivity from freshwater is limited. Various novel techniques were advanced and established to increase the solar still output yield. In the current work, experimental studies with modifications on the ordinary solar still have been conducted to investigate the performance of the new erected solar still. A hybrid solar distillation system comprising of corrugated and wick absorbers of solar stills is integrated with an external condenser to examine their performance. The first solar still is a base traditional type (CSS), while the other one is a corrugated wick still (CrWSS). The performance of CrWSS with internal reflectors, integrated with external condenser and using different types of nanomaterials is investigated and compared with the conventional still. The two types of solar stills are subjected to the same metallurgical conditions. The influence of saline water depth (1, 2, and 3 cm) on CrWSS performance was also investigated. Results showed that integrating an external condenser, with corrugated wick still, with reflectors improves the productivity of the modified solar still. Also; the yield of CrWSS with reflectors when providing a vacuum was enhanced to about 180% higher than the CSS. The productivity of the system is enhanced when using cuprous and aluminum oxides nano particles by an approximate percentages of 285.10% and 254.88% respectively.

1. Introduction

Water-related diseases like diarrhea are considered to be the primary cause for the annual death of approximately 1.8 million people; the majority of all such deaths are among children under five years of age, mostly in developing countries [1]. It is estimated that in developing countries, 85–90% of diarrheal diseases are linked to the causes of unsafe drinking water, limited water supply, insufficient sanitation, and lacking hygiene practices [2]. Clean water is very hard to find in poor societies and inaccessible areas that are often not connected to systems of piped water distribution. Young children, who commonly rely on potentially contaminated water resources, often drink poor quality water from resources like ponds, canals and rivers that are filled with garbage and dirt [3]. Evidence has indicated that the youngest children are particularly the most vulnerable to the effects of the contaminated water and the diarrheal diseases. The incidence of diarrhea was proved to be highest in the first two years of life and then decays as a child grows older.

One of the alternatives to convert contaminated water into safe drinking water, without affecting on the ecosystem, could be solar distillation through the use of solar still on a small commercial scale. However, desalination is energy intensive, and because of the scarce availability of wood and oil, solar desalination, based on renewable, safe, free and clean solar energy, is the promise for a cost-effective solution. Researchers found that the solar still is a suitable technology that may significantly and effectively reduce diarrheal disease for communities that have no other way to disinfect water [4]. Solar still can be used to distil, collect, and supply high quality drinkable water that is essential for the daily survival of the people that live in remote areas or in isolated small communities, and the supply of conventional energy is limited. Recent reviews of solar stills and the various factors affecting on their performance were made by Xiao et al. [5] and Sivakumar and Ganapathy Sundaram [6].

Many experimental and analytical attempts have been made to improve the performance of simple solar stills. The effect of using fins at the basin of the still was investigated by Velmurugan et al.

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[7]. Results revealed that the daily productivity was increased from 1.88 to 2.8 kg/m^2 more than other types of stills. The still productivity was increased by 75% when integrating the fin type still with sand and sponge [8].

Many attempts of enhancements have been conducted to improve the convective heat transfer coefficient through the heat transfer processes inside and outside the solar still. Kumar and Rosen [9] conducted an experimental setup to investigate the thermal performance of a solar system contained solar water heater integrated with a corrugated absorber. They get extra heat at higher temperatures when introducing the corrugated surface in a collector/storage type solar water heater. The experimental investigation of using fins and v-corrugated absorber was carried out by Omara et al. [10]. Results revealed that the output distillate from the finned and corrugated solar stills was increased by 40% and 21% respectively.

In addition, the more water surface area inside the solar still, the more evaporation of basin water. As a result, the effects of using wick materials [11] or a vertical jute cloth [12] were investigated. Moreover, Mahdi et al. [13] concluded that increasing the input feed water mass flow rate reduces the efficiency of the still when investigating experimentally a tilted wick-type solar still with charcoal cloth. Nafey et al. [14,15] enhanced the still productivity by 20%, 19% and 15% by using a black rubber, black gravel and black aluminum plate in the solar still respectively. Omara et al. [16] conducted an experiment using a new hybrid system, which included the evacuated solar water heater, wicks still, and solar still. An evacuated solar water heater is incorporated into the desalination stills for the purpose of evaluating the continuity output. The productivity increases by about 114%. A modified design of solar still was tried by Kabeel [17]. It consists of a pyramid shaped top surface with four glass covers. To increase the evaporative surface area, black paint coated jute wick is used. The average distillate productivity of the modified still during the 24 h time is about 4.0 l/m^2 and its efficiency reaches about 45%.

The evaporation rate inside the basin still can be enhanced when the condensation conditions are improved. The solar still productivity can be improved using an external condenser [18] where the temperature variance causes water vapor condensation on the glass cover as well as the sidewalls of the still. Such this system combination [19] is developed as an attempt to enhance the productivity. The solar still productivity reached 1.4 l/m^2/day, and the efficiency reached 30%. Madhlopa and Johnstone [20] investigated the effect of a separate condenser. The theoretical productivity was increased by 62% higher than that of the conventional one. The effect of using an outside condenser was studied by E1-Bahi and Inan [21]. They concluded that the yield reached 7 kg/m^2/day, and the daily efficiency was 75%.

Nanofluids are a new class of nanotechnology-based heat transfer fluids produced by dispersing nanoparticles with sizes typically smaller than 100 nm into traditional heat transfer fluids such as water, ethylene glycol, and engine oil. Due to small sizes and very large specific surface areas of the nanoparticles, nanofluids have novel properties like high thermal conductivity, superior critical heat flux (CHF), minimal clogging in flow, and improved heat transfer coefficient. These characteristics of nanofluids make them potentially useful in a plethora of engineering applications ranging from use in the automotive industry to the medical field to use in power plant cooling systems. A comprehensive literature review on the applications and challenges of nanofluids has been provided by Saidur et al. [22]. Choi [23] is the first who used the term nanofluids to refer to the fluids with suspended nanoparticles.

Nanofluids can be normally classified into two categories metallic nanofluids and non-metallic nanofluids. Metallic nanofluids often refer to those containing metallic nanoparticles such as (Cu, Al, Zn, Ni, Si, Fe, Ti, Au and Ag), while nanofluids containing non-metallic nanoparticles such as aluminum oxide (Al_2O_3), copper oxide (CuO) and silicon carbide (SiC, ZnO, TiO_2) are often considered as non-metallic nanofluids, Eastman et al. [24]. Xuan and Li [25] conducted a procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and a base liquid. By means of the procedure, some sample nanofluids are prepared.

Nanofluids thermophysical properties were investigated by several studies on thermal conductivity and convective heat transfer coefficient for different materials and particle size. Minsta et al. [26] measured the thermal conductivity of water-based nanofluids using CuO nanoparticles with an average diameter of 29 nm, and Al_2O_3 nanoparticles with average diameters of 47 and 37 nm respectively. They observed an enhancement between 2% and 24% at room temperature, for a volume fraction between 1% and 14% of CuO; an increase of the thermal conductivity up to 30% with Al_2O_3, in a range of volume fractions from 1% to 18%, but no clear differences of results for the particle sizes. Lastly, they noted a temperature dependence of the thermal conductivity.

Kim et al. [27] obtained a thermal conductivity enhancement of 8.0% and 11.0% with the dispersion of 3.0 vol% of Al_2O_3 nanoparticles, with an average diameter of 38 nm in water and ethylene glycol, respectively. Similar results were obtained using ZnO and TiO_2 nanoparticles, with average sizes of 60 nm and 34 nm, while better enhancements were measured with a particle size of 10 nm. A systematic experimental method of studying the heat transfer behavior of buoyancy-driven nanofluids conducted by Nnanna [28]. The test cell for the nanofluid is a two-dimensional rectangular enclosure with differentially heated vertical walls and adiabatic horizontal walls filled with 27 nm Al_2O_3–H_2O nanofluid. Simulations were performed to measure the transient and steady state thermal response of nanofluid to imposed isothermal condition. The volume fraction is varied between 0% and 8%. Results showed that for small volume fraction, 0.2–2% the presence of the nanoparticles does not impede the free convective heat transfer; rather it augments the rate of heat transfer. However, for large volume fraction 2%, the convective heat transfer coefficient declines due to reduction in the Rayleigh number caused by increase in kinematic viscosity.

Thermal conductivity of ethylene glycol and water mixture based Al_2O_3 and CuO nanofluids has been estimated experimentally at different volume concentrations and temperatures by Syam et al. [29]. The base fluid is a mixture of 50:50% (by weight) of ethylene glycol and water (EG/W). The particle concentration up to 0.8% and temperature range from 15 °C to 50 °C were considered. Both the nanofluids are exhibiting higher thermal conductivity compared to base fluid. Under same volume concentration and temperature, CuO nanofluid thermal conductivity is more compared to Al_2O_3 nanofluid. The effective thermal conductivity of three water based nanofluids (NFs) consisting of large aspect ratio fillers – carbon nanotubes (CNTs), silver nanowires, copper nanowires – were measured by transient hot wire method by Bangming et al. [30]. The results showed that silver nanofluid has the highest thermal conductivity compared with copper and CNTs nanofluids, while the latter two present almost the same thermal conductivity at the same volume fraction.

Lomascolo et al. [31] presented an overview about the main results available in the scientific literature in the field of heat transfer in nanofluids so far. In particular, that work deals with the most important experimental results obtained in the scientific community for conduction, convection and radiation in nanofluids. In addition, the effects of nanoparticle volume concentration, material, size, shape, effect of base fluid, temperature and clustering and of additives are discussed in details.

Otanicar et al. [32] reported experimental results on solar collectors based on nanofluids made from a variety of nanoparticles carbon nanotubes, graphite, and silver. We demonstrate efficiency