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Effect of the condenser type and the medium of the saline water on the performance of the solar still in hot climate conditions

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A R T I C L E I N F O

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A B S T R A C T

This paper presents an experimental work to study the effect of the condenser and the medium of saline water types on the performance of the solar still. Single slope solar still facing the south is used in this work. Also, four types of the condenser are tested: (i) glass, (ii) aluminum plate, (iii) aluminum heat sink with pin fins, and (iv) aluminum plate covered with an umbrella. Moreover, four mediums of the saline water inside the basin are examined: (i) only saline water in the basin, (II) Layers of black steel fibers in the basin, (iii) saturated sand with saline water, and (iv) mixture of sand and black steel fibers saturated with saline water. The solar still of only glass walls and only saline water in the basin is taken as a reference case. The performance of the other cases is referred to the reference case. The results indicate that using heat sink condenser increases the temperature of the saline water. Also, it increases the temperature difference between the condenser and the saline water relative to using glass condenser. Also, using a glass condenser with black steel fibers inside the water basin increases the daily productivity of freshwater by 35%. Using the heat sink condenser increases the daily productivity from 31% in the case of using only saline water to 52% in the case of using black steel fibers in the basin. Using an umbrella of 20 cm wide at the top of the aluminum plate condenser decreases the daily productivity by 26%. Increasing the umbrella wide to 40 cm decreases the daily productivity by 31%.

1. Introduction

The composition of water on the earth is about 97% saltwater, 2% frozen in glaciers and polar snow-caps and the rest is freshwater [1]. The requiring of fresh water production is growing progressively during the coming century due to the growth of the world population, the climate changes, and the industrial processes. By the year of 2025, it is expected that one-quarter of the world inhabitants will be affected by water shortage, and the rest of the population will experience vital water requirements conditions [2]. Therefore, the research in this domain is essential to discover new techniques or to develop the current techniques for the the efficient production of fresh water. Desalination is one of the important techniques that meet this demand. However, the conventional distillation processes such as flash distillation, multi-effect distillation, membrane distillation; thin film distillation, ion exchange, multi-effect fresh evaporation, electrodialysis, and forward and reverse osmosis [2,3,4] are not efficient for large freshwater requirements or are energy intensive techniques. In addition, the availability of energy in remote areas and most arid regions is low [5,6,7]. Therefore, solar distillation looks to be a promising process and an alternative way of providing small communities in remote regions and islands with freshwater. Solar distillation appears to be an economical, effective and eco-friendly technique overall the conventional distillation techniques. Additionally, it is a promising method for providing potable water to small communities in remote regions and islands [6]. Solar radiation is free, everlasting and available on site. Moreover, using the solar energy diminishes fossil-fuels consumption and pollutants. Numerous solar desalination devices have been developed over the years. The most conventional solar desalination units are solar stills. Solar still utilizes the solar energy to purify contaminated or saline water using distillation principle. In general, solar still works on the process of evaporation-condensation. The saline water inside the solar still is evaporated by utilizing solar energy, and the condensate is collected on the solar still walls and exits as freshwater. The solar still are mainly categorized into two categories: active and passive solar stills [8]. For passive solar still, solar radiation is the unique parameter which generates the evaporation but for active solar stills, evaporation is also generated by using an additional device like fan [9], pump [10], system of sun tracking [11] or solar collectors [12–14]. Many researchers have studied theoretically and experimentally the solar still

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performance. They concluded that active solar stills are less economical to produce fresh water in comparison to passive solar stills. But, active solar stills also could use waste heat from other processes or devices to improve the rate of evaporation of water and the productivity (yield) of water of the solar stills depends on climatic conditions and various other parameters [15]. Solar stills are cheap, simple, need low maintenance, do not need fossil fuels and environment-friendly technology, but they suffer from low productivity [1,4,5,16,17,18]. Because of the solar still advantages and to overcome its disadvantages, scientists have performed many studies to enhance the solar stills performance. The solar still efficiency depends on many parameters: solar still design, basin design, and conditions, climate conditions, an evaporation process of the saline water, condensation process of the humid air, etc. So, a large number of researchers has focused on these parameters during theoretical and experimental studies to increase the productivity and the performance of the solar still. Some of these researchers performed their work in the basin medium; Muftah et al. [19] reported a review paper on the factors affecting the productivity of the basin type solar stills. They concluded that the productivity of the solar still depends on its body, its orientation, water depth, vapor tightness, and inclination of condensing cover. Mahdi et al. [20] studied the performance of the wick type solar still, where the absorber/evaporator material is charcoal cloth, and it is used for saline water transport. Janarthan et al. [21], and Alaian et al. [22] presented an experimental investigation on the performance of a solar still with an evaporated surface of wicked pin fins. They concluded that the still productivity is improved when the wicked pin fins are applied in the basin. Sahota and Tiwary [23] found that a solar still with Al_2O_3 water nanofluid in the basin enhances the productivity by 12.2% while Omara et al. [24] achieved 25% higher productivity using the same nanofluid under vacuum conditions. Other researchers conducted their work by concentrated on the condensation process to increase solar still productivity. Kabeel et al. [25] presented a detailed review paper on solar still with an external condenser. Kumar et al. [26] provided an external condenser to collect part of the humid air from the solar still and to condense the vapor. Jianyin et al. [27] designed a new multi-effect solar still with an enhanced condensation surface, where it applies the corrugated shape structure. Belhadj et al. [28] studied a single-basin, double slope solar still joined with a condensation cell composed of liquid plate with feed reservoir. Other research studies aimed at climate conditions like Mohamed et al. [29] presented double slope solar still with sand as a porous medium in hot climate conditions. Kabeel et al. [30] enhanced the productivity of the solar still by using solar dish concentrator in hot climate conditions. The desalinated water cost decreases continuously because of the achieved improvements in the desalination techniques. The cost of the desalinated water by the solar still becomes economically feasible and competitive to the other methods in remote areas as it is a free energy cost. Srivastava1 and Agrawal [33] performed an economic study on the solar stilled water plant. The study revealed that the high-performance unit achieves a percentage decrement of 36% in the cost of the produced water relative to the conventional unit. Kumar1 et al. [34] introduced an economic analysis on a double slope solar still working under different additives to the saline water in the basin. They found that the payback period is 67 days. Malaiyappan and Elumalai [35] presented a thermal and economic study on a single slope solar still at three low-cost basin materials, they are glass, plastic, and aluminum. The plastic basin achieved the lowest cost and the aluminum basin achieved the highest productivity.

Despite the large number of researches on the solar still, still a work could be introduced to improve its productivity and performance. In this work, the effect of using two new proposed condenser types (aluminum heat sink and aluminum plate) on the performance of the solar still is studied. Also, the effect of using new medium in the basin (layers of black steel fibers) is presented in this work. Moreover, studying the effect of using an umbrella on the top of the condenser on the productivity of the solar still is considered. To the authors' best knowledge, no one studied the heat sink as a condenser and steel fibers in the basin before. Therefore, four types of the condenser are considered: glass, aluminum plate, heat sink with pin fins fabricated from aluminum, and aluminum plate covered with an umbrella. Four mediums of the basin are considered: only saline water in the basin with salinity percent 4% by mass for all case, saturated sand with saline water, steel fibers saturated with saline water, and a mixture of sand and steel fibers saturated with saline water. The reference case is the conventional solar still of glass walls and only saline water in the basin, and the performance of the other cases is compared to it.

Fig. 1. Front view of the solar still.

2. Experimental work

A single acting solar still is constructed and installed on the roof of the laboratory to perform the experimental study as shown in Figs. 1 and 2. Fig. 1 shows a front view of the solar still, Fig. 2a shows a back view of the solar still with glass condenser, Fig. 2b shows the solar still with heat sink as a condenser. Fig. 3 presents a complete layout of the experimental setup. The experimental work is carried out in the faculty of Engineering, Assiut University, Assiut, Egypt, where the latitude angle is 27° and longitude angle is 31°. The used solar still consists of shallow basin (1) which is made of 1 mm thick galvanized steel sheet with dimensions of 80 × 180 × 2 cm. Black paint paints the shallow to increase its absorptivity. The basin is located inside a wooden frame of 5 cm thickness for insulation purpose. The walls of the solar still are made of glass of 3 mm thickness with the dimensions shown in Fig. 3. The inclination angle of the front wall is set at 27° with the horizontal according to the latitude angle of Assiut city. Four cases are examined for the back wall (3) of the solar still which is called a “condenser” in our study. The examined case are: (i) a glass cover of 3 mm thickness, (ii) an aluminum plate of 1 mm thickness and (iii) a heat sink consists of an aluminum plate of 1 mm thickness with aluminum pin fins. The fins are made of aluminum rods of 15 mm diameter and 40 mm length. The fins are distributed uniformly on the aluminum plate with 75 mm apart from each other. The case (iv) is an aluminum plate of 1 mm thickness covered with an umbrella. Two width values of the umbrella are examined 20 and 40 cm. The solar still is supported by stands (4) fabricated from steel as shown in Fig.1. Two water tanks (5) are connected in series with the basin to supply it with makeup saline water. The first tank has a higher level corresponding to the second tank, and the second is used as a supply tank where its level is controlled by floats (Fig.3). The second tank is utilized to control the water level in the basin to achieve its level constant through all the experiments. The condensed freshwater is collected in a flask (6). The whole experimental setup is assembled and oriented to the south during all the experiments to receive the maximum solar radiation.