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Improving the productivity of solar still by using water fan and wind turbine

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ABSTRACT

This investigation explores the potential benefits of using water fan inside a conventional solar still (CSS) to solve the problems in our previous work (Kabeel et al., 2012) under different conditions. Two stills, CSS and fan solar still (FSS), were constructed and tested under environmental conditions. The fan fixed inside the FSS was operated using a wind turbine. Different water depths of FSS (1, 2, 3 and 4 cm) were investigated. It was found that the distillate of still increments with integrating the fan. During experimentations, the maximum productivity of FSS is achieved at water depth of 1 cm for fan rotational speeds less than 22 rpm, and at 3 cm for speeds greater than 22 rpm. Using water fan in CSS enhanced the daily productivity by about 17% at 3 cm and 30 rpm. Whilst, the daily efficiency of fan still was approximately 39.8% compared to 36.7% in our previous work at the same conditions.

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1. Introduction

Extracting the potable freshwater from saline/brackish water is a function of solar still that can be utilized. These devices are suitable for a single house or a small community for providing good quality drinking water. The productivity of fresh water by CSSs is limited as investigated by many researchers. In addition, thermal efficiency of CSSs is low (~35–40%) with normal daily productivity of 3–4 L/m^2 d (Yadav and Sudhakar, 2015).

Several techniques and designs have been developed to improve efficiency and productivity of CSSs, such as double-basin (Al-Karaghouli and Alnaser, 2004), multi-effect (Tanaka and Nakatake, 2007), regenerative (Abu-Arabi and Zurigat, 2005), stepped still (Ziabari et al., 2013), corrugated wick (Omara et al., 2015), tubular solar (Ahsan and Fukuhara, 2010), conical still (Gad et al., 2015), solar still with reflectors (Tanaka, 2010; Tanaka and Nakatake, 2009), rotating drum (Lilian et al., 2016), solar collectors (Voropoulos et al., 2003), with fins and sponges (Velmurugan et al., 2008), internal condenser (Al-Nimr and Dahdolan, 2015), and hybrid solar still (Voropoulos et al., 2003), special designs (hemispherical, spherical, triangular, concave, etc.) (Durkaieswaran and Kalidasa, 2015) and using nanofluids (Lovedeep and Tiwari, 2016). A review of different techniques and designs of various solar stills was made by (Mojtaba et al., 2016; Sivakumar and Ganapathy, 2013).

The various factors that affect the daily distillate of multiple-effect stills integrated with a solar collector were investigated by Tanaka and Nakatake (2007). Also, influence of inclination of external collector of conventional still in winter was conducted by the same researchers.

Ziabari et al. (2013) simulated a stepped still under two climatic conditions of Koshk and Bandar Abbas, Iran. Results demonstrated that the average productivity of freshwater was 6.7 L/m^2/d, which was higher by 26% in comparison with the initial site (Koshk village). Ahsan and Fukuhara (2010) proposed a new model of heat and mass transfer of a tubular still. They found that, the heat balance of the humid air and the mass balance of the water vapor in the humid air were formulized for the first time.

Tanaka (2010) conducted a numerical study to investigate the effects of external reflectors and internal reflectors on the conventional still. He concluded that the daily productivity could be increased by inclining the external reflector forward in all seasons except for in summer become backward. A conventional solar still integrated with a rotating drum enhanced more daily distillate compared with a conventional one (Lilian et al., 2016). The speed of drum and saline water level were ranged from 0.25 to 4 rpm and 1 to 5 cm, respectively. They found that daily distillate is inversely proportional to drum speed.

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A conventional still, a conventional collector and a storage tank were connected together (Voropoulos et al., 2003) to study the influence of augmentation on the solar still. The solar still inlet was connected to solar collector (fin type) as its outlet was fed to the solar still. They indicated that the productivity utilizing augmentation was improved by 52% with saline water as a feed. Al-Nimr and Dahdolan (2015) modeled a novel concentrated still that increases with an internal condenser and a porous evaporator, for different condenser and ambient temperatures, solar irradiations and wind speeds, using Microsoft Excel software. They concluded that a reduction in temperature of condenser and the speed of wind alleviated the efficiency and productivity of the solar still.

The daily distillate of still depends on the heat transfer mechanism and working temperature. The heat transfer coefficients can be increased by enhancing the thermo-physical properties of saline water. Suspension of nanoparticles into saline water is a simple technology which enhances the thermo-physical properties (Lovedeep and Tiwari, 2016).

The fresh water amount condensed in CSS depends on the glass cover temperatures and velocity of air flows on the outer surface of cover of glass. Al-Hinai et al. (2002) predicted dependency of solar still distillate on operational parameters and climatic by using a theoretical model. Their results showed that an increase of 1–3 m/s leads to 8% augmentation of distillate.

An experimental and theoretical study on a solar still was developed by Abu-Qudais et al. (1996). In this work, an increase in water productivity was observed when the velocity of air was higher than 1.5 m/s, and decreases for a velocity of air of 3 m/s. This means that any additional cooling reduced the water temperature in the basin, i.e. a slight breeze was sufficient to enhance the efficiency. An experimental research on a CSS was developed by Margarita et al. (2015). His results showed increments in the production and total efficiency when the velocity of air increases up to 5.5 m/s. Above this velocity, these increments were diminished. In addition, he concluded that the optimum velocity is achieved at 3.5 m/s.

Zeinab and Ashraf (2005) used a rotating shaft with horizontal axis introduced near to the water surface of the absorber of solar still to improve still performance. They used an electrical motor to rotate the shaft. Their results showed that the still thermal efficiency was improved by 5.5% at July, 5% at June, and 2.5% at May.

Eltawil and Zhengming (2009) presented a hybrid desalination system that constitutes of inclined solar water distillation (ISWD) and wind turbine (to rotating horizontal shaft) integrated with main solar still (MSS). The effect of change water depths (1, 2 and 3 cm), different flow rates of feeding water (25.0, 41.7 and 58.3 ml/min) and two modes of operation as due south and tracking the sun are consider. They indicated that the daily water productivity from the ISWD could be higher than the MSS by about 26.55–29.17%.

In our previous study (Kabeel et al., 2012), we have experimentally attempted to improve the fresh water production of CSS by using a rotating water fan with a vertical shaft. A photovoltaic system (PV) used to power a DC-motor, which used to rotate the water fan. The effect of the water fan speed (ranged from 30 to 45 rpm) and the saline water depth (ranged from 1 to 7 cm) on the performance of the still was studied. Experimental results indicated that the still production increases with fan speed and the maximum difference of yield between FSS and CSS is obtained at water depth of 3 cm (with fan rotation). In addition, we concluded that utilizing water fan enhances the yield by about 25% at a speed of 45 rpm, and a depth of 3 cm.

In the same study, some difficulties are created and not solved. The vertical shaft of rotating fan passes through the still base through ball bearing, so that this connection increases the chance of leaking. In addition, the initial cost of the PV system is high and the projected area of PV cell is considered in still efficiency calculations.

The aim of this study is solve the problems in our previous work. In the present work water fan powered by wind turbine is used to increase the distillate of CSS. The rotating shaft passes through back side wall of still, so there is not leaking. In addition, initial and maintenance costs are reduced. The new system has small space about previous system.

2. Experimental setup

To eliminate the influence of experimental conditions, two solar stills (FSS and CSS) were manufactured, Fig. 1. The FSS prepared with a water fan works with wind turbine.

2.1. Conventional still, CSS

A photograph of the fabricated FSS and CSS is indicated in Fig. 1. Each one has an absorber area of 0.50 m^2 (1.0 m × 0.50 m). The two stills were fabricated of sheets made of galvanized steel of, 2 mm thickness. The higher and lower wall heights are 0.3567 m and 0.16 m, respectively. Interior faces (back and two sides' walls) of the stills were painted by matt type black paint, matt type, to enhance the absorptivity of solar irradiation. The still was oriented towards south direction and covered with glass cover of 3 mm thickness from the top, inclined at 21.5° horizontally (the latitude of Al Kharj, KSA). The still was insulated from both of side and bottom walls by fiber glass of thickness 50 mm, which has low thermal conductivity. The condensed water was gathered in a collection trough, which is galvanized steel channel mounted at lower side of glass cover.

2.2. Fan still, FSS

The FSS has the same dimensions of the CSS with integration of water fan, wind fan, bevel gears and bearings. A schematic outline of a FSS is shown in Fig. 2, which explains different components of the FSS. To transmit motion from wind turbine to water fan, three shafts (each 2.4 cm diameter) made of Teflon bars are used. The first shaft is 1 m length and is located vertically outside the still where a wind turbine is fitted and welded to it.

In this experimental study, a small wind turbine is designed and attached with the fan solar still to operate rotating shaft provided with water fan. Fig. 3 shows a photograph of the wind turbine. The main purpose of the wind turbine is to use wind induction to operate a vertical rotating shaft. The wind turbine consists of 3 twisted blades (26 cm height), fixed on the top of the vertical shaft. The fan rotates horizontally on the pivot shaft (vertical position) making a rotor radius equal 32 cm. Two bevel gears of 22 teeth each to be utilized to transmit the horizontal rotation of the vertical shaft (wind turbine shaft) to vertical rotation on the horizontal shaft as shown in Figs. 2 and 4. Bevel gears have conical faces that operate on intersecting right axes with a 1:1 ratio. The horizontal and vertical shafts are supported by bearings, and care is taken to ensure that the wind turbine can rotate with low velocity of wind.

Also, two other bevel gears of 22 teeth each are used to transmit the vertical rotations of the horizontal shaft to vertical rotations on the second vertical shaft (water fan shaft), located at middle of fan still, as indicated in Figs. 2 and 3. The water fan has six flat blades made of iron plate sheet (15 × 4 cm, 0.5 mm thickness) fitted and welded in the second vertical shaft, as indicated in Fig. 4. The fan blades are situated over the bottom of still basin by around 3 mm. Water fan is utilized to break the boundary layer of the