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Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination

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HIGHLIGHTS

- Design and installation of solar dish concentrator (SDC)
- Simple solar collector
- Design a new boiler
- Two axes tracking system using an open-loop control based on PLC
- Photovoltaic powered the tracking system

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ABSTRACT

This work presents a design and installation of solar dish concentrator (SDC), simple solar collector and modified boiler for brackish water desalination. The design of two axes tracking system is performed using an open-loop control based on programmable logic controllers (PLC). Glass mirrors are used as reflective surface for dish concentrator. A coiled black rubber hose is used to preheat brackish water before feeding to the boiler. A mini single slope-air tight solar still is designed and installed at the focus of dish concentrator which is used as a boiler. The automatic tracking system, new boiler design; and with and without preheating of brackish water are investigated. The developed desalination system is evaluated and compared with the conventional solar still (CSS). The results indicated that, the daily average of distillate water was 6.7 l/m^2/day for SDC with preheating of brackish water, while the distillate productivity was 1.5 l/0.5 m^2/day for CSS. In the present study, the daily average efficiency of SDC and CSS was 68 and 34%, respectively. The increase in distillate production for SDC is about 244% and 347% higher than that of CSS without and with preheating, respectively.

1. Introduction

The energy and water are the two most essential things for sustainability of life. Both are to be conserved and preserved for the sustainable development of the world. There is an acute shortage of both energy and water, especially in the 3rd world countries. Most of the available water is either present as sea water or icebergs in the Polar Regions. About 97% of the earth's water is salty and rest is fresh water. Less than 1% fresh water is within human reach. Despite technological progress, renewable fresh water reserves on earth is only 0.3% of the world water [1,2]. Worldwide, 11% of the global population −783 million people—remains without access to an improved source of drinking water and, at the current pace, 605 million people will still lack coverage in 2015. Despite progress, 2.5 billion in developing countries still lack access to improved sanitation facilities [3]. There is need for concerted efforts in funding research to stern the tide of global water shortage.

To seek solutions for this problem, several processes were proposed among them solar desalination with its two conversion modes. The first conversion uses flat plate collectors, generally used for a temperature lower than 100 °C. While the second conversion uses solar concentrators for a higher temperature more than 100 °C [4].

Optical concentration is one option to increase the solar energy density resulting in the possibility to use absorbers with small surfaces. Higher temperatures can be achieved under concentrated conditions, because heat losses are proportional to the absorber surface. The parabolic dish system uses a parabolic mirror-shaped dish, or a modular mirror system that is similar to parabola, and incorporates two-axis of tracking to focus the sunlight onto receivers which is located at the focal point of the dish [5,6]. The receiver can absorb the energy and converts it into thermal energy. This can be either used directly in thermal

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applications or for power generation purposes. The operation of any solar thermal energy collector can be described as an energy balance between the solar energy absorbed by the collector and the thermal energy removed or lost from the collector [7].

Several types of concentrators were used over the years based on the applications. In case of desalination process, to achieve higher yield, the contractor was coupled with solar still by means of increasing water temperature in the basin. The natural circulation mode or forced circulation mode was used to supply water or oil to trough receiver pipe. Parabolic concentrator collector can be coupled to the basin still to increase the distillate productivity [8,9].

Placing a reflector (may be vertical) outside or inside the still leads to increase energy input to the still which consequently increases distillation productivity compared to that obtained with a conventional still [10,11]. It was found that, the use of fixed reflector does not improve significantly the distillate water production.

Bechir Chaouchi et al. [4] designed and built a small solar desalination unit equipped with a parabolic concentrator. The experimental and theoretical studies concluded with an average relative error of 42% for the distillate flow rate. The higher percentage of error refer to the imperfections in paraboloid geometry, the sun manual follow up and the system's tilt variation during the day. This error does not make it possible always to keep the absorber surface covered with salted water.

Zeinab and Ashraf [12] developed a desalination system by coupling solar parabolic trough with a focal pipe and simple heat exchanger (Oil serpentine) to a conventional desalination unit. They compared the performance of conventional system with the modified solar desalination system. The results indicated that fresh water productivity was increased by an average of 18%, due to the modification.

Tiwari and Tiwari [13] investigated the annual and seasonal performance analysis of single-slope passive solar stills having three different inclinations of condensing cover, namely 15, 30 and 45°. They observed that the 15° inclination of condensing cover gives maximum annual yield and distillation efficiency for New Delhi climatic conditions.

Kumar and Sinha [14] conducted the experimental analysis of a double slope solar still coupled with a non-tracking cylindrical parabolic concentrator through an electric pump (forced circulation mode). They found that, the concentrator-coupled still gives the maximum yield at all water depths in the basin. A higher thermal efficiency was achieved using concentrator-assisted regenerative solar still compared to the flat plate collector-assisted regenerative still at all water depths.

The working principle and thermal performance of a new v-trough solar concentrator were presented [15]. The collector system has thermal efficiency up to 38% at 100 °C operating temperature. A review of various designs of solar stills and solar concentrators was made by [16,17].

Solar collectors are composed of a concentrator and a focal absorber. The quality of the concentrator is closely related to the quality of the reflecting surface and the precision machining surface. This surface can wear once exposed to the harsh weather conditions. Its material must have a long life and affordable cost. In this case, the mirror will be protected from the environment by several methods like anodization for aluminum surfaces or transparent coating for reflecting surfaces painted with silver [18,19]. In order to minimize the cost and to increase life-span of the dish, the reflecting surface of concentrator was made of stainless steel sheets [18]. The performance of concentrators was much affected by the sun tracking mechanism. The tracking mechanism should move the collectors throughout the day to keep them focused on the sun rays to achieve the higher efficiency.

The concentrator with point focusing (parabolic dish) is advantageous over other systems due to minimal thermal losses, which induce high flux and high power delivered [19,20]. The current research is intended to design a standalone solar concentrating unit which can be useful for water desalination. The specific objectives are planned as follows: i) Design and evaluation of a solar dish concentrator with an automatic tracking mechanism to verify its efficacy for water desalination. ii) Design a new boiler (receiver) to enhance the distillate water productivity from the system. iii) Utilization of simple preheating system represented by a black hose collector to raise the incoming brackish water temperature before entering to the boiler.

2. Materials and methods

2.1. Experimental setup

The experiments were carried out in the premises of Kafrelsheikh University, Egypt which lies at 31.07°N latitude and 30.57°E longitude during the period of July to September 2012.

Solar dish concentrator (SDC) and conventional solar still (CSS) were designed and constructed to compare the performance of the solar desalination systems. A schematic diagram of the experimental setup is shown in Fig. 1 and photo is illustrated in Fig. 2.

The developed solar thermal desalination system consists of a brackish water tank, CSS (single slope basin solar still), SDC, boiler, heat exchanger (condenser), control unit (two-axes tracking system), PV system, simple solar collector, and modular programmable logic control (MPLC).

Feeding brackish water tank of $0.6 \times 0.6 \times 0.8$ m is used to feed water to the boiler as well as conventional still. The brackish water tank is connected to the main line with a control valve; which divided to two feeding water lines as shown in Fig. 1.

The CSS was made of galvanized sheet with 0.0015 m thick and has a basin area of 0.5 m^2 (0.5 m $\times$ 1 m). The height of high-side and the low-side walls of the basin is 0.44 m and 15 cm, respectively. The single slope basin was covered with glass sheet of 0.003 m thick inclined at nearly 30° horizontally, which is the latitude of Kafrelsheikh, Egypt. The whole basin surface was coated with black paint from inside to increase the absorptivity. The bottom and side walls of the basin were well insulated by fiberglass of 0.05 m thick. To collect the distillate output, a trough was fixed at the end of the low-side of basin. Plastic pipe was connected to the trough to drain the fresh water (distillate) to external calibrated flask. Other two pipes were connected to the basin bottom to feed brackish water and drain brine to waste.

The parabolic dish solar collector system is a point-focus collector that tracks the sun in two axes. The support of the SDC is made of Aluminum with 1 m in dish aperture diameter. The dish surface was covered with highly reflective glass mirror strips of 0.004 m thickness. The strips were assembled carefully to get a precise focal point. The parabolic dish dimensions are shown in Fig. 3.

With respect to tracking system, the PLC has a programmable memory in which the instructions are stored to implement the functions that used to control the tracking motor into the calculated positions. A 36 VDC motor was used to move a hydraulic actuator and some gears and levers to obtain the required position of the dish. The tracking motor and MPLC were powered by a 15 W Amorphous Silicon Solar photovoltaic (PV), charge controller, battery and inverter as shown in Figs. 1 and 2.

In this experimental work, a newly adapted boiler was designed and mounted at the concentrator focus. The receiver (boiler) size is optimized to be just large enough to admit most of the concentrated sunlight but small enough to limit radiation and convection losses. The boiler is shaped like single slop solar still, with a receiving surface of 0.046 cm^2. The boiler has a dimension of 0.27 m length, 0.16 m width, with 0.17 m height from back side and 12 cm height from front side. An air tight transparent glazing (glass cover) with a thickness of 0.003 m is fixed at the boiler top which inclines with 30° on horizontal. This glass cover is used to condensate some steam and the remaining steam passes into a coil condenser where it condenses. Also, the glass cover may allow some direct insolation to come inside the boiler and enhance the evaporation process.