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Experimental investigation of a solar desalination system using twisted tape and wire coil inside of spiral heat exchanger

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ABSTRACT

This study, which was carried out in a mild and wet region, designed and fabricated an indirect solar desalination system (double loops), to investigate effect of employing separate and combined insertion of twisted tape and wire coil turbulators in a spiral heat exchanger at diffrent mass rate of salty water on productivity of desalination in this system. After the presentation of the experiment data, the results are analyzed and discussed. In comparison to simple spiral tube heat exchanger, the insertion of the turbulators in a circular tube heat exchanger would enhance discharge rate between 2% to 14% in using Twisted Tape, and copmbined Twisted Tape & Wire Coil, respectively. In addition, simultaneous insertion of twisted tape and wire coil could increase the output to its maximum discharge. The best working conditions of this system was to put 1 lit/s mass rate of salty water. Productivity system increased up to 9.7% too.

1. Introduction

More than 70% of the earth's surface is covered with water, even though only 2–3% of these resources are potable water. The remainder due to the high level of salt and impurities would not be suitable for drinking and farming applications. The recent improvements in industries and agriculture-related technologies in addition to the population growth would result in special attention to precautionary rules to protect water resources and avoid wasting them. Furthermore, it is indispensable to people for not ignoring the development of available water resources. One of the best ways to produce drinking water is developing fresh water production technologies from sea or salty water. In other words, these systems can compensate the lack of necessary fresh water resources. A wide variety of methods can be used to fulfil this purpose such as evaporation, water condensation, sedimentation-related approaches, sand filtration, and finally countercurrent purification. In the regions with thermal energy resources, conventional routes, e.g. evaporation and condensation can meet the fiscal and economic requirements. Iran has considerable potential for solar energy which can be regarded as an alternative for fossil fuels; therefore, solar desalination systems tends to be an applicable technology due to high absorption of radiation and great brackish water resources in northern and southern Iran. According to recent studies, solar desalination systems have been changed to improve the productivity and researchers modified different components of them which will be mentioned.

In the most typical model of a solar still, the water is heated in a chamber via the greenhouse effect and after evaporation and condensation of water vapor on an upper glass cover, the water trickles down slope and eventually, it is collected through drainage.

Many researchers tried to ameliorate the operating conditions of basin solar stills. Consequently, they could enhance the distilled water production rate in the range of 50–70% [1–14]. The components of solar desalination systems have been modified form direct production of distilled water to indirect production of drinking water equipped with two or multiple wire coils. The systems with one wire coil were more efficient than those equipped with two wire coils, yet corrosion resistance of the stills showed a reverse trend caused systems with one wire coil did not perform appropriately in the long-term usage. Moreover, during a day, excess heat could be stored in a thermal storage tank and after sunset, this heat would be consumed to increase working duration of the system [15–17].

In these systems, the distilled water production unit is a separator modulewhich the cold salty water passes through upside while the warm salty water passes through downside leading to indirect condensation between fluids [12,18].

The overall performance of a solar desalination system is basically determined by various parameters such as operating duration, radiation intensity and duration of it, the structure of the solar system (active, passive, single-effect, double-effect, triple-effect to name but a few), type of heat exchanger, type of distillation system, operating temperature of the system [4], changes in mass flow rate and finally the type of heat transfer fluid [19]. It is worth mentioning that changes in the structure of heat exchanger have impacts on the heat transfer rate. However, three types of heat exchangers, including double-pipe, shell-and-tube, and finally fin-tube were mainly investigated by researchers [12,20]. Additionally, heat transfer enhancement of a simply spiral heat exchanger was studied [21].

Prabhanjan et al. [22] compared heat transfer coefficients of spiral pipes with plain pipe. They reported that the geometry of heat exchanger and the fluid temperature can significantly affect the heat transfer coefficient while the effect of changes in mass flow rate on this parameter was negligible. Their results also revealed that the heat transfer coefficient increased from 1.16 to 1.43 times by enhancing temperature from 40 to 50 °C, respectively. This phenomenon could be attributed to an increase in temperature difference between fluid in the pipe and the external fluid which could alter the floating of the external fluid. Furthermore, this temperature difference resulted in two pivotal effects, i.e. better fluid mixing due to the presence of secondary fluid, and an increase in the heat transfer rate inline with the enhancement of the heat transfer coefficient. In a review

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study, Naphon and Wongwises [23] investigated heat transfer of curved coils (helical coil tubes, spiral coil tubes, and other curved heat exchangers). They also categorized the previous studies in this area. These data suggested the formation of secondary fluid and changes in the boundary layer were pivotal reasons for increasing heat transfer in circular tubes in comparison to flat tubes. On the other side, the previous studies corroborated that the insertion of turbulators such as twisted tape in different shapes would considerably change flow pattern and heat transfer rate [24–36]. In addition, several studies were carried out on the separate [37,38]and combined [39,40]insertion of wire coil and twisted tape in a flat tube.

According to literature, three main parts of a solar desalination system which were responsible for heat generation were collector, thermal storage tank, and heat exchanger. The exergy analysis showed that the highest amount of waste heat was from the collector. This amount varied from 56% for the solar collector heat generator to 86% for a combined heat generator consisting of the solar collector and the thermal storage tank. The second waste exergy rate came from the heat exchanger varied from 9% for a combined heat generator system to 23% for a solar collector. In this case, the waste heat rate was 71% for a thermal storage tank acted as the only heat generator. On the other hand, the waste exergy rate for the thermal heat tank with a solar collector, an only heat generator, was 11% while this amount for the combined system (solar collector and thermal heat tank) was 0.5%. In the case of using thermal heat tank as a single heat generator, the waste exergy rate of this tank was 4% [41,42].

The modification of a solar still significantly increases the productivity that would not be successful due to great dependence of the system performance. This being on seasonal weather changes and conditions. Hence, according to author's knowledge, changes in the structure of the heat exchanger, that is one of the most important parts of the solar desalination system, have been investigated. In this study using indirect solar desalination systems (two loops) was considered. Moreover, the effect of novel techniques, i.e. using a spiral heat exchanger, and utilizing passive methods to increase the turbulency of the flow by separate and combined insertion of wire coil and twisted tape in deffrent mass rate of salty water, on productivity of desalination system were studied.

2. Experimental apparatus

Experimental apparatus consisted of two separate cycles. A closed cycle in which the water was heated in a collector and subsequently, it was circulated by a pump in a heat exchanger to transfer heat. Additionally, the second cycle contained salty water with total dissolved solid (TDS) content of 7000–8000. In this cycle, the cold salty water had passed from the tank to the upper section of the modules and then, water entered the heat exchanger and indirectly absorbed heat. In the next step, the vapor entered the lower section of the modules and after moving up, it was condensed by reaching the upper curved slope which was cooled down by the cold salty water. Finally, the condensed water was collected after passing througha channel located under the slope. In this cycle, the water was circulated by two different pumps installed before the heat exchanger (the first pump) and before the salty water storage tank (the second pump). A bypass was located after the first pump to investigate the effect of flow rate on the distilled water production. The amount of water passing through this route could change the flow rate of the cycle. The changes in the temperatures of the cycles were measured by a K type thermometer with $\pm$ 0.1 °C accuracy. In addition, the changes in the flow rate were measured by a flowmeter with $\pm$ 0.03 lit/s accuracy.

Working under experimental conditions would emancipate researchers from outdoor activities as a great deal of drudgery; thus, in this research, at first a solar water heater was investigated in an intended region over a period of one year. In the duration, information was gathered and recorded as output heated water temperatures and simulated the heated water temperature by electrical heater. In fact electrical heater was not an alternative to sun. After heater started working, the basin water was heated according to a determined schedule and it was circulated in the first cycle using the circulating pump. Other researchers separated vapor from distilled water via a membrane, but using this technology can impose limitations onhigh temperatures. In this experiment, inasmuch as the distilled water production modules did not use a membrane separation system, the hot water could be circulated through the heat exchanger without any temperature restriction. The heater temperature was controlled by a thermocouple to not exceed the set point of the program. In the current study, spiral tubes were utilized in the heat exchanger to enhance heat transfer surface area. In other words, the hot water passed through the spiral tubes while the salty water was circulated through the shell side. The spiral heat exchanger of this study was designed and fabricated by copper-type tubes with the diameter of 1.9 cm. The ring coil diameter was 20 cm and the number of coil's ring was 10 (Fig. 1).

Fig. 1. Spiral heat exchanger.