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Enhancement of solar still performance using a reciprocating spray feeding system—An experimental approach

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ABSTRACT

It is well-established that minimizing water depth is one of the most vital key features to enhance the performance of solar stills. Accordingly, the performance of most recent attempts and proposed ideas tackling this point is limited. Thus, this work introduces a new approach that permits governing the water depth as desired and simultaneously evades all previous experienced interrelated implications through creating a thin re-established film of saline water on a particular manner in the solar still. This has been performed by feeding the saline water into the still through a controlled transverse reciprocating spraying system on the form of fine droplets to spread on the top surface of a corrugated steeped shape absorber of solar still. The application of the saline water thin film with the very low warming up period on this way has numerous significant advantages on the still performance. Consequently, the present approach has undergone a systematic study to examine its anticipated validity in real practice and to optimize its performance at various varying operating conditions. The performance results at any operating conditions reveal extraordinary superiority over those obtained from other recent stills by other investigators. Instead, an optimum operating condition could be identified. At then, an accumulated productivity of 6.355 l/m^2 over only 10 working hours at high efficiency of 77.35% was gained. Similarly, the hourly productivity profiles exhibited good uniformity along the representative testing hours of the daytime with relatively high average values. These findings are a result of improving the performance along the whole daytime and, particularly, on the morning hours. This indicates the high response of the still to the increase of the solar radiation leading to the rapid heating up on launching phases. In addition, the performance distributions at various operating conditions showed slight deviations. This emphasizes the flexible, consistent and robust characteristics encountered with this approach that fold on many practical benefits.

1. Introduction

The lack of drinkable water for people around the globe is becoming a very serious problem, and recent published stories address the concerns from scientists around the world. Although three quarters of our planet is covered with water, the quantity of valid water as an essential prime need of all humankind, animals and flora is not only very limited, but also inappropriately distributed. In fact, a strong relationship between the existence of the drinking water and the population density per square kilometer is experienced throughout all eras. Due to the present continuous rapid growth in both the population and the development projects worldwide, particularly, in rural and arid areas to preserve the equilibrium in the entire society, the demand of the fresh water has increased. Therefore, every effort should be made to secure the drinking water supply independently of the other resources.

Conceptually, solar still technique is relatively simple. It is working to produce distilled fresh water from sea or brackish water in an artificial simulation processes. Historically, solar stills are the earliest shape in utilizing the solar energy in desalination field from many points of view such as their thermal operation, materials, installed prototype projects, difficulties, etc. They were broadly classified as single-effect and multiple-effect. Both types, in turn, could come on a few other designs of horizontal basin and inclined stills. In fact, solar stills of all of these kinds received a great attention from many broad numbers of researchers during the last three decades attempting to appreciate the performance characteristics encountered with each particular design.

Single-effect solar stills are the most attractive systems to develop for low capacity and autonomy applications. Badran and Al Tahran [1] and Terris et al. [2] integrated a flat plate collector with a single basin solar still. They found that the maximum increase in productivity of fresh water was 52%. A flat plate collector and flat plate collector with hot water storage tank [3–5] were integrated with solar stills. It was found that the amount of water produced was doubled that when the still was operated alone. El-Bahi and Inan [6] carried out the improving efficiency of solar still and found the daily output of up to 7 L/m^2 and efficiency of

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75% during the summer months. The solar still was operated without external condenser, its yield decreased to 70% of that with external condenser. In addition, analysis of a parallel double glass solar still with separate condenser was studied by El-Bahi and Inan [7]. It was found that the variations of solar radiation, ambient temperature, basin water temperature, vapor temperature and other important temperatures at different locations in the solar still are studied. The efficiency was increased from 48% to more than 70% when the condenser cover was cooled down. In addition, the authors designed a hybrid solar desalination and water heating system by Voropoulos et al. [8]. It was found that withdrawal of hot water from storage tank reduced the production of distilled water in a specific pattern. Productivity of fresh water increases 18% when sponge cubes were used in the saline water by Bassam et al. [9]. A multi-wick single slope solar still [10] was designed by Tiwari et al. [11]. Nafeyet al. [12] used black rubber and black gravel [13] for augmenting the productivity of the solar still. The productivity increases by about 20%, when black rubber was used and about 19%, when black gravel was used. Fresh water productivity increases by 20%, when a baffle suspended absorber was used by El-Sebaii et al. [14]. The effect of double glass in the still was studied by Zurigat and Abu-Arabi [15]. It was concluded that the productivity of the double glass regenerative solar still is more than 20% higher than that for the conventional still. Hayek et al. [16] studied the effect of using different designs of solar stills. Very few works integrated sun tracking system with a basin type solar still. A sun-tracking system was deployed for enhancing the solar still productivity by Abdallah and Badran [17]. A computerized sun-tracking device was used for rotating the solar still with the movement of the sun. A comparison between fixed and sun tracked solar stills showed that the use of sun tracking increased the productivity for around 22%, due to the increase of overall efficiency by 2%. It can be concluded that the sun tracking is more effective than the fixed system and it is capable of enhancing the productivity. Al-Hussaini and Smith [18] used vacuum technology. The results show that applying vacuum inside the solar still increases the water productivity about 100%. El-Sebaii [19] developed a triple basin solar still for enhancing productivity of the solar still. Velmurugan and Srithar [20] designed a mini-solar pond, integrated with a basin type solar still, and found that the productivity increases by 58% than the ordinary solar still. Tanaka and Nakatake [21] found that the productivity of fresh water by solar distillation depends mainly on the intensity of solar radiation, the sunshine hours and the type of the still.

Very few works have been carried so far in stepped solar still and constant depth trays are used in the basin plate. Abdallah et al. [22] studied the improvement in the performance of a traditional single slope solar still through three design modifications: addition of internal reflecting mirrors on all interior sides of still, using step-wise water basin instead of flat basin, and coupling the solar still with a sun tracking system. The inclusion of internal mirrors improved the system thermal performance up to 30%, while step-wise basin enhanced the performance up to 180% and finally the coupling of the step-wise basin with sun tracking system gave the highest thermal performance with an average of 380%. A stepped still with two different depth of trays is presented by Velmurugan et al. [23]. The basin plate contains 25 trays with 10 mm depth and 25 trays with 5 mm depth. Integrating small fins in basin plate and adding sponges in the trays were carried out experiments to improve the productivity. Theoretical, experimental and economic analyses for fin type, sponge type, and combination of fin and sponge type with stepped solar still are presented. The results show that, when the fin and sponge type steppe solar issued, the average daily water production has been found to be 80% higher than ordinary single basin solar still. The theoretical results agree well with the experimental.

2. New design of the system and the basic idea

Thus, based on the above discussion, it is obvious that the performance of a given still enhances with increasing the operating temperature of the saline water on the base of the still. In addition, as argued before, this temperature increases with the shrinking of the saline water depth. Unfortunately, the saline water depth in conventional basin and, even, in inclined stills can be only reduced to a certain limiting value due to a number of practical considerations. Hence, new ideas must be introduced, putting these considerations in concern. One of these ideas is the approach which is proposed in the present work. In this approach a transient re-established thin water film may be induced on a corrugated steeped shape absorber via a reciprocating spray feeding system. The main advantageous features of this proposed technique over other traditional single-effect stills may be identified as follows:

1. The absence of permanent water mass accelerates the heating up of the still base to achieve higher temperatures.
2. Also, the intermittent coverage of thin film of water due to the reciprocating water feeding mechanism on the hot regions of the still base away from the movable spreading zone permits the establishment of higher evaporation rate in these regions.
3. A relatively higher evaporation rate can be also expected to exist through the movable spreading zone on the hotter still base due to the small droplets size of the sprayed water with considerably large surface area.
4. The penetrated spray droplets and the permanent sliding of the un-evaporated excess saline water down the corrugated steeped shape absorber flush the still base continuously. Thus, the buildup of salt and other scales can be avoided.

Incidentally, an enduring source of power should be available on hand for driving the reciprocating spray feeding system. In the present work, the system was powered throughout the domestic grid. This was originally planned in the purpose of reducing the number of the encountered parameters and the well control of the systematic parametric study. In fact, providing the proposed approach with this modification will permit its application in remote regions. Also, this will improve the system performance as a result of eliminating the power consumed by the driving system and saving its running cost.

Therefore the main objectives of this work were to examine the validity of this proposed technique and to optimize the performance of the solar still with the application of it at different operating conditions like the sprayed saline water flow rate and the transverse reciprocating speed of the spray feeding system.

3. Experimental setup and procedure

In order to examine the effect of the proposed reciprocating spray-feeding technique on the solar stills performance, a test rig was prepared to investigate the proposed system. The investigation was carried out on sunny days throughout June and July months of summer 2008 under Tanta city (30° 49' 31.77" N latitude) climatic conditions. The experiments were started at 10:00 AM local time and ended at 7:00 PM. Hence, a single-slope solar still was manufactured and oriented to south direction. The still cover angle was permanently adjusted to be 30° with the horizontal, as shown schematically in Fig. 1.

This system includes stepped basin still; Fig. 1, with 10 steps; which represents the absorber with an area of 1.0 m^2 (1.54×0.65 m^2). The higher side and the two similar sides are constructed from 2 mm blackboard coated iron while the casing is constructed from 0.8 mm galvanized steel. The stepped-bed, higher side and the two sidewalls of the still are insulated with 30 mm glass wool (thermal conductivity of 0.036 W/m K) while the front wall (lower side) was normal to the bed and is made of a plastic sheet 3 mm thick in an aluminum frame like the cover. The main condenser is the still body cover, which is made up of 3 mm plastic sheet thickness (1.54×1.06 m^2) in an aluminum frame. There is a secondary condenser, which is constructed from 0.8 mm galvanized steel ($1.3 \times 0.1 \times 0.4$ m^3) and nine copper tubes 6.35 mm in diameter and 1.3 m in length. The system