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Research and Development in the Designs of Solar Stills: A Review

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ABSTRACT

Water is crucial to lifestyles and requirement of potable water cannot be underestimated. Solar energy is a renewable energy with easy access. Among the various uses of solar energy, solar desalination is one of the promising applications. The solar desalination techniques convert brackish water into potable water using the solar energy for human consumption. Major design parameters influencing the productivity are optimization of glass inclination, absorber plate, free surface area of water and depth of water. Researchers have put efforts to develop various designs of solar stills to keep the minimal depth of water utilizing wicks, steps within the stills to enhance the productivity. In this overview, we have tried to gain knowledge of the various specific designs, analysis, modeling, and absorbing material used to enhance the productivity of solar stills.

Keywords: *Solar desalination, conventional solar still, modified solar still, solar energy, saline water, brackish water, distillate, fresh water*

1. INTRODUCTION

The need of pure water is important in day-to-day life. The shortage of drinking water is one of the biggest problems of the world in this century due to extreme population growth and unsustainable consumption rates [1]. The use of water from rivers, lakes and underground is not always possible, especially due to the polluted environment. So search for other sources becomes inevitable. To overcome this problem, desalination is one of most popular methods which produce fresh or drinking water from sea water, saline water or brackish water [2]. The worldwide energy consumption has rapidly increased, basically due to the dramatic growth of the emerging countries' populations, economic and technological developments etc [3]. The solar energy is renewable source to fulfill demand of energy consumption for humans. It is freely available from the sun. The solar energy is also used in solar still which produces fresh water from saline water. Historically, solar still is a very old method of fresh water production. Solar still is mostly used for desalination in small scale. Solar still is very simple design, low maintenance cost and easily fabricated. The material used to manufacture solar still is locally and easily available. It is one of the most important and technically viable applications of solar energy. But the solar desalination using solar stills has low productivity [4]. The production capacity of a simple type solar still is in the range of 2–5 $l/m^2/day$. This makes the system highly uneconomical [5]. The various factors affecting the productivity of solar still are solar intensity, wind velocity, ambient temperature, water–glass temperature difference, free surface area of water, absorber plate area, temperature of inlet water, glass angle and depth of water. The solar intensity, wind velocity, ambient temperature cannot be controlled as they are metrological parameters, whereas the remaining parameters can be optimized to enhance the productivity of the solar stills [6]. Ample amount of research has been done by a lot of researchers to increase the distillate by using quite a lot of design parameters like different shapes, basin geometry, depths of water and heat absorbers. Many researchers worked on solar stills built-in with solar heaters, solar collectors and solar concentrators.

The pure water is also needed for the areas like hospitals and dispensaries, chemical industries, battery maintenance, laboratories etc. All these applications can be fulfilled by the use of solar stills at very low manufacturing cost and unskilled labour. Many researchers have reviewed on the developments in the research of solar desalination systems. For example, Murugavel et al. reviewed progresses in the works done on single basin passive types still to improve its productivity. They reviewed the optimization of orientation and for receiving maximum radiation and lower the condensation loss. Also, different materials used in the basin along with water to improve the heat capacity, radiation absorption capacity and enhance the evaporation rate were studied. Rubber is found to be the best basin material to improve absorption, storage and evaporation effects. One of the key factors that affect the fresh water yield is the depth of the basin water [7]. This article is an attempt to further enumerate new researches carried out in the field of solar desalination techniques worldwide.

2. WORK OF PREVIOUS RESEARCHERS

2.1 Analysis of basin type solar still with flat plate external bottom reflector

Tanaka introduced a basin type solar still with a flat plate external bottom reflector and internal reflector. An external reflector extending from the front wall of the solar still and addition of two internal reflectors in the basin (two sides and back walls) were used. He presented and analyzed theoretically on three days (the spring equinox and summer and winter solstices) at 30°N latitude. He found out that the use of external reflector increases distillate productivity. The daily yield of clean water by the solar still with internal and external bottom reflector is 41%, 25% and 62% on the spring equinox and summer and winter solstices respectively. These yields were higher than conventional basin type solar still [8].

2.2 Performance of stepped and single basin solar stills with mini solar pond

Velmurugan et al. made an attempt to improve the productivity of the solar stills with mini solar pond, steps and a single basin solar still in series. In the experiment the single basin solar still is replaced with wick type solar still. To increase the distillate many other materials or systems like baffle plate, pebble, fins, wicks and sponges are used. The productivity of solar still are studied day and night and daily efficiency are also calculated. The Industrial water is used to feed during the experimentation. The results of experimental and theoretical analysis shows that the productivity of modified solar still is much better as compared to conventional solar still [9].

2.3 Desalination of effluent using fin type solar still

Velmurugan et al. conducted experiments on a modified basin type solar still with fins at the basin plate. The industrial impure water is used as feed water in the still. Before this still the feed water is feed to a settling tank where it is clarified. This settling tank incorporated three chambers, consists of pebble, coal and sand for settling the impurities and removing the bacteria. Different types of absorbing materials were used to examine their effect on the yield of fin type solar still, viz. sponges, pebbles, black rubber and sand. These absorbing materials increase the area of evaporation and heat transfer also. The use of fin with basin solar still increases the surface area of evaporation thus enhancing the productivity and effectiveness of solar still. A theoretical analysis was also carried out which, validates with experimental results. The payback period of this still was 1 year. [10].

2.4 Theoretical and experimental investigation on double basin double slope solar still

Rajaseenivasan and Murugavel presented a theoretical and experimental work performed on a double slope single basin and double basin solar still. An additional basin was incorporated with conventional single basin still to improve the performance of the double slope solar still. Single basin and double basin double slope stills of the same area are constructed and investigated under the same climatic condition. It was found that providing an additional basin increases the fresh water yield significantly. A good agreement was made with theoretical and experimental results. The deviation between theoretical and experimental was within 10%. Double basin still production is higher than the single basin still by 85% for the same basin condition [11].

2.5 Optimum inclination of still and reflector of tilted wick solar still with external flat plate reflector

Tanaka presented a theoretical analysis of a tilted wick solar still with an external flat plate reflector. The reflector has the provision of adjusting tilt angle according to the seasons. The daily amount of distillate of the still was theoretically predicted all over the year, which varies with the inclination angle of both the still and reflector. The optimum inclination angle of the still as well as the optimum inclination angle of the reflector for each month at 30°N latitude was found out. The fresh water yield of the still can be improved by adjusting the inclination of both the still and reflector for the given season, thus producing an average of about 21% more than a conventional tilted wick still [12].

2.6 Performance of pyramid-shaped solar still

Taamneh et al. presented the effect of forced convection on the performance of pyramid-shaped solar still is under outdoor climatic conditions of Tafila City, Jordan. The experimental results revealed that the use of photovoltaic solar panels and fan is cost-effective and feasible option in enhancing the evaporation rate and hence distillate. The daily yield of distillate was increased up to 25% as compared to free convection solar still [13].

2.7 Theoretical and experimental parametric study of modified stepped solar still

Kabeel et al. carried out an experimental and theoretical investigation on a stepped basin to improve the performance of solar still. Two solar stills viz. a conventional single sloped solar still and a modified stepped solar still are used simultaneously. Feed water temperature to the stepped still is varied using a vacuum tube solar collector. For further enhancement of the productivity a wick on the vertical sides was added to the stepped still. A good agreement between the experimental and theoretical results was observed. The results show that the productivity of the stepped solar still strongly depends on the tray depth and width. Also it is found that maximum productivity of stepped still is achieved at a tray depth 5 mm and tray width 120 mm, which is about 57.3% higher than that of the conventional still. In this case the daily efficiency and estimated cost of 1 l of distillate for stepped and conventional solar stills are approximately 53%–0.039$ and 33.5%–0.049 $ respectively [14].

2.8 Effect of various absorbing materials on the thermal performance of solar stills

Abdallah et al. investigated the single slope solar still with the use of various absorbing materials to improve the performance of solar still. These absorbing materials were: coated and uncoated porous media and black volcanic rocks. The three solar stills contain black coated and uncoated metallic wiry sponges made from steel and black rocks collected from Mafraq, Jordan. The results showed that the uncoated sponge has the highest water collection during day time, followed by the black rocks and then coated metallic wiry sponges. The overall average increase in the collected distilled water taking into the consideration the overnight water collections were 28%, 43% and 60% for coated and uncoated metallic wiry sponges and black rocks respectively [15].

2.9 Experimental study of vertical multiple-effect diffusion solar still coupled with a flat plate reflector

Tanaka fabricated and investigated a vertical multiple-effect diffusion solar still, consisting of a series of closely spaced vertical and parallel partitions in contact with saline-soaked wicks, coupled with a flat plate reflector in outdoor conditions (Fukuoka, Japan). The vertical partitions reduce the diffusion gaps between partitions to increase distillate productivity. The overall daily productivity of the proposed still with 6-effect and 5 mm diffusion gaps was about 13.3 kg/m^2 day at maximum when the global solar radiation on a horizontal surface was 13.4 to 15.7 MJ/m^2 day and radiation on the glass cover was 20.2 to 22.9 MJ/m^2 day. The productivity of the still was greater than or approximately equivalent to other types of multiple-effect diffusion still [16].

2.10 Experimental evaluation of hybrid solar still using waste heat

Park et al. designed a multiple-effect diffusion (MED) hybrid solar still with dual heat sources of solar thermal energy and waste heat. Performance tests with waste heat were performed with three operational parameters: the amount of heat input into the hybrid still, the seawater flow rate to the wick, and the seawater level in the basin. It was found that the productivity of the hybrid still increases linearly with increasing heat input, recording 18.02 kg/m^2 at 22.37 MJ/d. The maximum productivity of distillate was obtained at the lowest seawater level even in the case of the experiment with waste heat source [17].

2.11 Sun tracking system for productivity enhancement of solar still

Abdallah et al. deployed a computerized sun tracking system for enhancing the solar still productivity. The use of sun tracking increased the productivity for around 22% leading to the increase of overall efficiency by 2% [18].

2.12 Modeling and parametric optimization of an active solar still for sea water desalination process

Hamadou et al. investigated a single slope solar still having a transparent glass cover which is heated at its bottom by a circulating heat transfer fluid. The rate of this flow and the temperature at the inlet of the still are controlled such that they are adjusted to the desired values. A modeling based on relevant correlations giving the heat transfer coefficients and the vaporization heat flux as function of Rayleigh number were derived. The obtained model enabled to take into account the effects of heat transfer fluid rate, inlet temperature, sea water rate, basin depth, ambient temperature, wind speed and relative humidity of ambient air. Extensive parametric studies were performed and optimization of the rate and yield of distilled water was discussed [19].

2.13 Performance and economic study of a modified basin type solar still

Ibrahim et al. investigated a solar desalination system working at sub-atmospheric pressure. The decrease of the saline water evaporation pressure allows a much reduction of energy required to operate the system. The desalination system consists of a solar basin connected to an external air-cooled condenser and utilizes a vacuum pump to develop the vacuum condition. The maximum desalination system efficiency obtained was 40%. The productivity and thermal efficiency were increased by 16.2% and 29.7% in, respectively in comparison to the conventional solar still. A cost analysis is carried out to evaluate the constructed desalination system economically [20].

3. CONCLUSION

From the above literature review it can be concluded that the various researchers have put efforts to develop various designs of solar stills for improving the productivity of solar stills. The most affecting factors of solar still which affect the performance of solar still are, slope of glass cover, basin area, depth of water. Lot of researchers introduce a basin with bottom external and internal reflectors to increase the productivity of solar still. The single basin, stepped with mini solar pond solar still has a very good productivity as compared to conventional solar still. Works like external flat plate reflector with tilted wick solar still, optimization of inclination of still and reflector and use of improved surface area of evaporation were also implemented for improving the productivity. The single slope solar still with integrated various absorbing materials like coated and uncoated porous media (called metallic wiry sponges) and black volcanic rocks the result show that 28%, 43% and 60% respectively night time. In the hybrid solar still use waste heat the result show that the MED section of the hybrid solar still plays a more important role than the basin section in the entire performance of the hybrid still. The sun tracking system in the solar still increased the productivity nearly about 22%. Some many researchers studied and developed for the new designs, model and analyses were also done. The cost analyses, economic study and modeling done by various authors are also presented by various researchers.

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