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Productivity enhancement of single slope solar still by preheater – an experimental investigation

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A B S T R A C T

Water is basic to life; clean water is required for domestic, mechanical, and farming purposes. Proficient creation or reusing of water is particularly required in this day and age utilizing sustainable power sources. Solar still has emerged as a life-saving technology to distillate brackish or saline water and produce potable water using solar energy. Single slope basin type solar stills are constructed at the angle of 15° according to the latitude conditions. The experimental investigation and comparison of passive and active solar stills have been done simultaneously in September 2018 at Coimbatore, Tamil Nadu. The work was inspired by the expanding consciousness of the requirement for improving water supplies that conspires in dry terrains including a suitable innovation for sun-powered vitality use in the desalination field. The difference in the active still is the still and spiral collector is integrated for preheating the inlet water. The active still gives higher efficiency than the passive still due to the preheating of inlet water through a spiral preheater setup. Passive still gives the yield of 1.5 kg/d and active still gives 3.2 kg/d which shows that modified still gives higher efficiency than passive still.

Keywords: Solar energy; Solar still; Ambient air; Radiation; Distillation; Preheater

1. Introduction

Nowadays desalination advancements are used for the creation of freshwater to meet all the shortage of consumable water. Sun based desalination utilizes sun oriented capacity to deliver usable water. The sun oriented still is a straight forward gadget put for the water generation from saline or salty water where the creation rate is very low in these arrangements, upgrading the efficiency is the extent of numerous scientists in bowl type solar energy-based still [1–5]. Productivity is increased by placing an external condenser and extended provision for the agitation effect. The evaporation rate was higher by the agitation process and the condensation rate increased by placing an external condenser [1]. Stills integrated with fins in the basin, heat storage materials, vacuum-assisted, black sponge materials give a higher yield than the conventional method, the latitude of that location, and glass cover inclination should be the same for higher yield [2,3]. Stepped solar stills having lower brine depth give higher yield because of its surface area [4]. Various cover designs with modifications by adding rotating drum have studied and the low basin water depth gives a higher yield on a single slope still than a double slope (or) curved shape condensing cover [5]. Modified still with the black light-weight slow rotating drum is studied analytically and compared with experimental results, which reveals higher yield in controlled still [6]. Computerized sun-tracking solar still increased the yield by 22% from fixed still [7]. A latent heat energy storage technology like PCM based solar stills improves the output [8].

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Solar still is equipped with a heat exchanger using nanofluids. The experimental value is compared with the theoretical, in which the usage of heat exchanger below 60°C is not more beneficial. The usage of nanofluids increases efficiency by 10% [9].

Reviewed the design parameters on the productivity of solar still, it shows that environmental factor affects the rate of yield. Insulation of the sun tracking system gives higher productivity because insulation increases the heating capacity and also increases the evaporation rate [10]. Experimental study on the inclined solar still designs gives better projection towards radiation, increases the effective area, high rate of evaporation these features are more effective than conventional still [11]. Modified solar still with the rotating drum is compared with the conventional still and it gives an average increase in daily productivity of 200%, the rotating drum eventually increases the evaporation rate by forming a thin water layer [12]. Single basin passive solar still with various special designs is reviewed, it concludes that productivity is low for passive still and the collector area is a key parameter for increasing productivity [13]. Various thermal models of the solar stills have been reviewed, the numerical results give relatively the same value with experimental values, along with many models single slope single basin type solar still occupied the best place based on its economy, material availability, operation, performance, etc [14]. The theoretical and experimental analysis has been carried out over three models respectively conventional, fin-type, fin-type mini solar pond integrated with fin-type solar still gives higher efficiency of 50% compared to other stills, fins give high heat transfer rate inside the basin [15]. The solar is still integrated with external condenser and nanofluids, an experimental investigation conducted on Kafr El-sheikh City (North of Egypt), mixing of nanoparticle gives higher efficiency of 116% compared to still without mixing of nanoparticles with water [16]. The experimental analysis and comparison made between two solar stills made up of copper sheet. The single slope solar still without modification and with modifications like black paint, pebbles, fins, and vacuum-assisted were compared. In this comparison, vacuum-assisted solar still gives higher yield and high performance than other modifications [17]. Four modified stills were compared with conventional still for the enhancement of productivity. The still integrated with an evacuated tube, condenser, and internal reflector give higher yield with higher efficiency of 33.4% [18]. Pyramid type solar stills are experimentally investigated and compared for active and passive solar stills. Studies on active still coupled with straight heater and spiral heater give a maximum yield of 6.35 kg/m^2 for spiral heater coupled solar still [19]. Double slope solar still equipped with the thermoelectric module was experimentally investigated to improve the thermodynamic performance. By implementing a thermoelectric module the water temperature was raised and it reduced the temperature drop in late afternoon and night. Exergy analysis was also carried out for this experiment and the maximum efficiency of 25% occurred [20]. Two single slope solar stills are investigated experimentally and numerically in Iran's location. Conventional still was compared with modified still in which the still is partitioned due to this the temperature difference increased and productivity was higher for modified still. The higher efficiency of 8.16% occurred for modified solar still [21]. This article was an attempt to improve the performance of single slope solar still by partition installation. Sensitivity and optimization analyses were performed by response surface methodology to obtain the optimum parameters for maximum Nusselt number. The setup of partition results in an increase in vortices ranges with smaller sizes. Smaller vortices offer enough time to exchange heat and increase the efficiency of the still. There is a quick change in the temperature near the glass cover or water surface due to the process of condensation and evaporation [22]. The single slope solar still is simulated with the volume of the fluid model to know the enhancement of productivity using Al_2O_3-water nanofluid. Entropy generation was also determined by the point of the second law of thermodynamics. It reveals that productivity increases with an increase in the solid volume fraction value of nanoparticles. The high heat transfer and viscous occurred at the top and bottom layer of the solar still. The study also shows that both steady and unsteady ones are similar for average temperatures [23]. Experimental investigation and exergy analysis have been carried out between conventional and modified solar still in which reticular porous layer were inserted, Modified still gives higher efficiency due to the implementation of porous media [24].

2. Materials and methods

2.1. Working principle

The desalination process produces potable water. This requires an energy input such as heat, electricity and solar radiation can be the source of energy. Solar desalination is the process of using solar energy for distillation.

Solar distillation is an attractive process to produce potable water using the free cost of solar energy. For absorbing solar energy and evaporate water a device termed as a solar still is used. Solar stills are used in cases of arid areas and water recycling process. A solar still has a top cover made of glass, with an interior surface made of a waterproof membrane. This interior surface uses a blackened material to improve the absorption of the sun's rays. Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation (shortwave) to pass into the still, which is mostly absorbed by the blackened basin. The water thus gets heated up and the moisture content of the air trapped between the water surface and the glass cover increases due to this. The base also radiates energy in the infra-red region (long-wave) which is reflected back into the still by the glass cover, trapping the solar energy inside the still (the greenhouse effect). The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. There are no moving parts in a solar still and only the sun's energy is required for operation. They still will continue to produce distillate after sundown until the water temperature cools down. Feedwater should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process.

The most important elements of the design are the sealing of the base with black color to improve the absorption of heat. Previously, when the still was used without any modifications the evaporated rate was observed to be slower. By using an air-tight chamber and preheated raw water get evaporated at a faster rate compared to conventional still.

2.2. Passive solar still

The conventional or passive solar still consists of an air-tight chamber in which evaporation and condensation of water take place simultaneously.

Table 1 shows the selection of the materials for the passive still. The main components of the still are basin, outer box, insulation, and glass cover. In this experimental setup the still basin is made up of a galvanized iron (GI) sheet of size 1,000 mm × 500 mm × 150 mm with a thickness of 1.5 mm. The basin of the still is colored with black to absorb more heat from the sun. GI sheet was chosen for the low cost, easily available material, and corrosion-resistant. It is easy for folding and machining according to our design so the construction is easier.

The outer cover of the still is made up of a plywood size of 1,100 mm × 600 mm with a thickness of 2 cm. This material was chosen for low-cost and stability. The plywood has a thermal conductivity of 0.13 W/m K. So it conducts heat in a slow manner and also acts as an insulator. The sides of the basin are covered with thermocol for insulation to prevent heat loss from the basin. It has a thickness of 2.5 mm with thermal conductivity of 0.033 W/m K. It has been chosen for low cost and availability.

The glass cover is chosen for the transmission of solar energy, for this purpose 4mm thickness of the glass is chosen and placed in the still at the tilt angle of 15° which is normal to the latitude of Coimbatore location (11.0300°N, 77.1300°E) as shown in Fig. 1. The condensed droplets are trickled through the inner surface of the glass due to inclination and the distilled water is collected in the measuring jar through the poly vinyl chloride pipe fixed at the end of the glass.

The other accessories, PVC pipe, reducers, and taps are used for the inlet and outlet of feed water and collection of freshwater. Saline water is stored in the tank and fed inside the basin manually according to the depth. The depth of the water was measured by a measuring scale which was fixed at one corner of the basin. The still should be air-tight to reduce the evaporation loss so the edges of the glass were sealed with insulation tape. So it will be air-tight and the productivity will be increased.

2.3. Active solar still

Active still is that of the addition of external heating setup which is also known as a preheater. The preheater setup consists of a copper coil placed above the tray. The tray was made to stand at an angle of 15° the same as to the location. Higher the water temperature gives a high productivity rate so the preheater setup has been coupled with the conventional still.

In this process, the copper tubes are made as a flat spiral coil and placed above the basin made up of a GI sheet tray.

The tray dimensions were 0.5 m × 0.5 m. In this area, a flat spiral coil is made to 8 turns. These turns were passed through the aluminum bars to make more efficient heat transfer to the copper coil as shown in Fig. 2. In which the copper tubes of 6 mm were used for the flat spiral coil, copper has high thermal conductivity and corrosion-resistant.

The solar radiation was high at the same latitude positions so the setup was also made at the same latitude angle of 15° which was also similar to that of the glass cover angle of the solar still.

In the active solar still, the saline water is stored in the storage tank then it passes through the preheater after the circulation of water through all the turns the preheated water was passed into the still with a slow and constant mass flow rate as shown in Fig. 3. The continuous water supply from the preheater outlet causes the difference in temperature of the basin water. The evaporation rate would be higher due

Fig. 1. Single slope basin type passive solar still.

Table 1
Selection of materials

Parts name	Material	Size	Purpose of selection
Still outer box	Plywood	1,100 mm × 600 mm × 320 mm	Low cost and stability
Still basin	GI sheet	1,000 mm × 500 mm × 100 mm	Cheap and resistant to corrosion
Top glass cover	Glass	1,100 mm × 600 mm × 4 mm	High transitivity
Insulation	Thermocol	25 mm thick	Insulation and low-cost
Tray	GI sheet	500 mm × 500 mm	Easy construction and low-cost
Spiral coil	Copper tube	6 mm	High thermal conductivity and resistant to corrosion

to the high-temperature water inside the still, due to the increase in the evaporation rate the productivity also increased.

2.4. Error analysis and instrumentation

To measure various temperatures of basin water, glass temperature, ambient temperature, and inlet and outlet temperature of the preheater. The digital thermometer (Probe type) is used. To measure the solar insolation solar power meter (TENMARS TM-207) is used.

A plastic measuring jar is used for the measurement of yield. Wind velocity is measured using a vane-type digital anemometer the various measuring devices accuracies are tabulated in Table 2.

3. Results and discussion

The comparative study on single basin single slope passive and active solar still with black coated GI sheet was conducted in Coimbatore, Tamil Nadu, India (11.0300°N, 77.1300°E). Experiments were carried out from 10:00 to 17:00 h during clear sunny days.

During the experiments, an hourly variation of solar intensity, wind velocity, ambient, glass outside, vapor, water inlet, outlet, and distillate yield were recorded. In which the readings were taken in 6 d for finding the optimum depth of the saline water inside the basin. To find the higher efficiency of stills the readings were taken separately in the month of September 2018 to get the average readings. The readings were taken at the optimum depth for both the stills. The optimum depth of 1 cm has been taken for this experiment. For the optimum depth, the stills were compared and the active still yields higher productivity due to the temperature variation of water and glass cover.

The average outside glass temperature was high at 2 to 3 p.m. at 57°C. The temperature decreases in the evening after 3 p.m. as shown in Fig. 4. This glass temperature depends on solar insolation. It shows clearly that for both stills the outside glass temperature was relatively close enough. The difference between the inner glass and outer glass temperature varies productivity. Moreover higher the temperature variation higher the productivity.

Fig. 5 shows the variation of solar intensity with respect to time. It plays an important role in the production of potable water many parameters like basin water temperature, evaporation rate, etc. depend on the solar intensity. It was high from 11 a.m. to 2 p.m. every day and it decreases gradually in the late evening it depends on the weather conditions. For the experimental time, the high solar intensity of 800 W/m^2 and a lower value of 500 W/m^2 have been recorded on clear sunny days.

Fig. 6 denotes the variation of wind velocity in the experimental hour's wind velocity varies every time. It has been observed if the wind velocity is high, the rate of condensation is high and the air flows above the glass cover give the cooling effect inside the glass to create a temperature difference inside the chamber and glass cover. This variation in temperature produces an effect on condensate droplets of water.

Fig. 7 shows the variation of yield in an hourly manner for both active and passive stills. The outlet water from the

Fig. 2. Experimental setup of the preheater.

Fig. 3. Experimental setup of active solar still.

Table 2
Error analysis and instrumentation

S. No	Instrument	Range	Accuracy	Expected error (%)
1	Solar power meter	0–2,000 W/m^2	±10 W/m^2	5
2	Digital thermometer	0°C–120°C	±0.2°C	0.3
3	Anemometer	0–30 m/s	±0.2 m/s	10
4	Measuring jar	0–2,000 mL	±0.2 mL	1

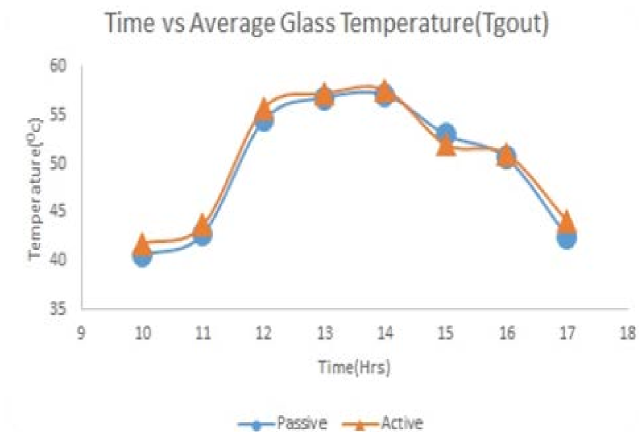

Fig. 4. Time vs. glass temperature.

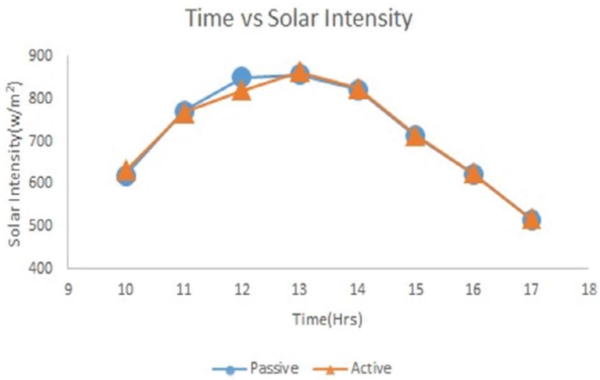

Fig. 5. Time vs. solar intensity.

still is measured in the measuring jar for every hour. It shows that a high yield of 700 mL and a minimum yield of 190 mL and a maximum of 341 mL and a minimum yield of 98 mL obtained for both active and passive stills respectively. The productivity of freshwater increases from 1 p.m. to 2 p.m. and then it reduces gradually till the evening. For the conventional still, the average productivity was 1.5 kg/d up to 5 p.m. and for the active still, it gives the yield of 3.2 kg/d.

Fig. 8 gives the detail about the average temperature inside the chamber; the evaporative temperature is high at 1 p.m. of about 68°C. This evaporative temperature increases the productivity rate; the temperature variation creates the cycle of evaporation and condensation inside the still.

Fig. 9 shows the difference between inlet and outlet temperature in the spiral heat exchanger, the inlet temperature and outlet temperature are recorded by the digital thermometer. It shows the water to be desalinated is preheated before entering into the basin of the solar still. The outlet temperature was high in the first cycle after the flow continues water temperature was low, it acts as a solar collector. At first, the outlet temperature was maximum and it had been recorded as 48.4°C then it was low because of the continuous flow in the spiral heater. The solar radiation which fell on the glass cover also fell over the preheater so that active still water gained more amount of heat over the surface.

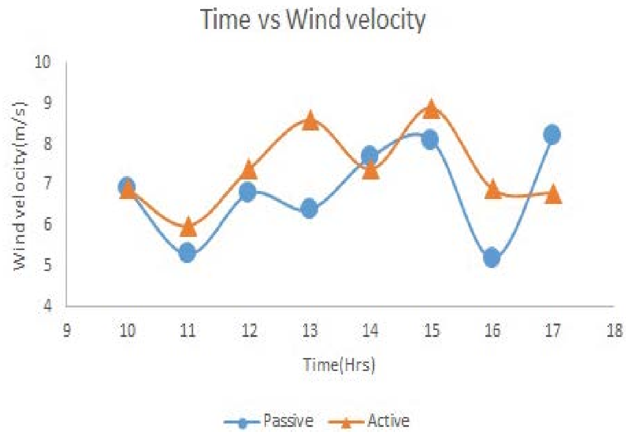

Fig. 6. Time vs. wind velocity.

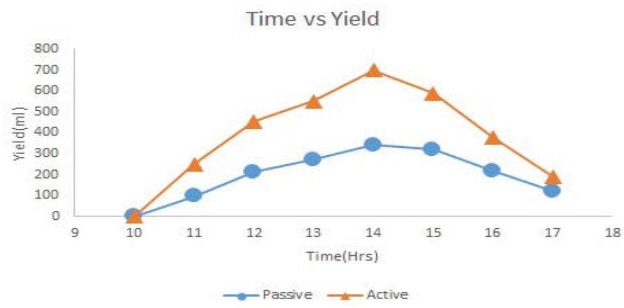

Fig. 7. Time vs. yield.

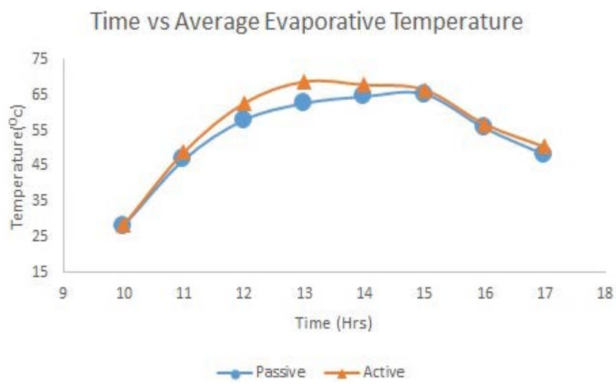

Fig. 8. Time vs. average evaporative temperature.

Fig. 10 denotes the air temperature with respect to the time in hours, ambient temperature is recorded for every hour. It denotes that the temperature increases gradually from the morning. The ambient temperature was also dependent on solar radiation. It also reveals time lag in ambient temperature and solar radiation this is due to the thermal properties of the ambient air like humidity, density, etc. may also affect.

Fig. 11 shows the basin water temperature which depends on the solar intensity. In active still, the water temperature is high due to the preheating of inlet water. The basin also acts as the absorber plate to receive high solar energy.

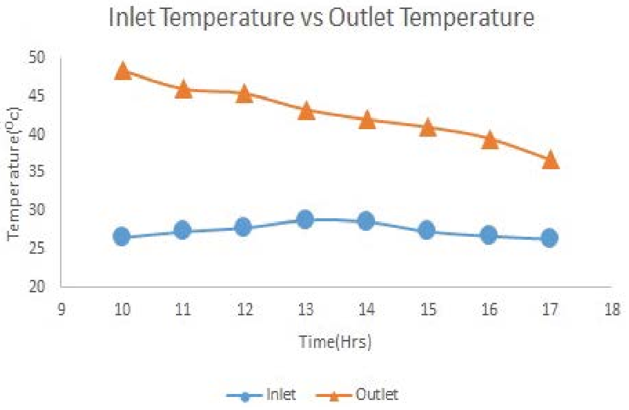

Fig. 9. Inlet temperature vs. outlet temperature.

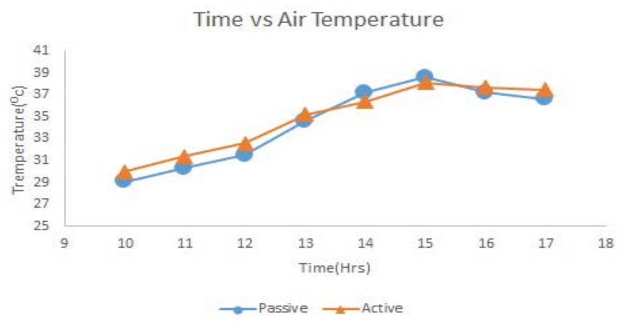

Fig. 10. Time vs. air temperature.

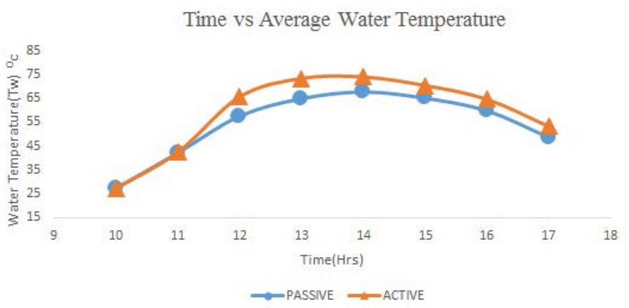

Fig. 11. Time vs. water temperature (T_w).

These experimental values clearly denote that the maximum temperature of 74.6°C for the active still. Due to the influence of the spiral collector, the basin water temperature was higher for active still. This high heat energy breaks down the water molecules at a faster rate. Higher the evaporation rate and higher productivity.

4. Conclusion

The passive solar still is constructed with the basin made of GI sheet 0.5 m². To observe more heat the basin is painted black color. The passive still experimentally studied for various depths (1, 2, 3 cm) of saline water inside the basin of the still. The optimum depth has been found as 1 cm and for that optimum depth, the comparative analysis has been conducted experimentally for passive and active stills simultaneously. In this investigation, the various parameters like basin water temperature (T_w), evaporative temperature (T_e), outside glass temperature (Tg_{out}), ambient temperature (T_a), solar intensity, yield and wind velocity are compared simultaneously for both the stills. Readings were taken from 10 a.m. to 5 p.m. in the month of September 2018 to find out the average values. While comparing both stills the active still gave a higher yield than the passive still. The readings show an increase in the high evaporation rate and heat transfer rate when the basin water temperature was high for active still. Maintaining a lower depth of basin water gives a higher yield. Copper tubes in the spiral collector increase the temperature of the inlet water in the active still with an air-tight chamber gives a higher condensation rate. Productivity increased with an increase in solar intensity and ambient temperature. Wind velocity also plays a role in the productivity of still if higher the wind velocity higher the condensation rate. The experimental investigation revealed that the cost of the active solar still is higher than that of the passive solar still. It is concluded that the efficiency values are 42.7% and 32.57% for active and passive still respectively. The productivity of the proposed active solar still with the spiral collector is higher and hence it is recommended for higher yield.

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