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A Comparative Experimental Study of Single Slope Conventional and Stepped Solar Stills

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Abstract—*A single slope conventional solar still and a stepped solar still with seven trays (100 mm width × 10 mm depth) with a basin area of 0.7 m2 (1 m length x 0.7 m width) were studied experimentally. Several experiments with constant feed water depth of 10 mm in both the solar stills were carried out in the month of March 2018 at Jaipur (India) to compare the performance of the two stills. The experimental results show that daily distillate output of solar still majorly depends on the depth of water layer. The temperature of vapour and basin water in stepped solar still were higher by 7 ˚C and 6 ˚C than that of conventional solar still. The daily yield distillate was 3850 ml/m2 and 2625 ml/m2 and for stepped solar still and conventional solar still, respectively. Thus the stepped solar still gives a daily distillate output of 31.81% higher than that by a conventional solar still.*

Keywords: *Stepped Solar Still, Solar distillation, Solar Still.*

1. Introduction

The availabilityofpotable water is essentialfor the survival of human lifeupon Earth.With the ever-increasingpopulation of the world and standard of living, the demand for potable water is ever increasing. However, with industrialization leading to deforestation, the availability of potable water is on the decline. Nearly 70% of Earth's surface is covered by water, out of which 97% is salt water, 2.5–2.75% is freshor potable water andthe remaining less than 1%containsplenty of harmful impurities.To overcome the problem of scarcity of potable water desalination of salt water is possible and an important option. Solar desalination is a potential solution for reducing water scarcity in rural areas close to the coastline because it is a low-cost system having simple technology that requires less or no maintenance.

Solar desalination can be sub-divided into two categories,i.e.direct and indirect desalination processes.Indirect desalination systems solar energy directly heatsthe saline water and converts it into distillate directly. Thisis used in standalone solar stills. Whereas, in indirect desalination systems, solar energy is collected separately by a solar thermal collector which is used subsequently in a solar still.

Conventional basin type simple solar stills can produce around 2-3 l/m²/dayof the distillate.A simple and promising modification is to use stepped solar stills. Several research works are focused on methods to improve the productivity and the efficiency ofa solar still.Various techniques employed to improve the performance of a stepped solar still were reviewed by Kabeel, Omara, and Younes [1].Theyfound that productivityof stepped solar still can beincreased by usingPCM, wicks on the vertical side, external condenser, reflectors, fins, sponges, solar air heater,cooling of the glass cover, and traysof differentshapes, width and depth.

El-Agouz [2] investigated a stepped solar still with black cotton absorber in which saline water was suppliedcontinuously. The daily productivity of distilled water for this stepped still was higher by 53% and 47% than that ofthe basin type solar stillfor seawater and salt water, respectively.Abdullah [3] found that glass cover cooling in stepped solar still coupled with solar air-heater increased its performance by 112% as compared to that of the basin type solar still, whereasfilling of Aluminum under the horizontal blackened surface as energy storage medium increased the output by 53%.The production rate of distilled water in stepped solar stillcan be enhanced with the use of fins, sponges and pebbles.V. Velmurugan, Kumar, Haq, and Srithar [4] and Velmurugan, et al. [6] mentioned thatthe performance of a stepped solar canbe improvedby using sponges, fins and pebbles in the basinbyabout 98%.Omara, Kabeel, and Younes [5,8] found that by using internal and external reflectors in stepped solar still, a daily distillate from the still can be increasedsignificantly. El-Samadony and Kabeel [7] theoretically examined the effect of water film flowing over the glass cover and concluded that low temperature of glass cover increases the rate of condensation which in turn enhances the productivity but the increase in the output varies with the flow. El-Samadony, El-Maghlany, and Kabeel [9] analyzed the effect of the inclination angle of glass cover onthe distillate output of a stepped solar still and suggested to include the shape factor for accurate analysisof productivity.An experimental, as well as theoretical parametric study of modified stepped solar, still wascarried out by Kabeel, Khalil, Omara, and Younes [10]. They studied the effect of varying the width and the depth of trays on the performance of a steppedsolar still. The results showed that maximum productivity of stepped still is achieved for a tray having a width of 120 mm and a depth of 5 mm. The increase in productivity was about 57.3% higher than that of the conventional still. Also, by using wicks on the vertical wall of a stepped still the distillate output was found to increase from 3% to 5%.

The performance of a solar still largely depends on the ambient conditions and their shape. Therefore, in the present study A single slope conventional solar still and a stepped solar still with seven trays (100 mm width × 10 mm depth) and both having a basin area of 0.7 m^2 (1 m length x 0.7 m width) and same orientation were studied experimentally at the same location and time.

2. Working of a Solar Still

In solar distillation processes, solar energy enters the solar still through a clear glazing surface such as a transparent glass or a plastic sheet. A part of the radiations falling on the solar still is back by the cover, a second part of the radiations falling on the cover is absorbed by the cover and the remaining part of the solar radiations enter the still. The radiations entering the still are absorbed either by water, walls or blackened bottom surface of the still.As a result temperature of water in the basin rises and it evaporates. Warm vapours of water riseup by leaving all the impurities in the basin. These vapours condense on the underside of the cover. The condensed water vapours formwater droplets which slide to throughdue to gravity and are collected in a storage tank. The water thus collected is as pure as distilled water. The heat of condensation released by water vapoursis lostto the atmosphere through the glass cover. A part of the thermal energy is also lost to the atmosphere through the walls and the bottom of the still.

3. Experimental setup

An experimental setup wasdesigned and fabricated to compare the performance of a conventional still anda stepped solar still.The base ofthe twostillsweretaken as 0.7 m^2 (i.e. 0.7 m width x 1 mlength). Height of the front and the back wallswere taken as 150 mmand 510 mm, respectively, such that the glass cover would have the same angle as latitude of the place where the experimentwas performed, i.e. Jaipur. The schematic view of the two solar stills is shown in figure-1.

The stepped solar still had same geometrical dimensions as that of the conventionalsolar still, except that the absorber plate was made up of 7 trays, each having a size of 1 m (length) x 0.1 m (width) x 10 mm (depth).

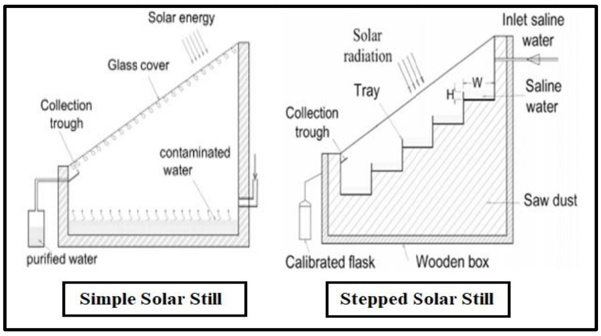

Figure 1. Schematic view of the experimental setup.

The solar stillswerefabricatedby 2mm GI sheet. The inside surfaces of the basinswere painted black to increase theirabsorptivity. The bottom and sidewalls of the conventional solar still were constructed as a double-wallcontaining a 10 mm thick thermocol (thermal conductivity = 0.0314 W/m K) sheet.Top of the still top was covered by a plane transparent glass sheet of 5 mm thickness (1.03m lengthx 0.79 m width) which was inclined at an angle of 27°to the horizontal(latitude of Jaipur)such that glass cover was facing southdirection to receive the maximumirradiation.

Figure 2. Experimental Setup

The stepped solar still walls were insulated by sawdust (thermal conductivity of 0.06 W/mK) to prevent the heat transfer from the sides and bottom of the solar still to the atmosphere.

3.1 Experimental procedure

The depth of the water in both the stills was kept constant as 10 mm. During the experiment makeup water equal to the amount of hourly water distillate was added, every hour, manually. The temperature at different locations,i.e., absorber plate, basin water, glass cover andwater vapour and the ambient temperature were measured using calibrated copper constantan type thermocouples (T-type thermocouples) which were connected to a 24-channel temperature indicator (Masibus scanner 85XX).The solar radiation intensity was measured by a solar power meter(0 to 1000W/m2).A flask of 1-litrewas used to measure the hourly distillate output. The wind speed at the experimental site was measured by a vane-type anemometer with a range of 0–15 m/s.

Table 1. Weather conditions of Jaipur.

Parameter	Value	Values for March 2018
Latitude	26° 51' 46.8"N	-
Longitude	75° 48' 38.16"E	-
Annual average daily solar irradiations for Jaipur	5.68 kWh/m^2/day	-
Highest daily solar radiation	7.43 kWh/m^2/day in May	6.59 kWh/m^2/day in May
Lowest daily solar radiation	3.98 kWh/m^2/day in December	5.20 kWh/m^2/day in May
Average ambient temperatures	24-30˚C	25˚C
Maximum ambient temperatures	41-49°C in May	35˚C
Minimum ambient temperatures	4-9°C and fall below zero deg in December	17˚C
Average Relative humidity	20-35%	35%
Average monthly wind speed	3-10 kmph	2-8 kmph

The wind velocity, solarradiationanddistilled water output were measured every one hour whereas all the temperatures weremeasured every halfhour, starting from 10am to 5pm. The total distillate output for the day and night i.e. during the 24 hourswas also measured. The weather details of the place of the experiment are given in table 1.

4. Experimentalresults and discussion

Experiments were conducted for fifteen days in a row.During the experiments, the wind velocity was recorded in the range of 0.10-11 m/s whereas the ambient temperature was found to be in between 23°C and 36°C on different days.

4.1 Observations

The incident radiations were measuredwith the help of a solarimeter placed on the glasscover. The sensor of the solarimeter was placedso that it was facing the Sun directly. The distillate output was measuredwith the help of a measuring cylinder. The experiments were done for the same quantity of water in both the stills. At the end of every experiment, i.e. in the morning, the amount of water that had evaporated during the previous day was addedthe next day morning before the start of the experiment again.

4.2 Effect of Insolation:

Figure-3shows the temperature of basin water, absorber plate, glass cover, vapour and surroundings and solar intensity for both the solar stills. It was observed that temperature at various point in the still increases from their minimum values in the early morning to their maximum values sometime in the noon - about an hour after the peal solar radiations were reached

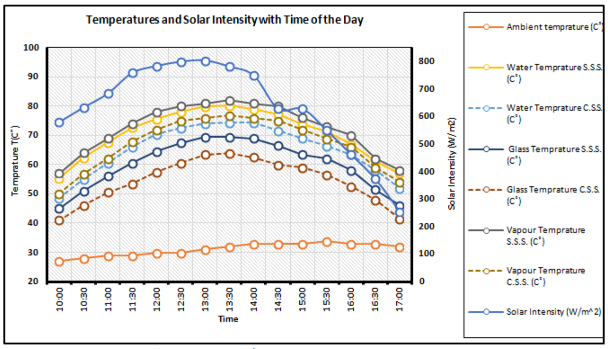

Figure 3. Temperatures and Solar Intensity with Time of the Day for Conventional and Stepped Solar Stills

The temperature difference betweenthe corresponding points i.e., basin water, absorber plate, glass cover and vapour for both the stillsvaries from 3 to 10°C. The two main reasons for this temperature difference are:

- Smaller spaceavailable for vapours insidethe stepped solar still leads to faster heating of the trapped water vapoursthat leads to higher temperaturesinside the stepped solar still.
- Due to reduced vapour space, less area of the side walls remains exposed to hot water vapours. As a result heat loss from the side walls reduces, leading to higher temperatures and higher distillate output in the stepped solar still as compared to the conventional solar still.

4.3 Distillate output:

Figure-4 shows hourly distillate output for both the stills. The hourly distillate output increases from morning till noon, i.e. around 1 to 2 pm and then decreases continuously until the end of the day. The peak hourly output is obtained about half an hour after the peak solar intensity is achieved. This is due to the thermal mass of the stills leading to thermal lag.

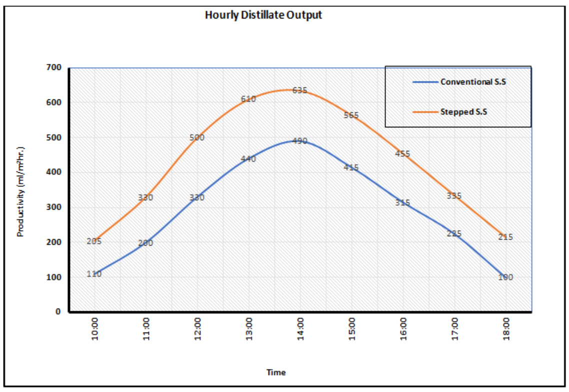

Figure 4. Hourly Distillate Output for Conventional and Stepped Solar Stills.

Solar stills continue to give distillate output during the night. After the sunset, i.e. during the dark hours of the day, the ambient temperature falls while water present in the solar still basin remains warm enough to evaporate and produce distilled water. The cumulative distillate output for both the stills for aday is shown in Figure 5. The stepped solar still gives much higher output for the day as compared to conventional solar still. The figure shows that total distillate output during a day, i.e. for a day and the following night, for stepped solar, still was about 30% higher than that for the simple still.

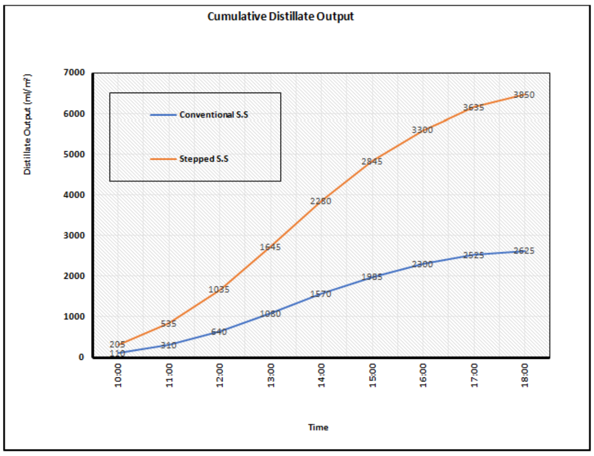

Figure 5. Cumulative Distillate Output for Conventional and stepped solar stills

The dailyoutput of both the stills for all the days for which experiments were performed, is shown in figure 6. It shows that the daily distillate output for a stepped solar still is about 30-32% higher than that produced by the simple solar still

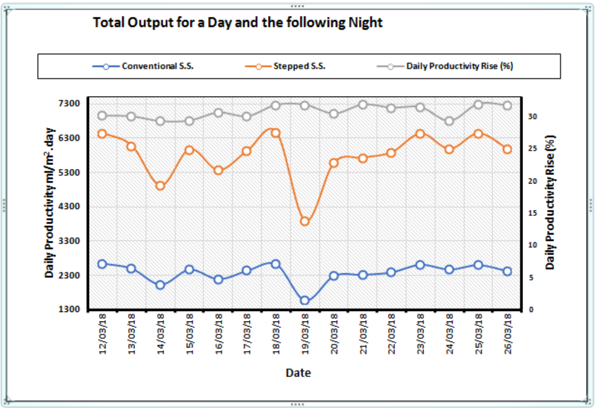

Figure 6. Comparison between total output for a day and the following night for conventional stepped solar stills.

5. CONCLUSIONS

Following conclusions can be made from the above study

- The maximum temperaturesofbasin water, glass cover, water vapour,and the absorber platefor stepped solar still are 81°C, 82°C, 82°C, and 68°C respectively, whereas the same for the conventional solar still are 74.5°C, 75°C, 77°C and 64°C, respectively. The temperatures in stepped solar stills are about 4-6°C higher than that in the conventional solar still.
- The maximum hourly productivity for any one hour time interval for stepped and conventional solar stills was observed between 1 to 2 pm. It was 635 ml/m^{2}hr and 490 ml/m^{2}hr, respectively for stepped and conventional solar stills.The maximum hourly output for the stepped solar still was about 30% higher than that for the conventional solar still.
- The daily yield of distilled water for stepped still was 3850 ml/m^{2}which wasapproximately 31% higher than 2625 ml/m^{2}of distilled water obtained from the conventional solar still.

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