# PERFORMANCE ENHANCEMENT OF A SOLAR STILL USING COTTON REGENERATIVE MEDIUM

by

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Original scientific paper
https://doi.org/10.2298/TSCI17S2427T

*This paper presents the performance of a single slope solar still using cotton cloth regenerative medium. The performance was evaluated under the metrological conditions of Chennai city in India during the summer months of 2016. Two single-slope solar stills are fabricated with an effective area of 0.5 $m^2$ with various thicknesses (2, 4, 6, and 8 mm) of cotton cloth were used for the performance comparison. The results showed, the solar still with 6 mm thick cotton assisted regenerative solar still has about 28% improved productivity when compared to conventional solar still.*

Key words: *cotton cloth, solar still, regeneration solar still*

## Introduction

The drinking water requirement is getting increased due to increase in human population. But, the drinking water availability is getting depleted. Hence, it is essential to identify a sustainable technology for producing good drinking water. The solar energy is an economical option for producing good drinking water in rural locations with good potential of solar irradiation. Many research and development initiatives have been reported on the performance of solar stills using heat storage materials and regenerative medium.

In a related work, the performance of a solar still was improved by providing sponge cubes over the water surfaces [1]. The sponge cubes increased the surface area and enhances the rate of evaporation. The performance of the still was improved by about 18%. In a similar work, Murugavel *et al.* [2] presented the research progresses on passive type solar stills and concluded that, use of heat storage materials, wick materials and reducing water depth in the basin has significantly improved the still output. In another work, Velmurugan *et al.* [3] increased the exposure area of the water surface using sponges and fins in a single basin solar still and concluded that the productivity of the still increases from 1.88 to 2.8 kg/m$^2$/day. Similarly, Nafey *et al.* [4] used a floating perforated black plate to maintain thin film evaporation. Productivity increased by 15% when the saline depth was 30 mm and the enhancement in productivity was more significant. Tiwari *et al.* [5] have studied the performance of a double condensing multiple-wick solar still. In that, experiment the condensing surface area has been increased by introducing an additional galvanized iron sheet just below the blackened wet jute

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cloth. Arjunan *et al.* [6] had conducted the experiment on single slope solar still with its inner surface covered with sponge. Productivity of the still was increased by 34% compared with conventional solar still. Omara *et al.* [7] presented the research on stepped solar still through internal reflectors and concluded that stepped solar still with and without reflector gives higher yield than conventional solar still about 75% and 57%, respectively. Eltwail *et al.* [8] conducted experiments on solar still with flat plate solar collector, spraying unit perforated tubes, external condenser and solar air collector are compared with conventional solar still and concluded that the developed solar still gives higher productivity in all aspects. Akash *et al.* [9] have experimentally evaluated the performance of a single-basin solar still using different absorbing materials like rubber mate and charcoal to increase the absorption of the still basin and reported with significant improvement. Kumar *et al.* [10] estimated that the operation of multi stage solar still with number of collectors beyond three would not be economical. The distillate productivity with optimum solar collectors for triple effect active basin still was estimated to be 12.0 kg/m$^2$d. Karuppusamy *et al.* [11] reported that integrating the evacuated glass tube collector with solar still has increased the efficiency by about 50%. Tiwai *et al.* [12] has proved that, solar still coupled with flat plate collector increases distillate output by about 24% when compared with single slope single basin solar still. Dimri *et al.* [13] reported that, use of flat plate collector with higher thermal conductivity material has produced higher distillate output as well as efficiency compared with single slope solar still. Abad *et al.* [14] integrated pulsating heat pipe with solar still and reported with remarkable improvement in productivity. Sakthivel *et al.* [15] have investigated the performance of a regenerative solar still using jute cloth as energy storage medium. The latent heat of condensation accumulated in the air gap was utilised. An increase in the yield and efficiency by 20 and 8% were achieved, respectively.

The cited literature confirms that, many research investigations have been reported on the performance of solar still. However, the performance of solar still under the influence of thick cotton cloth was not reported in open literature. Hence, the main objectives of this study are formulated as (1) to improve the performance of the conventional solar still using cotton cloth, and (2) to find the optimum thickness of cotton cloth.

## Experimentation

Two single slope single basin-type solar stills are fabricated with the same design parameters with an effective area of the basin is 0.5 m$^2$. The basin surface is painted black and placed with its long axis east-west direction to absorb the maximum amount of solar radiation incident on them. An ordinary clear window with a glass thickness of 4 mm was used as the top cover of the solar still and was inclined at an angle of 10°. Glass cover has been framed with wood and sealed with rubber which acts as anti-air leak and C-clamps are used to seal between the glass cover and the body of the still to avoid the leakage of vapour. The entire still is kept inside the wooden frame of thick 12.5 mm and insulating material such as thermocol of thick 25.4 mm is placed between the still and wooden frame. A collecting trough made by G. I. sheet is used in the still to collect the distillate condensing on the inner surfaces of the glass covers and to pass the condensate to a collecting flask. Steel rule is fixed along the inside wall for measuring water levels. The experimental set-up was positioned to the direction of south to get the maximum solar radiation. The geometrical constructions of the solar still are given in fig. 1, and pictorial view of the solar stills is shown in fig. 2. The design and technical parameters of solar still are given in tab. 1. During this experiment, the intensity of solar radiation, ambient temperature, water temperature, basin liner temperature, inner wall temperatures, outer wall temperatures, bottom side temperature and wind velocity were recorded every hour. The hourly productivity of fresh water is collected and measured in a measuring jar. The daily productivity is obtained as a summation of day and night productivity.

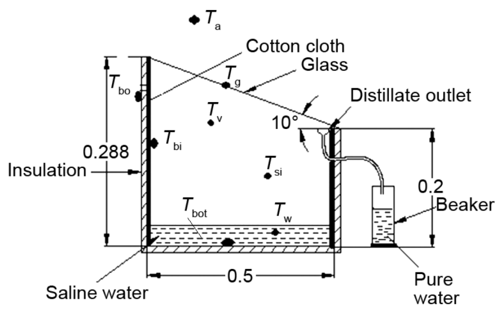


**Figure 1. Schematic diagram of the single slope solar still with cotton cloth at inner walls**

**Figure 2. Photographic view of experimental set-up**

**Table 1. Specifications of single slope solar still**

| S. no. | Dimensions | Measurements |
|---|---|---|
| 1 | Length | 1 m |
| 2 | Width | 0.5 m |
| 3 | Glass cover inclination | 10° |
| 4 | Number of glass | 1 |
| 5 | Thickness of glass cover | 4 mm |
| 6 | Glass area, $A_g$ | 0.508 $m^2$ |
| 7 | Basin area $A_b$ | 0.5 $m^2$ |
| 8 | Back wall area, $A_{bw}$ | 0.488 $m^2$ |
| 9 | Side wall area, $A_{sw}$ | 0.234 $m^2$ |
| 10 | Mass of saline water | 10 kg |
| 11 | Thickness of thermocol, $L_{th}$ | 25.4 mm |
| 12 | Thickness of wood, $L_{wood}$ | 12.5 mm |

Experiments were conducted simultaneously with conventional and cotton cloth assisted regenerative solar still under similar ambient conditions. The experimental observations were recorded at every one hour interval for the period of 24 hours. The accuracy, range and percentage errors in experimental results are listed in tab. 2. Solar intensity meter, mercury thermometer and cup-type anemometer were used to measure intensity of solar radiation, atmospheric temperature and wind velocity, respectively. Twelve k-type thermocouples were used to measure the temperature at typical locations in the basin. The water level in the basin was monitored using a calibrated measuring scale fixed in the vertical wall of the basin. The distillate output was recorded using a calibrated jar.

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**Table 2. Instruments and its accuracy range and error limits**

| Instrument | Accuracy | Range | % error |
|---|---|---|---|
| Digital thermometer | ±1 °C | 0-100 °C | 0.25 |
| Thermocouples (type-k) | ±0.1 °C | 0-100 °C | 0.5 |
| Solarimeter | ±1 W/m$^2$ | 0-2000 W/m$^2$ | 2.5 |
| Electronic digital anemometer | ±0.1 m/s | 0-15 m/s | 10% |
| Measuring jar | ±10 ml | 0-1000 ml | 10% |

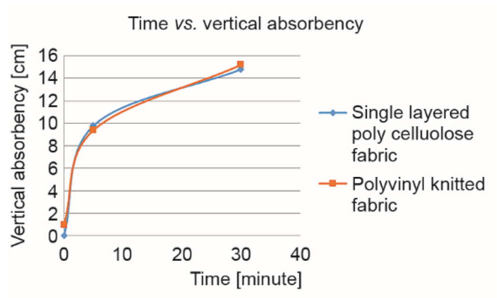


**Figure 3. Absorbency testing of cotton cloths**

**Figure 4. Pictorial view of modified solar still with cotton cloth**

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## Instrumentation

### *Characteristics of cotton regenerative medium*

The cotton cloth has good absorbing capability of water and it can reduce heat loss by means of conduction. The various cotton cloths like, polyvinyl acrylite cellulose knitted fabric, single layered poly cellulose fabric have been tested and its characteristics are depicted in fig. 3. It is observed that, water absorbency in the tested regenerative medium was increased during initial 30 minutes interval. Moreover, it is noticed that, polyvinyl acrylite cellulose knitted fabric cotton regenerative medium has more vertical absorbency characteristics when compared to the other materials. Figure 4 displays photographic view of pasted cotton cloth on the inner wall of the solar still.

## Result and discussion

The performances of a solar still with and without the use of cotton cloth are presented in this section. A series of experimental observations have been made on both the solar stills with the use of cotton regenerative medium. More experimental observations have made for the period of sixty days to study the transient behaviour of the solar still and also to avoid the erroneous experimental data. The performance of a solar still observed during the typical day with minimum fluctuations in solar irradiation was considered for discussion. The average solar irradiation and wind velocity observed during experimentation are illustrated in fig. 5. The solar irradiation was varied from 750 W/m$^2$ to maximum value of 950 W/m$^2$ during experimental observations between 9.00 and 17.00 h. The wind velocity was varied between 0.5 and 2.5 m/s.

In fig. 6, the hourly variations of different component temperatures of the conventional still with 10 L capacity and 20 mm water depth. It was observed that water, glass, and basin temperatures were gradually increased and reached the maximum value in the afternoon due to increase in solar irradiation during morning hours. It was observed that, the water temperature and absorber plate temperature are almost similar because of the continuous contact between them. The highest temperature was observed at the inner wall surfaces during 14:00-15:00 h, whereas the lowest temperature is recorded between 16:00-17:00 h at the atmosphere side. It also indicates that, from 12:00 h onwards, the maximum basin temperature was observed till the end of the experiments. It was understood that the inner wall surface absorbs and retains considerable amount of heat. This may be due to direct fall of the high solar irradiation on this surface. Some portion of irradiation is reflected to the still components like water, basin liner and vapour, *etc.* The remaining energy is stored in the inner wall surfaces. The influence of cotton cloth on the inner wall surfaces makes larger differences in the temperature of the still components. The hourly temperature variations of basin water, basin liner, glass, and vapour temperature of the conventional still and the still with cotton cloth are depicted in figs. 7-10. It was observed that, during the early morning hours and late afternoon hours, temperature of regenerative medium (cotton cloth) was closer to the still temperature. The solar still with 8 mm cotton cloth components like glass, water, basin liner *etc.*, attain higher temperature than 2, 4, and 6 mm cotton cloth. This may due to the solar still with high thickness cotton cloth absorb more amount of water from the basin due to capillarity, thus leading to decreased water capacity in the basin, higher temperature of the water, So, it maintains the water level and leads to lower temperature of the water as well as other the components of the still. fig. 10 shows that the vapour temperature of the cotton cloth stills was lower than the conventional solar still. This may be due to water present in the cotton cloth still absorbs the heat energy from the vapour side.

It was observed that the productivity is increasing until it reaches the maximum in the afternoon, then decreases in the late afternoon. From early morning hours the cotton cloth

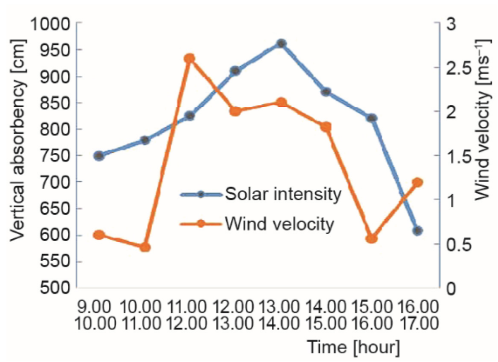


**Figure 5. Variations of solar radiation and wind velocity**

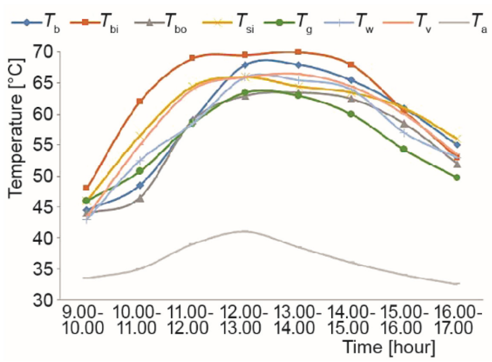


**Figure 6. Hourly variation of temperatures at typical locations**

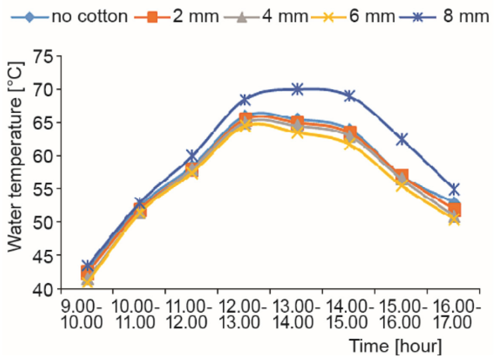


**Figure 7. Hourly variations of water temperature**

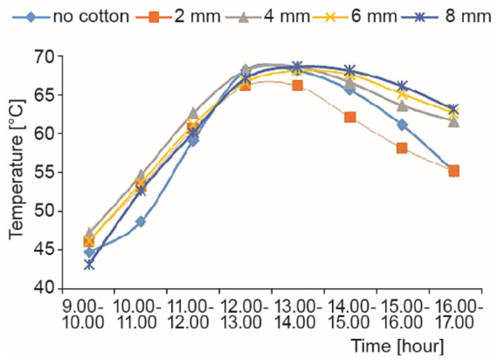


**Figure 8. Hourly variations of basin liner temperature**

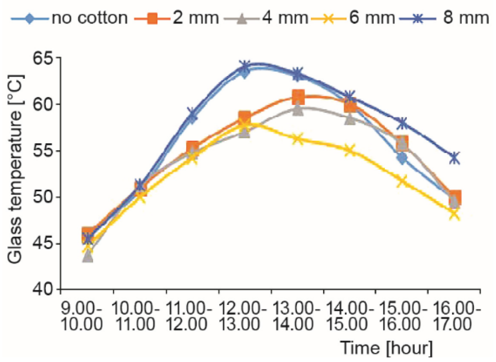


**Figure 9. Hourly variations of glass temperature**

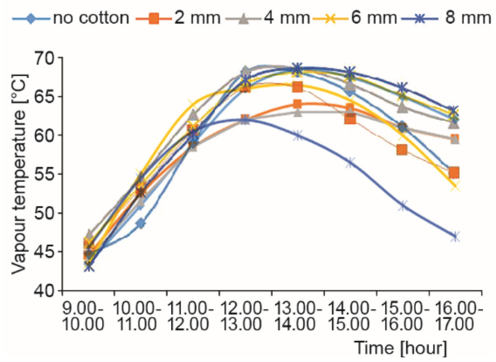


**Figure 10. Hourly variations of vapour temperature**

stills give more yield than conventional still. This may be due to the water available in the cotton extracts heat from inner wall surfaces and vapour, this result in getting additional productivity. The solar still with 8mm cotton cloth give lesser productivity due to the higher components temperatures, the convection and radiation heat losses from glass to ambient will be more which leads to low productivity and the heat energy available in the inner wall surfaces is not sufficient for complete evaporation of water present in the cotton. It is observed that, the solar still with 6 mm thick cotton cloth gives more yield than other stills and is equal to 1.42 kg per day, which is 29.5% higher than the conventional still. From fig. 11 it is observed that, the productivity of the solar still was improved with increase in thickness of regenerative medium (cotton cloth) up to 6 mm. However, beyond 6 mm thickness, the productivity of the still gets dropped. The productivity of the solar still also depends on the temperature difference between water and glass. The hourly variation of temperature difference between water and glass using different thickness of cotton regenerative medium is shown in fig. 12. It clearly indicates that, the solar still with 6 mm thick cotton cloth regenerative medium has generated maximum temperature difference between water and the glass. The lowest temperature difference between water and the glass ($T_w - T_g$) was observed in the conventional still throughout the day. During morning hours (from 9:00-11:00 h) these differences are in negative due to the lowest heat capacity. The temperature of the glass is higher than the water temperature during this period. After 11:00 h, solar irradiation falls on the solar still is getting increased. Due to high absorptivity of absorber plate and the presence of cotton regenerative medium, the water temperature in the basin was maintain higher than ambient conditions till the end of the day.

The cumulative production of a solar still using different thickness of cotton cloth are illustrate in fig. 13. A maximum of 1420 mL per day was obtained by 6 mm thickness. Cotton cloth with 2 and 4 mm thickness gave 1295 mL per day and 1350 mL per day, respectively. In fig. 14, the performance of the solar still using different thickness of regenerative medium is presented. The cotton cloth with 6 mm thickness has about 28.2% higher production when compared to the conventional solar still without cotton regenerative medium. The solar still efficiency was considered as the most important parameter to evaluate the system and to ensure the best still design. The efficiency of the stills with cotton cloth was higher than that of conventional still. The cotton cloth regenerates the heat and enhances the evaporation rate of water stored in the basin.

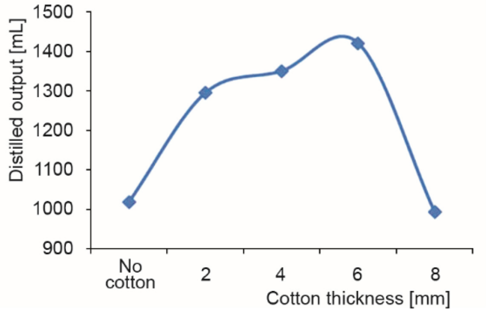


**Figure 11. Total distilled output variations**

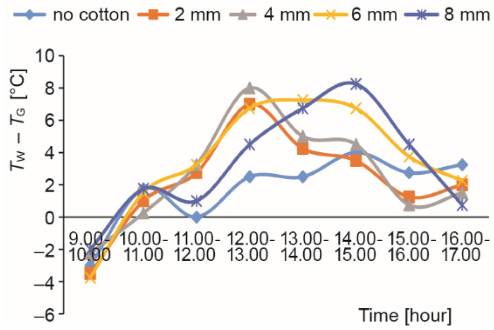


**Figure 12. Variation of temperature gradient between water and glass**

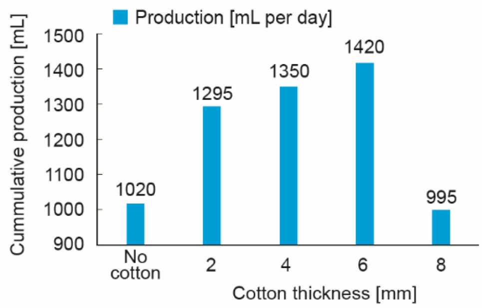


**Figure 13. Cumulative production**

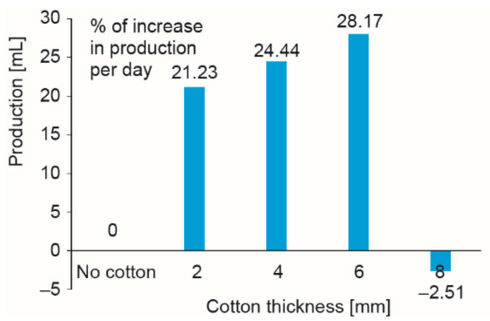


**Figure 14. Percent increase in production of different thickness**

## Conclusions

The performance of a solar still using cotton cloth regenerative medium was experimentally investigated in this work. The following conclusions are drawn based on the experimental observations.

- The inner walls of the solar still have attained maximum temperature, which enhances the rate of evaporation.

- The maximum water, basin and glass temperatures were observed in the solar still using 6 mm thick cotton regenerative medium.
- The maximum temperature difference between water and glass for 6 mm thick regenerative medium.
- Solar still with 6 mm cotton cloth gives maximum yield of about 1.42 kg per day when compared to other thickness.
- The productivity of a regenerative solar still using 6 mm regenerative medium has improved the productivity by about 28% when compared to conventional still.

## Nomenclature

$A_g$ – glass area, [m$^2$]
$A_b$ – basin area, [m$^2$]
$A_{bw}$ – back wall area, [m$^2$]
$A_{sw}$ – side wall area, [m$^2$]
$L_{th}$ – thickness of thermocol, [mm]
$L_{wood}$ – thickness of wood, [mm]
$T_b$ – basin bottom temperature, [°C]
$T_{bi}$ – inner back wall temperature, [°C]
$T_{bo}$ – outside back wall temperature, [°C]
$T_{si}$ – inner side wall temperature, [°C]
$T_g$ – glass temperature, [°C]
$T_w$ – water temperature, [°C]
$T_v$ – vapour temperature, [°C]
$T_a$ – ambient temperature, [°C]

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Paper submitted: March 20, 2017
Paper revised: May 25, 2017
Paper accepted: June 13, 2017