Augmenting Distillate Output of Single-Basin Solar Still Using Cement Blocks as Sensible Heat Energy Storage

Jyoti Bhalavi, Bhupendra Gupta, P. K. Jhinge and Mukesh Pandey

Abstract Solar still is a green energy product. It uses heat energy of the sun to purify muddy or salty water. Single-basin passive solar still is the best choice for drinking water-prone remote areas. Investigations show its limitation because of its lower performance in terms of distillate output. Several attempts were made by different researchers for improving the performance of conventional solar still. One of the proven methods to improve the output of solar still is to incorporate sensible heat energy storage material. In this experimental work, prime focus is to enhance the output of the single-basin conventional solar still by putting cylindrical cement blocks as a heat storage material in basin water. A comparative study between the modified still (with cement blocks) and conventional still (without cement blocks) of the same size was carried out for the same experimental condition of Jabalpur, India (23° 10′ N, 79° 59′E), with different depth of water ranging from 2 to 5 cm. Result recorded indicates that the output depends on the water depth and mass of sensible energy storage material. The maximum yield was obtained for least water depth of 2 cm. The daylight yield was found enhanced up to 67% in the modified still as compared to conventional still, while decreased performance is observed in overnight productivity. The overall yield increased by 17% considering 24 h. of output. Uncertainty and error analysis have also been carried out.

Keywords Distillate output · Cement blocks · Water depth · Sensible energy storage material · Passive solar still · Daylight and overnight productivity · Uncertainty and error analysis

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Nomenclature

T_a	Ambient temperature (°C)
T_w	Basin water temperature (°C)
T_v	Vapor temperature (°C)
T_{gi}	Inside surface temperature of glass (°C)
T_{go}	Outside surface temperature of glass (°C)
I_g	Solar radiation (W/m^2)
D_w	Water depth (cm)
PCM	Phase change material

1 Introduction

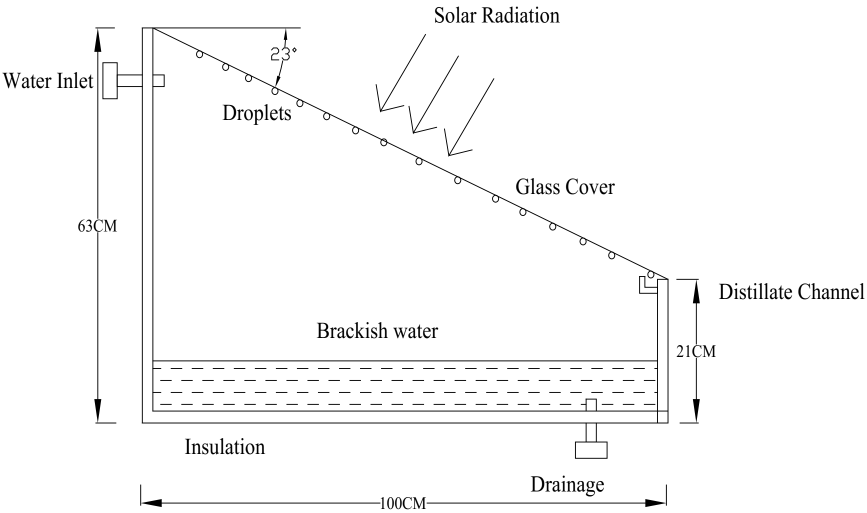
Pure and drinkable water is primitive to life and sustainable development. Today, most of the health problems are because of non-availability of hygienic drinking water. Water availability, as well as clean drinking water on earth, has reduced drastically in recent years due to, climate change, industrialization, increased population drought, etc. According to the survey, about 79% of the water on the earth is saltwater, 20% is brackish, and rest 1% of all the water on earth is freshwater [1] hence to resolve the problem of freshwater, solar desalination is proven technique. It is an environment-friendly method used to convert salty water into drinkable water. Extensive research work has been carried out to find out ways to improving the efficiency of solar still. Velmurugan and Srithar [2] reviewed the performance analysis on the factors affecting the productivity of solar still and concluded that productivity enhancement can be done by changing the various operational parameters with modification in the solar still. Abdallah et al. [3] used black rocks and black (coated and uncoated) metallic wiry sponges as a heat absorbing material and found yield increment around 60, 43, 28%, respectively. Srivastava and Agrawal [4] modified a single slope solar still with twin reflector booster and blackened jute cloth as floating absorbers. It recognized that the modification in the solar still enhanced the yield by 68%. Panchal and Mohan [5] have studied and reviewed the numerous methods used to increase solar still output. It is fin attachment, energy storage materials, and multi-basin solar still for improvement in distillate output. They concluded that all the three approaches contribute significantly to increment in distillate production. Gupta et al. [6] evaluated and compared the performance of two solar stills. He modified the conventional solar still by painting it white at inside walls and attached a water sprinkler on the glass cover. They concluded that the overall efficiency is increased by 21%. Gupta et al. [7] in his another work used nanoparticles to improve thermal characteristics of the fluid and found that the yields increase from 2351 to 2814 ml/m^2-day in the modified solar still. Sellamia et al. [8] used layers of blackened sponge on absorber surface and premeditated the sponge thickness effect on the efficiency of the solar stills. It was found that distillate output is increased by 57.77 and 23.03%, with sponge thicknesses of 0.5 and 1.0 cm compared with a conventional solar still. Akash [9] conducted experiments using different absorption materials. They achieved increment of daily still yield around 35, 45, and 60% with use of black rubber mat, black dye, and black ink, respectively. Bassam et al. [10] anticipated an alteration to increase the distillate production by using sponge cubes on the water surface. They concluded that the evaporation surface area of water increased, hence, caused the augment of yield by 18%. Murugavel et al. [11] experimented with cement concrete pieces, washed stones quartzite rock, red brick pieces in the solar still basin at least water depth and found 19 mm quartzite rock as the best option. Velmurugan et al. [12] used sand, gravel, pebbles sponges, and black rubber as storage material in modified still and found 14% yield increment with sand as compared to the conventional still. Kabeel and Abdelgaied [13] experimentally investigated the effect of paraffin wax as PCM on the behavior of the solar still he concluded 67.18% yield improvement as compared to the conventional solar still.

Literature review shows a research gape of work with natural heat absorbing materials with different shape and weight configurations. So, in this work, the effect of cement blocks as heat storage material in conventional solar still has been analyzed. The experiment is performed at water depth of 2, 3, and 5 cm at the same ambient conditions and results of modified solar still are compared with the results of conventional solar still.

2 Experimental Setup

Figure 1a, b shows actual photographs and schematic of solar still fabricated on-site at Jabalpur, India. Two identical solar still were designed, fabricated, and installed at Jabalpur Engineering College, Jabalpur, India. The solar stills are kept facing South–North direction to get utmost solar energy. Basin of solar still is made by 1 mm thick galvanized iron sheet having the basin area of 1 m^2 (1 m × 1 m). Front wall height of solar still is 21 cm and rear wall height is 63 cm. Basin of solar still is painted black color to absorb maximum radiation. Thermocol sheets are used as insulation material to prevent heat losses from the sidewalls and bottom of the solar still. 10 mm thick plywood is used for outside support of both solar still, and 5 mm thick plain glass inclined at 23° to the horizontal is used to cover the top of both the solar stills. An arrangement of inlet and outlet valve is provided to supply saline water into basin and distillate output from the basin. Setup is well equipped with instruments such as K-type thermocouple is used to measure the temperatures of various sections of solar still. Solar radiation is measured with the help of solar radiation meter. A measuring flask was used to measure distillate yield from modified and conventional solar stills.

(a) Various Images



(b) Schematic diagram

Fig. 1 Experimental setup of solar still

3 Experimental Procedure

The experimental procedure was carried out in January and February 2018 at Jabalpur city, Madhya Pradesh, India. Thirteen cement blocks of weighing 300 g each were tapped in the basin. Experiments were executed to compare output of modified solar still at three different water depths by maintaining the equal number of cement block. The results are compared with conventional solar still set aside at the same ambient condition. At the beginning of the experiment, the water depth of 5 cm was maintained inside both the basins. Hourly measurements were taken from 9 am to 6 pm. Variables measured in the present experiments were ambient temperature, water temperature, inside and outside glass temperature, vapor temperature, and distillate output. The distillate is measured at every hour in daytime and collectively for the night at next morning. The days with clear sky conditions were considered for experimentation and assessment. Similar tests were repeated with the water depth of 3 cm 2 cm and again distillate output is compared. All these measurements were recorded manually.

4 Error Analysis

Several parameters were measured throughout the experiments, in order to assess the performance of solar still. Owing to the limited precision of the instrument and uncertainty of the method of measurement, some inaccuracies are present in measured parameters that are recognized as percentage of uncertainty. The accuracies and ranges of instruments used are presented in Table 1. The uncertainty percentage of experimental measurement has been measured by adopting the method proposed by Holman [14] based on the precision of measuring equipment the maximum uncertainty was found about 2%.

5 Results and Discussion

5.1 Variation of Ambient Temperature with Solar Radiation

Figure 2 shows a typical hourly variation of solar radiation and ambient temperature at Jabalpur on February 28, 2018. It is observed that both solar radiation intensity and ambient temperature increases to the extreme level around mid-day and steadily decrease after that. Solar variation is parabolic and reached up to 750, 740, and 860 W/m^2 at around 2 pm, 12 noon, and 1 pm, respectively, on January 25, 2018, February 23, 2018, and February 28, 2018 and goes to zero at 6 pm on respective days. Peak ambient temperatures are observed 30, 36, and 35 °C at 3 pm and 12 noon, respectively.

Table 1 Ranges and accuracies of instruments used

S. no.	Device	Range	Accuracy
1.	Thermocouple	–100 to 200 °C	±1 °C
2.	Solar power meter	0–2000 W/m^2	±1 W/m^2
3.	Measuring beaker	0–100 ml	±5 ml

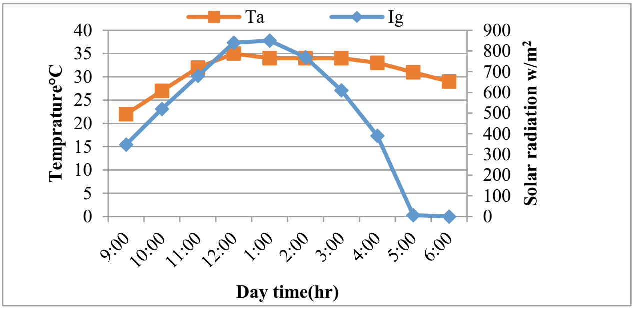
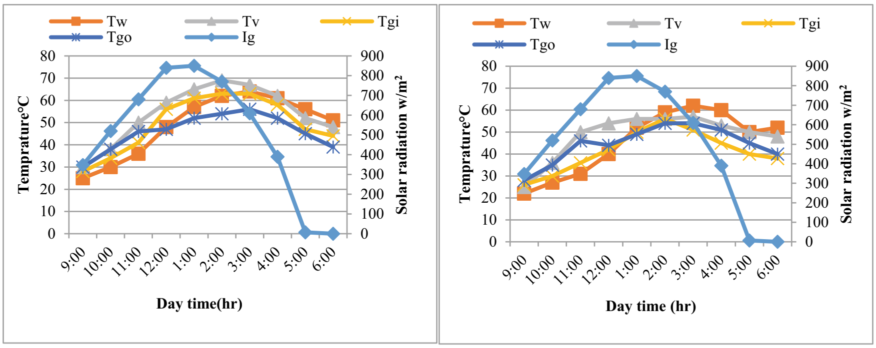


Fig. 2 Hourly variation of solar insolation, ambient temperature for February 28, 2018

5.2 Solar Still Temperatures Variation with Solar Radiation

Figure 3a, b shows solar still temperatures variation with daytime at the water depth of 2 cm. In case of modified solar still having cement blocks, the highest water temperature attended in basin is 64 °C, glass temperature at inside and outside are in the ranges of 28–63 and 30–56 °C, respectively. The maximum basin water temperature is 62 °C in conventional solar still, and inside and outside glass temperature are in the ranges of 26–56 and 28–54 °C, respectively. The basin water temperature in modified still is higher than the conventional solar still by about 0–10 °C. This is primarily because the high heat energy storage capacity of cement block, and it continuously dissipating heat to the basin water as a heat source. The maximum water temperature occurs at 3–4 pm.

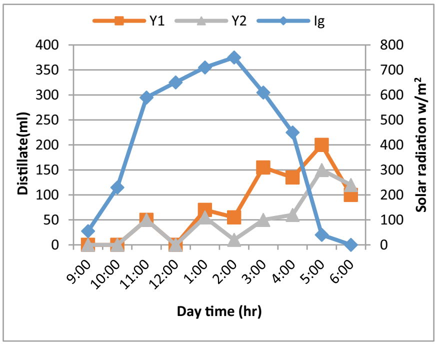


(a) Modified Solar Still **(b)** Conventional Solar Still

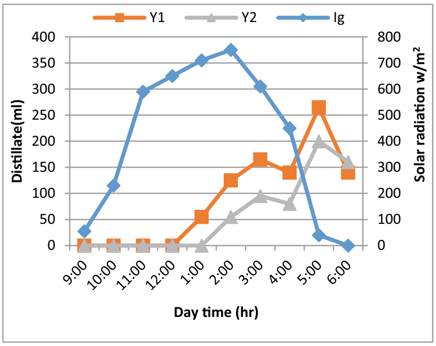
Fig. 3 Variation of temperatures at different locations with 2 cm water depth on February 28, 2018

5.3 Hourly Output Variation During Daylight Hours

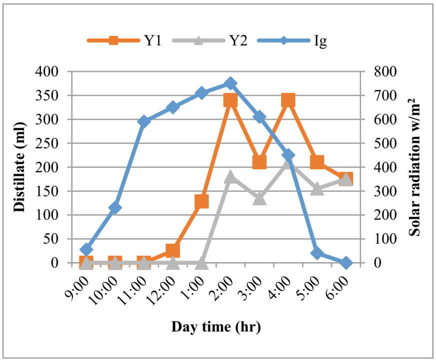
Figure 4a–c shows hourly distillate variation for both solar stills with 5, 3, and 2 cm basin water depth. The underneath area of the curve shows the daylight output of modified and conventional stills. It is observed that daylight yield reduces with increasing water depth. Maximum daily distillate is obtained for the least water depth of 2 cm. Maximum hourly output is observed at 4 pm, i.e., 155 ml for 5 cm depth, 265 ml for 3 cm depth, 340 ml for 2 cm depth.



(a) At 5 cm water depth



(b) At 3 cm water depth



(c) Hourly variation of yield for both solar still for 2 cm water depth

Fig. 4 Hourly variation of yield for both solar stills

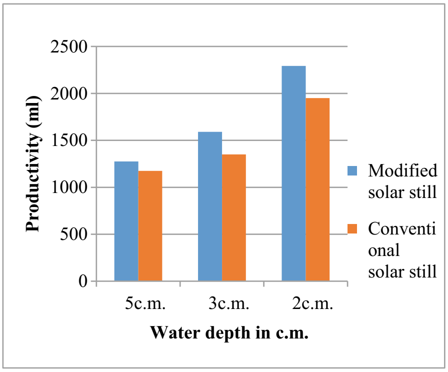


Fig. 5 Productivity variation with water depth

5.4 *Daily Productivity*

Figure 5 shows accumulated freshwater productivity variation with different water depths. At 5 cm water depth, distillate yield of 1275 and 1175 ml/m^2-day was obtained for modified and conventional solar stills respectively. At 3 cm water depth, distillate yield of 1590 and 1350 ml/m^2-day was obtained for modified and conventional solar stills respectively. At 2 cm water depth, distillate yield of 2293 and 1955 ml/m^2-day was obtained for modified and conventional solar stills, respectively.

6 Cost Analysis

The project must be economically viable for its success. Table 2 indicates apparatus/utilities and associated cost. Life span of the setup is implicit to be 10 years. In a year, sunlight is available roughly around 300 days. At 3 cm of water

Table 2 Cost of modified and conventional solar still

Material units	Modified solar still cost (INR)	Conventional solar still cost (INR)
Galvanized iron sheet	1200	1200
Plain glass	540	540
Black paint	300	300
Plyboard	750	750
Padding	150	150
Stand	780	780
Manufacturing cost	800	800
Cement blocks	600	–
Total fixed costs	5120	4520

depth in the basin, the approximate cost of water was obtained INR 1.13/L and INR 1.07/L for conventional and modified still. While at 2 cm water depth in the basin, it was INR 0.77/L for conventional still and INR 0.74/L for modified still respectively. Higher total fixed cost for modified still with cement blocks is compensated by positive increment in freshwater productivity.

7 Conclusions

Experiments were conducted with cement blocks as sensible heat storage material in a conventional solar still. The distillate productivity is compared with the conventional solar still (without cement blocks). Following points are drawn:

- Cement blocks in basin water increase evaporation rate. They act as heat storage material and liberate energy to water thereby increasing the overall productivity.
- Daytime output of modified still is 67% more than conventional solar still while off-daytime productivity was 27% lowered.
- Output trend reverses after sunset, and yield gradually starts increasing in the conventional still as compared to modified.
- Overall productivity (yield) increases by 17% in modified still. This implies that cement blocks satisfactory working as heat storage material.

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