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Enhancement of upper basin distillate output by attachment of vacuum tubes with double-basin solar still

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ABSTRACT

Generally, the distillate output of a solar still is low; hence it is not practicable for the solution of drinkable water in the universe today. Here, a new concept is utilized to increase distillate output of a solar still in use, the double-basin solar still integrated with vacuum tubes. In this research paper, an analysis of the top basin of present solar still with different energy absorbing materials like calcium stones, black granite gravel and pebbles for enhanced surface area of water is performed. Numerous experiments have been conducted in climate conditions of Mehsana (23.6000˚ N, 72.4000˚ E) Gujarat, from April to September 2013 with a constant depth of 2 cm inside top basin. Six months' result shows that, the distillate output of basing material with calcium stones found were more when compared with black granite gravel and pebbles.

Keywords: Double-basin solar still; Calcium stones; Pebbles; Granite gravel; Distillate output

1. Introduction

Water is essential for all life forms on the earth plants, animals and human. The lack of fresh water has always a trouble for humanity. Rapid industrial growth and worldwide population explosion have resulted in a huge rise in demand for fresh water, both for household needs and for crops, to produce adequate quantities of food [1]. Distillate output of single-basin single-slope solar still is very less and efforts have been taken by many researchers to increase the distillate output. Many researchers have found that the reduction in water depth increases the distillate output of the still [1–4]. The addition of dye in the basin water has raised the absorption of solar radiation and distillate output [5–7]. Various energy absorbing materials have been used to increase the distillate output of solar still [8]. Madani and Zaki [9] put rubber mate for the enhancement of the efficiency, and Naim and Abd El Kawi [10] have used charcoal as the absorbing material in the basin to raise the absorption of solar radiation. Furthermore, Nafey et al. [11] and Abdel-Rehim and Lasheen [12] have used to increase the distillate output using black materials, glass, rubber and black gravels. Kalidasa Murugavel et al. [13] put the spreading materials with a thin layer of water to increase the surface area of the basin. Arjunan et al. [14] have made requirements to store excess heat energy in solar stills during daytime and to store energy during night time for increasing the nocturnal production using a blue metallic stone as the energy storage medium. Kalidasa Murugavel et al. [15] have made an attempt to raise the distillate output using a layer of water and different sensible

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heat storage materials like quartzite rock, red brick pieces, cement concrete pieces, washed stones and iron scraps. Kalidasa Murugavel and Srithar [16] put various energy storage materials like light cotton fabric, sponge sheet, coir mate, waste cotton pieces and aluminium rectangular fin arranged in different shapes in the basin. Abdallah et al. [17] used various energy storage materials like black-coated and uncoated wiry sponges and quartzite rocks to increase the distillate output of solar still. Recently, Rajaseenivasan et al. [18] used various different wick and porous materials like black cotton cloth, jute cloth, waste cotton pieces, clay pots facing up and down and mild steel pieces in double-basin still and single-basin solar still and found that the double-basin solar still with mild steel plates was more productive when compared with other materials.

In this paper, a double-basin solar still with vacuum tubes made in locally available materials for increasing the distillate output of top basin was tested experimentally with various sensible energy storage materials like pebbles, black granite gravel and calcium stones for six months from April to September 2013 in climate conditions of Mehsana, Gujarat.

2. Procedure of experiment

The experimental set-up is installed at the Terrace of Gujarat Power Engineering & Research Institute, Mehsana Gujarat, India. Mehsana is a city with more than 250 d of sunshine in a year and an average solar insolation of more than 800 W/m^2. Hence, it is the best location for solar energy experiments. The experimental set-up mainly consists of a double-basin solar still with vacuum tubes, as shown in Fig. 1. The data logger attached to the solar still is demonstrated in Fig. 2. The hourly temperatures recorded in the computer with the help of the data logger are illustrated in Fig. 3. The overall size of the inner basin used is 1,006 × 325 × 380 mm and the outer basin is 1,006 × 536 × 100 mm. The absorber plates used in the inner and outer basins were made of aluminium sheet with black chrome paint for increasing the absorptivity of solar radiation. An insulation of 4 cm in thickness was provided at the bottom and the sides of the outer basin to prevent heat losses. Here, polyurethane foam with a thermal conductivity of 0.025 W/(m^2$K) was used for the present experiment. The evaporated water inside the inner and the outer basins was condensed by toughened glasses of 3 cm in thickness. The condensed water of the inner and outer basins was collected by hanging jars. A silicone rubber sealant was provided to hold the toughened glass in contact with solar still surfaces. A total of four holes were made on the inner and outer basins for the location of thermocouples. Here, 14 vacuum tubes were coupled with a hole of 6 cm in diameter in the lower side of the inner basin. The vacuum tubes were connected to the still stand at an angle of 35° with respect to the horizontal axis. Rubber gaskets were provided to fix the vacuum tubes attached to the inner basin of the solar still. The bottom portion of the vacuum tubes was connected to a sponge material to prevent the breakage of vacuum tubes. The instruments used in the present experiment with their accuracy, range and percentage of error are listed in Table 1.

3. Experimental set-up

Solar radiation was transmitted through the toughened glass cover to the saline or brackish water in the basin. Thus, the water in the basin got heated and evaporated. The evaporated water particles condensed on the inner side of the glass cover. The condensed water flew down the cover due to the slope and reached the distillate channel, where it was collected by the flask. At the beginning of the experiment, the water level inside both the basins was maintained at 2 cm in depth. The experiment was commenced after 24 h, from 7:00 am to 7:00 am the next day with the assumption that steady-state conditions were built every hour. For each experiment, the glass cover was cleaned to avoid dust concentration on the top of the glass cover of the outer basin solar still. The experiments were conducted on sunny days from April to September 2013. The variables measured in the present experiments were the water temperature of the top basin (T_{w1}), the inner glass cover temperature of the top basin (T_{gi1}), ambient temperature (T_a), vacuum tube temperature (T_b), solar radiation on evacuating tubes (Ie(t)), solar radiation with glass cover (Ig(t)), wind speed (v) and distillate output (m). Here, all the experiments were conducted during sunshine hours only with the help of the data logger. Hence, cloudy days were not preferred. The average velocity of wind is 2–3 m/s.

4. Results and discussion

Fig. 4 presents the comparison of distillate water output from the double-basin solar still with a constant water depth and different basin materials inside the top basin of the solar still. It shows that distillate output is higher with calcium stones compared with that of black granite gravel and pebbles as basin materials during the heating period. For all basin materials, the

Fig. 1. Experimental set-up of double-basin solar still with vacuum tubes.

maximum distillate output is obtained during 1:00 pm. Fig. 4 clearly shows that, during the cooling period, the distillate output of the top basin is also higher; hence, the nocturnal distillate output of calcium stones as basin material is higher compared with that of black granite gravel and pebbles as basin materials.

Fig. 5 shows the comparison of cumulative distillate output of the top basin with various basin materials. Here, all observations have been made by constant water depth and moderate sizes of basin materials; hence readings gained in the research are clear and easily understood. Fig. 6 clearly demonstrates that that distillate output is higher for calcium stones as basin materials during heating as well as cooling periods. Black granite gravel is also a good basin material to increase the distillate output after calcium stones and least cumulative distillate output is achieved by pebbles as basin material.

For a deep basin, a solar still with different wick-type materials, porous materials and energy storage materials were used by many researchers all around the world to enhance the distillate output of a solar still [9–11]. When the water layer in the solar still is low and different basin materials are applied to distribute water throughout the catchment area for increasing the surface area; a good result is received. There are many other basin materials available, so this leads to further study of such materials to increase the distillate output of a solar still.

Fig. 6 shows the comparison of top basin water temperature with different basin materials. The temperature rise is higher for the still with calcium stones as basin material during the heating and cooling periods. During the heating period, black granite gravel as basin material reaches its highest temperature at around 2:30 pm. For other basin materials, the water

Fig. 2. Data logger attached to double-basin solar still with vacuum tubes.

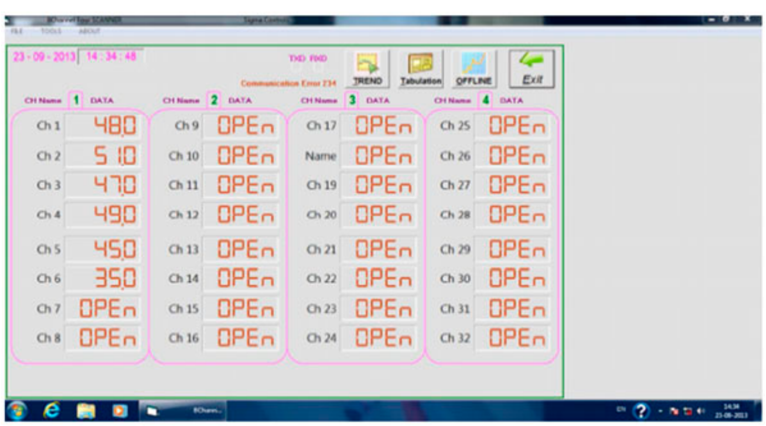

Fig. 3. Recorded readings of different temperatures in computer with the help of a data logger.

Table 1
List of Instruments with accuracy, range and percentage error

S. No.	Instrument	Accuracy	Range	% error
1	Thermometer	±1°C	0–100°C	0.25
2	Copper constantan thermocouple	±0.1°C	0–100°C	0.5
3	Solarimeter	±1 W/m²	0–2,500 W/m²	2.5
4	Anemometer	±0.1 m/s	0–15 m/s	10
5	Measuring jar	±10 ml	0–1,000 ml	10

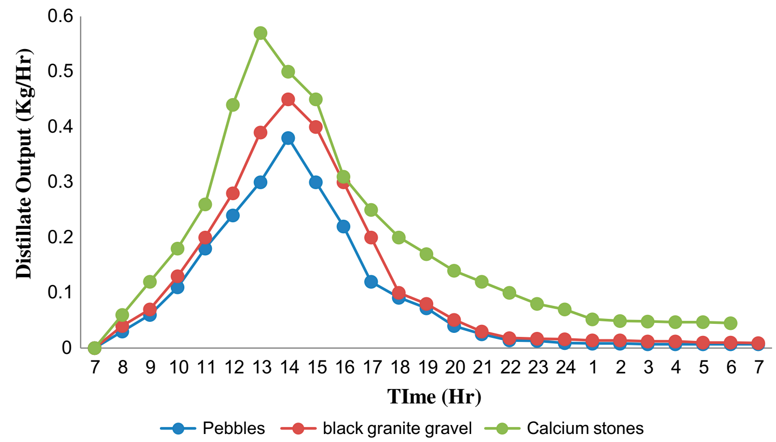

Fig. 4. Comparison of distillate output of top basin solar still with vacuum tubes.

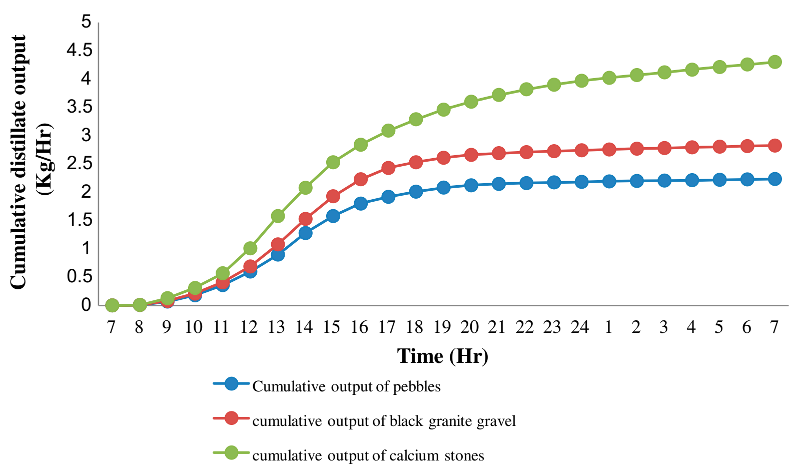

Fig. 5. Comparison of cumulative distillate output of top basin with various basin materials.

temperature rise in the top basin is uniform but it takes more time compared with black granite gravel. During the cooling period, the top basin with calcium stones and black granite gravel maintains higher water temperatures. Similar effects are obtained for inner glass cover temperature during the heating and cooling periods for the top solar still with the same basin materials, as shown in Fig. 7.

From the above analysis, it is evident that the distillate output from the solar still increases with increase in the water temperature during the heating period for all basin materials. During the heating

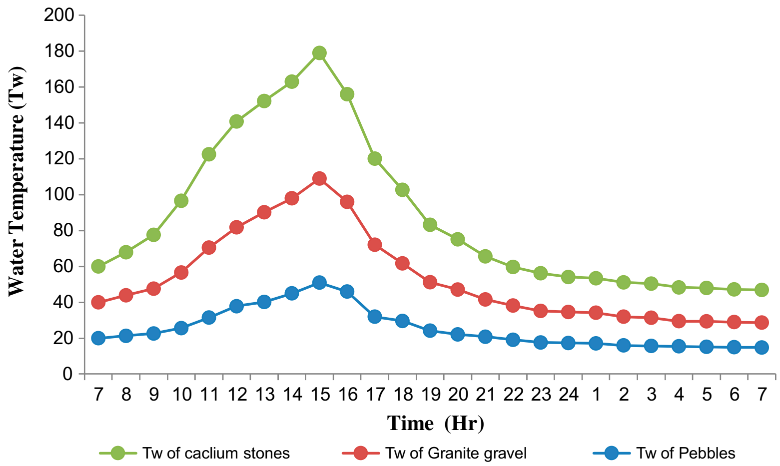

Fig. 6. Comparison of water temperatures of top basin with various basin materials.

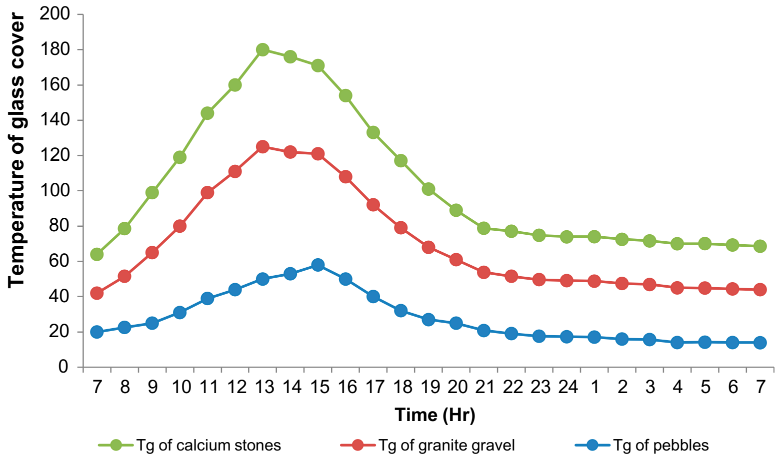

Fig. 7. Comparison of inner glass cover temperature of top basin with various basin materials.

period, as the water temperature increases, the glass cover temperature also increases. This is a very normal behaviour for each solar still but if the maximum water temperature condition is taken into consideration, at that time, a lower water temperature could also gain a remarkable distillate output when black granite gravel is used as basin material. During the cooling period, the solar still with higher water and glass cover temperatures increases the distillate output, while lower water and glass cover temperatures decrease the distillate output. Hence, the solar still with calcium stones as basin material gains remarkable distillate output during the cooling period due to higher water and glass cover temperatures and the solar still with pebbles as basin material gains a lower distillate output due to lower water and glass cover temperatures.

The distillate output of the top basin solar still increases with the increase in temperature difference between water and glass cover temperatures. Figs. 8–10 show the comparison of water temperature (T_{w1}), glass cover temperature (T_{g1}), difference of water and glass cover ($T_{w1} - T_{g1}$) temperature and distillate output of the top basin with different basin materials. It is clearly demonstrated that for each top basin material, it reaches its highest distillate output just before its water temperature reaches its highest value. For all basin materials, the distillate output increases with the increase in the temperature difference between water and glass cover temperatures ($T_{w1} - T_{g1}$). This value arrives at its maximum when the water temperature reaches 50–60°C during the heating period only, and decreases gradually after the completion of the heating period. This is the versatile behaviour of the solar still

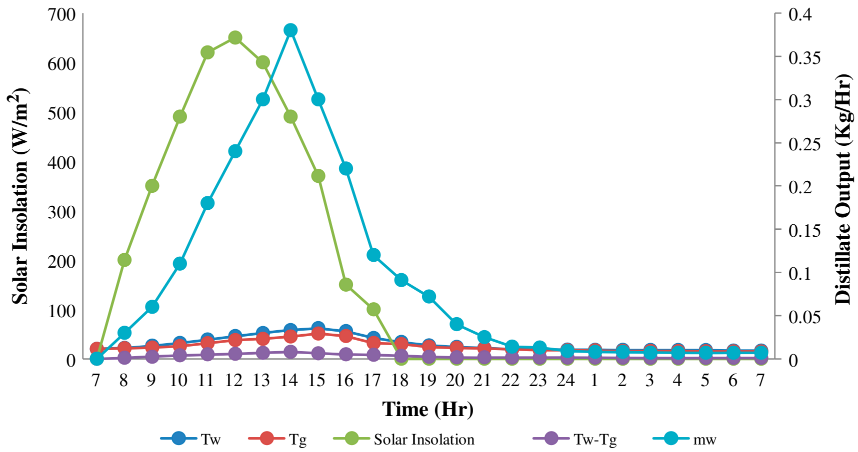

Fig. 8. Comparison of temperatures and distillate output of top basin solar still with pebbles as basin material.

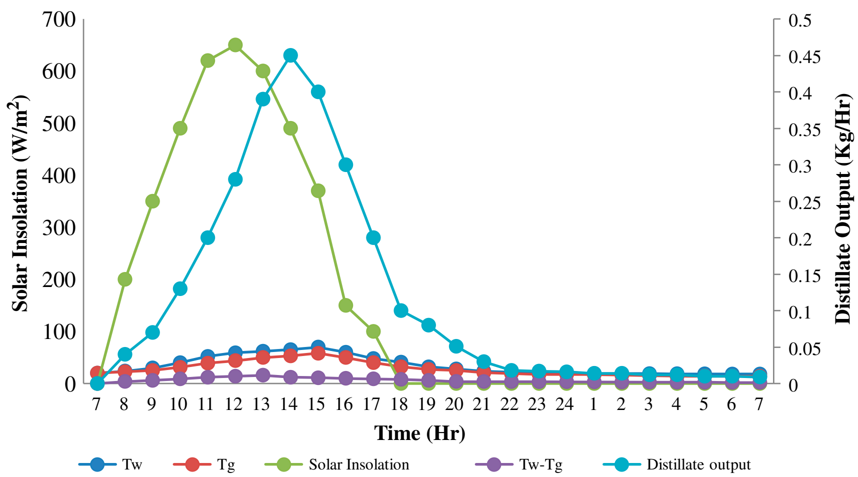

Fig. 9. Comparison of temperatures and distillate output of top basin solar still with black granite gravel as basin material.

noticed in every experiment. One more good behaviour of the solar still is that during the above period for certain duration, the distillate output decreases with the increase in basin water temperature, but when solar still reaches its maximum water temperature at that time, the solar still distillate output becomes lower than the maximum.

It is observed that for calcium stones in the basin, there exists a remarkable temperature difference between water and glass cover temperatures. Due to that difference, the distillate output increases linearly with the increase in temperature difference during bright sunshine hours, and the minimum water depth in the basin is maintained by the constant water depth in the top basin by suitable arrangement, which enhances the remarkable distillate output due to the low thermal capacity of the water in the basin. Rajaseenivasan et al. [18] used gravel as storage a material in vacuum tube integrated with solar still. He found a great increase in distillate output. Table 2 tabulates the density, thermal conductivity and specific heat capacity of basin materials used in the present experiment. Of all basin materials, calcium stones have a higher specific heat capacity than any other basin materials. Hence a large amount of solar energy utilized and stored during sunshine hours is relieved during the absence of the sun (night time). Calcium stones have pore holes. Hence they allow the saline water to store inside and energy stored during sunshine hours is gained by the saline water inside pore holes. As a result, during the absence of the sun, distillate output is higher.

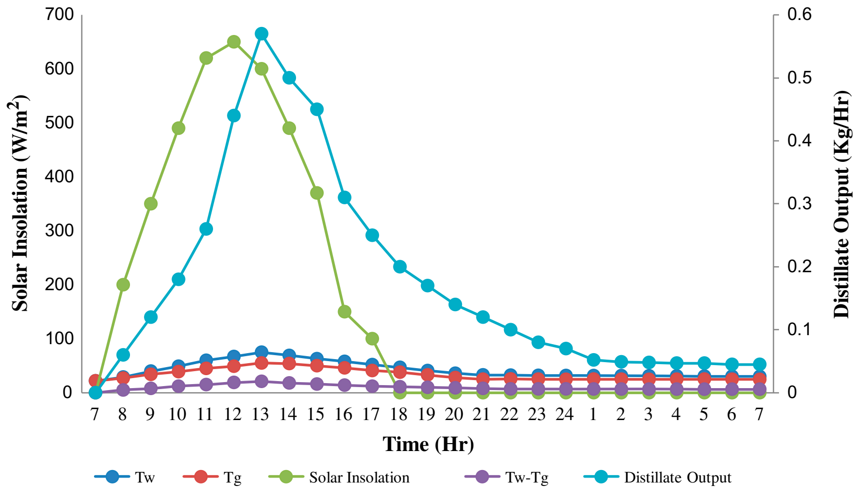

Fig. 10. Comparison of temperatures and distillate output of top basin solar still with calcium stones as basin material.

Table 2
Density, thermal conductivity and specific heat of various basin materials

S. No.	Materials	Density (kg/m^2)	Thermal conductivity (W/m K)	Specific heat capacity (J/kg K)
1	Calcium Stones	2,560	1.26–1.33	910
2	Pebbles	3,330	2.4–2.6	720
3	Black granite gravel	3,000	2–2.2	800

Calcium stones having a remarkable specific heat capacity of 910 J/(kg K) are the best basin materials compared with 3/4 inches quartzite rock with a specific heat capacity of 775 J/(kg K) [15] and blue metal stones [14] in the basin for efficient distillation. Table 3 presents the average distillate output gained by the top basin solar still from April to September 2013 with a constant water depth of 2 cm in the top basin. It is clearly indicated that the highest average distillate output is gained by calcium stones as a basin material in the top basin solar still (4.1 kg/h) and the lowest is gained by pebbles as storage material (2.9 kg/h). Black granite gravel is also a good basin material, with an output of 3.4 kg/h.

Table 3
Average distillate output of top basin solar still with various basin materials

Month	Water depth (m)	Pebbles distillate output	Granite gravel distillate output	Calcium stones distillate output	Alone solar still
Apr-13	0.02	3	3.4	4	2.7
May-13	0.02	2.8	3.3	4.2	2.6
Jun-13	0.02	3	3.4	4.3	2.8
Jul-13	0.02	3.1	3.5	4	2.8
Aug-13	0.02	3	3.4	4.1	2.6
Sep-13	0.02	2.9	3.4	4	2.7
Average distillate output of six months		2.9	3.4	4.1	2.7

5. Conclusion

In this present work, double-basin solar still with vacuum tubes having the overall size of the lower basin used is 1,006 × 325 × 380 mm, and upper basin is 1,006 × 536 × 100 mm fabricated from locally available materials and tested in climate conditions of Mehsana with 2 cm depth of water in top basin. For maintaining a constant layer of water in top basin, water should be spread in the entire basin, hence various basin materials like pebbles, black granite gravel and calcium stones are used. The variation of distillate output, cumulative distillate output, water and glass cover temperatures, difference of water and glass cover temperatures are analysed for various basin materials, hence, the following results have been obtained.

- Calcium stones are one of the best basin materials to increase the distillate output during sunshine and off-sunshine hours.
- Calcium stones have higher specific heat capacity when compared with other basin material to get higher distillate output with top basin water.
- Constant water depth of 2 cm inside the top basin has significant influence on thermal performance of top basin solar still.
- Difference of basin water temperature and inner glass cover temperature of calcium stones as basin material are higher compared with pebbles and black granite gravel as basin materials.
- Calcium stones posses good pore holes within its volume, and it helps to store the solar energy as well as saline water hence during night time, the distillate output of calcium stones as a basin material is remarkable.
- Average six months distillate output of calcium stones as basin material is higher of 4.1 kg/h compared with black granite gravel and pebbles like 3.4 and 2.9 kg/h.

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