Experimental Study of the Effect of Water Depth on the Productivity of Double Basin Solar Stills in Seawater Desalination

Chawisorn Phukapak*
Department of Energy and Environmental Engineering, Faculty of Engineering, Rajabhat Maha Sarakham University, Maha Sarakham, Thailand

Sorawin Phukapak
Department of Mechanical Technology, Faculty of Technology, Udon Thani Rajabhat University, Udon Thani, Thailand

* Corresponding author. E-mail: chawis_champion@yahoo.com DOI: 10.14416/j.ijast.2015.12.004
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Abstract

This research article studied the experimental of the effect of water depth on the productivity of double basin solar stills in seawater desalination. The experiment was carried out with the water depths at 1, 2, 3, 4 and 5 cm in order to obtain the appropriate water depth for purified water production during the day and at night and to analyze its efficiency. The study's results revealed that the basin single and double slope solar stills at the water depth of 1 cm produced the maximum purified water at 2,285 ml/day and 2,620 ml/day, respectively. During the day, the production rates of purified water were 1,628 ml/day and 1,869 ml/day. At night, the production rates were 657 ml/day and 751 ml/day, respectively. The efficiency was 24.46% and 28.04%. However, at the water depth of 5 cm, the lowest purified water production rates were 1,044 ml/day and 1,389 ml/day. During the day, the production rates were 744 ml/day and 989 ml/day while at night it was produced 300 ml/day and 400 ml/day, respectively. The efficiency was 11.42% and 15.19%. The lower water depth provides better productivity than the higher water depth since the surface of water is less, so it is able to accumulate higher thermal energy obtained from the transmission of heat from the sun until it reaches the latent heat of vaporization and it evaporates into the glass surface. Then the condensation is fast made, so it provides a long period of desalination. This results in more production rate.

Keywords: Solar still, Water depth, Production, Double basin, Efficiency, Seawater desalination

1 Introduction

Water is one of nature's most important gifts to mankind. It is essential to life as a person's survival depends on drinking water. About 97% is salty seawater and 2% is frozen in glaciers and polar ice caps [1]. Thus, 1% of the world's water supply is a precious commodity necessary for our survival. Solar desalination is the best method for purifying the impure water in a small scale. Solar stills are widely used in solar desalination but the productivity of the solar stills is very low. To enhance the productivity of the simple solar still, several research works are being carried out. Badran *et al*. [2] and Tiris *et al*. [3] integrated a flat plate collector with a single basin solar still. Influence of water depth on internal heat and mass transfer in a plastic solar still was studied by Phadatare and Verma [4]. Desalination of the brackish water using a passive solar still with a heat energy storage system was studied by Ansari *et al*. [5].

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Different works have proposed several cover inclination angles; 4°C [6], 10°C [7], [8], which include the use of reflective surfaces 15°C [9], 16°C [10], 40°C [11], and 23°C [12], [13]. Nevertheless an optimal angle of 14°C was proposed in Thailand, allowing more uniform production during the year, because in winter, (when, the angle increases), the efficiency increases, whereas for the summer (when the angle decreases), the efficiency decreases. Murugavel *et al*. [14] reviewed different passive methods to improve the effectiveness of the single basin solar still. They reported that, the direction and inclination of the transparent cover, cover material, thickness and temperature are responsible for the performance of the still. Water depth and materials used in the basin also affect the performance of the still [15]. One of the solar devices which can be used for fresh water production is single slope solar stills. Due to the low volume of purified water produced by the single basin still, it is not accepted in some instances. Therefore, there is a need to improve the efficiency of such type of stills [16]. Multi-wick passive stills possess two or more stages, where reutilization of latent heat of condensation occurs [17]. In order to minimize the convective and radiation losses, double-basin type still is fabricated. It possesses an additional transparent sheet of material fixed in between the basin liner and the glass cover [16]. Ghoneyem and Ileri [18] carried out experiments with different thickness glass covers and reported 16.5% more production in 3 mm thickness cover plate. Murugavel *et al*. [19], [20] and Rajaseenivasan *et al*. [21] concluded the considerable effect of energy storing and wick materials on the productivity of the solar still. Provision of additional glass basin is another method for increasing the productivity by means of latent heat recovery [22]–[24]. Tiwari and Mohamed Selim [25] reported that FRP multi-wick solar still is the more economical and efficient one than the conventional still. Cappelletti [26] experimentally studied the performance of the double basin solar still fabricated with Plexiglas. It gave a maximum productivity of 1.7–1.8 l/m^2/day with the efficiency about 0.16. Phadatare and Verma [4] experimentally investigated the performance of the single slope single basin plastic solar still. The sides of the still were made up of 3 mm black acrylic sheets and insulated with 2.5 cm glass wool. At 2 cm water depth, maximum distillate production of the solar still.

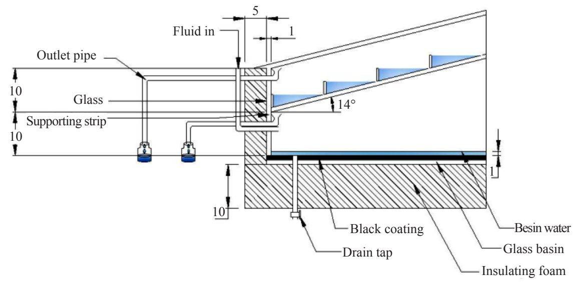

Figure 1: Schematic diagram of a double basin single slope solar still (SS).

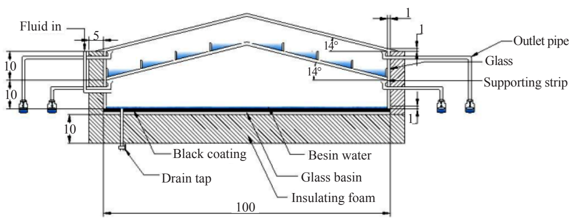

Figure 2: Schematic diagram of a double basin double slope solar still (DS).

In this work, double basin single and double slope solar stills were entirely fabricated with cheaply available window glass. The experiments were conducted to study the effect of water depth on the productivity of the solar stills. The productivity of the single slope solar stills was compared with the productivity of the double slope solar stills.

2 System Description and Experiments

The double slope single and double basin glass based solar stills were used in the study. The size of the still was 1 m × 1.5 m × 0.5 m with a drainage tap. The height of each floor was 0.1 m. It was made of glass with 14°C inclination to receive the thermal energy from the sun. At the top of the basin, the glass was designed as a series of steps to add more space in order to allow it to receive more thermal energy. The bottom of the basin was packed with 0.1 m foam, 0.01 m glass and 0.01 m black coating. The experiment was carried out at the bottom of the basin with the water depth of 1, 2, 3, 4 and 5 cm in order to obtain the appropriate water depth for purified water production during the day and at night and to analyze the efficiency of the double basin single and double slope solar stills as shown in Figure 1 and 2.

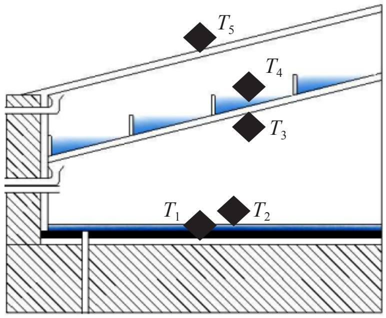

Figure 3: Location of temperature sensors (SS).

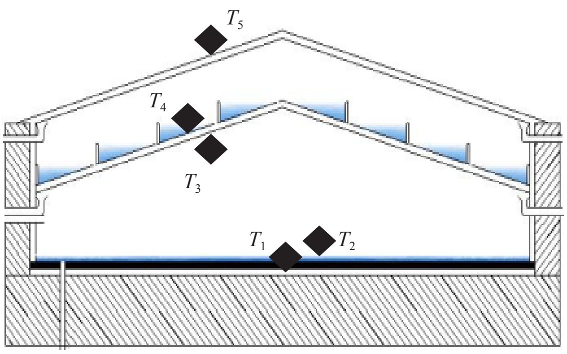

Figure 4: Location of temperature sensors (DS).

This research was conducted to study the depths of the water affecting the efficiency of the double basin single and double slope solar stills. The solar radiation, the changes of the temperature in the still, and the volume of purified water accumulated throughout the day in each floor were measured and analyzed for the efficiency. The water depths were varied at 1, 2, 3, 4 and 5 cm. The solar still was installed to face the east and the west directions in order to get appropriate thermal energy from the sun. Thermo Couples were set at different areas of the solar still to measure the temperature. It was defined as T_1, T_2, T_3, T_4 and T_5 representing the temperature at the black absorbtion coating, the bottom surface of water, the bottom floor of the glass, the upper surface of the water and the upper floor of the glass, respectively as shows in Figure 3 and 4. After that the Thermocouples were connected to the thermometer to measure the temperature at varied water depths of 1–5 cm. The volume of purified water then was measure by a beaker; the anemometer was used to measure wind speed; and the wet bulb and dry bulb thermometers were used to measure the temperature in order to identify relative humidity. The measurements were measured at various points every 1 hour starting from 01:00 a.m. to 12:00 a.m.

Table 1: Calibrations and error limits for various measuring instruments

SI. no	Instrument	Accuracy	Range	% error
1	Thermocouple	+0.1°C	0–100°C	0.5%
2	Thermometer	+1°C	0–100°C	0.25%
3	PV type sun meter	+1 W/m^2	0–2500 W/m^2	2.5%
4	Anemometer	+0.1 m/s	0–15 m/s	10%
5	Beaker	+10 ml	0–500 ml	10%

The principles were as follows. The thermal energy from the sun was passed to the transparent cover which made of glass on the top and the thermal energy absorbed by water in the solar still. When water was heated up, it evaporated because the vapor pressure increased and the water evaporated up to the top of glass by the convection and the steam was distilled at the bottom of the glass. Therefore, the glass must be arranged in the right position to get the thermal energy from the sun and the slope must be appropriately managed to make the purified water flow to the pipe along the length of the solar still without any drops of water flowing back into the still in order to make the purified water flow to the container at the bottom of the solar still.

The formula to calculate the efficiency of desalination (η) was derived from the equation of [27], [28], as in Equation (1).

$$\eta = \frac{Vh_{fg}}{I_{av}\, t3600} \tag{1}$$

When V is the distillate volume (kg/m^2), h_{fg} is latent heat of vaporization (kJ/kg), I_{av} is the average of solar radiation (W/m^2) and t is the duration of solar radiation time in hours (s).

3 Results and Discussion

The experiment was conducted at varied water depths of 1, 2, 3, 4 and 5 cm. The solar radiation, the changes of the temperature in the still and the volume of purified water accumulated throughout the day were measured and the data were presented as follows.

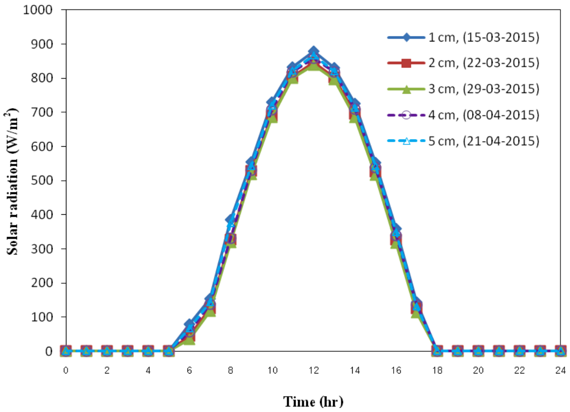

Figure 5: Variation of solar radiation.

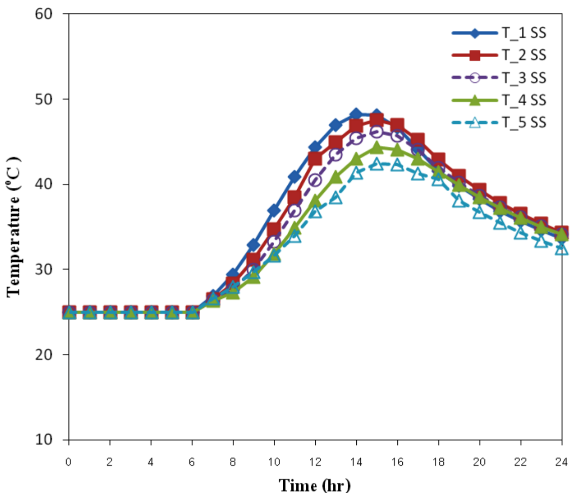

Figure 6: Variation of temperature distribution for asingle slope solar still.

Figure 5 represented the data of solar radiation throughout the day from March 2015 to April 2015. It was found that on 15 March 2015 at 1.00 p.m., the highest solar radiation was recorded: 878.66 W/m^2. The average solar radiation of the day was 518.96 W/m^2. The sun shined from 06.00 a.m. – 06.00 p.m., and the light intensity lasted for 12 hours throughout the day.

Figure 6 and 7 shows the variation of temperature distribution for the double slope solar still. In this part, the researcher would like to present the experiment of the double basin single slope solar still at the water depth of 1 cm. It was found that the highest temperature was at the black absorbtion coating (T_1) at 48.22°C. The temperature at the first floor (T_2) was 46.89°C which was higher than those of the second floor (T_4)

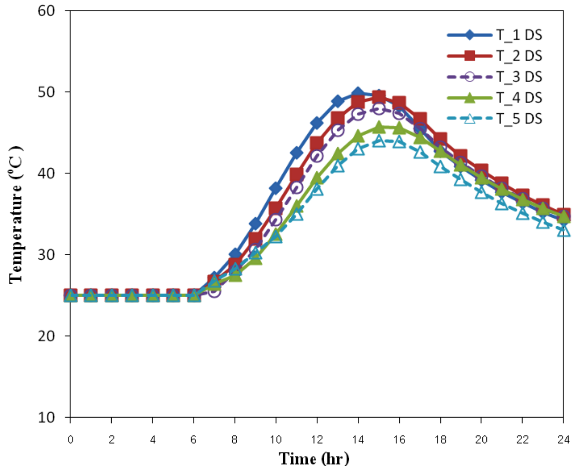

Figure 7: Variation of temperature distribution for adouble slope solar still.

which was 43.00°C. Also, the temperature at the first floor of glass (T_3) was 45.45°C which was higher than those of the second floor (T_5) which was 41.41°C. However, regarding the variation of temperature distribution of the double basin double slope solar still at the water depth of 1 cm, it was revealed that the highest temperature was at the black absorbtion coating (T_1) at 49.87°C. The temperature at the first floor (T_2) was 48.77°C which was higher than those of the second floor ($T4$) which was 47.33°C. In addition, the temperature at the first floor of glass (T_3) was 44.63°C which was higher than those of the second floor (T_5) which was 43.03°C. Moreover, the highest temperature throughout the day of the double basin double slope solar still at the water depth of 1 cm was 48.90°C.

Figure 8 presented the cumulative production rate of the double basin single and double slope solar stills at the water depth of 1 cm. The cumulative production rate of the double basin single slope solar still at the first floor was 906 ml/day while those of the second floor was 1,379 ml/day. On the contrary, the cumulative production rate of the double basin double slope solar still at the first floor was 1,078 ml/day while those of the second floor was 1,542 ml/day.

According to the experiment comparing the volume of water accumulated throughout the day in both double basin single and double slope solar stills, it was found that purified water started to be accumulated at 9.00 am., and the best output was obtained from 1.00 a.m. to 6.00 pm., noticing from the steepest slope of the

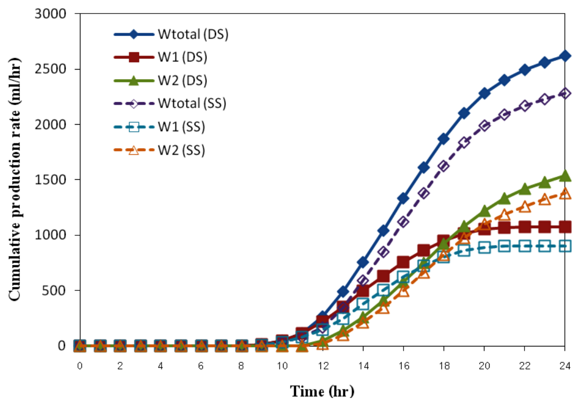

Figure 8: Cumulative production rate of double basin single and double slope solar stills.

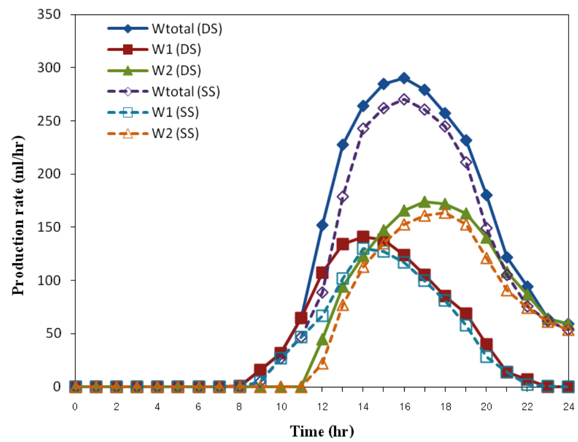

Figure 9: Compare production rate of double basin single and double slope solar stills.

graph of the day. From 6.00 a.m. to 9.00 a.m., it was the period of maximum solar radiation. However, there was no purified water production rate at this time since the water was needed to accumulate the heat until the latent heat of vaporization was reached and it then evaporated into the glass surface. The condensation then was made.

Figure 9 shows the comparison of the production rate of the double basin single and double slope solar stills at the water depth of 1 cm. The results revealed that at the first floor, the purified water was distilled before 9.00 a.m. while at the second floor; it was produced at 11.00 a.m. However, the production rate of the second floor was less than those of the first floor. At 3.00 p.m., the production rate of the second floor had been increasing and it finally was more than the production rate of the first floor. After 3.00 p.m. the production rate of the first floor started to decrease. This was because the heat accumulated in the first floor decreased since the heat had passed from the second floor to the first floor. But, the water was still normally insulated since a lot of heat was accumulated. At 6.00 p.m., the production rate started to drop but the condensation was still going on when there was no sunlight because the temperature difference between the glass and the surface water still occurred. However, the rate of condensation reduced.

Figure 10 presented the difference production rate of the double basin single and double slope solar stills. It showed that the production rate of the second floor was higher than those of the first floor. When comparing among the water depths of 1, 2, 3, 4 and

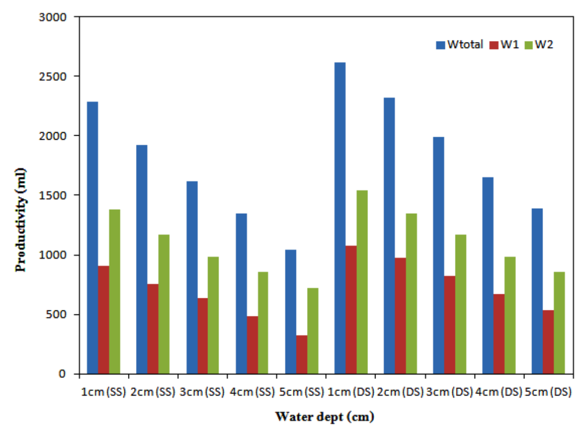

Figure 10: Difference production rate of double basin single and double slope solar stills.

5 cm, it was found that at the water depth of 1 cm of the double basin single and double slope solar stills, the maximum production rates provided at the first floor were 906 ml/day and 1,078 ml/day, and those of at the second floor were 1,379 ml/day was 1,542 ml/day. At the 5 cm of water depth, the least production rates at the first floor were 325 ml/day and 534 ml/day, and those of at the second floor were 719 ml/day and 855 ml/day. This was because the shallower level of water absorbs thermal energy better than the deeper level of water as the surface area of water was less. The temperature reached the latent heat of vaporization and it then evaporated into the glass surface and the condensation was fast made, resulting in more production rate.

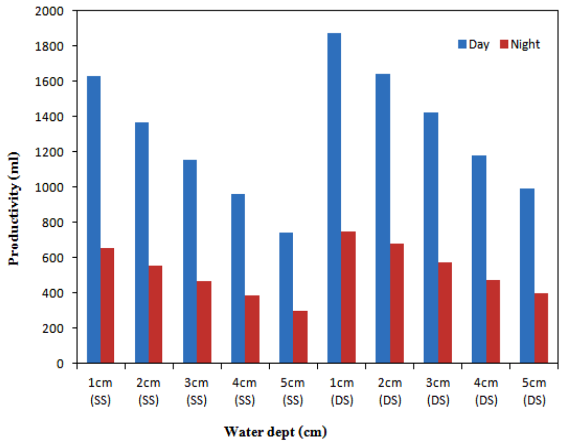

Figure 11: Day and night productivity rate of double basin single and double slope solar stills.

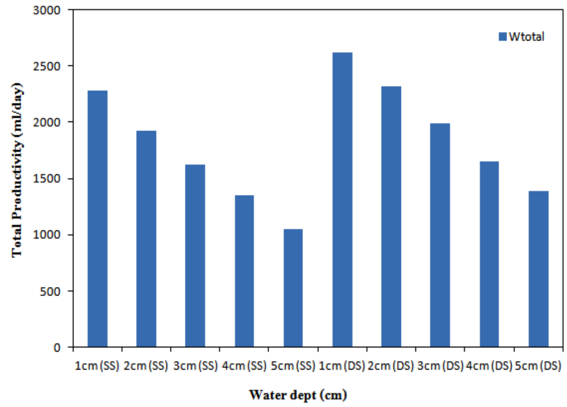

Figure 12: Total daily production rate of double basin single and double slope solar stills.

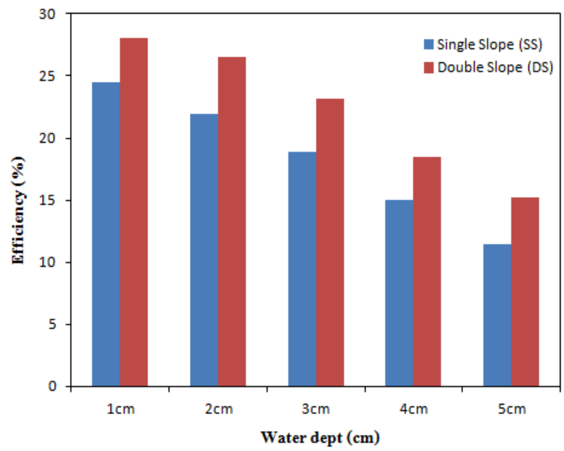

Figure 13: Accumulative efficiency of double basin single and double slope solar stills.

Figure 11 shows day and night productivity rates at the water depths of 1, 2, 3, 4 and 5 cm of the double basin single and double slope solar stills. During day time, the production rate was higher than those of the night time because the thermal energy was directly obtained, so the temperature reached the latent heat of vaporization and it then evaporated into the glass surface and the condensation was fast made. This resulted in more production rate. On the contrary, during the night, there was no thermal energy transmission, but thermal energy had been accumulated during the daytime. So, it provided less production rate at night. It was also found that the maximum production rates of the double basin single and double slope solar stills at the water depth of 1 cm were 1,628 ml/day and 1,869 ml/day during the day while they were 657 ml/day and 751 ml/day at night.

Figure 12 was the total daily production rate at the water depths of 1, 2, 3, 4 and 5 cm of the double basin single and double slope solar stills. At the water depth of 1 cm, it can produce the maximum volume of purified water. However, at the water depth at 5 cm, the lowest purified water production rates.

Figure 13 shows the accumulative efficiency of the double basin single and double slope solar stills. It was found that the accumulative efficiency of the double basin single slope solar still at the water depth of 1 cm was 24.46% which was the maximum efficiency while those of at the water depth of 5 cm was 11.42% which was the least efficiency. The accumulative efficiency of the double basin double slope solar still at the water depth of 1 cm was 28.04% which was the maximum efficiency while those of at the water depth of 5 cm was 15.19% which was the least efficiency. It was obviously seen that the efficiency of the double basin double slope solar was still higher than that of the double basin single slope solar. Therefore, the conclusions of the experiment of the double basin single and double slope solar stills, including the average radiation, the production rates and the efficiency were presented in the table 2.

Table 2: Variation in operating parameters of double basin single and double slope solar stills

Date	**15/3/2015**		**22/3/2015**		**29/3/2015**		**08/4/2015**		**24/4/2015**	
Dept of Basin Fluid	**1 cm**		**2 cm**		**3 cm**		**4 cm**		**5 cm**	
Operating Condition	**SS**	**DS**	**SS**	**DS**	**SS**	**DS**	**SS**	**DS**	**SS**	**DS**
Average radiation (*W/m²*)	518.96		487.15		478.43		498.57		507.86	
Day production (*ml*)	1,628	1,869	1,369	1,643	1,156	1,419	961	1,179	744	989
Night production (*ml*)	657	751	552	679	466	572	388	475	300	400
Production rate of 1 floor (*ml*)	906	1,078	754	976	637	825	488	672	325	534
Production rate of 2 floor (*ml*)	1,379	1,542	1,167	1,346	985	1,166	861	982	719	855
Total production (*ml/day*)	2,285	2,620	1,921	2,322	1,622	1,991	1,349	1,654	1,044	1,389
Accumulative efficiency *(%)*	24.46	28.04	21.91	26.48	18.83	23.12	15.03	18.43	11.42	15.19

4 Conclusions

According to the experiment of the production rate at the water depths of 1, 2, 3, 4 and 5 cm, it was found that the production rates of the double basin double slope solar still were higher than those of the double basin single slope solar still in all water depths since the thermal energy was obtained by both sides. Also, the differences of the water depths at 1, 2, 3, 4 and 5 cm also affected the production rate because the shallower level of water provided better production rate as the surface area of water was less than the deeper level of water. So, it can accumulate the thermal energy better and this allowed the temperature to reach the latent heat of vaporization and it then evaporated into the glass surface. The condensation then was fast made, and this resulted in more production rate. At the water depth of 1 cm, the double basin single slope solar still produced the maximum production rate. The cumulative production rate of the double basin single slope solar still at the first floor was 906 ml/day while those of the second floor was 1,379 ml/day. During the day, the maximum production rate was 1,628 ml/day while it was 657 ml/day at night. The efficiency was 24.46%. At the water depth of 5 cm, the least production rate. The production rate of the first floor was 325 ml/day and that of at the second floor was 719 ml/day. During the day, the production rate was 744 ml/day while that of at night was 300 ml/day. The efficiency was 11.42%. According to the double basin double slope solar still, the maximum production rate at the water depth of 1 cm. At the first floor, the production rate was 1,078 ml/day while that of the second floor was 1,542 ml/day. During the day, the production rate was 1,869 ml/day while at night it was produced 751 ml/day. The efficiency was 28.04%. At the water depth of 5 cm, the least production rate. The production rate of the first floor was 325 ml/day 534 ml/day and that of the second floor was 855 ml/day. During the day, the production rate was 989 ml/day while that of at night was 400 ml/day; and the efficiency was 15.19%.

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