Effect of Depth of Water on the Performance of Stepped Type Solar Still

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***Abstract-* The research work carried out so far in the field of solar desalination is related to the single basin type solar still only. The effect of changes in design, climatic and operational parameters on the distillate yield has been studied but limited to the single basin type solar still. The increase in productivity by connecting a flat plate collector which is called as active solar desalination has also been studied but limited to the single basin type solar still. Present study deals with a stepped type solar still to improve the performance of single basin type solar still by increasing the production rate of distilled water. The modifications in the design of single basin type solar still are introduced by replacing the flat basin by a stepwise structure. The stepped type solar still selected in this case has 8 number of steps of size 620 mm(L) x 100 mm(W) and total absorber area equal to 0.5093 m^2. The characteristic feature of stepped type solar still is that it provides an additional 40% absorber area as compared to the single basin type solar still.**

In this work, three number of stepped type solar stills with varying depth of water and other design parameters like thickness of glass cover, insulation thickness, condensing cover material, shape of the absorber surface, absorbing material provided over the basin surface, angle of inclination of the still etc. being fixed have been selected for experimentation. The depth of water provided in solar stills A, B and C was 5 mm, 7.5 mm and 10 mm respectively. After conducting experiments for the varying depths of water, it has been observed that the distillate yield of solar still A is greater than solar still B and C by 14.15% and 22.64% respectively. Thus, as depth of water goes on increasing, the distillate yield produced per unit area of absorber surface goes on decreasing. Also, an economic analysis was made. The payback period of solar still A, B and C is 823 days, 958 days and 1064 days respectively. Thus, the solar still A with 5 mm depth of water gives the returns within the least possible time as compared to other two types of stepped solar stills.

Keywords- Stepped Type Solar Still; Depth of Water; Distillate Yield; Thermal Performance

I. INTRODUCTION

Water is one of the prime elements responsible for life on earth. It covers three-fourths of the surface of the earth. However, most of the earth’s water is found in oceans as salt water, contains too much of salt, cannot be used for drinking, growing crops or most industrial uses. The remaining earth’s water supply is fresh water. Most of this is locked up in glaciers and ice caps, mainly at the north and south poles. If the polar ice caps were to melt, the sea level would rise and would flood much of the present land surfaces in the world. The rest of the world’s supply of fresh water is found in water bodies such as rivers, streams, lakes, ponds and in the underground. Our drinking water today, far from being pure, contains some two hundred deadly commercial chemicals, toxins and impurities. So there is an important need for clean and pure drinking water. In many coastal areas where sea water is abundant but potable water is not available, solar water distillation is one of the many processes that can be used for purification as well as desalination. Solar still is the widely used solar desalination device. But the productivity of the solar still is very low. To augment the productivity of the single basin type solar still, much research works has been carried out. The work is summarized as follows.

The effect of depth of water on the performance of a single basin type solar still has been studied by a number of investigators around the globe but its effect on a stepped type solar has not been studied yet. G. N. Tiwari and Madhuri [1] have studied the effect of water depth on daily yield of a single basin type solar still using transient analysis. It is found that the dependence of yield on water depth is a strong function of initial temperature of the brine in the basin of the still. It is concluded that the daily yield increases with depth for an initial temperature of the brine $\geq 45^0$C and decreases with depth for an initial temperature of the brine $\leq 40^0$C. This also has been verified experimentally at IIT, Delhi. A. S. Nafey, M. Abdelkader, A. Abdelmotalip and A. A. Mabrouk [2] have investigated the main parameters affecting solar still performance under the weather conditions of Suez Gulf area. The numerical result illustrates that as the brine depth increases, the solar still productivity decreases. G. N. Tiwari, Vimal Dimri and Arvind Chel [3] have undergone the parametric study of an active and passive solar stills based on the computer based thermal models. It is seen that the daily yield decreases with the increase of water mass in case of passive solar still. Whereas in case of passive solar still it is found that as the depth of water increases, the daily yield increases and after reaching the peak value at 11 cm; the daily yield decreases.

B. A. Akash, M. S. Mohsen and W. Nayten [4] have conducted experiments on the basin type solar still under local climatic conditions at Applied Science University, Amman, Jordan. The results showed that water production decreased in a somewhat linear relationship with increasing water depth in the still.

Malik et al. [5] have reviewed the work on solar distillation that includes various designs of solar stills like single basin still, multiple effect still, inclined solar still, solar still greenhouse combination and other designs of solar still, economic aspects of solar distillation and effect of meteorological and still parameters etc. In the studies on the effects of still parameters it is concluded that there is a variation of 30% in daily yield for variation in depth from 1.27 cm to 30.5 cm. In their conclusions the authors have not mentioned the inlet temperature of the brine in the basin which is the most sensitive parameter. Only the experimental fact has been referred to. In this communication, analytical transient expressions for water and glass temperatures and hourly yield of the still as a function of initial brine temperature, water depth, solar intensity and ambient temperature etc. are presented. For the evaluation of water and glass temperatures, evaporative, convective and radiative heat transfer coefficients from water to glass have been considered as temperature dependent parameters. Numerical calculations have been made for a typical summer day, viz. June 18, 1983 at Delhi. On the basis of numerical calculations, the following conclusions have been drawn:

(i) There is a decrease in daily yield, about 44%, by changing water depth from 1cm to 20 cm with initial water temperature at 35^0 C, which is in agreement with the result of Cooper [6] and Bloemer et al. [7].

(ii) There is an increase in daily yield by about 25% by changing water depth from 1 cm to 12 cm for an initial temperature of the water of 50°C. A good agreement between experimental and theoretical results has also been observed. It is also concluded that the evaporative heat transfer coefficient from water to the glass can only be considered as an average constant value at higher depth (i) about 25 cm for lower initial water temperature and (ii) about 10 cm for higher initial water temperature.

The objective of this work is to optimize the depth of water in the basin of a stepped type solar still. In this work, three different stepped type solar stills A, B and C with depth of water equal to 5 mm, 7.5mm and 10 mm respectively were used. The effect of depth of water on the distillate yield of these solar stills was observed. Theoretical analysis is also made by solving energy balance equations and compared with experimental results.

II. EXPERIMENTAL SETUP

The experimental setup consists of a saline water storage tank and a stepped type solar still mounted on an iron stand as shown in Fig. 1. The absorber plate in the still is looking like a stepped type of structure. The absorber plate is made up of galvanized iron sheet of 1mm thickness i.e. 22 gauge. The size of the absorber plate is 620 mm (W) x 808 mm (L). There are totally 8 number of steps in the absorber plate. Each individual step is of 100 mm (W) x 620 mm (L) cross-section and 36 mm height.

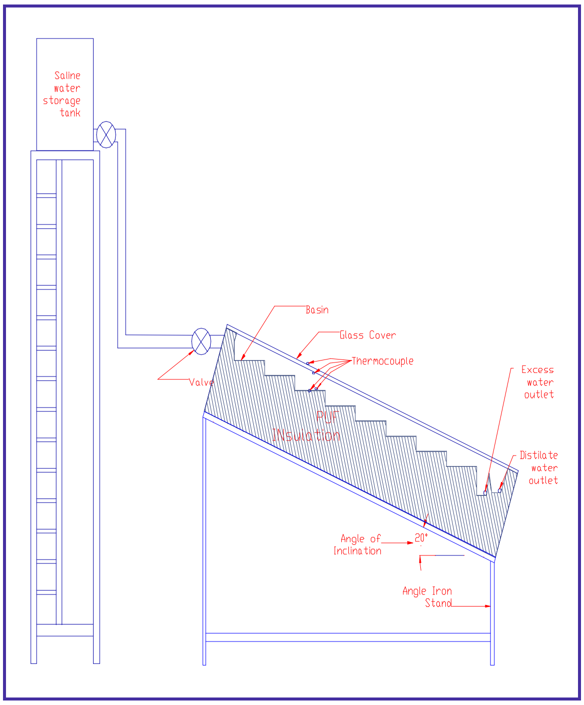


Fig. 1 Schematic diagram of the experimental setup

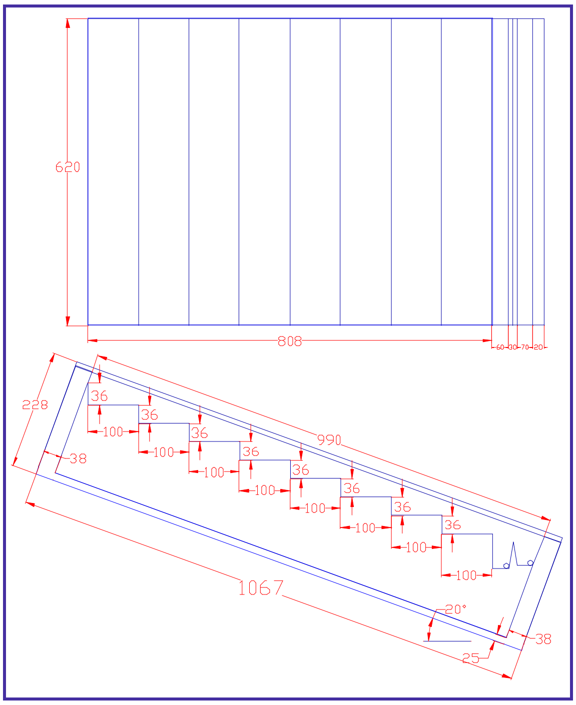


Fig. 2 Plan and elevation of the stepped type solar still

The stepped type structure of the absorber plate is coated with heat absorbent black dye because it is an established fact that black dye is the best solar radiation absorbing material. The absorber plate is placed inside a sheet metal box of size 620 mm (W) x 990 mm (L). The space between the sheet metal box and stepped type absorber plate is filled with polyurethane foam

(PUF) to avoid the heat loss from the bottom and sides of the solar still. The cover of the solar still is made up of 4 mm thick simple window glass. The saline water is supplied to the solar still from the saline water storage tank through poly vinyl chloride (PVC) hosepipe. The steps are filled with saline water one after another starting from the top and the excess water comes out from the excess water channel provided at the bottom. The excess water, if any is collected for reuse in the solar still. When solar radiations fall on the glass cover, it gets absorbed by the black absorber plate. Due to this, the water contained in the steps begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. When the water absorbs maximum solar radiations equal to the specific heat capacity of its mass, it is saturated and evaporation of water takes place. The basin also radiates energy in the infrared region, which was reflected back into the solar still by the galas cover, trapping the solar energy inside the solar still. The water vapors formed due to the evaporation of water are condensed at the inside of glass cover, as its temperature is less. To ensure that vapors are not lost to the atmosphere, the glass cover is sealed with a rubber gasket using an adhesive of Araldite and Bond-Tite. The condensed water trickles down to the distillate collection trough provided at the bottom and is collected into a glass beaker by using a hose pipe which is mounted at the side of the solar still.

As evaporation of water in the steps takes place, the saline water level in the solar still decreases. To compensate the loss of water, for every half an hour, the makeup water is added to the solar still from the storage tank. A separate hole is also drilled in the sidewall of the still to fix thermocouples to sense the temperatures of water in the basin, absorber plate temperature and inner glass cover temperature. The whole unit is placed on an angle iron stand inclined at an angle of 20^0 equal to the latitude of Buldana to the horizontal. The solar still is oriented due south as the location lies in the northern hemisphere to receive maximum solar radiation throughout the year. This stepped type solar still system has been fabricated in the workshop of Rajarshi Shahu College of Engineering, Buldana.

III. EXPERIMENTATION

The experimental work was carried out on the roof of the Non-conventional Energy Systems Laboratory of Mechanical Engineering Department. The experiments were performed during the months of January 2012 to April 2012 when the sky was clear i.e. on sunny days. The average sunshine in Buldana was 5.83 kWh/m^2/day during the above said period.

Five different thermocouples were installed on the soar still system at different locations. These locations were (i) bottom of the basin to measure the temperature of absorber plate, T_b (ii) inner surface of the glass cover, T_i (iii) outer surface of the glass cover, T_o (iv) water temperature in the basin, T_w and (v) ambient temperature, T_a. A multi-channel digital temperature indicator was provided to measure these temperatures. The collecting vessel is used for measuring distillate yield and a vane type digital anemometer is used for measuring wind velocity. The alloy combination, polarity and measurement range for the thermocouples are given in the Table-I.

TABLE I THERMOCOUPLES SPECIFICATION

S.N.	Item	Specification
1	Type of thermocouple	J – Type Iron constantan thermocouple
2	Alloy of positive wire	Iron (100% Fe)
3	Alloy of negative wire	Constantan (55% Cu – 45% Ni)
4	Temperature range	0 – 750^{0}C

The operating parameters and electrical specifications of anemometer are given in Table-II.

TABLE II ANEMOMETER

S.N.	Item	Specification		
1	Type of anemometer	Vane type digital anemometer		
2	Operating temperature	0 to 50^{0}C		
3	Operating humidity	Less than 80% RH		
4	Measurement in m/s	**Range**	**Resolution**	**Accuracy**
		0.4-30m/s	0.1m/s	±2%+0.2m/s)

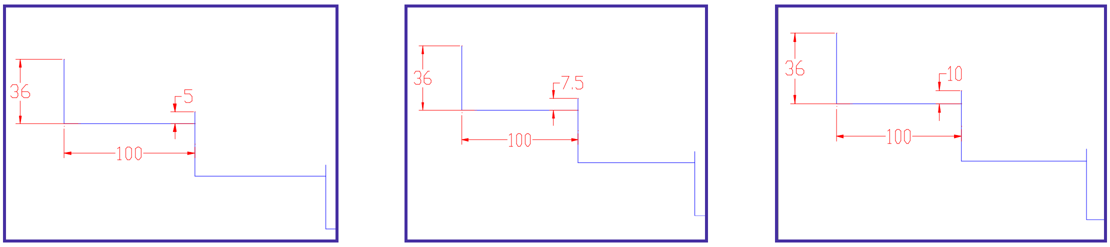
A. Stepped Type Solar Stills with Varying Depths of Water

The configuration and design parameters of solar stills A, B and C are given in the Table-III.

TABLE III DESIGN PARAMETERS OF SOLAR STILLS A, B AND C

S. N.	Type of solar still	Glass cover thickness in mm	Shape of absorber surface	Depth of water in mm
1	A	4	Flat	5
2	B	4	Flat	7.5
3	C	4	Flat	10

Stepped type solar still with depth of water equal to 5 mm(A), 7.5 mm(B) and 10 mm(C).



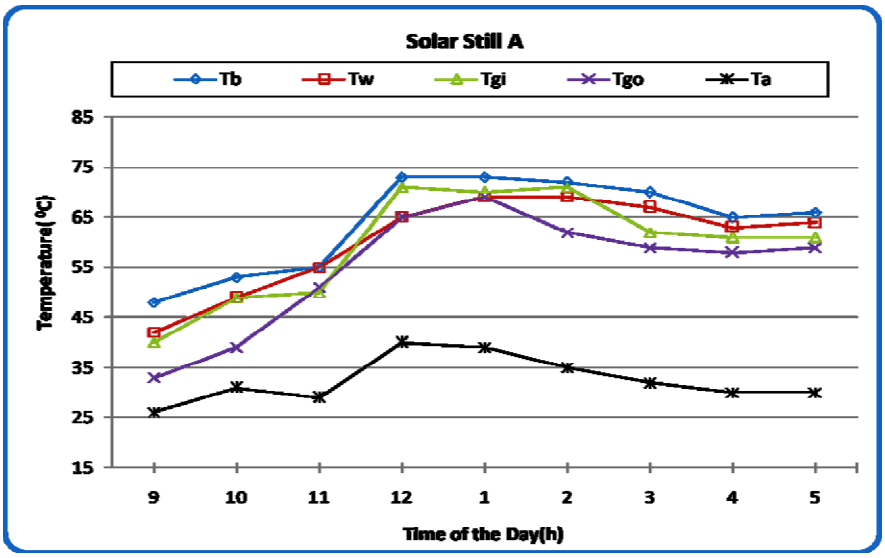
(A) (B) (C)

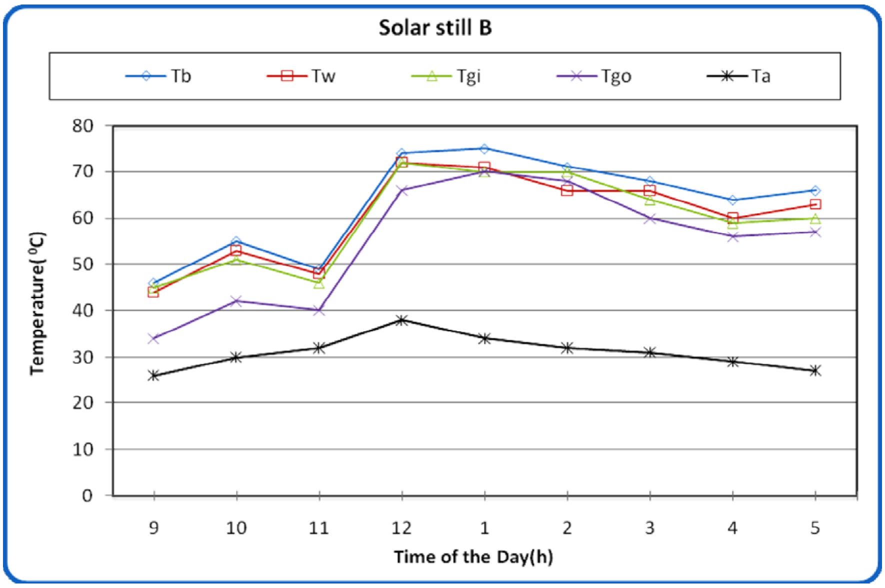
Fig. 3 Side view of absorber plate with depth of water equal to 5 mm(A), 7.5 mm(B) and 10 mm(C) respectively

IV. RESULT AND DISCUSSION

Fig. 4 represents the variation of hourly temperatures for an experiment conducted on the 5th March, 2012 for solar stills A, B and C. Similar trends were noticed on all other days.

Different variables were measured hourly, such as inner glass temperature (T_{gi}), outer glass temperature (T_{go}), ambient temperature (T_a), water temperature (T_w), basin temperature (T_b), wind speed (V) and distillate yield (Y). It can be seen that the temperature of the basin plate is the maximum followed by the temperature of water contained in the basin; which is heated due to incident rays. Then the temperature of the inner glass; where the condensation of vapours takes place and then the outer glass that transmits the incident rays and it is in contact with the surrounding. The ambient temperature is the least one out of all these temperatures. The maximum basin plate temperature occurs between the hours of 12.30 pm to 1.30 pm. It ranged between 60^0C and 70^0C. Ambient temperatures for all experiments were in the range of 22^0C to 33^0C.





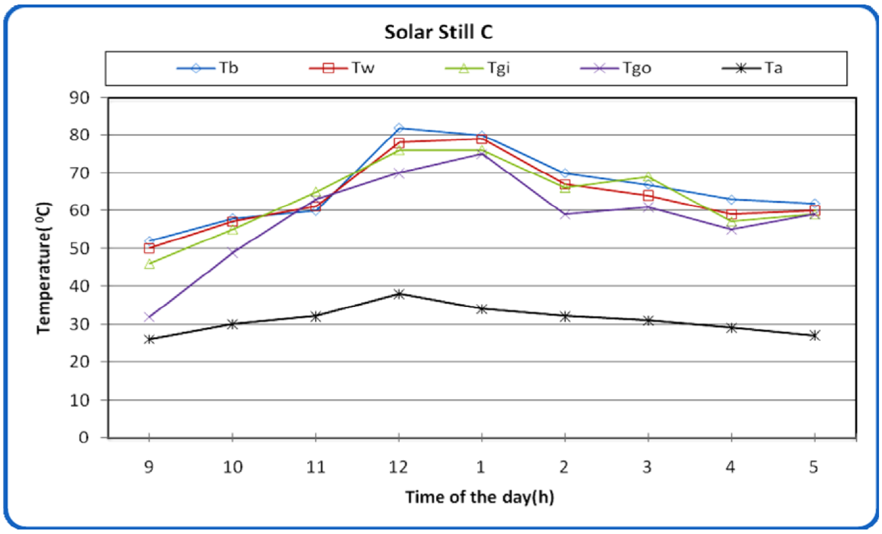


Fig. 4 Hourly variation between the temperatures at different locations of the solar stills A, B and C

Figure 5 shows the hourly variation of distillate yield for solar stills A, B and C respectively. On 5th March 2012, the distillate yield of solar still A with 5 mm depth of water is observed to be 1440 ml during the period from 10 am to 5 pm.

The depth of water in the basin of solar still B is 7.5 mm and the distillate yield obtained is 910 ml during the period from 10 am to 5 pm on the same day. Due to the increase in depth of water, the distillate yield decreases by 530 ml and this is 36.80% lesser than the stepped type solar still A.

The depth of water in the basin of solar still C is 10 mm and the distillate yield obtained is 745 ml during the period from 10 am to 5 pm. Due to the increase in depth of water, the distillate yield decreases by 695 ml and this is 48.23% lesser than the stepped type solar still A.

The effect of depth of water on the distillate yield of the stepped type solar stills A, B and C shown in the figure indicates that the distillate yield decreases with the increase of depth of water. This is due to the fact that at lower water depths, the specific heat capacity of water is less due to decreased water mass. This results in increase in water temperature causing faster evaporation of water in the basin. Hence, the distillate yield increases at lower water depths.

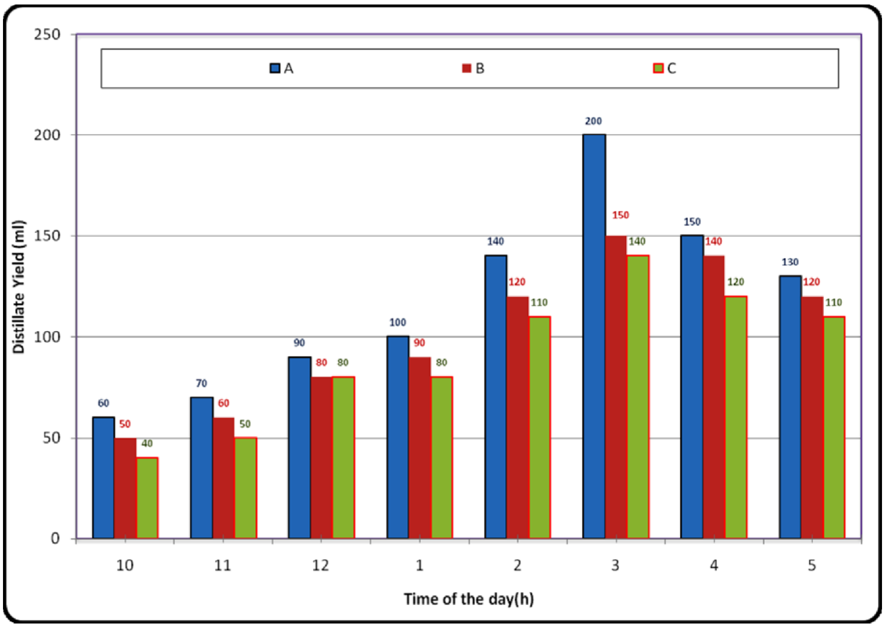


Fig. 5 Variation of distillate yield in ml with time of the day for solar still A, B and C

V. ECONOMIC ANALYSIS

The cost of distilled water produced by the stepped type solar still depends upon the following factors:

i) Capital cost of the solar still: The capital cost gets reduced if locally available materials are used.

ii) Cost of the energy source utilized for the purpose: As the solar energy is available free of cost, it has no effect on the total cost of the solar still.

iii) Operation and maintenance cost other than energy: The operation and maintenance cost is almost negligible.

The production rate of distilled water is proportional to the area of the solar still, which means that the cost per liter of water produced is nearly the same regardless of the size of the fabricated still.

The payback period of the experimental setup depends on overall cost of fabrication, maintenance cost, operating cost and cost of feed water. The overall fabrication cost is Rs. 8723. It is not necessary to take into account the operation and maintenance cost and the cost of feed water, which is almost negligible. As seen from the Table IV, the payback period of solar still A is less than that of still B by 135 days and that of still C by 241 days. Thus, the payback period of the setup A with 5 mm depth of water is the minimum of all the three setups compared in this case and it is 823 days.

TABLE IV CALCULATION OF PAYBACK PERIOD

Item	**A**	**B**	**C**
Overall cost to be considered	*Rs. 8723	Rs. 8723	Rs. 8723
Cost per litre of distilled water	Rs. 10	Rs. 10	Rs. 10
Average productivity of solar still	1.06 litres per day	0.91 litres per day	0.82 litres per day
Cost of distilled water produced per day	Rs.10.6	Rs.9.1	Rs.8.2
Payback period of solar still	823 days	958 days	1064 days

**:Rs. - Indian Rupees (₹)*

VI. SUMMARY AND CONCLUSION

The performances characteristics of stepped type solar still with different depths of water are analyzed in terms of productivity. Three number of stepped type solar stills with different depths of water in the basin were installed and tested. Solar still A has 5 mm depth of water, B has 7.5 mm depth of water and C has 10 mm depth of water in the basin. The readings were taken from 10 am to 5 pm. Hourly variations of solar radiation and distillate yield were recorded. It has been observed that the distillate yield of solar still decreases as the depth of water in the basin increases. For the given set of design and climatic conditions, the minimum depth of water resulting in the maximum distillate yield is found to be 5 mm. Also, an economic analysis was made. The payback period of the solar still A with 5 mm depth of water is the least as compared to other two types of solar stills and it is 823days.

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