Experimental Study on Double Basin Solar Still with Evacuated Tubes and Reflector

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Abstract

In this study the double basin with the size of 1000mm×330mm×380mm and 1000mm×590mm×310mm are used. This basin type solar still is a simplest method to produce clean potable water. Distillation is a technology to develop by using solar still. The natural water cycle is a type of distillation. In this project work, the experiments are carried out at different constant input conditions by maintaining a constant depth of water. Hourly inner as well as outer glass temperature, ambient air temperature was recorded during clear sunny days of Nagpur. The variation in production rate of different parameters has been analyzed. It is observed that the production rate increases by coupling evacuated tubes and reflector. The difference in rate of productivity of single and double basin is observed. The payback period for solar still is 137days.

Keywords: Double Basin Solar Still, Distillate Output, Evacuated Tube, Glass, Productivity, Reflector

I. INTRODUCTION

Water covers 71% of earth's surface. On earth 96.5% of the planet's crust water is found in seas and oceans, 1.7% in glaciers and the ice caps of Antarctica and Greenland, 0.001% in the air as vapour clouds and precipitation. Only 2.5% of this water is fresh clean water and 98.8% of that water is in ice and ground water. Less than 0.3% of all fresh water is in rivers, lakes and the atmosphere and an even smaller amount of the earth's freshwater 0.003% is contained within biological bodies and manufactured products. A greater quantity of water is found in the earth's interior. The safe drinking water is essential to human's and other life forms even though it provides no calories or organic nutrients. Access to safe drinking water has improved over the last decades in almost every part of the world, but approximately one billion people still lack access to safe water and over 2.5billion lack access to adequate sanitation. The human body contains 55% to 78% of water, depending on body size. To function properly, the body requires between six and seven liters of water per day to avoid dehydration the precise amount depends on the level of activity, temperature, humidity and other factors. Though most specialists agree that approximately 2 liters of water daily is the minimum to maintain proper dehydration.

Shanmugan et al.,[1] analysed a single basin single slope with hot water provision. Analysis is carried out for natural circulation with continuous output temperature of 53°C and the overall output of the still was found 4.915[kg/m^2]. Kalidasa et al.,[2]experimented with passive type double slope single basin still with 1.75m^2area, and the varying depths ranging from 2cm. Verified different input conditions for production rate with various temperatures. Model is predicted to use with minimum depth of water in basin in the range of 2cm to 2mm. and for basin water temperature up to 80°C. Rajamanickam et al.,[3] performed a single basin double slope with thin film of water. Still productivity was compared with size of still and effect of orientations like east-west and north-south on productivity. The flow rates obtained in the range of 100ml/min to 1800ml/min and the optimum flow rate was found to be 250ml/min. the maximum output of distillate was obtained 3.98L/Day/$m^2$with minimum depth of 10mm of water. Mitesh Patel et al [4]The solar still basin area of 1m^2 is to be tested with different surface coatings/materials and take performance variation with different sensible heat storage materials black, blue and red dye used inside the brackish water. The test results are to be compared with literature and with & without absorber media inside the still with different heat and mass transfer coefficients like evaporative, radiative and convective heat transfer. When it is kept in sunlight temperature inside the evacuated glass tube is more than 800C. The experimental set up was analysed by with and without dyes. It has been seen that output with black dye is higher compare to other dyes, while output was lower without dye. The authors found that, the distillation output increases slightly when the plate number is over 5, and it increased by about 34% and 15% when the evaporating plate numbers are 1 and 6, respectively. Collector area of 1.4m2, Collector angle of 150.The numbers of evaporative plates are optimized as 5 for the water flow rate is 50 kg/h. Only few researches have been reported and concluded that. The average distillate water production of 5 kg/m2 day was obtained by using 5 numbers of evaporative plates.

The objective of this project is to obtained maximum distilled water by double basin solar still. By this unit the clean potable water is used in the remote areas by using salted water as input. It requires less floor area and useful in any season. Two basins with double slope are used in the experiment.

II. EXPERIMENTAL SETUP AND METHODOLOGY

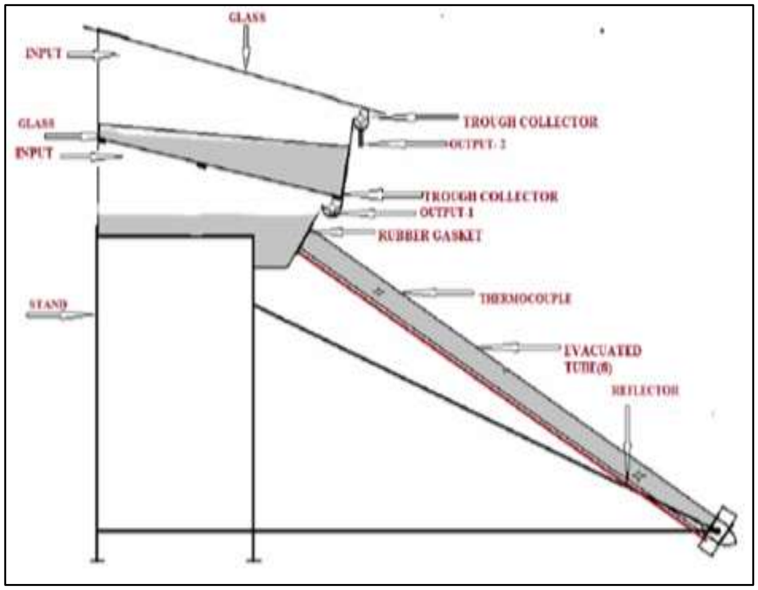

Fig. 1: Schematic of the experimental setup

The experimental setup was designed and installed at Nagpur, India. The major elements used in the experimental setup are double basin solar still and evacuated tubes. The experimental setup used for this project is shown in fig 1. The double basin solar still is made up of mild steel. Basins are painted with black colour. Water is filled in both basins for a height of 15cm at the bottom. Less water in the basin increases the temperature of water. Water indicators are provided in both basins. An insulation of 10mm thickness is provided at all sides of the basin to reduce the heat losses from basins. Cerawool with the thermal conductivity of 0.12w/mkis use for this purpose. The water in the basin is condensed by using an ordinary window glass of size for lower and upper basin is of 1000mm×580mm and 1000mm×600mm and the thickness is 5mm. The purified water condensed from the glass is collected by collecting trough. Collecting trough is in size of 1000mm×65mm×55mm. The collecting trough is connected with rubber pipe to collect the distillate water in a jar. A silicon rubber sealant is used to hold the glass intact with the still surface and to prevent the vapour leakages from the still. Holes are made in the upper side of both basin still for the inlet pipe and for the output from the basin. The outlet hole is from collecting trough. Thermocouples are fixed in both basins and for measurement of temperature 12no.K-type thermocouple is used. Another important part of this project is evacuated tubes. Arrangement of double basin solar still augmented with evacuated tubes is shown in fig. 2. Total 10 no. of evacuated tubes are coupled at lower side.

Fig. 2: Pictorial view of double basin solar still augmented with evacuated tubes

The inner and outer diameter of the evacuated tube is 45mm and 48mm with the length of 1500mm are used for this study. Rubber gasket is used as sealant to prevent the heat losses between the solar still and evacuated glass tubes as well as leakage losses. The evacuated tubes are placed on a metal frame at a height of 1m in order to absorb maximum radiations during a day period and it is connected to the still at an angle of 35° to 37° with horizontal surface. Reflector plate is made up of Aluminium in corrugated structure are used to increase the reflective radiation falling on evacuated tubes and it is fixed above the metal frame. The bottom end of the evacuated tube is well supported with sponge materials in a separate metal structure of the frame with the height of 0.5m. The glass of the tube absorbs the solar radiations and it transfers it as heat energy to the water in the tube. Vacuum space between the two glasses reduces the heat losses. The water circulation flows naturally through the single ended tubes. Water in the evacuated tubes is heated by the solar radiation and hot water rises to the still basin due to the density difference. The high temperature water from evacuated tube gets mixed up with the low temperature water in the lower basin still. This makes the low temperature water from the basin to flow back to the evacuated tubes and this process continues. The wind speed is measured using digital wind anemometer with the range of 0-15 m/s and accuracy of $\pm$ 0.1m/s. During the experimental analysis the wind speed measured was in the range of 2-5m/s. The temperature of distillation unit at various locations in the still was measured by "K" type thermocouples with the12 channels and the range of 0 °C – 1400 °C and accuracy of $\pm$ 1°C. A plastic measuring jar of 1500ml capacity is used for the collection of distillate output.

III. EXPERIMENTAL PROCEDURE

The incident solar radiation is transmitted through an tilted glass cover to the basin water in the upper basin. Thus the upper basin water gets heated up and the evaporation starts. The evaporated water particles condense in the inside layer of the toughened glass cover. This condensed water flows down the cover due to the slope provided and reaches the collecting trough, where it is collected by the collection jar. Water in the lower basin is heated by the water heat loss from upper basin and the heated water from evacuated tubes. Same procedure is done in a lower basin of solar still. At the beginning of the experimental analysis, salted water is filled in both basins up to 6 cm height through the inlet pipe. The experiment is commenced after 24 hours of assembling the glass cover, so as to enable the setup to reach the steady state condition. Daily the experimental analysis starting from morning 9 am to evening 6 pm at hourly intervals. Here these hours are selected because of bright sunshine occurs during such hours. For each experiment glass cover is cleaned to avoid dust collection on the top of glass cover of the outer basin solar still. Here, the experiments have been conducted in the sunny days of May, 2016. The variables measured in the present experiments are Ambient temperature(Ta), Inner basin temperature(Tb1), Outer basin temperature(Tb2), Outer glass cover temperature of the inner basin (Tg1), Outer glass cover temperature of the outer basin(Tg2), Vapour temperature of inner basin(Tv1), Vapour temperature of outer basin(Tv2), Evacuated tube inlet temperature(Tei), Evacuated tube outlet temperature(Teo), Radiation on evacuated tube(I(t)e), Radiation on still(I(t)s), Wind speed(V), Distillate output. Three conditions are experimented through this setup such as single basin solar still with evacuated tubes, double basin solar still with evacuated tubes, double basin solar still with evacuated tubes and reflector.

IV. CALCULATIONS

The performance of a solar still is generally expressed as the quantity of water evaporated by unit area of the basin in one day cubic meters or liters of water per square meter of the basin area per day. The internal heat transfer in the still from basin water to condensing cover can take place by convection, radiation, evaporation.

A. Internal Heat Transfer by Convection

Inside the still heat transfer takes place by free convection. This is because the actions of buoyancy force due to the variation in density of humid fluid that occurs on account of temperature difference in the fluid, the rate of heat transfer from the basin water surface to condensing cover can be find by

$$q_{cw} = h_{cw}(T_w - T_g)$$

Where,

$$h_{cw} = 0.884\left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9 \times 10^3 - P_w)}\right]^{1/3}$$

B. Internal Heat Transfer by Radiation

For a small cover inclination and large width of the still the water surface and cover are considered as parallel surfaces. The rate of radiative heat transfer from water surface to cover is given by

$$q_{rw} = h_{rw}(T_w - T_g)$$

Where,

$$h_{rw} = \varepsilon_{eff}\sigma\left[(T_w + 273)^2 + (T_g + 273)^2 + T_w + T_g + 546\right]$$

$$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$$

$$\varepsilon_{eff} = \left[1/\varepsilon_g + 1/\varepsilon_w - 1\right]$$

$$\varepsilon_g = \varepsilon_w = 0.88$$

C. Internal Heat Transfer by Evaporation

The evaporative heat transfer coefficient is given by

$$h_{ew} = \frac{16.273 \times 10^{-3} \times h_{cw}\left(P_w - P_g\right)}{\left(T_w - T_g\right)}$$

$$q_{ew} = h_{ew}(T_w - T_g)$$

V. RESULT AND DISCUSSION

The experiment is carried out for double basin solar still with evacuated tube, Evacuated tube are used to increase temperature of water from starting point to end point because of vacuum present in it which leads to increase rate of evaporation, rate of condensed and increasing the output of basin and productivity of the double basin solar still. The heat loss in lower basin is then transfer to upper basin in order to increase the temperature of upper basin which leads to increase productivity of double basin solar still. The system is operated in a month of May 2016 with clear sun sky of Nagpur, Maharashtra. The main aim of this project is to increase the output of double basin solar still. Temperatures are recorded at different points are shown in following table with the help of K type thermocouple.

Figure 3 shows the solar radiation intensity with respect to time. The variation of radiation increases with respect to time and the maximum range was 12:00pm to 2:00pm and then radiation decreases. The solar radiation received during the experimentation was in the range of 550W/m^2 to 1500W/m^2.

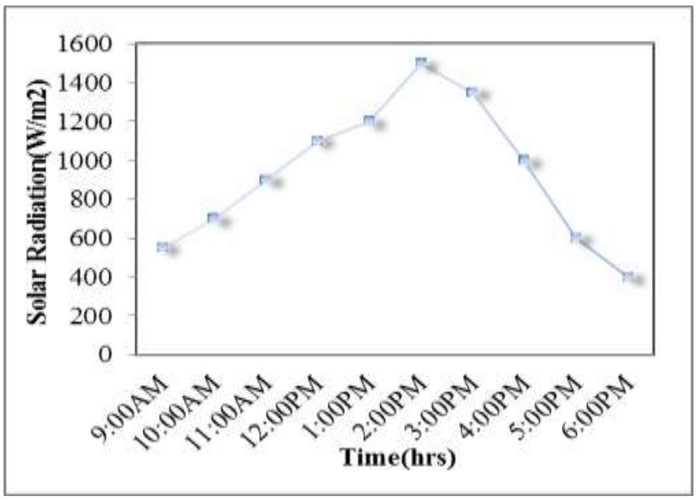

Fig. 3: Hourly solar radiation intensity

A. Comparison of Evacuated Tubes Inlet and Outlet Temperature

The inlet and outlet temperature of evacuated tubes is measured. Inlet temperature is lower than the outlet temperature. At 9am the temperature measured is 39°C. at 2pm surrounding temperature reaches maximum so the evacuated tube temperature obtained is 77°C. After that temperature becomes low slowly. Small change in temperature obtained. During the experimentation temperature range recorded was 37°C to 45°C.
(Temperature of evacuated tubes measured in °C)

Table – 1
Temperature of evacuated tube of double basin solar still

Sr. no.	*Time (Hrs)*	*1st Evacuated tube*		*5th Evacuated tube*		*10th Evacuated tube*	
		Tei	*Teo*	*Tei*	*Teo*	*Tei*	*Teo*
1	*9am*	*39*	*41*	*38*	*40*	*36*	*38*
2	*10am*	*43*	*45*	*40*	*43*	*40*	*41*
3	*11am*	*48*	*53*	*46*	*48*	*47*	*53*
4	*12pm*	*56*	*65*	*55*	*63*	*59*	*62*
5	*1pm*	*69*	*75*	*69*	*76*	*70*	*73*
6	*2pm*	*77*	*83*	*78*	*86*	*80*	*89*
7	*3pm*	*76*	*84*	*79*	*85*	*78*	*83*
8	*4pm*	*75*	*82*	*76*	*83*	*73*	*79*
9	*5pm*	*71*	*79*	*70*	*78*	*72*	*75*
10	*6pm*	*69*	*73*	*64*	*71*	*70*	*71*

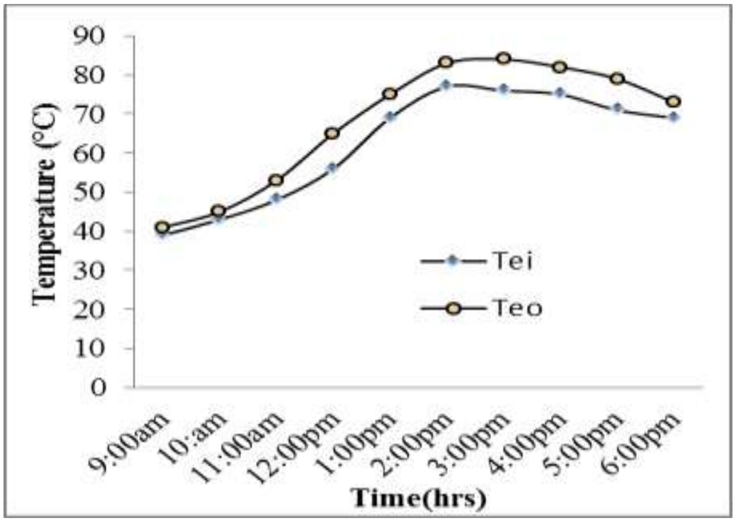

Fig. 4: Comparison of inlet and outlet temperature of evacuated tube

B. Temperature at Various Points of Distillation Unit

Various point temperature are measured in a distillation unit. Ambient temperature (Ta), Basin temperature (Tb), Glass temperature (Tg), Vapour temperature (Tv), Evacuated inlet temperature (Tei), Evacuated outlet temperature (Teo).

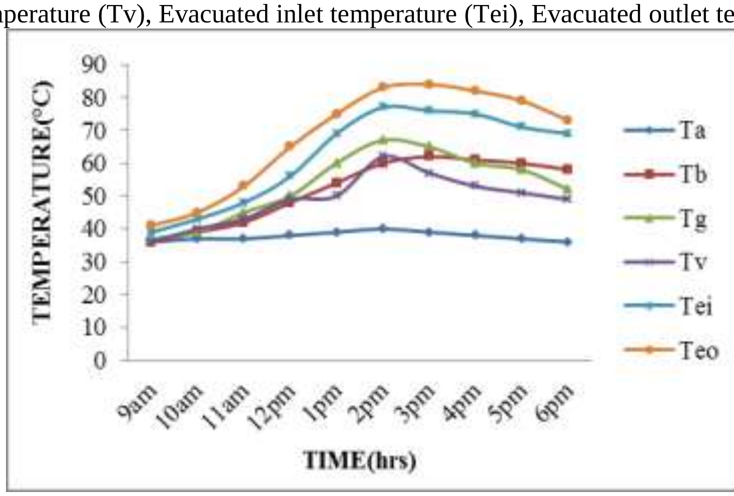

Fig. 5: Temperature at various points of distillation unit

C. Comparison of Distillate Output of single and double basin solar still

Single basin solar still with evacuated tube output is compared with double basin solar still with evacuated tube. Following graph is plotted.

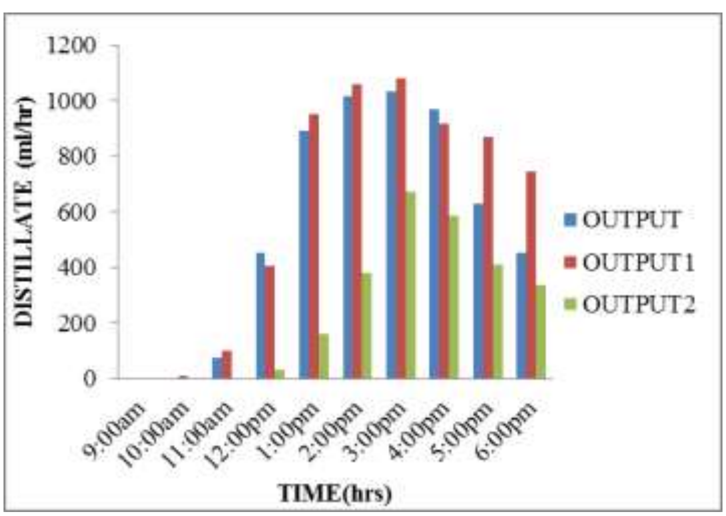

Fig. 6: Comparison of the output of single and double basin solar still

The output of distilled water was tested in laboratory. The parameters tested in a lab was colour, odour, TDS, turbidity, total hardness, chlorides, alkanity, calcium, magnesium, pH

Table - 2
Parameter

	Parameters	*Result*
1	*Colour*	*<1*
2	*Odour*	*Unobjectionable*
3	*pH*	*6.57*
4	*Total dissolved solids*	*60*
5	*Turbidity*	*0.3*
6	*Total hardness*	*28*
7	*Total alkanity*	*22*
8	*Phenolphthalein alkalinity*	*nil*
9	*Chlorides*	*8.99*
10	*Calcium*	*6.41*
11	*Magnesium*	*2.92*
12	*Residual free chlorine*	*<0.1*

VI. ECONOMIC ANALYSIS

The payback period of the experimental setup depends on the fabrication cost, operating cost maintenance cost, cost of feed water. Whereas cost of feed water is negligible.
Fabrication cost to be considered = Rs. 13000
Operating cost = Rs. 8/day
Maintenance cost = Rs. 5/day
Cost of distilled water/lit = Rs. 10
Productivity of the solar still = Rs. 10/day
Cost of water produced per day = cost of water/litre × Productivity = 10×10 = Rs.100
Net earnings = cost of water produced – maintenance Cost = 100 – 5 = Rs. 95
Payback period = Investment/Net earnings = 13000/95 = 137 days

VII. CONCLUSION

Experimental analysis was done for single and double basin solar still in order to increase the percentage of output water. Following observations are found.

1) Amount of water quantity measure for double basin solar still is higher as compare to single basin solar still because of maintaining heat in lower basin of double basin solar still.
2) Minimum 50.8% and maximum 62.1% productivity increased by double basin as compare to single basin.
3) Total heat loss from lower basin still is transfer to the upper basin of double basin which increases the productivity.
4) The influence of side insulation is significant on the rate of water production, and the temperature remains same at 3 pm. Minute change obtained in the decrease in temperature
5) Maximum output is obtained by connecting reflector with evacuated tube.
6) It is easy and very convenient process of distillation.
7) The payback period was determined to be 137 days.

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