DESIGN AND STUDY OF TWO SLOPE SOLAR STILL WATER DISTILLATION IN SINGLE BASIN

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ABSTRACT

In this work, performance of a single basin two slope solar still has been studied theoretically and experimentally. A single basin does two slope solar still of 450mm x 600 mm basin area is fabricated from an acrylic sheet of 3.5 mm. The condensing glass covers of 4 mm thickness with 30° tilt angle are used. In the present work, an attempt has been made to investigate the effect of the various parameters on the productivity of solar still like water depth, wind velocity, solar radiation, etc. Average values of maximum and minimum atmospheric temperatures, wind velocities were taken from last five years. The rate of production variation and the total production for first day of every month had been calculated. The overall production of the still was higher during March, April, August, November and December and it is around 4 liters/day. The average production of the still was 2.1 liters/day/m2. The hourly temperature has been recorded for water, basin liner, and glass surfaces. It is seen that the production rate increases with increase in wind velocity and cooling of glass covers.

Keyword: solar still, theoretical analysis, experimental analysis, transmittance variations, year round performance

1. INTRODUCTION

Drinking water is still a big problem in most arid and remote areas. About 97 % of water available earth are brackish or saline and 2 % of water available in the form glaciers. Thus, only 1% of the earth, water are potable i.e. drinkable. Single basin solar still is a valuable solution for this problem. This type of still is capable of producing clean potable water from available brackish or wastewater throughout the year. Single slope still is suitable at higher latitude place, while at lower places two slope still is preferred.For theoretical analysis, the transmittance of the cover plate is assumed as constant [2-7] and the irradiance on the horizontal basin area is taken as energy input [2,3,5-7]. However, the transmittance of the cover depends on many parameters like incidence angle, cover plate material and its thickness [8]. Only few authors have considered this effect during the analysis [9-11]. Experiments have been conducted by with different thicknesses of commercially available window glasses at different inclination, orientation and radiation conditions. Correlation has been obtained to estimate the transmittance of the given glass at any place, time, inclination, and orientation. From the above experimental results, it is learnt that, for given glass cover, the transmittance is a strong function of

Solar angle of incidence (AOI) for most of the daytime. However, during morning and evening, the transmittance of the cover mainly depends on the diffused irradiance fraction.

Hence, for same irradiance conditions, the performance of the still varies place to place and day to day due to the changes in solar AOI and transmittance. The year round performance of the still in a particular place is mainly affected by the variations in transmittance of the covers and solar irradiance on the covers.

Commercially available window glass was used as cover plate and its thickness was chosen as 4 mm to withstand the self-weight and thermal stresses. The inclination has been 30o for maximum productivity. The irradiance received by the inclined cover plate was taken as input to the still and the energy transmitted through the cover was calculated using the transmittance of the cover plates [12]. The global and diffused solar irradiances on horizontal plane and on the cover plate surfaces were estimated using radiation model. In this work, using the experimental and theoretical data the year round performance of the still for the year 2019 has been estimated for local place, Nagpur(21.14580 N, 79.080 E)

2. Estimation of solar irradiance

As recommended by ASHRAE [20], hourly global irradiance (I), hourly direct irradiance (Ib) and hourly diffuse irradiance (Id) on the horizontal surface on a clear day are calculated, using the following equations.

$$I = I_b + I_d \quad (1)$$

$$I_b = B \sin\alpha \exp[-C/\sin\alpha)] \quad (2)$$

$$I_d = D\, I_{bn} \quad (3)$$

where B, C and D are ASHRAE constants.

The angle between the sun rays and the horizontal plane (i.e. sun elevation angle □) and the angle between the sun rays and the vertical plane (i.e., the AOI □) can be calculated using the relation [21],

$$\sin\alpha = \cos\phi \cos\delta \cos\omega + \sin\phi \sin\delta = \cos\theta \quad (4)$$

where $\phi = 21^o14'$ is the latitude of the G H Raisoni Academy of Engg. & Technology, Nagpur, India; the sun declination (δ) is the angle between the sun's rays and the plane of the Earth's equator which varies with season for one year; the hour angle (ω) of the place is the angle through which the earth would turn to bring the meridian of the place directly under the sun. The sun elevation angle (α) and AOI (θ) are complementary angles.

3. Theoretical analysis

The theoretical analysis of the still is done using the new model proposed by Kalidasa Murugavel et al. [8]. The total energy available for utilization by the still for given instant is the total

irradiance transmitted (Qt) through the covers for given time and it is given by,

$$Q_t = Q_{tN} + Q_{tS} \quad (10)$$

where Q_{tN} (= $\tau_N A_{gN} I_N$) and Q_{tS} (= $\tau_S A_{gS} I_S$) *are the irradiances transmitted through the north and south covers,* τ_N and τ_S are transmittances of the glass covers, A_{gN} and A_{gS} *are cover areas and I_N and I_S are incidence irradiances on the covers.*

Since, the basin and water temperatures, production rate of the still and instantaneous efficiency vary with time, a numerical approach was used for their calculations. For still – theoretical, the irradiance was calculated using the radiation model for every 10 seconds. The heat transfer coefficients were calculated using the initial values of water and glass temperatures, solar still parameters and other climatic conditions at 6 AM. Using this heat transfer coefficients, values of basin and glass temperatures were calculated at the end of first interval of 10 seconds. Using these temperatures, heat transfer coefficients were calculated and the above step was repeated to calculate the temperatures for the next interval. During the interval, the temperatures and climatic conditions were assumed to be constant. The fresh water production rate was calculated for each interval. The calculations were done for 24 hours duration starting from 6 AM for every first day of the month

4. Experimental setup and procedure

A single basin double slope solar still (here simply referred to as "still-solar") was fabricated with mild steel plate as shown in fig. 1. The overall size of the basin is 2.3 m $\times$ 1 m $\times$ 0.25 m. The bottom of the still was leveled with 5 cm thick concrete to minimize heat loss through the basin and to spread the water uniformly. The concrete surface was black painted to improve the irradiance absorption capacity. The top is covered with two glasses of thickness 4 mm inclined at 30o on both sides supported by wooden frame. The outer surfaces are *covered with insulating glass wool and thermocole layers. The condensed water is collected in the V-shaped drainage provided below the glass lower edge on both sides of the still. The condensate collected is continuously drained through flexible hose and stored in a measuring jar. A hole in the basin side wall allows to insert the thermocouples for the measurement of the basin water, still and condensate temperature. Four thermocouples were placed in the basin at different locations. Two thermocouples are placed in the each side of the drain to measure the condensate temperature. The hole is closed with insulating material to avoid the heat and vapour loss. Another hole is provided for water inlet. Through this hole, water tube from piezometer is inserted to supply raw water continuously to the basin from storage tank through control valves which regulates the flow, to keep the mass of water in the basin always constant*

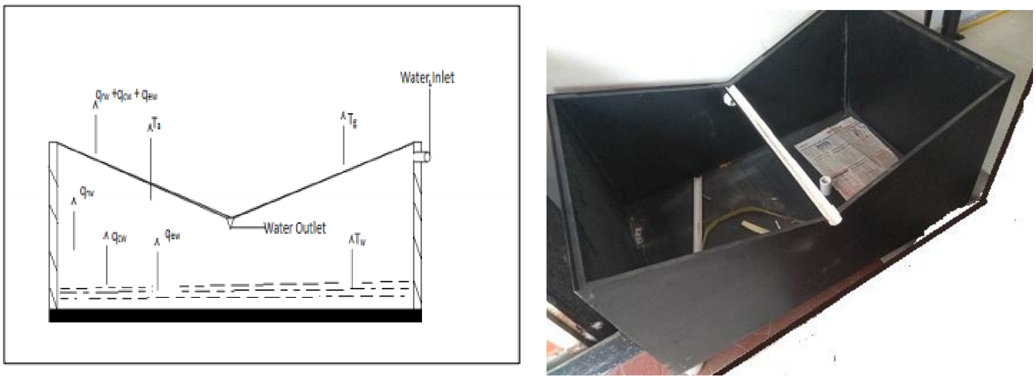

Figure. 1 Single basin two slopes experimental still

The raw water was supplied using measuring tube. The total and diffused irradiance on horizontal, inclined plane facing south and north were measured using a calibrated photovoltaic type sun meter. The distillate from the still was measured using a measuring jar. The raw water was supplied using measuring tube. The total and diffused irradiance horizontal, inclined plane facing south and north were measured using a calibrated photovoltaic type sun meter. In this meter, the pv panel can be set at any inclination and orientation to measure the irradiance. This sun meter is calibrated frequently using the standard pyranometer available in our energy laboratory. The diffused irradiance on inclined surfaces was measured by blocking the direct irradiance on the photovoltaic surface. The wind velocity was measured with electronic digital anemometer..

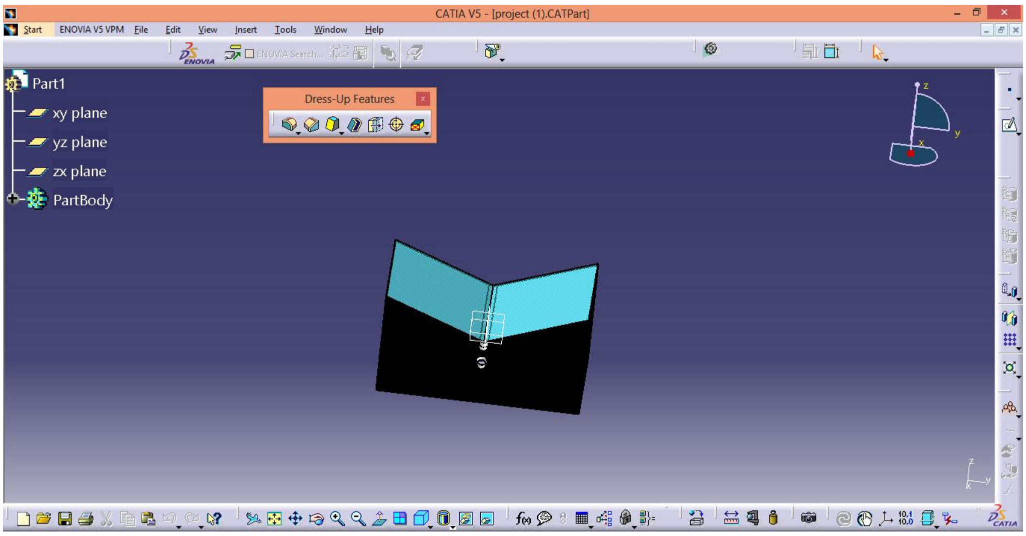

Figure. 2: Cad Model Single basin two slopes experimental still

The maximum possible error occurred in any instrument is equal to the ratio between its least count and minimum value of the output measured.

Table 1. Accuracies and error for various measuring instruments

Sl. No.	Instrument	Accuracy	Range	% error
1	Thermometer	± 1 °C	0 – 100 °C	5 %
2	Thermocouple	± 0.1 °C	0 – 100 °C	0.5%
3	PV type sun meter	± 1 W/m^2	0 – 1,500 W/m^2	2.5 %
4	Anemometer	±0.1 m/s	0 – 15 m/s	10%
5	Measuring jar	±10 ml	0 – 1000 ml	10%
6	Measuring tube	±10 ml	0 – 500 ml	10%

The experiments were conducted at the open terrace of the Department of Mechanical Engineering during March 2019. Experiments were carried out for different depths from 0.5 cm to 6 cm. The observations were taken for 24 hours starting from 6 AM, corresponding to the predicted data of the section above. The global and diffused irradiances on horizontal and irradiances on inclined planes, the temperatures of the atmosphere, condensate and basin water, and the masses of raw water supplied and condensate collected were recorded every 30 minutes

1.6 Results and Discussions

Figures 2(a) and 2(b) show the estimated year round variation of global solar irradiance. The north facing cover receives more global irradiance during March to May, while south facing cover receives more irradiance during October to March. In September, both covers receive the same amount of irradiance. During November, December, January and February, the south facing cover receives the irradiance close to normal during noon period with steep variation in incidence

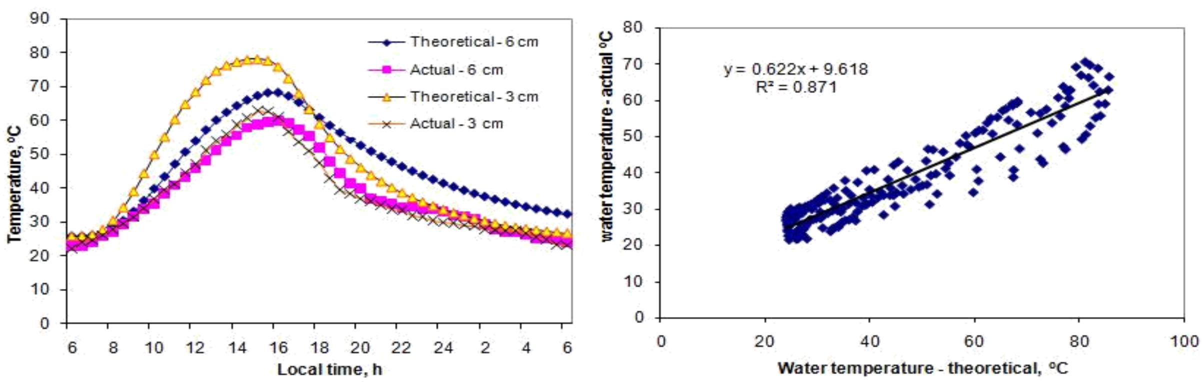

Figure 2. The total solar irradiance on north and south covers as a function of local time for various for the year 2019

The comparison of theoretical and actual water temperatures is shown in fig. 3. At higher depth, the deviations between the theoretical and actual values are less. At lower depth, the deviation is higher. In the higher water temperature range, the deviations between the theoretical and actual values are higher. At higher water *temperature, the water vapour proportion is high in the still air. This effect is not considered in the theoretical analysis. This is the reason for higher deviation between the theoretical and actual values. However, the variation pattern is similar for theoretical and experimental values.*

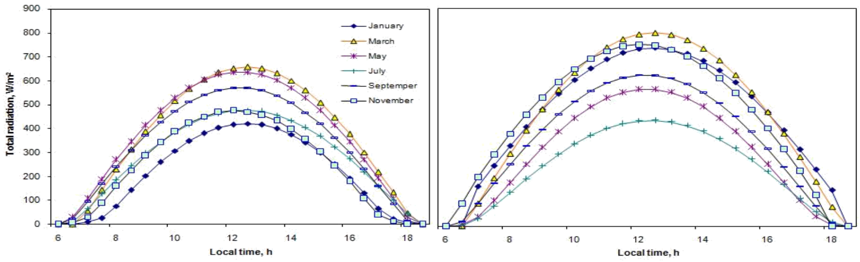

Figure 3: Actual and theoretical water temperature variations and Correlation plot for water temperature

Figure 3. shows the correlation between the still - theoretical and still – solar values. At lower water temperature, the model values are close to actual values. But at higher temperature, the deviation is higher.

Figure 4 shows the comparison between the theoretical and actual production rate for the depths of 6 cm and 0. 5 cm. The theoretical [8] model over predicts the production. At lower depth, the water temperature is high. At higher water temperature, the proportion of water vapour in the still air is high and this effect is not included in the theoretical model. This is the reason for higher deviation between theoretical and actual production rates at lower depth of 0.5 cm. During this region, the production rate is inversely proportional to the water – glass temperature difference. Hence another thermal model is required to predict the production rate accurately using the estimated temperatures

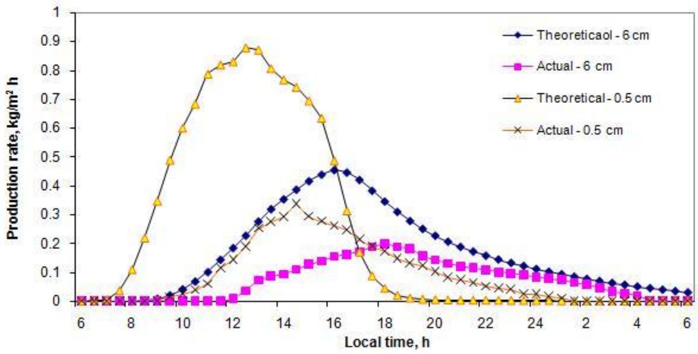

Figure 4. Actual and Theoretical production rate

A correlation developed [8] as thermal model (still – thermal) in terms of different temperatures is applied, for the accurate prediction of the production rate of the still

2. Conclusion

In the design of single basin two slope solar still is fabricated and tested. The production rate variations for different months have been studied as a function of local time. A V-type basin solar still has been fabricated and tested. The efficiency of the still has been calculated as 28% and the distillate output collected as 4L/m2/day. The still is expected to work 10 years with nominal maintenance and the production cost per liter is calculated as Rs 0.32/-. The cost effective design is expected to provide the rural communities an efficient way to convert the brackish water into potable water. Producing fresh water by a solar still with its simplicity would be one of the best solutions to supply fresh water to villages and ruler regions. In November and March the variations are steeper. Similarly the time for maximum production rate is also different for different months. This is due to variations in irradiance incidence on the covers, atmospheric temperature and wind velocity. The overall production is higher in March, April, August, November and December.

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