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RESEARCH ARTICLE

THEORETICAL AND EXPERIMENTAL INVESTIGATION ON A SINGLE BASIN DOUBLE SLOPE SOLAR STILL

Venkataraman, Dr. Anandavelu, K., *Mahabubadsha, A. and Thiruvasagamoorthi, K.

MRK Institute of Technology, Kattumannarkoil (TK), Cuddalore (DT), Tamil Nadu, India

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ABSTRACT

Solar still, which converts available brackish or impure water into potable water, can be used to supply drinking water for the people living in arid and remote areas. But, this still is not popular because of its lower productivity. This research work presents the theoretical and actual performance of the single basin double slope solar still and explores the different methods to improve the efficiency. A single basin double slope still with overall size of 2.5 m x 1.5m x 1 m was fabricated and tested under laboratory conditions (still – laboratory) and in actual solar radiation conditions (still – solar) at Chidambaram (9o11'N, 77o52'E), a city in southern India. Experiments were conducted for different depths of water up to 0.2 cm and with different basin materials. Different wick materials like light cotton cloth, jute cloth and light sponge sheet were used. Aluminium rectangular fins arranged in length and breadth wise covered with cotton cloth and jute cloth were also used in the basin. The solid materials like quartzite rocks of different sizes, naturally washed stones, cement concrete pieces and, brick pieces and iron turnings were used in the basin. The above said solid materials were not used so far. Experiments were conducted using different glass thickness with different inclination and orientation and the variations in transmittance were studied. A regression equation was established, to calculate the transmittance of the given thickness glass plate at any place and at any time for given radiation conditions. The variations of energy losses at cover plates were studied.

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INTRODUCTION

A new model is proposed for the theoretical analysis by considering the transmittance variations of the cover plates and radiation received at the glass cover as input. In the earlier work, constant transmittance was considered and radiation on the horizontal basin area was considered as input. From the theoretical analysis of the still (still – theoretical) using proposed model, it was found that, the still production was increasing with the decrease in depth. In addition to the study of variations of water temperature, glass temperature and production rate with local time, the variation of water – glass temperature difference with local time and production rate were also studied. At low basin water temperature, below60oC, water – glass temperature difference was having proportionate variationwith production rate. At higher water temperature above 60^{o}C, the still behavior was different and the production rate varied inversely with this temperature difference. During this different operation condition, the production rate was high. This different operation region was prolonged for more duration for lower depth and higher solar intens. The experimental results of still – laboratory and still – solar were compared with still – theoretical with proposed model, for different depths and different basin materials. The production rate, water temperature, glass temperature and glass – atmospheric temperature difference variations were similar. The still with 0.5 cm depth was more productive. For still – laboratory and still – solar, from 60oC water temperature point to maximum production rate point, the still operation was different and the water – glass temperature difference is inversely proportional to production rate. From thecorrelation graph forproduction rate, it was observed that, for higher water temperatures, the production rate was complex function water, glass, atmospheric, water – glass temperature difference and glass – atmospheric temperature difference. Also, the proposed theoretical model predicted theproduction rate with higher deviation with actual. Hence, to predict the production rate accurately, a thermal model, which was the refinement of the proposed model, was established and validated.

***Corresponding author: Mahabubadsha, A.**
MRK Institute of Technology, Kattumannarkoil (TK), Cuddalore (DT), Tamil Nadu, India.

The need for desalination

Clean potable water is a basic necessity for man along with food and air. Fresh water is also required for agricultural and industrial purposes. The main sources ofwater are rivers, lakes andunderground water reservoirs. However, direct uses of water from such sources are not always advisable, because of the presence of higher amount of salt and harmful organisms. The higher growth rate in world population and industries resulted in a large escalation of demand for fresh water. The natural source can meet a limited demand and this leads to acute shortage of fresh water. Hence, there is an issue to essentially treat the salt and contaminated water into purified water.

Experimentation

Experimentation on window glasses

Experimental setup

The experiment was carried out using a commercially available tracking type Photovoltaic (PV) sun meter (Figure 1). The meter had 0.36 m 0.17 m size PV panel to sense the sun radiation. The panel was fixed on a stand so that it can be set at any inclination with horizontal. The panel stand was mounted on a base with leveling screws. A display unit was connected with PV panel. The unit was calibrated to display the radiation inW/m2. The instrument measures the total radiation, when the panel is exposedto sunlight. When the beam radiation on the PV panel is shaded, it measures diffused radiation. A black umbrella fixed on the movable black vertical pipe, placed 5’ above the PV panel, is used as shading device. When a glass is placed on the PV panel, the display reads the radiation transmitted through the glass.

Experimental procedure

The experiment was conducted during NOV. 2015 to DEC.2015 at the terrace of the Mechanical Engineering Department main building, M R K institute of technology, Kattumannarkoil (9o11’N, 77o52’E). The sun meter was placed on the table, so that the panel was along north south direction. The level screws were adjusted to bring the base of the panel in perfect horizontalposition. Commercially available window panel glass of different thicknesses 2 mm, 3 mm, 4 mm, 5 mm and 6 mm were used for transmittance analysis. Total and diffused radiations were measured for horizontal, 10, 20 30 and 40 degree inclination towards north and south plane with and without glass on the PV panel. The ratio between the radiation transmitted (radiation reading with glass) and radiation received at the top surface (radiation reading without glass) is the transmittance of the glass. Readings were taken daily frommorning 6 am to evening 6 pm with one-hour interval. A single basin double slope solar still has been fabricated with mild steel plate as shown in Figure 2. The overall sizes of the inner and outer basins were 2.08 m 0.84 m x 0.075 m and 2.3 m x 1 m x 0.25 m, respectively. The gap between the inner and outer basin was air tightly packed with rice husk. The outer basin was made up of mild steel sheet. Thetop was covered with two glasses of thickness 4 mm, inclined at 30o on bothsides using wooden frame. The outer surfaces were covered with glass wool and thermo cool insulation. The condensed water was collected in the V-shaped drainage, provided below the glass lower edge on both sides of the still. The condensate collected was continuously drained through flexible hose and stored in a measuring jar. K – Type thermocouples were inserted through a hole in the basin side wall for the measurement of the basin water, still and condensate temperature. Four thermocouples were placed in the basin at different locations. Two thermocouples were placed in both the drainage, to measure the condensate temperature. The hole was closed with insulating material to avoid the heat and vapor loss.

Figure 1. Experimentalsetupofstill–laboratory

Mercury thermometer was used to measure the atmospheric temperature. Another hole was provided for water inlet. Through this hole a small tube was inserted, to supply compensation raw water continuously from storage tank using a measuring tube. The control valves arrangement was used to keep the mass of water in the basin always constant. By adjusting the control valves V1 and V2, required quantity of raw water was stored in the measuring tube. When these two valves kept closed and V3 is opened, the water stored in the measuring is supplied to the basin. The heating coil of 2000 W was placed below the inner basin to supply necessary heat to the basin. The AC electrical power wassupplied to the heater through a control circuit. The input power was varied using a variable voltage transformer. An AC digital watt meter was fitted with the circuit to measure the input power. Figure 3 shows the photographic view of the still– laboratory.

Figure 3. Experimentalsetupofstill–solar

To convert the still - laboratory into still - solar, the heater, power supply, power measurement system and inner mild steel basin were removed. The bottom of the still was leveled with 5 cm thick cement concrete to minimize heat loss through the basin and to spread the minimum depth of water uniformly as shown in Figure 2. The concrete surface was black painted to improve the radiation absorption capacity. The total and diffusedsolar radiations at the horizontal, the plane inclined at 30o facing north andsouth was measuredusing the calibrated photovoltaic type sun meter.

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The raw water input was supplied through a measuring tube with least count of 10 ml. The distillate output still was measured using measuring jar of least count 10 ml. The AC power was measured using digital watt meter with the least count of 1 W. The total and diffused radiation on 30o inclined plane facing south and north were measured using a calibrated Photo voltaic type sun meter having a least count of 1 W/m2. The diffused radiations on inclined surfaces were measured by shading the beam radiation on the photovoltaic surface. The ambient air velocity was measured with an electronic digital anemometer of having a least count of 0.1 m/s with ±2% accuracy on the full- scale range of 0 – 15 m/s.

Still-laboratory

The experiment on a fabricated still – laboratory was carried out atSteam Laboratory, National Engineering College, Kovilpatti (9o11’N,77o52’E), a city in southern India during January 2006 to March 2006. The heat input was given to the still using heating coil. Two types of experiments were carried out. In the first work, the heat input was varied to match with respect to actual solar radiation condition. For various water depths this experiments were conducted. In the second work, the experiments were conducted for constant depth with different constant power inputs. For a given constant depth of basin water condition, the input to the heater was varied forevery 15 minutes from 0 - 775 W/m2 between 6 am and 12 noon and from775 - 0 W/m2 between 12 noon and 6 pm to match with the local average solar radiation condition (Anna Mani 1980). The heater was switched off during night.The experiments were conducted for 2 cm, 1.5 cm, 1 cm, 0.5 cm and0.2 cm water depths in the still basin for same varying heat input conditionwithout freeze. For experiments with depth of water 0.5 cm and 0.2 cm, a light black cotton cloth were used to spread the water through the entire area of thebasin. For given depth, all the observations were taken for 24 hours duration starting from 6 am. The temperatures of the atmosphere, basin water and the condensate were noted for every 30 min. The watt meter reading and condensate collected on both side of the still were also noted. Since, the thermocouple fixed on the glass cover will not read correct temperature due to sun radiation effect, the condensate temperature was considered as glass temperature. The experiments were conducted with a layer of water equivalent to0.2 cm depth in the basin with wick materials like light cotton cloth, light jute cloth and sponge sheet of 2 mm thickness and solid materials like washed natural rock of average size 3/8”x 1/4” and quartzite rock of average size3/8”. These wick and solid materials were used to spread the layer of water through the entire area of the basin. The still was also tested under various constant input conditions with constant basin depth of 1 cm. The heat is supplied by the heater until the steady state condition was reached still. Then the power was cut off and the still was allowed to cool naturally to reach equilibrium state with atmosphere. The basin water temperature, condensate temperature and condensate collected were recorded for every 30 minutes. The experiments were carried out for the constant input powers of 300 W, 600 W, 900 W, 1200 W and1500 W.

Still–solar

The experiment with still – solar with concrete basin at actual sunshine condition was conducted at open terrace of the main block, Department of Mechanical Engineering, National Engineering College, Kovilpatti. The experiments wereconducted during January to April 2007. The experiments were also conducted with mild steel basin during January to April 2008. Experiments were conducted in still – solar with concrete and mild steel basin for various depths of 8 cm, 5 cm, 2 cm, 1 cm and 0.5 cm. A light black cotton cloth was used in the basin to spread the water when the water depth is 0.5 cm for concrete and mild steel basin. The experiments were conducted in still – solar with mild steel basin with various basin conditions. The experiments were conducted with a layer of water and different wick and solid materials during August 2008 to October 2008. Different wick materials used in the basin along with 0.5 cm depth of water were light cotton cloth, light jute cloth, sponge sheet of 2 mm thickness and coir sheet made up of fiber from coconut shell. The different solid materials used along with 0.5 cm and 0.75 cm depth of water were washed natural rock of average size 3/8”x1/4” and quartzite rock of average size 3/8. These wick and solid materials wereused tospread the layer of water through the entire area of the basin. Experiments were also conducted with aluminium rectangular fins in thebasin arranged inboth length and breadth wise arrangements covered with light cotton cloth and jute cloth.The observations were taken for 24 hours duration, starting from6 am to next day 5 am. The total radiation on horizontal plane, atmospheric temperature, basin water temperature, still air temperature, condensate temperature and the condensate collected were noted for every 30 minutes. For every 30 minutes, the compensating raw water equal to distillate collected was supplied to the basin from storage tank through measuring tube and the control valves arrangements.

RESULTS AND DISCUSSION

Figure 5 shows the variation of transmittance of 2 mm thick glass at various inclinations during a day in the month of January at Chidambaram. It is seen that, the transmittance is increasing from 7 am to 12 noon then decreasing slowly up to 4 pm. in most of planes. During this period, the diffused radiation fraction is less as shown in Figure 6. The maximum proportion of radiation is by direct radiation, on most of the planes. Hence, the transmittance in this period depends on the incidence angle. The diffused radiation fractions are maximum at early morning and decreasing towards noon and again increasing towards evening. This variation is due to higher air mass and humidity during morning and evening hours. For the planes with higher inclination angle towards north, the diffused radiation fraction is dominating through out the day. The 20, 30 and 40 degree inclination glasses facing north receive sun rays at higher incidence angles. Hence the transmittances are lower from 9 am to 5 pm. But during morning, due higher diffused radiation fraction, the transmittances are higher for all planes.

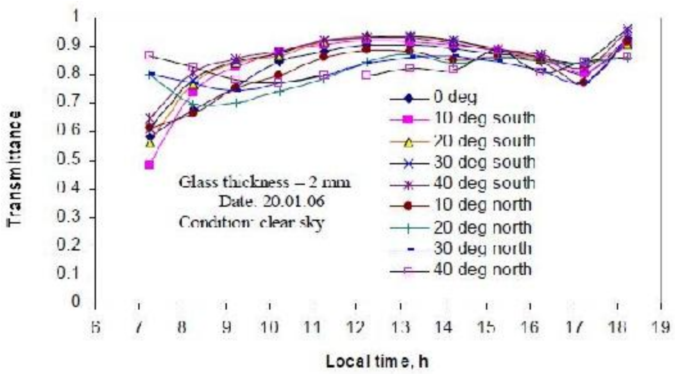

Figure 5. Variation of transmittance – low thickness glass

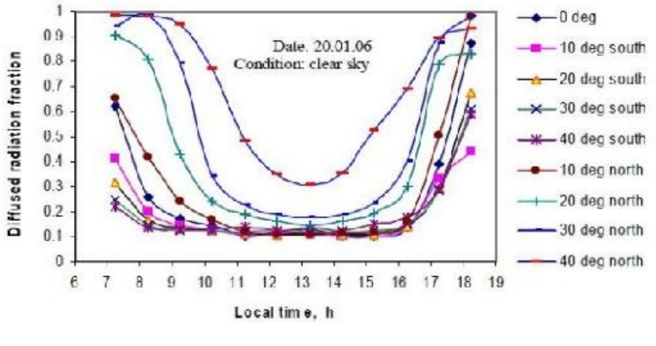

Figure 6. Variation of diffused radiation fraction – clear sky

During the month of January, the south facing planes are receiving more direct radiation than the planes facing north. But planes facing north receive more amount of diffused radiation than south facing. The diffused radiation fraction increases with the angle of inclination of the plane facing towards north at any time. The direction and the amount of diffused radiation from different directioncannot be predicted. This results an unpredictablevariation of transmittance in the higher diffused fraction regions. For higherinclination angle glass towards north, transmittance variation is not uniform with solar incidence angle and local time due to higher amount of diffused radiation fraction through out the day as shown in Figure 6. Figure 7 shows the variation of diffused radiation fraction for a day during January with intermittent cloud passing. During cloud passing, the diffused radiation fraction is higher and it affects the transmittance variations.

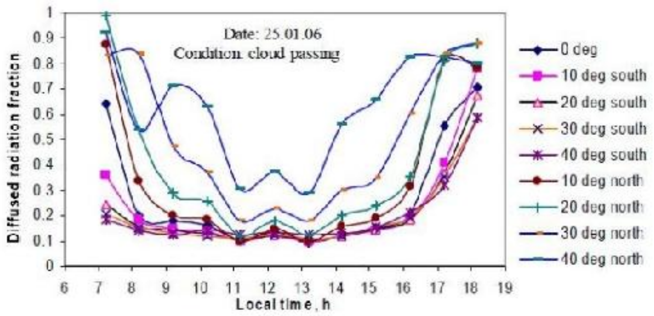

Figure 7. Diffused radiation fraction variation – cloud passing

The variations in transmittance during the cloudy day are shown in Figure 7 for 5 mm glass plate. During cloud passing, the diffused radiation fractions on north facing glasses are higher. Correspondingly, the transmittances of these glasses are higher. Even during 10 pm to 4 pm the increase in diffused radiation fraction increases the transmittance, but the effect is less compared with morning. Hence, it is observed that, the transmittance for the given transparent material is strongly a function of the solar angle, thickness of the glass plate and diffused radiation fraction (Kd).

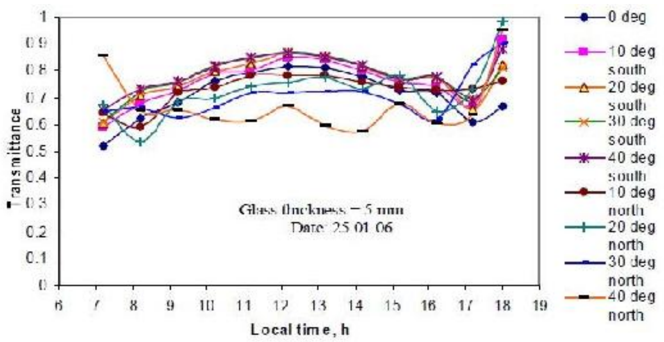

Figure 8. Variation of transmittance – higher thickness glass

The increase in glass thickness reduces the transmittance proportionally. The transmittance decreases with incidence angle for given thickness. But the effect of diffused radiation fraction on transmittance is not proportionate and depends on solar angle. These effects were clearly explained in Figure 9, which compares the transmittance of various thickness glass plates. Figure 9 shows the variation of transmittance for different glass plate thicknesses of 2 mm, 3 mm, 4 mm, 5 mm and 6 mm for entire range of incidence angle and Kd. For lower range of incidence angle (0o - 30o), the effect of variation of transmittance on Kd, is less and transmittance is a function of thickness and incidence angle. In the higher incidence angles, ranging from 60o to 90o, the transmittance is mainly the function of Kd. When the Kd value exceeds 0.2, its effect on transmittance is significant in all range of incidence angle.

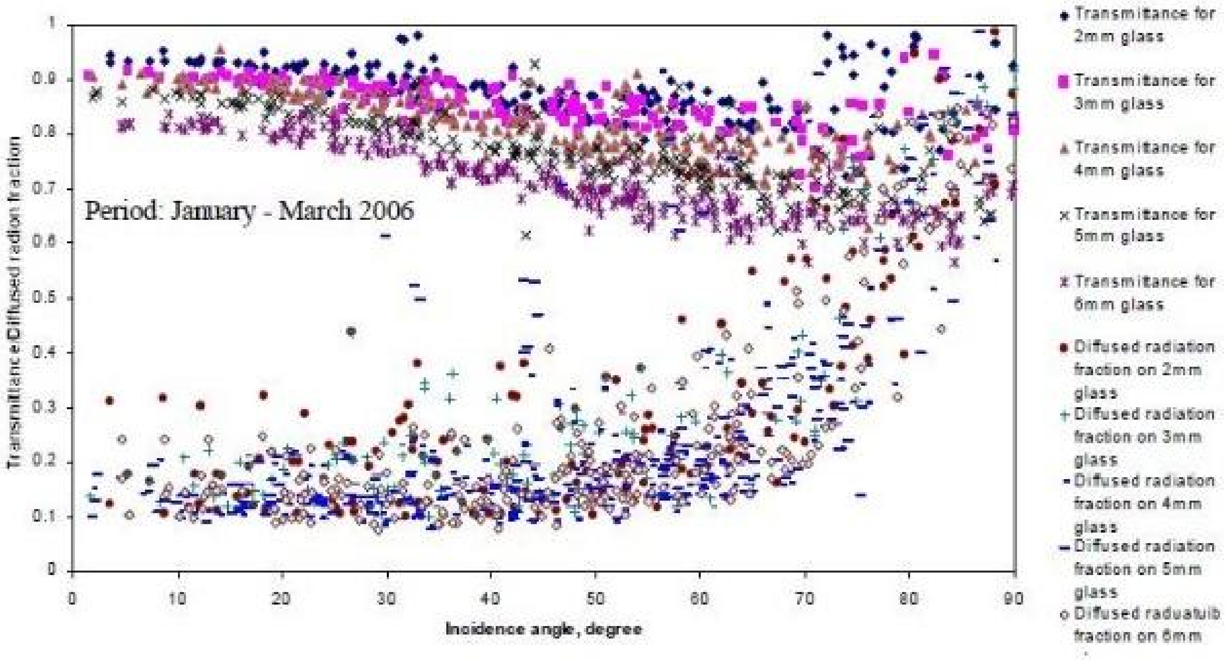

Figure 9. Transmittance variations – A summary

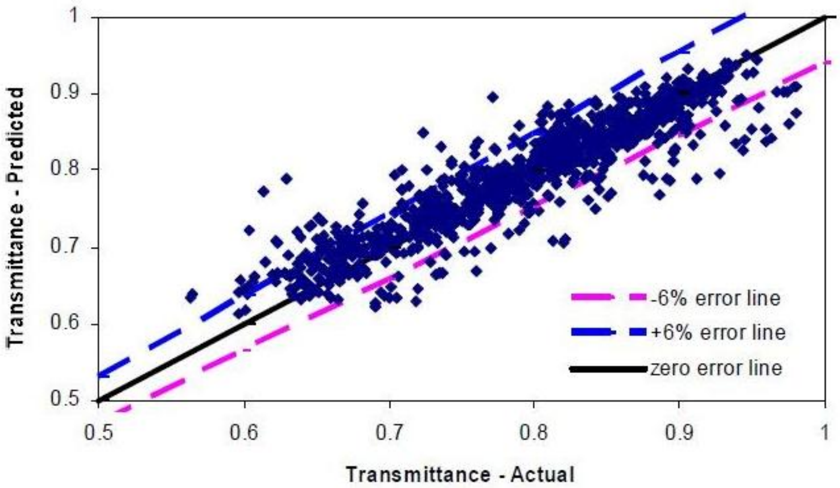

Fig.10. Actual and predicted transmittance values

For higher range of incidence angles (higher than 70^{o}), the transmittance is a strong function of diffused radiation fraction and thickness (Figure 4). The incidence angle is having only negligible effect on transmittance in this range. For a given thickness, the transmittance is increasing with diffused radiation fraction and increasing with incidence angle. A regression is established, to estimate the transmittance of the various thickness window glasses at different solar angles and radiation conditions using the software Mathcad – 12. Around six hundreds set of values are used to develop the regression equation and given as,

$$\tau = [1.005\times10^{-4}\times(90-\theta)\times K_d] - [5.204\times10^{-3}\times K_d\times d] + (0.095\times K_d^2) + (0.029\times K_d) + [3.837\times10^{-4}(90-\theta)\times d] - (3.299\times10^{-3}\times d^2) - (0.028\times d) + [9.117\times10^{-4}\times(90-\theta)] + [2.417\times10^{-7}\times(90-\theta)^2] + 0.859$$

where - transmittance, Kd – diffused radiation fraction with the range of 0 to 1, d – thickness of the glass in mm with the range of 2 mm to 6 mm and θ– incidence angle in degree with the range of 0 to 90o. Error analysis is made with more than 1000 set of values. The Figure 10 shows the comparison between measured and calculated values of transmittance using the above regression equation. More than 90% of the values are with in 6% error limit.

Conclusion

Experiments were conducted on different thickness window glasses to study its transmittace behavior for various solarradiation conditions. It was found that, the transmittance was indirectly proportional to thickness of the glass, indirectly proportional to solar incidence angles and diffused radiation fractions. The transmittance mainly depended on diffused radiation fraction athighe rincidence angles. There gression equation could be usedto estimate transmittance of the glass at any location and at any time for different radiation conditions.

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