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INFLUENCE OF WATER DEPTH ON THE PERFORMANCE OF A DUAL PURPOSE SINGLE BASIN DOUBLE SLOPE SOLAR STILL

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ABSTRACT

An attempt has been made to analyze the performance of a dual purpose single basin double slope solar still. Experiments have been carried out for number of days during September – November 2012 at Karpagam University, Coimbatore. The energy balance equations have been written for different elements of the solar still such as glass cover, basin water, still basin and heat exchanger tube. A computer program has been written for analytical solution of the energy balance equations. The optimum water depth has been found with heat exchanger coil by doing experiments for higher productivity and extraction of thermal energy from the still. The productivity of the still is higher when least water depth is maintained due to low thermal capacity and also the heat exchanger tube has not affected the evaporation process during the working hours of the still. The maximum temperature of the water from the outlet of the heat exchanger is found to be 60 ºC and the overall efficiency of the still is found to be 40%. Theoretical results are in good agreement with the experimental results.

Keywords: Solar Distillation, Heat Extraction, Solar Energy, Water Depth, Water Heater.

I. INTRODUCTION

Solar still is a simple device, which is used to produce clean water from available source of water. Moula and Karimi [1] have developed a mathematical model for a solar still and simulation work has been done for the rate of production of fresh water and inferred that the experimental and calculated results are in good agreement. Tiwari et al. [2] have analyzed a solar distillation unit integrated with a collector through a tube in-tube heat exchanger. It is concluded that the instantaneous efficiency of the system with an increase of collector area. Al-Hinani et al., [3] have studied the effect of climatic, design and operational parameters such as solar radiation intensity, wind velocity, ambient temperature and glass cover slope angle, feed water temperature, water depth on the basin, and basin material on the distillate output of basin type solar still. It has been found that the shallow water basin with 23□ cove tilt angle, 0.1m insulation thickness and asphalt coating of the solar still are the optimum parameters for producing higher yield. Yousef H. Zurigat, Mousak. Abu-Arabi [4] has modeled a regenerative distillation unit and evaluate the performance of the regenerative still is 20% higher compared to the correlation still. The effect of water depth and the transient performance of a double basin solar still has been investigated by Tiwari et al., [5].

Akash et al., [6] have determined the effect of cover tilt angle, the salinity of water and water depth. It has been concluded that the optimum cover Tilt angle is 35□ for maximum distilled water production in the still during the month of May. Also the salinity of water effect the distillate production when salt concentration is low and the production rate is increased when the concentration is increased and maintaining low thermal capacity of the water in the basin. The performance of a solar still with a layer of water in the basin with different spread materials have been compared by Kalidasa Murugavel et al., [7]. The result shows that the with block cotton cloth was found to be more effective for higher distillate yield.

Further Kalidasa Murugavel et al., [8] have fabricated and tested single basin double slope solar still with minimum basin depth with the energy storing materials in the basin. It has been found that, the still with 3/4in.sized quartzite rock is the effective basin material. The theoretical results are good agreement with the experimental results. Ahmed Z Ai-Garni et al., [9] have studied the effect of glass slope angle and water depth on the productivity of double slope solar still. It was found that, the optimum tilt angle is 35□ for both summer and winter seasons. The best water depth for higher productivity in summer and winter is found to be 0.01m. the numerical results are good agreement with the experimental result. Kalidasa Murugavel and Srithar [10] have studied the performance of basin type double slope solar still with different wick materials with minimum mass of water. It has been shown that the still with light black cotton cloth produced higher distillate output than other wick materials. The effect of various parameters on the performance of single basin double slope solar still has been studied by Panchal [11]. The black dye in the basin water has significant impact on the performance of the still. Moreover, the effect of water depth and still orientation and productivity for passive solar distillation has been studied by Wasil Jamal and Altamush Siddiqu [12]. The result shows that, the yield are maximum for shallow water depth in the basin and when the still is placed in the North-South orientation. Ajeet Kumar et al., [13] have made an attempt to find the most suitable water depth and still orientation for maximum yield from a double slope solar still. It was observed that, the highest output is obtained at lower depth and gain of 60-65% in distillate output when the still was oriented towards North-South direction. Mahmoud Shatat et al., [14] have developed mathematical model for psychometric solar water distillation system and the experimental and theoretical values for the total daily distillate output were found to be closely correlated. It is concluded that the by utilizing the concept of humidification and dehumidification, a compact water distillation unit coupled with solar collector can significantly increase the potable water supply in remote area.

In the present an attempt has been made to design and fabricated a dual purpose single basin double slope solar still from locally available materials. The main objective of this work is to predict the performance of the dual purpose single basin double slope solar still. The influence of water depth on the daily productivity of the solar still and heat exchanger tube in the still basin has been investigated by doing experiments Karpagam University, Coimbatore, and Tamilnadu, India.

II. EXPERIMENTAL METHOD

Design of the System

A schematic diagram of the single basin double slope solar still with heat exchanger tube in the basin is shown in Fig.1. A galvanized iron sheet (0.001m Thick) is used for fabricating the still with depth of 0.10m height and basin area is 1m2. The inner side of the basin is painted black to increase the absorption of incident solar radiation. The solar still is enclosed with two layer of ply wood with a gap of 0.05m between them. The gap between enclosures os filled with the 0.05m thick layer of glass wool, in order to reduce the heat loss from the bottom and sides of the still. The solar still is covered by two glasses (0.004m thick) each with inclination of 11□ to obtain double slope. The condensed water is collected in the V-shaped channel provided below the glass cover edge on the both sides.

A heat exchanger (HE) tube is made of aluminium with the length of 12m and bent to get six squares of increasing edge length. The schematic diagram of the heat exchanger tube in the still basin is shown in Fig.2. The heat exchanger tube just fixed to surface of the still absorber plate. The absorber plate and heat exchanger tube are painted black to increase the amount of absorption of incident solar radiation. The inlet of the HE is connected to a gate valve of the water tank and required pressure is maintained to get optimum flow rate through the heat exchanger tube. The heat energy is extracted from the still through the outlet of the heat exchanger tube.

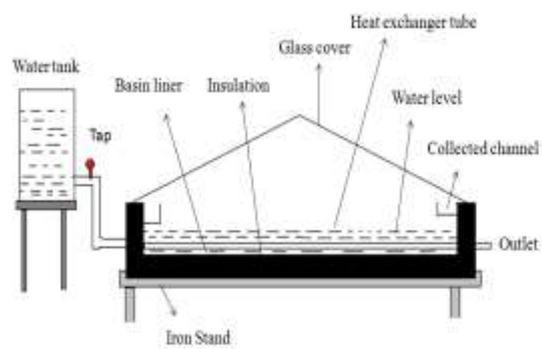

Fig.1. a schematic diagram of the Dual purpose single basin double slope solar still

III. EXPERIMENTAL PROCEDURE

Experiments have been carried out on at Department of Physics, Karpagam University, Coimbatore – 641 021 (latitude 11°N, longitude 77°52’E), Tamilnadu, India. The Fig.3. Shows photograph of the dual purpose single basin double slope solar still. Observations have been made with regular intervals of 30minutes. The solar radiation monitor and digital thermometer were used to the measure intensity of the solar radiation and temperature of the ambient respectively. Thermocouples have been used to measure the temperature of the glass cover, still basin, heat exchanger tube and output fluid temperature. The optimum water depth has been found by doing experiment for maximum productivity of distillate yield and heat extraction from the still. Thermal analysis has been carried out and the analytical result has been evaluated for one of the typical days during the September-November 2012.

Fig.2. Pictorial view of the experimental system

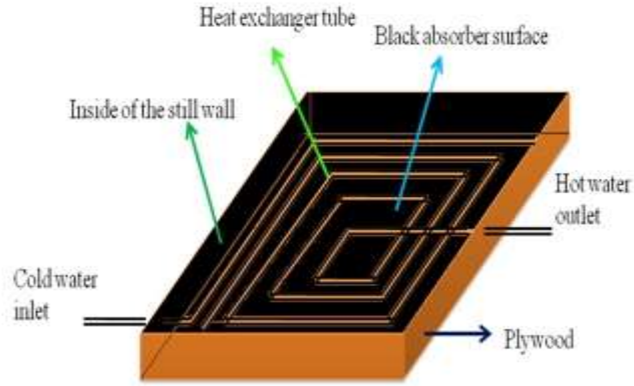

Fig.3. Schematic diagram of the heat exchanger tube in the still basin

IV. THERMAL ANALYSIS

The energy balance equations have been written for different elements of the still such as, glass covers, basin water, still basin and heat exchanger tube and are

For glass cover

$$\alpha_g H_s A_g + h_1(T_w - T_g) = h_2(T_g - T_a) \quad 1$$

Where, $T_g = (T_{gn} + T_{gs})/2$

For still basin

$$\alpha_b \tau_g \tau_w H_s A_b = h_{cbw}(T_b - T_w)A_b + h_3(T_b - T_a) \quad 2$$

Where, $h_3 = \frac{L}{K}$

L = thermal conductivity of the glass wool (0.0328W/mK)

K = thickness of the glass wool (0.05m)

For water mass

$$\alpha_w H_s A_w + h_{cbw}(T_b - T_w) = m_w C_w \frac{dT_w}{dt} + h_1(T_w - T_g) \quad 3$$

Where $h_1 = h_{cwg} + h_{rwg} + h_{ewg}$ and $h_2 = h_{cga} + h_{rga}$ is the total internal and external heat transfer coefficient

Heat exchanger tube

$$H_s(1 - \propto_g)\tau_{g2}\tau_{g1}\tau_w \propto_{ht} (1 - 12\pi R) = h_{chtf}(T_{ht} - T_f) \quad 4$$

Rearranging Equation 1 and 2 following results has been obtained.

$$T_g = \frac{\alpha_g H_s A_g + h_1 T_w + h_2 T_a}{h_1 + h_2} \quad 5$$

$$T_b = \frac{\alpha_b \tau_g \tau_w H_s A_B + h_{cbw} T_w + h_3 T_a}{h_{cbw} + h_3} \quad 6$$

Eq. (4) can be solved to get the equation for T_{ht}

$$T_{ht} = \frac{I(t)(1 - \propto_g)\tau_{g1}\tau_{g2}\tau_w \propto_{ht}(1 - 12\pi R) + h_{chtf} T_f}{h_{chtf}} \quad 7$$

Substituting for T_g, and T_b in equation 3 and rearranging, we get

$$M\left(\frac{dT_w}{dt}\right) + BT_w = G(t) \quad 8$$

Where,

$$G(t) = \alpha_w H_s A_w + \frac{h_{cbw}\alpha_b \tau_w H_s}{h_{cbw} + h_3} + \frac{h_{cbw} h_3 T_a}{h_{cbw} + h_3} + \frac{h_1 \alpha_g H_s}{h_1 + h_2} + \frac{h_1 h_2 T_a}{h_1 + h_2}$$

$$B = -\frac{h_{cbw} h_{cbw}}{h_{cbw} + h_3} + h_1 - \frac{h_1 h_1}{h_1 + h_2}$$

And $M = m_w C_w$

The solution of equation 6 is

$$T_w = \left(\frac{\overline{G(t)}}{b}\right)\left[1 - \exp\left(\frac{-bt}{M}\right)\right] + T_w exp\left(\frac{-bt}{M}\right)$$

Where,

T_w is the temperature of the water.

The amount of distilled water collected for unit time for unit area is given by

$$M_w = \frac{Q_{ew}}{L} \quad 9$$

Where, L is the latent heat of vaporization of water

The efficiency of the still is given by

$$\eta = \frac{\int M_w \times L}{\int H_S \times 30 \times 60} \quad 10$$

V. RESULT & DISCUSSION

The hourly variations of solar radiation and ambient temperature for three typical days during September-November 2012have been shown in Fig.4. It is clear that the intensity of solar radiations is gradually increased during morning hours up to 1.30pm and decreased in the afternoon hours.

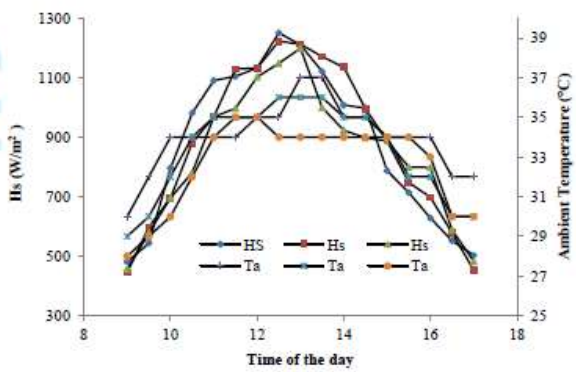

Fig.4. Hourly variations of the solar radiation intensity and ambient temperature for the experimental days

The variations of ambient temperature has similar trend as that of the solar radiation during the day. The maximum intensity of the solar radiation and temperature of the ambient air is recorded 1250W/m^2 and 36°C.

The temperature difference between water and glass cover with respect to the depth of the water in the basin (1.5cm, 2cm, and 3cm) is illustrated in Fig.5. It is seen that the temperature difference between water and glass cover is higher when least water depth (1.5cm) is maintained due to low thermal capacity. The maximum temperature difference between water glass cover with different depth is found to be 18 (1.5cm), 12 (2cm), and 11°C (3cm). Theoretical results are in good agreement with the experimental results.

The variations of temperature of the heat exchanger tube and outlet fluid are shown in Fig.6 and 7. From Fig.6 it is observed that the temperature of the heat exchanger tube is higher than the water temperature as the heat exchanger tube gained energy from still basin and water mass by convective heat transfer. The temperature of the heat exchanger tube for the depths 1.5cm, 2cm, and 3cm are found to be 57°C, 52°C and 50°C. It has been observed that the temperature of the heat exchanger tube reached a maximum of 57°C for the depth of 1.5cm in the basin. This is because, for the least water depth in the basin, the water temperature increases predominantly due to low thermal capacity and convection from water to heat exchanger tube is more. The theoretical results for the temperature of heat exchanger tube have same trend as that of the experimental results.

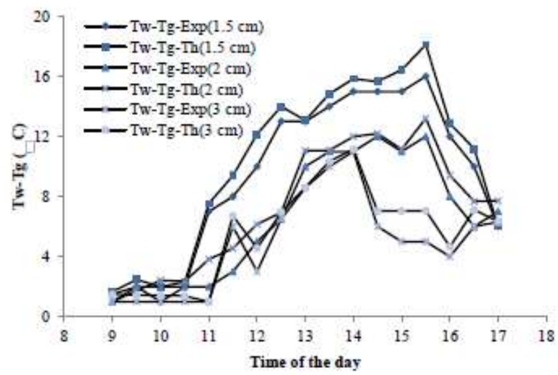

Fig.5. Variations of temperature difference between water and glass cover with different depths for the experimental days

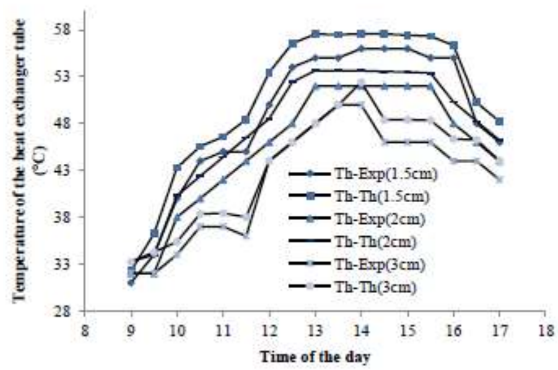

Fig.6. variations of temperature of the heat exchanger tube for different depths

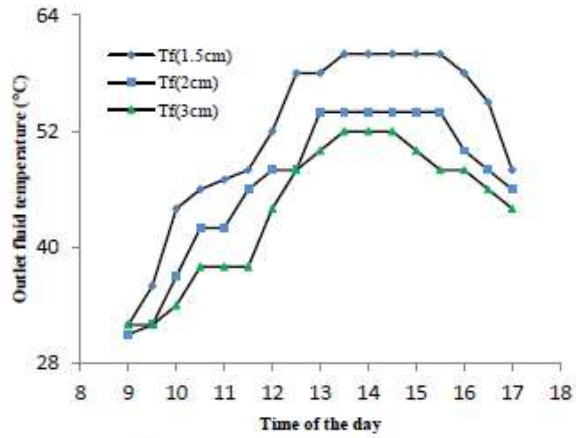

Fig.7. variations of the outlet fluid for different water depths

Figure 7 shows that the temperature of the outlet fluid temperature for different depths of water in the basin. It is inferred that the temperature of the outlet fluid is higher when least water depth is maintained in the still basin. The temperature of the outlet fluid is recorded as 60°C, 54°C and 50°C at 1.30pm for 1.5cm, 2cm, and 3cm water depths.

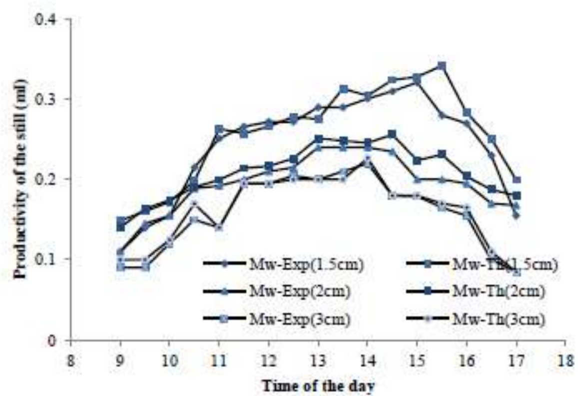

Fig.8. shows the productivity of the solar still with different water depths

Fig.8 shows the variation of daily productivity of the solar still different depths of water (1.5cm, 2cm, and 3cm) in the basin. It is found that the daily productivity of the still is increased when depth of water in the basin is 1.5cm due to low thermal capacity and also the heat exchanger tube has not affected the evaporation process during the working hours of still. The daily productivity of the still increase with increase of temperature difference between water and glass cover. And from the experiments it is concluded that, when water depth decrease inside the basin, heat capacity of basin water decrease and results in higher temperature inside solar still and better evaporation and condensation produces improved distillate output. The maximum hourly productivity of the still for different depths (1.5cm, 2cm, and 3cm) is found to be 0.321ml, 0.240ml, 0.226ml. From these results it is confirmed that the 1.5cm water depth is the optimum for maximum productivity of the solar still. The theoretical results obtained from the analytical solutions are in good agreement with the experimental results.

The average daily productivity of the still for different depth water is illustrated I Fig.9 and maximum average daily distillate output is found to be 4.12L/m^2 day. The optimal water depth of 1.5cm enhanced evaporation and condensation process and increase the output rate, due to the large temperature difference between water and glass cover. The variation of instantaneous efficiency of the solar still different depth is shown in Fig.10. It is confirmed that the efficiency of the still is increased when depth of water layer in the basin is decreased and instantaneous of heat extraction. The maximum average instantaneous efficiency of the solar still with different depths (1.5cm, 2cm, and 3cm) is found to be 39.50%, 31.79% and 28.72%. The theoretical results are in good agreement with experimental results.

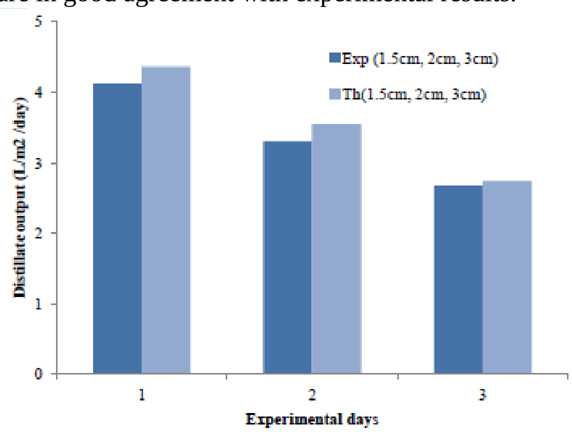

Fig.9. shows the average daily productivity of the solar still with different depths

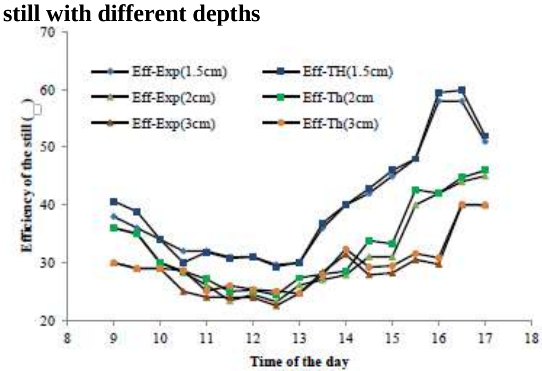

Fig.10. shows the instantaneous efficiency of the solar still with different depths

VI. CONCLUSIONS

In this work dual purpose a double slope single basin solar still with basin area is $1m^2$ is fabricated and tested under laboratory conditions for different depth of water in the still basin. The following conclusion has been drawn from the above said results

- The performance of the proposed solar still is seems to be good for least water depth in the basin.
- The optimum depth of water in the basin is found to be 1.5cm.
- The daily productivity of the solar still for least water depth (1.5cm) is found to be $4.2L/m^2$
- The instantaneous efficiency of the still is increased when depth of water layer in the basin is 1.5cm. The average efficiency of the still was found to be 39.50%.
- The maximum outlet temperature of the heat exchanger tube was found to be 60°C.
- The water can be heated during sunshine hours and thermal energy stored in water mass, and can be extracted from the still by using heat exchanger tube.
- The temperature of the water, basin and productivity of the solar still is not affected by the heat exchanger tube in the still basin.
- The proposed thermal model can be used to optimize the parameters for large scale installations.
- The dual purpose single basin double slope solar still can be used as good water heater and water purifier in winter and summer seasons.

VII. NOMENCLATURE & UNITS

h_{cwg} Convective heat transfer coefficient from water to the glass cover, W/m^2
h_{rwg} Radiative heat transfer coefficient from water to the glass cover, W/m^2
h_{ewg} Evaporative heat transfer coefficient from water to the glass cover, W/m^2
h_{cga} Convective heat transfer coefficient from water to the glass cover, W/m^2
h_{rga} Radiative heat transfer coefficient from water to the glass cover, W/m^2
T_w Temperature of the water, °C
L Latent heat of vaporization of water (2372KJ/kg)
M_w Mass of the distilled water output, ml
P_g Partial pressure of saturated vapor at the glass covers temperature, W/m^2
P_w Partial pressure of saturated vapor at the glass covers temperature, W/m^2
H_s Solar insolation, W/m^2
α_g Absorptivity of glass cover
T_{wp} Temperature of water in the pond (°C)
T_g The average temperature of the glass cover (°C)
T_a Temperature of the ambient (°C)
T_b Temperature of the still basin (°C)
τ_g Transmissivity of the glass cover
α_w Absorptivity of water in the pond
m_w Mass of water (kg)
C_w Specific heat capacity of water (J/kgK)
τ_w Transmissivity of the water
h_1 Total internal heat transfer coefficient
h_2 Total external heat transfer coefficient
L Thermal conductivity of the glass wool (0.0328W/mK)
K Thickness of the glass wool (0.05m)
α_{ht} Absorptivity of spiral coil heat exchanger tube
h_{chtf} Convective heat transfer coefficient from spiral coil heat exchanger tube to the fluid through it
T_f Temperature of fluid flowing through the heat exchanger (°C)

VIII. GREEK SYMBOLS

ε Emissivity
σ Stefan-Boltzmann's constant, W/m^2
Efficiency of the solar still, %
η Efficiency of the solar still, %

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