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Performance Evaluation of a Solar Still

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ABSTRACT

More than 97% of earth's water is salty and remaining 3% is fresh water and less than 1% of fresh water is provided to people. Water is primary source of life. Desalination techniques which can be used for purification of water are reverse osmosis, electro dialysis, vapor compression and solar distillation. Solar still (solar distillation system) is a very simple device used to convert impure water into pure water for drinking purpose. This device requires less maintenance and can be fabricated easily. Because of low productivity, it is not usually used. Distillate output from a solar still depends on many parameters like climate parameters such as solar insolation, wind speed, ambient air temperature, atmospheric humidity, sky condition etc. and design parameters such as thermo physical properties of the material used in its construction, orientation of solar still, tilt angle of cover, spacing between water and cover surface, insulation of the base, vapor tightness, absorptance transmittance properties of still, etc. and operating parameters such as water depth in the basin, initial water temperature, water salinity etc.
This paper shows the effect of various values of three different parameters namely condensing cover inclination, water depth and different insulation on the performance of solar still. Evaporative, radiative, convective heat transfer coefficients are calculated. It is found that hourly water temperature and yield are a strong function of water depth. Productivity is increased as the water depth decreases. Use of insulation reduces the heat loss and increases yield of a solar still.

***Keywords*— cover inclination, distillation, heat transfer coefficient, heat loss, productivity, water depth**

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I. INTRODUCTION

Water is a key and primary source of life, only 3% of earth water is fresh water and only one third is accessible at the lakes and rivers. Fresh water is required for industries, agriculture, domestic purpose (for cooking, drinking, to wash utensils, etc.), Food industries, laboratory, greenhouse application. Distillation of brackish or saline water, wherever it is available, is a good method to obtain fresh water. However, the conventional distillation processes such as vapour compression, Reverse osmosis, Electrolysis all these are energy intensive techniques, and are the feasible for large quantity of water-required application. The alternative solution of this problem is a device, which works on solar energy to distillate the water that is solar still. Solar distillation system (Solar still) is cost-effective device, it provide clean water for use, it has less moving parts and pollution free. Due to its low productivity it is not widely used in society. Solar still is working on solar light, which is available in high amount of energy, and free of cost and pollution, but it is vary according to the climate condition and season. Distillate output from a solar still depends on many parameters like climate parameter, design parameter, operating parameter [1, 2]. This paper shows the effect of various values of three different parameters namely condensing cover inclination, water depth and different insulation on the performance of passive type of solar distillation system. Various heat transfer coefficients such as convective, radiative, evaporative heat transfer coefficient are

Calculated to show its relationship with water depth and insulation. Hashim A.Y., [3] symmetric double slope still with 45° inclination of cover and lesser inner surface area gives better effeciency, Panchal H [4] sprinkler and dies are used to increase condensation rate and evaporation rate these both are leads to increase productivity of still, in case study of Patel N.S. [5] it is clear that step wise basin solar still gives better result than conventional and concave type of solar still due to increasing absorbing area of basin. Medugu D. W [6] has shows the theoretical analysis of solar still similarly Gupta B [7] has described theoretical analysis for active type of solar still. Badran O. [8] gave review of governing parameters and modelling equations available for suitable selection. Tripathi R. [9] estimate effect of water depth on internal heat and mass transfer coefficient for active solar still by using flat plate collector, Tiwari A.K. [10] and [11] has describe behavioural variation in internal heat transfer coefficient with respect to water depth in still, they used the concept of solar fraction, hourly value of solar azimuth and altitude angle in thermal, modelling to analyse the different parameters. Muafag Suleiman K. [12] productivity of solar still is strongly depend on climate and operating parameters, condensation rate can increase by cooling upper surface of cover. Rajamanickam M.R [13] studied the effect of operating parameters on solar stills , productivity of double slope still is maximum as compare with single slope solar still. Tiwari A.K [14] 15° and 45° inclination of cover plate gives maximum yield in summer and winter respectively, 11.82% productivity can increase by cooling outer surface of cover plate. Zeroual M.[16]. 10° is optimum inclination angle which allow receiving a maximum solar radiation for still, asymmetric solar still with double effect process gives highest productivity than symmetric one with double slope still. Abderachid trad [17], Bhardwaj R.[18] glass is preferable material for cover plate. Suneesh P.U. [19] V type of solar still with cotton gauze top cover cooling with air flow over glass cover gives maximum productivity.

II. SOLAR STILL

Solar energy is passing through glass cover and heats up the brackish water inside the basin; this causes the water to vaporize. The vapour then starts to rise and condenses on the inner surface of the glass cover while condensing it release latent heat which get absorbed by glass cover, condensed water runs down in to distillate trough (condensed water collector), while this process some part of heat is get lost by conduction, convection, radiation mode through basin that is side wall, bottom and top surface, and some heat is lost by vapour leakage through still.

III.EXPERIMENTAL PROCEDURE

Fig.1 shows a photograph of schematic arrangement of single slope solar stills having three different inclination of cover plate that is 15^0, 25^0 and 35^0. The cover plate is made up of plain glass of thickness 4mm.The basin is made up of mild steel having thickness1.2mm.

Fig.1 Actual setup of solar still for three different inclination of cover plate

The area of basin is 0.5m*0.5m. Surfaces of still are painted with black paint to increase its absorptivity and heat carrying capacity of the still. The trough is tilted by 3^0 so that distilled water can drain out easily in measuring jar.

Gasket is provided so that proper airtight can be achieved in system to increases its performance. The output valve of still is connected through pipe to the measuring jar. To avoid adulteration of pure water with impure water the lower vertical side is kept at 0.18m whereas the higher vertical side is kept at0.45m, 0.65m and 0.88m respectively. To measure various temperatures for analysis purpose sensors are used. In addition, anemometer is used to measure air velocity.

The experiment process was started in the month of April in the campus of KJ's educational institute of Trinity college of engineering and research, Pune, India. The experiment were conducted from 9 AM to 4PM For constant height of water depth the test were performed for all three solar still for 3 days. After comparing the outputs of these three stills next test was performed on still, which is having optimum output.

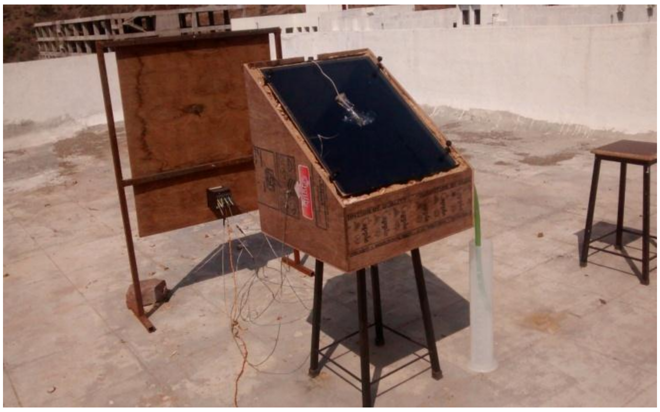


Fig.1 Plywood insulated solar still with 35° cover inclination.

Test has been conducted for 4 days for 4 different water depths that are 0.08m, 0.04m, 0.02m and 0.01m.Temperatures were recorded of inner and outer surface of basin wall, inner and outer surface of glass, water and vapour temperature with the help of sensors per hour. Once the reading for different water depth is finished. Thermocol and plywood insulation is provided to solar still. Fig. 2 shows plywood is placed around the solar still to reduce heat loss from side and bottom .for further analysis and readings are recorded for per hour.

A. Energy balance equation

$$I(t) * \alpha_w * \tau_g = q_{(\text{internal heat loss})} + q_{(\text{top heat loss})} + q_{(\text{side and bottom heat loss})} + m_w \times C_w \times \Delta T \quad (1)$$

B. Internal heat transfer

In solar still, internal heat is transferred by evaporation, convection and radiation. The convective and evaporative heat transfers takes place simultaneously and are independent of radiative heat transfer.

1) Radiative heat transfer:

The view factor is considered, as unity because of glass cover inclination is small in the solar still. The rate of radiative heat transfer between water to glass is given by,

$$q_{r(w-g)} = h_{r(w-g)} \times (T_w - T_{gi}) \quad (2)$$

$h_{r(w-g)}$= Radiative heat transfer coefficient between water to glass,
ε_{eff} = Effective emission between water to glass cover.

2) Convective and evaporative heat transfer:

Natural convection takes place across the humid air inside the basin due to the temperature difference between the water surfaces to inner surface of the glass cover.

$$q_{c(w-g)} = h_{c(w-g)} \times (T_w - T_{gi}) \quad (3)$$

$h_{c(w-g)}$= Convective heat transfer coefficient depends on the temperature difference between evaporating and condensing surface, physical properties of fluid, flow characteristic and condensing cover geometry.

$$h_{c(w-g)} = 0.884\, T_w - T_{gi} + \left[\frac{(P_w - P_{gi})(T_w + 273)}{268.9 \times 10^3 - P_w}\right]^{1/3} \quad (5)$$

The various models were developed to find the convective heat transfer coefficient. One of the oldest methods was developed by Dunkle's [20] and his expressions have certain limitations, which are listed below.

I. Valid only for normal operating temperature (≈500°C) in a solar still and equivalent temperature difference of ΔT=17°C.
II. This is independent of cavity volume, i.e., the average spacing between the condensing and evaporating surfaces.
III. This is valid only for upward heat flow in horizontal enclosed air space, i.e., for parallel evaporative and condensing surfaces.

Therefore according to Tiwaris model

$$Nu = \frac{h_{c(w-g)} \times L_c}{k} = C(Gr.Pr)^n \quad (4)$$

$$h_{c(w-g)} = C(Gr.Pr)^n \times \frac{k}{L_c} \quad (5)$$

The distillate output in kg from the unit can be obtained by the relation

$$M_{ew} = \frac{q_{e(w-g)} \times A_w \times t}{\Delta h_v} \quad (6)$$

3) Evaporative heat transfer:

The performance of solar still depends on the evaporative and convective heat transfer coefficients. Various scientists developed mathematical relations to evaluate the evaporative and convective heat transfer coefficients

$$q_{e(w-g)} = h_{e(w-g)} \times (T_w - T_{gi}) \quad (7)$$

$h_{e(w-g)}$= Evaporative heat transfer coefficient

$$h_{e(w-g)} = 0.01623 \times h_{c(w-g)} \times \left[\frac{(P_w - P_{gi})}{(T_w - T_{gi})}\right] \quad (8)$$

From equation, (5)

$$h_{e(w-g)} = 0.01623 \times C(Gr.Pr)^n \times \frac{k}{L_c} \times \left[\frac{(P_w - P_{gi})}{(T_w - T_{gi})}\right] \quad (9)$$

The total heat transfer coefficient of water to glass is defined as

$$h_{t(w-g)} = h_{r(w-g)} + h_{c(w-g)} + h_{e(w-g)} \quad (10)$$

The rate of total heat transfer of water to glass is defined as,

$$q_{t(w-g)} = h_{t(w-g)} \times (T_w - T_{gi}) \quad (11)$$

C. External heat transfer

The external heat transfer in solar still is mainly governed by conduction, convection and radiation processes, which are independent each other.

1) Top loss heat transfer coefficient:

The heat is lost from outer surface of the glass to atmosphere through convection and radiation modes. The glass and atmospheric temperatures are directly related to the performance of the solar still. So, top loss is to be considered for the performance analysis. The temperature of the glass cover is assumed uniform because of small thickness. The total top loss heat transfer coefficient is defined as
The overall top loss from the glass to the atmosphere,

$$q_{t(g-a)=} = U_{(g-a)} * (T_{gi} - T_a) \quad (12)$$

The overall heat transfer coefficient is expressed as

$$U_{(g-a)} = \left[\frac{X_g}{k_g} + \frac{1}{h_{c(w-g)}} + \frac{1}{h_{r(g-a)}}\right]^{-1} \quad (13)$$

2) Side and bottom loss heat transfer coefficient:

The heat is transferred from water in the basin to the atmosphere through insulation and subsequently by convection and radiation from the side and bottom surface of the basin
The total side loss,

$$q_{t(side\ wall-a)} = U_{(\text{side wall}-a)} \times (T_{\text{side wall}} - T_a) \quad (14)$$

The total side loss overall heat transfer coefficient,

$$U_{(side\ wall-a)} = \left[\frac{X_b}{K_b} + \frac{X_{insulation}}{K_{insulation}} + \frac{1}{h_{c(side\ wall-a)}} + \frac{1}{h_{r(side\ wall-sky)}}\right]^{-1}$$
(15)

There is no velocity in bottom of the solar still. By considering air velocity zero heat transfer coefficient. The bottom loss heat transfer coefficient from the water mass to the ambient through the bottom can calculate, the overall heat transfer coefficient can expressed as,

$$U_{(b-a)} = \left[\frac{X_b}{K_b} + \frac{1}{h_{c(b-a)}} + \frac{1}{h_{r(b-a)}} + \frac{X_{insulation}}{K_{insulation}}\right]^{-1}$$
(16)

The total bottom loss,

$$q_{t(b-a)} = U_{(b-a)} \times (T_{bottom} - T_a)$$
(17)

D) Efficiency calculation

Overall thermal efficiency of solar still is,

$$\eta = \left\{\frac{\sum M_{ew} \times \Delta h_v}{[\sum I(t) \times A_b + (m_w \times C_w \times \Delta T)]}\right\} \times 100$$
(18)

IV. RESULT & DISCUSSION

Fig.3. represents that glass cover inclination increases from 15° to 35°. When the solar rays are perpendicular to the surface then it allows receiving a maximum solar radiation for still. To reduce fall back of drop to the basin maximum tilt of cover plate is good, so by considering these factors 35 ° gives best results.

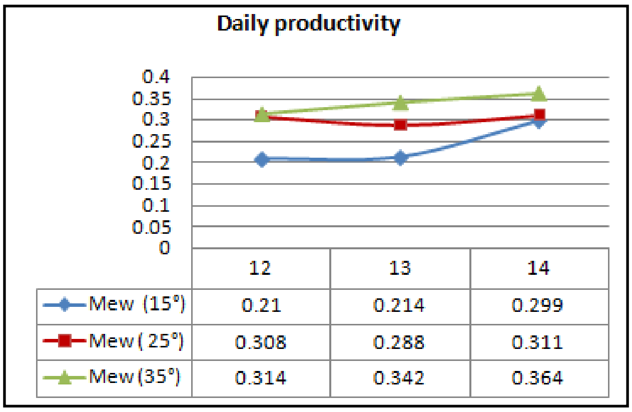


Fig.3 Daily productivity variation for different cover inclination

Due to the maximum condensing area of glass it allow better heat exchange between cover and atmosphere air thus the temperature difference between cover and water will increase which ultimately increases yield of solar still, and droplets of condensing surface will be directly collected in to the trough. Maximum angle help to accelerate the drop to flow in to the trough in film wise condensation mode. Film wise condensation mode is better than drop wise condensation mode because it does not stick the glass and therefore it does not increase resistance and reflection of solar rays.

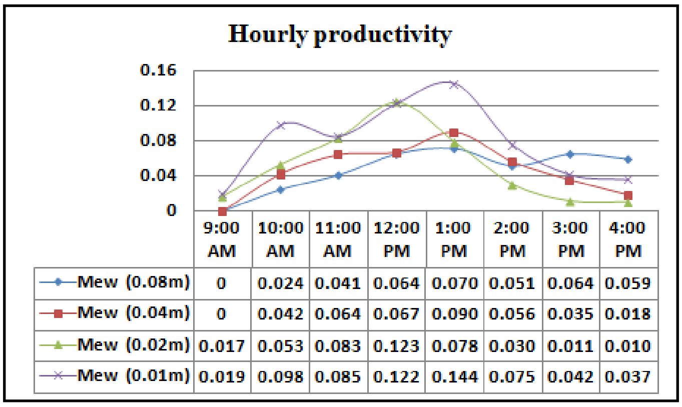


Fig.4 Hourly variation of productivity for different water depth

Fig.4 shows as a water depth decreases water depth increases, due to low storage capacity of water at lower water depth.

The value of C and n obtain, these value found very realistic for the positive temperature difference as compare negative temperature difference. Analysis for all water depth is carried over for the hours when the water temperature becomes higher than inner glass temperature to obtain better realistic result.

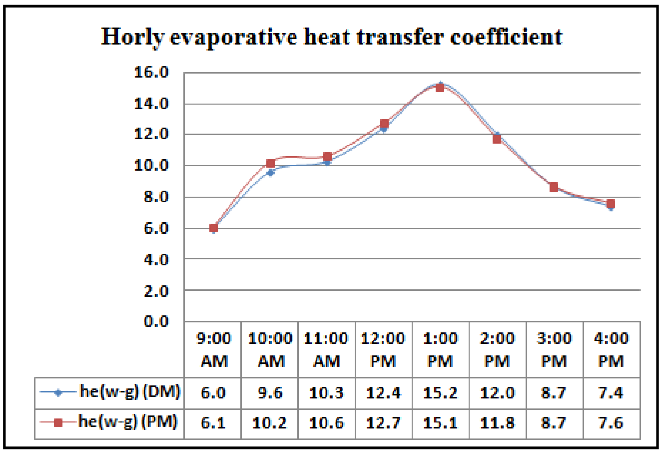
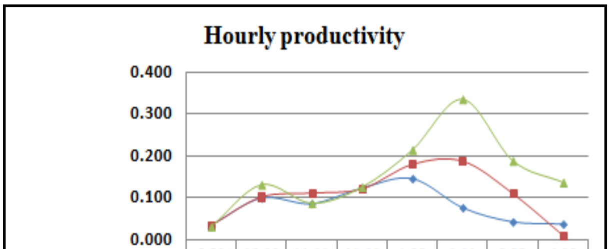


Fig.5 Hourly variation of evaporative heat transfer coefficient by using both model.

Fig.5 shows difference between convective and evaporative heat transfer coefficient for 0.01m water depth by Dunkles model (DM) and by Tiwaris that is present model (PM), due to limitations of Dunkles model, which are explained in thermal analysis.

In the morning due to low intensity of sunrays, productivity is minimum, around 11 AM to 2 PM there is high rate of productivity and after 3 PM this rate start to fall due to low intensity of sun ray. As water depth decreases productivity increases it is effect of heat storage capacity of water, which leads to increase evaporation rate and ultimately productivity of solar still. The side losses are minimum in case of plywood as shown in fig 6.Where as in case of thermocol and solar still without insulation the losses are found to be high as compared to plywood. At a certain instance, the losses in case of thermocol increases this is due to high temperature difference between wall and atmosphere.

Plywood acts as a best insulation for solar still than thermocol due to low thermal conductivity. It reduces side and bottom heat losses of solar still.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM
Mew (without insulation)	0.033	0.098	0.085	0.122	0.144	0.075	0.042	0.037
Mew (thermocol)	0.034	0.101	0.111	0.120	0.179	0.186	0.109	0.009
Mew (plywood)	0.031	0.131	0.087	0.125	0.214	0.335	0.188	0.137

Fig.6 Hourly variation of productivity for different insulation

V.CONCLUSION

It is found that 35° inclination cover plate gives better result than 15° and 25° inclination. Convective and evaporative heat transfer coefficients are affected by water depth, which is useful for designing efficient solar distillation system. It has also been seen that maximum yield is obtained at lower water depth. Proper use of insulation on solar still reduces heat losses from wall to the atmosphere which increases the productivity of solar still. Plywood gives maximum result than thermocol.

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