Effect of Water Depth on Productivity of Solar Still with Thermal Energy Storage

Sathish Kumar T R[1], Raja Bharathi B[2]

[1]Department of Mechanical Engineering, Sri Ramakrishna Engineering College,
Coimbatore, Tamil Nadu, India
prof.trs@gmail.com

[2]Department of Mechanical Engineering, C K College of Engineering & Technology,
Cuddalore, Tamil Nadu, India
brbccc@yahoo.com

Abstract: ***Solar desalination is a simple and economical method which utilizes solar energy for producing fresh potable water from sea water or brackish water. In the present work a double slope single basin solar still has been constructed coupled with inbuilt thermal energy storage material. A comprehensive study was made to evaluate the effect of water depth in the basin on productivity of the still. Experiments were conducted in different conditions with black gravel powder as thermal energy storage material. The results indicated decreasing water depth increased the productivity of the still.***

Keywords: Solar desalination, solar still, water depth, thermal energy storage, water productivity.

1. Introduction

The demand for potable water is increasing day by day due to population growth and unsustainable consumption rate. In developing countries, rapid growth of industries to a greater extent pollutes the available fresh water resources like rivers, lakes and underground water. Solar desalination is a simple, economical and most promising technology for producing fresh water in the remote, arid and semi arid regions where water scarcity is more.

Solar distiller consists of a black painted basin contained by saline water enclosed by a transparent cover. The entire set up is kept air tight in order to maintain vacuum pressure inside the still. Incident solar radiation passes through the transparent cover and is absorbed by the basin. The basin gets heated up and it transfers the heat to the saline water contained in it. Since the pressure inside the still is vacuum pressure, the water gets saturated at low temperature and is evaporated. The water vapour rises over the surface and touches the surface of the transparent cover which is relatively cooler, so that it gets condensed as pure water which is collected through an enclosed container. This process has an advantage of zero fuel cost but it requires a large space for the collection of solar radiation.

Numerous works has gone on solar still to increase its productivity and has been published by many researchers [1][2][3]. O.O.Badran and S.Abdullah has coupled the sun tracking system to the solar still and has observed 22% increase in productivity and 2 % increase in overall efficiency [4]. K.Srithar et.al has optimized the orientation and inclination of the glass cover and has lowered the condensation loss. Also they used different materials for basin to improve the heat capacity, radiation absorption capacity and to enhance the evaporation rate and they have suggested rubber as best basin material to improve absorption, storage and evaporation effects [5]. O.O.Badran has increased the productivity by 51% by using combined enhancers such as asphalt basin liner and sprinkler. He observed that the night production in the absence of solar radiation contributed to 16 % of the daily output due to the difference in temperature between the cover and water and the decrease of heat capacity [6]. Suresh.C.Ameta et al., has increased the productivity of the still using photo catalysts. They have increased the overall efficiency of the conventional still by coating semiconducting oxides like CuO_2, PbO_2 and MnO_2 over the basin and they observed PbO_2 is most effective among all other oxides [7].

In the present work, a comprehensive study is made on single basin double slope solar still with integrated thermal energy storage system to evaluate the effect of water depth on the productivity of the system. Experiments were conducted on the still by varying the depth of water on the basin (20 mm, 30 mm and 40 mm). All the sets of readings were taken at similar climatic conditions. The obtained results clearly states that productivity of the still is inversely proportioned to the water depth in the basin.

2. Experimental Setup

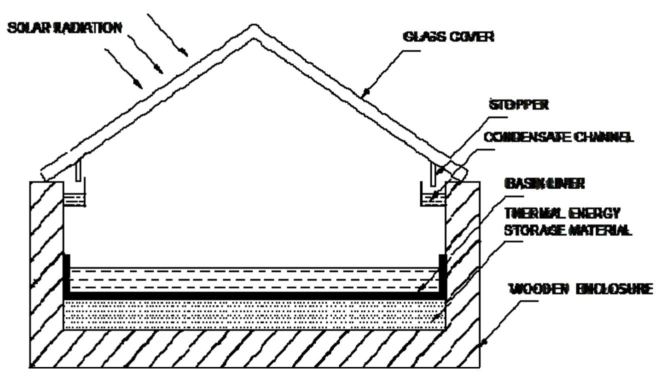

Figure1. Single Basin Double Slope Solar Still

A double slope single basin solar still shown in Fig.1 is constructed using locally available materials, after carefully considering the aptness of the materials in different portions of the still. The entire set up is housed inside a wooden box of 40 mm thickness.

2.1 Basin liner

The basin liner is the main part of the solar still. It absorbs the incident solar radiation transmitted through the glass cover. In the present study, the basin liner was made up of galvanized iron sheet of 3 mm thickness with the area of $0.5m^2$.The basin surface was thoroughly polished and painted black with corrosion resistant paint.

2.2 Glass cover

A 3 mm thick glass sheet was used to cover the still in the present work. Four different glass sheets were cut at different shapes and sizes and are bonded using silicon rubber which is a suitable adhesive material to bond the glasses and the glass with other materials. The glass cover is kept inclined at 32^o with the horizontal and was fitted in an iron frame. The frame holding the glass cover was tightened to the still with bolts, using a rubber gasket to avoid vapour leakage.

2.3 Distillate channels

An aluminium channel is chosen as the distillate channel for its non corrosive nature. It is attached to the lower edge of the glass cover to collect the distillate water and to carry to the collecting jar through the exit hose. A hole is drilled on the side wall of the still for feeding the brackish water and tap is provided to drain the saline water.

2.4 Measuring Devices

2.4.1 Measurement of Temperature

The thermocouples (k- type) are used to measure the temperatures at various location of the still. The temperature of basin liner, water in the basin, glass cover inside and outside surface and ambient temperature are measured. The thermocouples are connected to a multi channel temperature recorder.

2.4.2 Measurement of Wind Speed

Wind speed plays a vital role in cooling of the glass cover which in turn increases the yield of the still. The local wind speed over the surface of the glass cover is measured using a digital anemometer. During the present experimental work, the wind speed was in the range of 2.5 m/s to 4 m/s.

2.4.3 Solar Radiation

In the present work, a Solarimeter is used to measure the global solar radiation incident on a horizontal surface. The device can measure solar intensity in the range of 1 to 100 mW/cm^2 with an accuracy of 2 mW/cm^2.

3. Governing Equations

The following assumptions have been made for framing the energy balance for each of the components present in the solar still under study;

(i) There is no temperature stratification along the water column and glass thickness.
(ii) The system is air tight and there is no leakage from the corners of the glass cover

3.1 Thermal analysis of glass cover

The solar energy absorbed by the glass cover is given as,

$$q_g\left(W/m^2\right)=\alpha_g I_s - q_{\lg} \quad (1)$$

Where, I_s is the solar insolation on the glass cover, q_{lg} is the heat losses from the glass cover and the surrounding air by convection and by radiation ($q_{cg} + q_{rg}$)

$$q_{cg}\left(W/m^2\right)=h_{cg}\left(T_g - T_o\right) \quad (2)$$

Where, h_{cg} is the heat transfer coefficient from the glass cover to the surrounding which is a function of wind speed (W_s) and can be calculated using the following relation [8]

$$h_{cg}\left(W/m^2K\right)=5.7+3.8W_s \quad (3)$$

$$q_{cg}\left(W/m^2\right)=\varepsilon_g\sigma\left[T_g{}^4-\left(T_a-11\right)^4\right] \quad (4)$$

Where, ε_g is the emissivity of the inner glass surface = 0.89 [9], σ is Stefan Boltzmann constant = 5.669 x 10^{-8} W/m^2K^4

3.2 Thermal analysis of basin water

The heat absorbed by the water stored in the basin of are 1 m^2 is given as,

$$q_w\left(W/m^2\right)=\tau_w\alpha_w I_s - q_{lw} \quad (5)$$

Where, q_{lw} is the total heat losses of the basin water which is given as,

$$q_{lw}\left(W/m^2\right)=q_{ew}+q_{rw}+q_{cw}+q_{lb} \quad (6)$$

Where, q_{ew} is the evaporative heat transfer rate at the saline water surface and is the function of yield of the still (W_p, l/m^2h), given as,

$$q_{ew}\left(W/m^2\right)=\frac{\left(W_p\times10^{-6}\times\rho_w L_w\right)}{3600} \quad (7)$$

Where, L_w is the latent heat of water which is equal to 2.4 x 10^6 J/kg [10].

$$q_{rw}\left(W/m^2\right)=F_{(w-g)}\sigma\left(\varepsilon_w T_w{}^4-\varepsilon_g T_g{}^4\right) \quad (8)$$

Where, $F_{(w-g)}$ is shape or view factor which depend upon the geometry of the still. The value of shape factor is taken as 0.9 by approximating the geometry by two parallel planes. ε_w is the emissivity of saline water surface and ε_g is the emissivity of the inner glass surface whose values are 0.96 and 0.85 respectively.

Where, q_{cw} is the convective heat transfer rate between the saline water and the inner glass cover surface which is given as,

$$q_{cw}\left(W/m^2\right)=h_{cw}\left(T_w-T_g\right) \quad (9)$$

Where, h_{cw} is the convective heat transfer coefficient between the saline water and the inner glass surface of the still which can be calculated using the relation,

$$h_{cw}\left(W/m^2\right)=8.84\times10^{-4}\left[\frac{\left(P_w-P_g\right)T_w}{2.69P_a-P_w}+\left(T_w-T_g\right)\right]^{\frac{1}{3}} \quad (10)$$

Where, P_w, P_{wg} and P_a are vapor pressures of water at water surface temperature, glass cover temperature and at atmospheric pressure respectively, N/m^2.

Where, q_{lb} is the heat losses by convection through the base of the basin and side walls to the surrounding which is given as,

$$q_{lb}\left(W/m^2\right) = h_{lb}\left(T_w-T_a\right) \quad (11)$$

Where, h_{lb} is the equivalent heat transfer coefficient by convection from the basin to the surrounding and is derived from the following equation,

$$h_{lb}\left(W/m^{2^o}C\right)=\frac{K_{ins}}{X_{ins}} \quad (12)$$

Where, K_{ins} and the X_{ins} are values of thermal conductivity and the thickness of the insulation material.

3.3 Thermal analysis of the thermal energy storage layer

Thermal energy storage material feed the solar still during the absence of effective solar insolation over the system. The aim of using the thermal energy storage layer is to increase the distillate water output per day. The governing equation during day time is given as,

$$q_{pd}\left(W/m^2\right)=m_pC_{p_p}\frac{\partial T_{pd}}{\partial t} \quad (13)$$

$$q_{pd}\left(W/m^2\right)=A_pI_s\left(\alpha\tau\right)_p+A_wI_s\left(\alpha\tau\right)_w-q_{lp} \quad (14)$$

During night time the equation is given as,

$$q_{pn}\left(W/m^2\right)=m_pC_{p_p}\frac{\partial T_{pn}}{\partial t} \quad (15)$$

$$q_{pn}\left(W/m^2\right)=m_pC_{p_p}\frac{\partial T_{pd}}{\partial t}+m_wC_{pw}\frac{\partial T_w}{\partial t}-q_{lp} \quad (16)$$

Where, m_p and m_w are the mass of thermal energy storage material and the saline water respectively in kg, A_p and A_w are the surface area of the thermal energy storage material and the saline water in m^2, $(\alpha\tau)_p$ and $(\alpha\tau)_w$ are the absorptivity trasmissivity of the thermal energy storage layer and the saline water respectively, q_{lp} is the het losses between the thermal energy storage layer and the saline water in W/m^2.

The efficiency of the solar still integrated with thermal energy storage is evaluated by the ratio of daily yield (W_p, l/m^2 day) of the still to the total solar energy (q_t, W/m^2) utilized for the evaporation of the water in the basin of the basin. The equations to determine the efficiency of the still are as follows,

$$q_t\left(W/m^2\right)=q_g+q_w+q_p \quad (17)$$

$$W_p\left(l/m^2day\right)=\frac{q_{ew}}{\rho_wL_w} \quad (18)$$

$$\eta_p=\frac{q_{ew}}{q_t}=\frac{W_p\times10^{-6}\times\rho_wL_w}{3600I_s}=\frac{2.35\rho_w\times W_p}{3600I_s} \quad (19)$$

Where, I_s is the daily total solar radiation, $J/(m^2$ day), W_p is the daily yield of the still, $l/(m^2$ day), and L_w is the latent heat of the water evaporated which is equal to 2.35×10^6 J/kg.

4. Results and Discussions

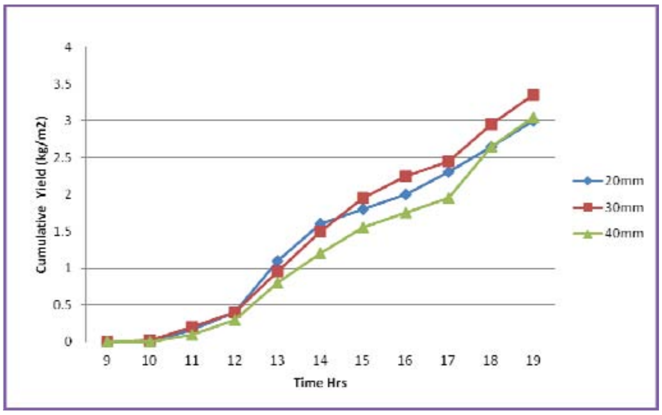

Figure 2. Variation of Cumulative yield of the still with respect to Time.

The Fig.2 shows the variation in cumulative yield of the solar still with the time for different depths of saline water. The cumulative yield of the still is more when the saline water depth is 30 mm. The difference in cumulative yield between the other two water depths is more between 13.00 and 17.00 hours and became almost same at the end of the day, since the productivity increased for 40 mm depth saline water during off shine period.

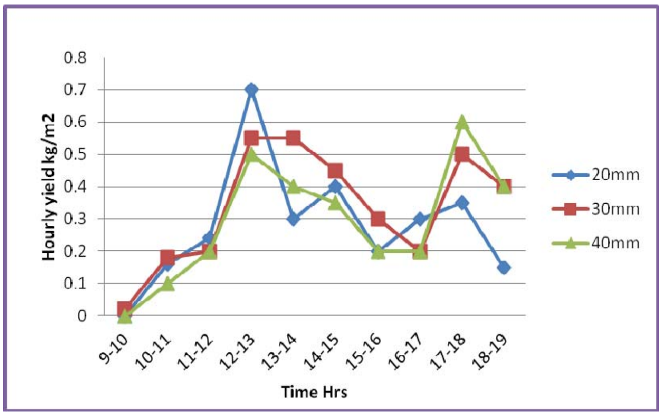

Figure 3. Variation of Hourly yield of the still with respect to Time.

Fig.3 shows the hourly yield of the still with 20 mm depth saline water is high between 12.00 and 13.00 hours due to high solar intensity. For higher saline water depths the hourly yield increases rabidly during the off shine hours due to high heat capacity of the water

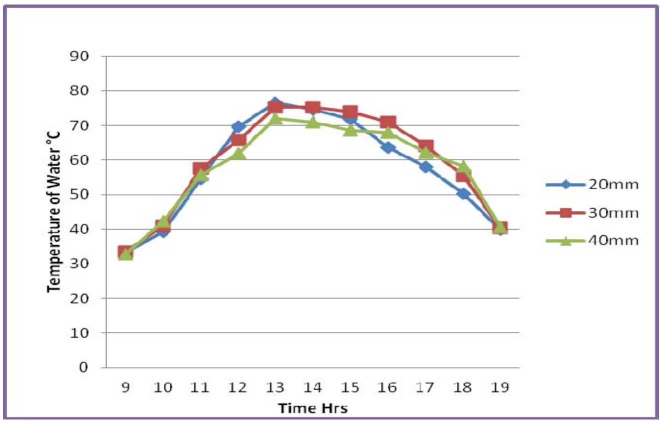

Figure 4. Variation of Temperature of water in the basin with respect to Time.

From the Fig.4, it is evident that the saline water temperature reached highest value when depth is 30 mm when compared to the 20 mm depth and 40 mm depth. For 20 mm depth water temperature reaches maximum level almost equal to 30 mm depth saline water and remind there for a short duration due to its low heat capacity. In contrast, the temperature of 40 mm depth saline water is found to be comparatively higher when the solar intensity has reduced due to its high heat capacity.

Fig.5 shows the variation of temperature difference between the saline water and the glass cover which is the one of the parameter affecting the productivity of the still. At high solar intensity the temperature difference is more for 20 mm depth and less for 40 mm depth. The condition is vice versa during evening hours when the solar intensity is low.

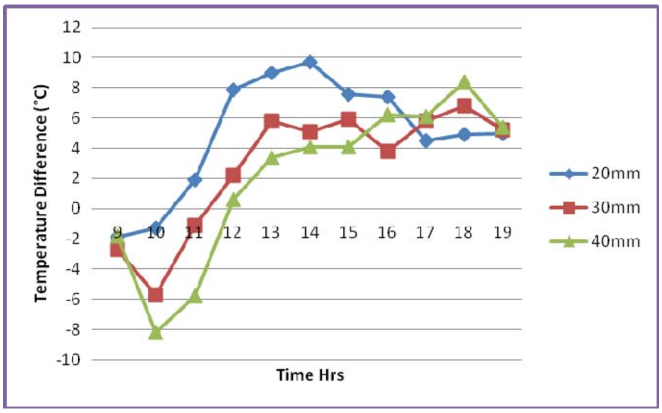

Figure 5. Variation of Temperature difference between saline water and glass with respect to Time.

5. Conclusion

The effect of water depth over the productivity of the modified solar still is studied experimentally and the performance of the still is compared with the conventional still. The following conclusion are drawn;

1. The cumulative yield of the modified still is 11% more than the conventional still.
2. The maximum yield of the still attained when the saline water depth is 30mm.
3. The maximum efficiency of the still is 48% which is 9% higher than conventional solar still

References

[1] G.N.Tiwari, S.k.Shukla and I.P.Singh, "Computer modeling of passive/active solar stills by using inner glass temperature", Desalination, 154(2003) 171-185.

[2] G.N.Tiwari, J.M.Thomas and Emran Khan, "Optimization of glass cover inclination for maximum yield in solar still", Heat recovery Sys. CHP, 14 (1994) 447-445.

[3] H.Yousef and Mousa Abu-Arabi,"Modeling and performance analysis of a regenerative solar desalination unit", Applied Thermal Engineering, 24(2004) 1061-1072.

[4] O.O.Badran and S.Abdullah, "Sun tracking system for productivity enhancement of solar still", Desalination 220 (2008) 669-676

[5] K.Srithar, K.Kalithasa Murugavel, Kn.K.S.K.Chokalingam, "Progresses in improving the effectiveness of the single basin passive solar still", Desalination 220 (2008) 677-686

[6] O.O.Badran, "Experimental study of the enhancement parameters on a single slope solar still productivity", Desalination 209(2007) 136-143.

[7] Suresh.C.Ameta, "Use of photo catalysts inn solar desalination", Desalination 189(2006) 287-291.

[8] Duffie JA, Backman WA, "Solar engineering of thermal processes, New York: Wiley, 1991.

[9] Bahadori MM, Edlin FE, "Improvement of solar stills by the surface transparency of the glass", Solar Energy 1973, 14: 339-52.

[10] G.Mink, M.Aboabbous and E.Karmazsin, Design parameters, performance testing and analysis of a double glazed, air blown solar still with heat recycling, Solar Energy, 62(1998) 309-317.

Author Profile

Sathish Kumar. T. R received his B.E Degree in Mechanical Engineering from Amrita Institute of Technology and Science, Coimbatore in 2002 and M.E Degree in Thermal Power from Annamalai University in 2004. He has more than eight years of teaching experience at engineering college level. At present he is working as Assistant Professor in Sri Ramakrishna Engineering College, Coimbatore, India.

Raja Bharathi. B received his B.E Degree in Mechanical Engineering from Annamalai University in 2003 and M.E Degree in CAD/CAM from Arunai Engineering College in 2006. During 2003-2004 he worked as Safety Engineer in BAVA Erectors (NLC). From 2007 he started his teaching career. At present he is working a s Assistant Professor in C K College of Engineering and Technology, Cuddalore, India.