Performance Evaluation of Tilted Wick-Type Solar Still Integrated with Shallow Solar Pond

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Abstract

An attempt has been made to integrate tilted-wick type solar still with a shallow solar pond and tested. Analytical equations have been derived for the temperature elements of the still and pond by solving the energy balance equations of the systems separately. Experiments have been carried out with the still provided with single and multiple wick in the tilted portion of the still. The analytical results have been validated with the experimental observations of both the still and the pond for one of the typical days in the month of April 2012 at Karpagam University, Coimbatore, Tamilnadu, India. The result shows that the still provided with multiple wick integrated with shallow solar pond has enhanced the productivity and efficiency in an impressive manner. Still with multiple wick is recommended in the case of integrating the wick type solar still with solar pond.
Keywords: daily productivity, experimental observations, preheated water, Shallow solar pond, wick type solar still

I. INTRODUCTION

Water is the essential thing for our survival on earth. Absence of water is the one of the main reason for no identification of lives in the remaining planets of our solar system. Even though the earth contains 1.4 billion km^3 of water in it, only 2.5% is in the form of fresh drinking water. The available fresh water sources on the earth are in the forms of rivers, lakes, wells, ground water etc… This less available amount of drinking water is being contaminated by human being activities. Release of industrial outlets into the rivers, wasting the fresh water without knowing its importance, release of toxic gasses into the atmosphere resulting in reduced rainfall are some of the examples. This made the researchers to search in for fresh water all the times since ancient days which are partly satisfied by one of the renewable energy source called solar energy.

Researchers improved their search for drinking water decade to decade by modifying their solar distillation systems. Because solar distillation systems stood back for their time consuming and lower yielding methodology. Many researchers have undergone researches and concluded that, wick-type solar stills stands as a next level after basin type solar stills, on considering the concept of increase in productivity. Huanmin Lu et al. [1] have made an attempt to couple solar pond with a solar still in the year of 2001. The proposed work of coupling the solar still with salinity-gradient solar pond inferred that, SGSP is one of the promising ponds for water purification. Caruso et al. [2] have conducted research on high-energy efficiency desalination using full titanium desalination unit with solar pond as the heat supply and found that, the result shows that, more fresh water can be produced and also the agreement of analytical and experimental simulations. Velmurugan and Srithar [3] in 2007, integrated a mini solar pond to a solar still and proposed that, the average daily productivity of the still have increased considerably when integrated with a mini solar pond.

Garman and Muntasser [4] in 2008, have studied the sizing and thermal study of salinity gradient solar ponds connected to a MED desalination unit and suggested optimum heights for each layers of the salinity gradient solar ponds and the optimum values are 0.3m, 1.1m and 4m for upper, non-convective and lower convective zone. Further, Velmurugan et al. [5, 6] have integrated a mini solar pond to a stepped solar still and to a single basin solar still in series and separately. He concluded that the stepped solar still with fins have shown better result and the use of pebbles enhanced the night time productivity when connected in series. When connected separately, the fin, pebble and sponge materials have provided more output. Finally the thermal performance of a active single basin solar still coupled to a shallow solar pond and a single basin solar still integrated to a shallow solar still have been done by El-Sebaii et al. [7,8] and inferred that the daily productivity of the active and passive single basin stills resulted in increased output when the still is coupled with SSP compared to the output of the still alone.

In the present study, an effort has been taken to find the impact of integration of wick-type solar with shallow solar pond. Experiments have been carried out to find the effectiveness of single and multiple wicks in the still integrated with the pond. Analytical solutions have been proposed for the temperature elements of the pond and still and validated with the experimental observation for one of the typical days in Karpagam University, Coimbatore, Tamilnadu, India.

II. NOMENCLATURE

A. *Shallow Solar Pond:*

- $H_s(I)$ - Incident solar radiation (W/m^2)
- l_{he} - Length of the heat exchanger tube (m^2)
- h - Convective heat transfer coefficient from water to glass cover (W/m^{2}K)
- h_1 - Convective heat transfer coefficient from glass cover to ambient (W/m^{2}K)
- h_2 - Convective heat transfer coefficient from absorber plate to ambient (W/m^{2}K)
- h_3 - Convective heat transfer coefficient from water to ambient (W/m^{2}K)
- h_5 - Convective heat transfer coefficient from water to heat exchanger (W/m^{2}K)
- h_6 - Convective heat transfer coefficient from heat exchanger to fluid (W/m^{2}K)
- P - Perimeter of the heat exchanger tube (m), $P = 2\pi r$
- m_{he}, m_f - Mass of the heat exchanger tube and heat exchanger fluid (kg/m^2)
- C_{he}, c_f -Specific heat capacity of the heat exchanger tube and heat exchanger fluid (J/kg K)
- $\alpha_g, \alpha_p, \alpha_w$- Absorptivity of the glass, absorber plate and water
- T_w, T_g, T_p, T_f- Water, glass, Absorber plate and Fluid temperatures (K)
- $A_g, A_p, A_s, A_w, A_{he}$-Area of the glass cover, absorber plate, sky, water and heat exchanger tube (m^2)

B. *Tilted Wick-Type Solar Still:*

- A_{eff} - Effective area of the wick surface (m^2)
- l_g, b_g - Length and breadth of the glass cover (m^2)
- h_{cwg} - Convective heat transfer coefficient from wick to glass cover (W/m^{2}K)
- Q_{cwg} - Convective heat transfer from wick to glass cover (W/m^2)
- h_{ewg} - Evaporative heat transfer coefficient from wick to glass cover (W/m^{2}K)
- Q_{ewg} - Evaporative heat transfer from wick to glass cover (W/m^2)
- h_{rwg} - Radiative heat transfer coefficient from wick to glass cover (W/m^{2}K)
- h_{cga} - Convective heat transfer coefficient from glass cover to ambient (W/m^{2}K)
- h_{rga} - Radiative heat transfer coefficient from glass to ambient (W/m^{2}K)
- Q_{rwg} - Radiative heat transfer from wick to glass cover (W/m^2)
- P_w, P_g - Saturated vapour pressure of vapour at water and glass temperatures (Nm^{-2})
- h_1 - Total heat transfer coefficient from wick surface to the glass cover (W/m^{2}K)
- h_2 - Total heat transfer coefficient from glass cover to ambient (W/m^{2}K)
- h_3 - Total heat transfer coefficient from bottom and side walls to ambient (W/m^{2}K)
- M_{dwt} - Mass of the distillate yield (kg/m^2/ 30mins)
- L - Thickness of the glass cover (0.004 m)
- T_{srg} - Tilted solar radiation on the glass cover (W/m^2)
- dt - Time interval
- T_w, T_a, T_g- Wick, ambient and glass Temperatures (K)

C. *Greek Symbols*

- ε- Emittance (dimensionless)
- σ - Stefan-Boltzman constant. (W/m^{-2} K^{-4})
- Instantaneous Thermal efficiency of the still (%)
- α - Absorptance, (dimensionless)
- τ_g - Transmittance of the glass cover, (dimensionless)
- $\alpha_g, \alpha_w, \alpha_p$-Absorptivity of the glass cover, wick surface and the absorber plate.

III. DESIGN OF THE SYSTEM

The current system consists of a tilted wick-type solar still (TWSS) accompanied by another heat source which is a shallow solar pond (SSP). The figure shows the schematic representation of the proposed model. It consists of a water tank containing brackish water, a shallow solar pond and a tilted wick-type solar still. From the water tank the brackish water was allowed to flow through the SSP by a controlled valve 1. The outlet of the SSP was connected to the TWSS. For controlling flow, from SSP to TWSS, control valve 2 is used. To preheat the brine in SSP, a swirled copper tube was used. Heat from the solar pond can be extracted by two modes namely batch mode and continuous mode. Here in this work, water flow from SSP is continuous to the TWSS. Whole throughout the day, the hot water is taken from the SSP and sent to the TWSS. A continuous mode of extraction is used in this system.

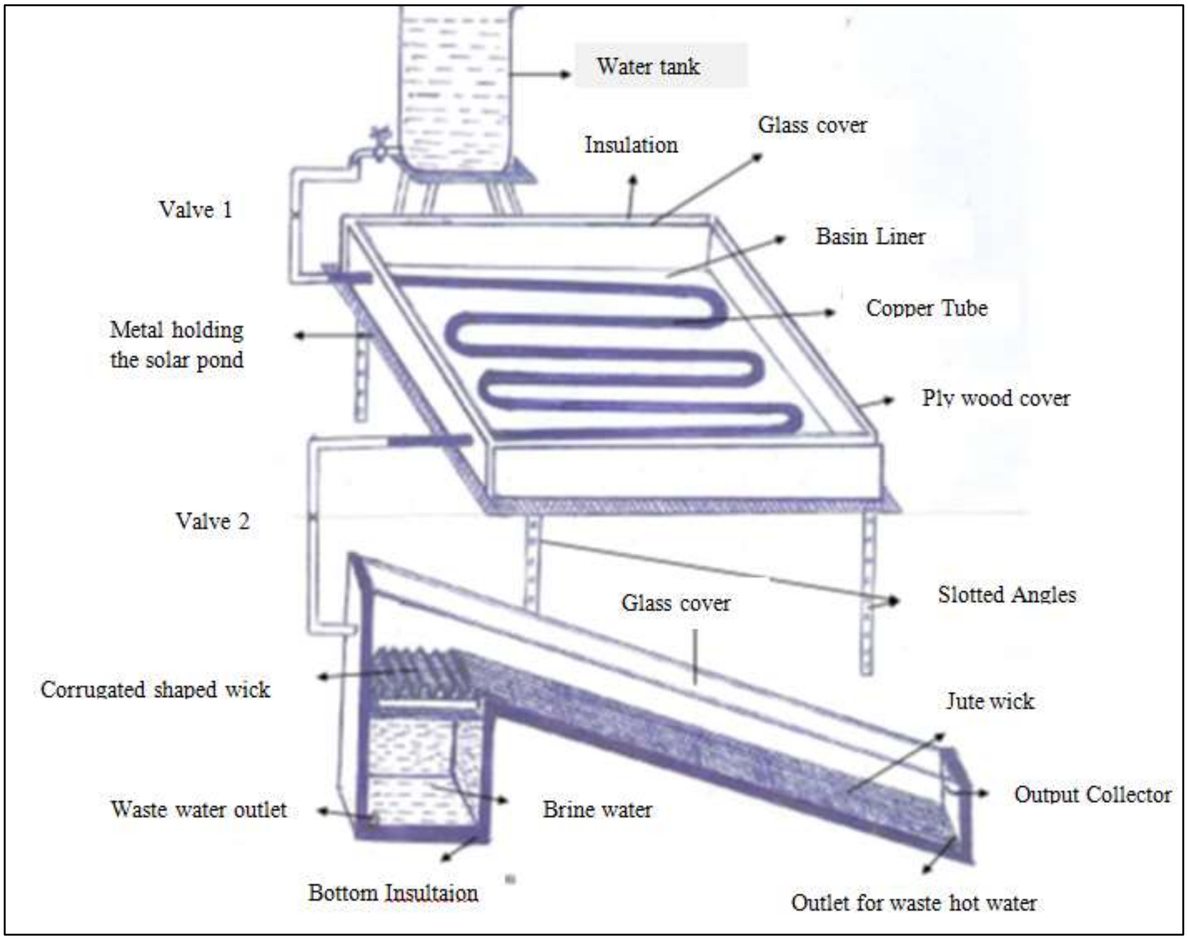

Fig. 1: Schematic representation of SSP and TWSS.

Figure 1 shows the schematic diagram of a SSP and TWSS of area $1m^2$. The bottom surface of the still was painted black for greater absorptivity. The glass cover of 4mm thickness covers the still. The inner dimension of the still is 1m by 1m by 0.38 m and the outer dimension is being 1.17m by 1.17m by 0.53m. The gap between the inner and outer dimensions is filled with thermal insulator to minimize the heat loss. A jute wick material painted black is spread over the 13° tilted portion and the remaining part of the wick has been prepared in corrugated shape and made to float over the water reservoir of the still with a thermocole of 0.002m thick. The water level in the reservoir was maintained so as not to overflow in the tilted portion and always to be 0.025m below the tilted portion through an inlet controlled by a valve 2. The corrugated floating wick always coincides with the upper level of the water in the reservoir which makes tilted wick always wet due to capillary action. This arrangement causes evaporation from the tilted wick and floating wick surfaces.

IV. PERFORMANCE ANALYSIS

Energy balance equations have been written for the temperature components of the proposed system. The energy balance for the solar pond has been written with the following assumptions and are

- The surface area of the glass cover, pond water and absorber plate are equal.
- Evaporative heat transfer is absent in the pond, as the glass cover is always in contact with the water.
- There is no temperature gradient across the thickness of the pond water.

- The heat capacities of the glass cover, absorber plate and insulating material of the SSP are negligible compared to that of the water.

A. *For Glass Cover of the SSP (T_g):*

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

$$T_g = \frac{H_s(t)\times\alpha_g\times A_g + h(T_w)A_w + h_1(T_a)A_g}{h_1A_g + hA_w} \quad (2)$$

B. *For Pond Water of SSP (T_w):*

$$H_s(t)\tau_g\alpha_w A_w + h_2[(T_p - T_w)(A_p - A_{he})] = m_w C_w \frac{dT_w}{dt} + h(T_w - T_g)A_w + h_5[(T_w - T_a)A_s \quad (3)$$

On solving and rearranging the above equation, gives

$$H_s(t)\tau_g\alpha_w A_w + hT_gA_w + h_2T_pA_p - h_2T_pA_{he} + h_5T_aA_s = m_wC_w\frac{dT_w}{dt} + h_2T_wA_p - h_2T_wA_{he} + hT_wA_w + h_5T_wA_s$$

By substituting the values of Eq. 2 in Eq. 3, gives

$$\left[H_s(t)\tau_g\alpha_wA_w + h\left(\frac{H_s(t)\times\alpha_g\times A_g + h(T_w)A_w + h_1(T_a)A_g}{h_1A_g + hA_w}\right)\right]A_w + T_p(A_p - A_{he})h_2 + h_5T_aA_s$$
$$= m_wC_w\frac{dT_w}{dt} + h\left(\frac{H_s(t)\times\alpha_g\times A_g + h(T_w)A_w + h_1(T_a)A_g}{h_1A_g + hA_w}\right)A_w - hT_gA_w + h_5T_wA_s - h_5T_aA_s$$

On solving the above equation and dividing it by m_wC_w, can obtain

$$\frac{H_s(t)\tau_g\alpha_wA_w}{m_wC_w}(h_1A_g + hA_w + h_2A_p - h_2A_{he} + h_3A_g) + \frac{H_s(t)\tau_g\alpha_wA_w}{m_wC_w}(hh_2A_wA_p - hh_2A_wA_{he} + hh_3A_gA_w) + \frac{H_s(t)\tau_g\alpha_wA_w}{m_wC_w}(h_1h_2A_p^2A_g - h_1h_2A_{he}A_gA_p + hh_2A_p^2A_w - hh_2A_{he}A_pA_w) + \frac{h_1h_2hT_aA_wA_g}{m_wC_w}(A_p - A_{he}) + \frac{hh_3T_aA_w}{m_wC_w}(h_1A_g^2 + h_2A_p^2) + \frac{hH_s(t)\alpha_gA_wA_g}{m_wC_w} - \frac{hh_1A_gA_w}{m_wC_w}(T_w - T_a) + \frac{h_5T_aA_s}{m_wC_w}(h_1A_g + hA_w) = \frac{dT_w}{dt} + T_w\left(\frac{h^2h_2A_w^2A_{he}}{m_wC_w} - \frac{h^2h_2A_w^2A_p}{m_wC_w} - \frac{h^2h_3A_w^2A_g}{m_wC_w} - \frac{h_1h_2^2A_p^2A_g}{m_wC_w} + \frac{h_1h_2^2A_pA_{he}A_g}{m_wC_w} + \frac{h_1h_2^2A_pA_{he}A_g}{m_wC_w}\right) \quad (4)$$

The equation is of the general form as

$$\frac{dy}{dt} + py = Q \quad (5)$$

$$\frac{dT_w}{dt} + pT_w = Q \quad (6)$$

On integrating the eqn. (6), the analytical solution for the pond water is obtained.

$$T_w = \frac{Q}{p} + c.e^{-pt} \quad (7)$$

At t=0, $T_w = T_{wi}$, then

$$c = T_{wi} - \frac{Q}{p} \quad (8)$$

Therefore,

$$T_w = \frac{Q}{p} + \left(T_{wi} - \frac{Q}{p}\right)e^{-pt} \quad (9)$$

C. *For Heat Exchanger Tube (T_{he}):*

$$({}^{p}/_{2})H_s(t)\tau_g\tau_w\alpha_wl_{he} + h_5({}^{p}/_{2})(T_w - T_{he})l_{he} = h_6({}^{p}/_{2})(T_{he} - T_f)l_{he} + m_{he}C_{he}\left(\frac{dT_{he}}{dt}\right)l_{he} \quad (10)$$

The solution is similar to that of the pond water equations and the temperature of heat exchanger tube can be obtained from the following equation.

$$\frac{({}^{p}/_{2})H_s(t)\tau_g\tau_w\alpha_wl_{he}}{m_{he}C_{he}l_{he}} + \frac{h_5({}^{p}/_{2})l_{he}}{m_{he}C_{he}l_{he}}\left(\frac{Q}{p} + \left(T_{wi} - \frac{Q}{p}\right)e^{-pt}\right) + \frac{h_6({}^{p}/_{2})T_fl_{he}}{m_{he}C_{he}l_{he}} = \frac{dT_{he}}{dt} + T_{he}\left(\frac{h_5({}^{p}/_{2})l_{he}}{m_{he}C_{he}l_{he}} + \frac{h_6({}^{p}/_{2})l_{he}}{m_{he}C_{he}l_{he}}\right) \quad (11)$$

The equation is of the general form as

$$\frac{dy}{dx} + py = Q \quad (12)$$

$$\frac{dT_{he}}{dt} + AT_{he} = B \quad (13)$$

On integrating the eqn. (13), the analytical solution for the heat exchanger is obtained.

$$T_{he} = \frac{B}{A} + c.e^{-At} \quad (14)$$

At t=0, $T_{he} = T_{hei}$, then

$$c = T_{he(I)} - \frac{B}{A} \quad (15)$$

Therefore,

$$T_{he} = \frac{B}{A} + \left(T_{he(I)} - \frac{B}{A}\right)e^{-At} \quad (16)$$

D. *For heat exchanger fluid(T_f):*

$$h_6\left(\frac{p}{2}\right)(T_{he}-T_f)l_{he} = m_f c_f\left(\frac{dT_f}{dt}\right) \qquad (17)$$

On solving the eq. 17, gives

$$h_6\left(\frac{p}{2}\right)(T_{he})l_{he} = m_f c_f\left(\frac{dT_f}{dt}\right) + h_6\left(\frac{p}{2}\right)(T_f)l_{he}$$

Substituting the value of (T_{he}), gives

$$h_6\left(\frac{p}{2}\right)\left(\frac{B}{A}+\left(T_{he(I)}-\frac{B}{A}\right)e^{-At}\right)l_{he} = m_f c_f\left(\frac{dT_f}{dt}\right) + h_6\left(\frac{p}{2}\right)(T_f)l_{he}$$

Dividing both sides by $m_f c_f$

$$\frac{h_6\left(\frac{p}{2}\right)\frac{B}{A}l_{he}}{m_f c_f} + \frac{h_6\left(\frac{p}{2}\right)e^{-At}}{m_f c_f}\left(T_{he(I)}-\frac{B}{A}\right) = \frac{dT_f}{dt} + \frac{h_6\left(\frac{p}{2}\right)(T_f)l_{he}}{m_f c_f} \qquad (18)$$

The eq. (18) is of the general form as

$$\frac{dy}{dx} + py = Q$$

$$\frac{dT_f}{dt} + CT_f = D \qquad (19)$$

Then, on integrating the eq. 19, gives

$$T_f = \frac{D}{C} + c.e^{-Ct} \qquad (20)$$

At t=0, $T_f = T_{fi}$, then

$$c = T_{f(I)} - \frac{D}{C} \qquad (21)$$

Therefore,

$$T_f = \frac{D}{C} + \left(T_{f(I)} - \frac{D}{C}\right)e^{-Ct} \qquad (22)$$

Energy balance equations for the still have been written for the tilted wick-type solar still with the following assumptions and are

1) The still is made vapour tight
2) There is no temperature gradient on the glass cover of the still.
3) The still is well insulated to prevent the conduction and convection losses through bottom and side walls.
4) The glass cover and the wick are parallel to each other.
5) The capillarity of the wick surface is streamline and prominent.

E. *For Glass Cover:*

$$\alpha_g T_{srg} l_g b_g + h_1(T_w - T_g)A_{eff} = h_2(T_g - T_a)\, l_g b_g \qquad (23)$$

F. *For Wick Surface:*

$$\alpha_w \tau_g T_{srg} l_g b_g = M_w \frac{dT_w}{dt} A_{eff} + h_1(T_w - T_g)A_{eff} + h_3(T_w - T_a)A_{eff} \qquad (24)$$

From Eq. 23, T_g can be written as

$$T_g = \frac{\alpha_g T_{srg} l_g b_g + h_1 T_w A_{eff} + h_2 T_a\, l_g b_g}{h_1 A_{eff} + h_2\, l_g b_g} \qquad (25)$$

Substituting for T_g in Eq. (24) and can be written as

$$\alpha_w \tau_g T_{srg} l_g b_g = M_w \frac{dT_w}{dt} A_{eff} + h_1\left(T_w - \left\{\frac{\alpha_g T_{srg} l_g b_g + h_1 T_w A_{eff} + h_2 T_a\, l_g b_g}{h_1 A_{eff} + h_2\, l_g b_g}\right\}\right)A_{eff}$$
$$+ h_3(T_w - Ta)A_{eff} \qquad (26)$$

After suitable rearrangement, the equation can be written as

$$\frac{\alpha_w \tau_g T_{srg}\, A_{eff}}{M_w\, A_{eff}} + \frac{h_1 \alpha_g T_{srg} l_g b_g A_{eff}}{M_w A_{eff}(h_1 A_{eff} + h_2\, l_g b_g)}$$
$$-T_a\left[\frac{h_1 h_2 l_g b_g\, Aeff}{M_w A_{eff}(h_1 A_{eff} + h_2\, l_g b_g)} - \frac{h_3 A_{eff}}{M_w A_{eff}}\right] = \frac{dT_w}{dt} + T_w\left[\frac{h_1 A_{eff}}{M_w A_{eff}} - \frac{{h_1}^2 A_{eff}^2}{M_w A_{eff}(h_2\, l_g b_g)} + \frac{h_3 A_{eff}}{M_w\, A_{eff}}\right] \qquad (27)$$

Eq.27 resembles the form

$$\frac{dT_w}{dt} + PT_w = Q \qquad (28)$$

Where,

$$P = \frac{h_1 + h_3}{M_w} - \frac{{h_1}^2 l_w b_w}{M_w(h_1 l_w b_w + h_2\, l_g b_g)}$$

$$Q = \frac{\alpha_g \tau_g T_{srg} l_g b_g}{M_w} + \frac{h_1 \alpha_g T_{srg} l_g b_g}{M_w(h_1 l_w b_w + h_2\, l_g b_g)} + T_a\left[\frac{h_2 l_g b_g}{M_w(h_1 A_{eff} + h_2\, l_g b_g)} - \frac{h_3}{M_w}\right]$$

The solution of Eq. 28 can be written as

$$T_w.e^{Pt} = \frac{Q}{P}.e^{Pt} + C \tag{29}$$

When $t = 0$, $T_w = T_f$

Therefore $C = T_{w0} - \frac{Q}{P}$

Substituting the value of C in Eq. 7, we get

$$T_w = \frac{Q}{P} + (T_f - \frac{Q}{P})e^{-Pt} \tag{30}$$

Analytical solutions for wick and glass cover temperature have been used to evaluate the instantaneous distillate yield and efficiency.

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

$$M_w = \frac{h_{ewg}\times(T_w - T_g)}{L} \times 1800 \frac{kg}{m^2 30\ minutes} \tag{31}$$

The instantaneous efficiency of the still is given by.

$$\eta_{inst}(\%) = \frac{M_w \times L}{1800\times\int Transmitted\ solar\ radiation\ X\ dt} \times 100 \tag{32}$$

Computer simulation programs have been written for the solution of energy balance equations for different parts of SSP and TWSS. The input parameters to the programs includes the climatic, temperature components and operational parameters. The climatic parameters are solar intensity and ambient temperature. They were taken from their observed practical values for Coimbatore (Lat 11° N, India) during the months of March and April 2012 and one of the typical days is considered for calculation. Using the initial temperatures, different internal and external heat transfer coefficients of the proposed system were calculated. Using the standard correlations given by Duffie and Beckmann. The correlations which were used are given in the appendix. The half hourly and daily productivities as well as daily efficiency of the system were also calculated. Numerical simulations have been made and compared with the experimental results and validated. They forund to be in good agreement between each other. These experiments have been done by placing the system due south to maximize the solar radiation receiving by the pond. Solar intensity monitor and copper contantine thermocouples were used to measure the solar intensity and the different elements of the still by connecting the another end to a digital multimeter. The mass flow rates of pond and storage heat exchanger fluids have been measured by collecting a certain volume of water flowing in the basin in certain time period. The mass of the collected water was divided by the time in seconds to give mass flow rate in (kg/s).

V. RESULTS AND DISCUSSIONS

Experiments have been conducted with the proposed still with single and multiple wick in the tilted-wick portion and observations have been used for the validation of the theoretical results obtained. A special arrangement has been made to feed pre-heated saline water from the swirled coil heat exchanger in the shallow solar pond to the tilted-wick portion of the still. The arrangement is made with a PVC pipe of 1m length and fine holes have been made on the PVC pipe with an interval of 0.007m. The pipe has been fixed breadthwise in the tilted-wick portion with an inlet valve connected to the outlet of the swirled coil heat exchanger of the shallow solar pond. The rate of flow of water to the heat exchanger of the pond is 2.310 l/30 minutes which is obtained with the help of a pressure head. Fig. 1 shows the variation of solar radiation and ambient temperature for one of the typical days in the month of April 2012 at Karpagam University, Coimbatore.

Energy balance equations for the temperature elements of the shallow solar pond have been solved for the analytical solutions and analytical results are obtained. A graph has been drawn between the theoretical results and experimental observations of the temperature elements of the shallow solar pond and shown in the Fig. 2.

The theoretical value of temperature of the glass cover of shallow solar pond underestimates in late working hours than the experimental observation. This is due to the fact that the analytical solution for the glass cover temperature depends on the climatic parameter i.e., solar radiation intensity. The increase in the intensity shows increase in theoretical value of glass cover temperature and vice-versa. But experimentally, it is clear that the thermal energy stored in the water during peak sunny hours is convected to the glass cover when solar radiation is low leading to the temperature of the glass cover higher than the theoretical value. Except the glass cover temperature of the shallow solar pond, analytical results for the water, heat exchanger and heat exchanger fluid temperature are slightly higher than the experimental observation in the evening hours. This is due to the fact that the water, heat exchanger and heat exchanger fluid temperature depends on the thermal capacity of the pond. Since the thermal capacity is high, large amount of heat energy is trapped inside the pond in the evening hours.

The flow rate of fluid in the heat exchanger has been fixed as 0.770 l/10 minutes i.e., 2.310 l/30 minutes with the help of a pressure head. The fluid absorbs the heat from the heat exchanger coil by convection and the hot fluid is allowed to flow through the tilted wick portion with the help of the arrangement made within the still.

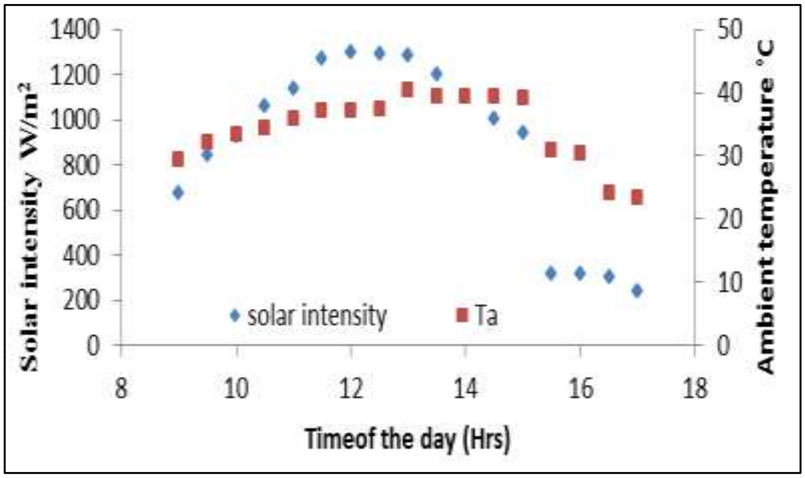

Fig. 1: Variations of solar intensity and Ambient temperature with respect to time.

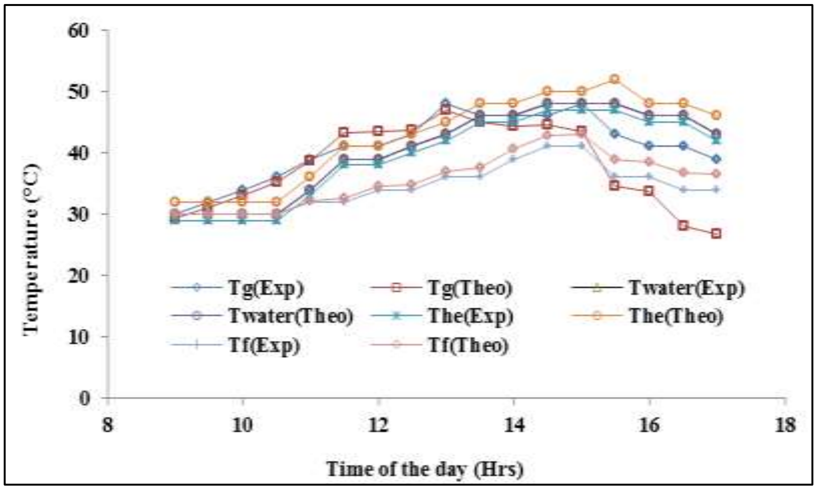

Fig. 2: Experimental and theoretical values of temperature elements of the pond.

Fig. 3 shows the experimental and theoretical value of wick and glass cover temperature of the still and it is clear from the graph that the theoretical results are in mere agreement with the experimental observations. Moreover, the temperature of the wick surface is higher than the conventional wick-type solar still due to the introduction of preheated saline water in the tilted-wick portion of the still from the shallow solar pond.

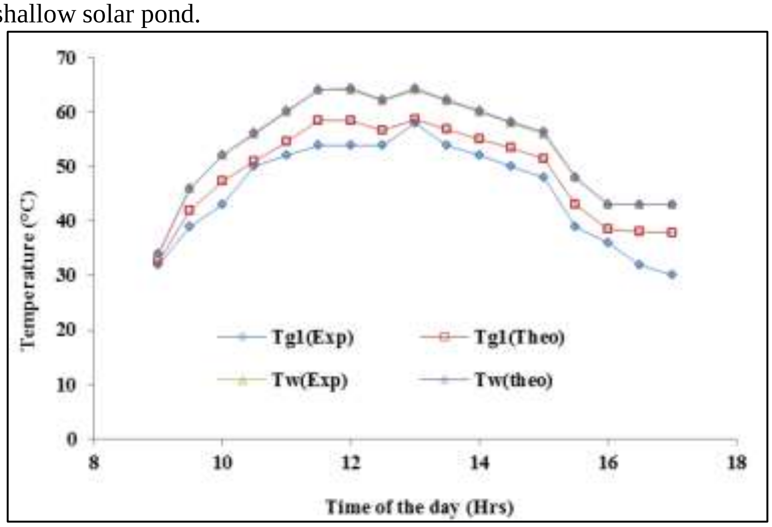

Fig. 3: Experimental and theoretical values of temperature elements of the solarstill with single wick material.

The glass cover temperature reaches a maximum of 58°C at 13:00 hrs which is higher than the glass cover temperature in conventional wick-type solar still. The temperature of the glass cover is high because there exists increased amount of heat transfer from the wick surface by convection and radiation. Since the glass cover temperature partially depends on the wick surface temperature, it increases when the wick temperature increases and vice-versa. The preheated water from the pond into the tilted-wick portion of the still did not show significant temperature difference between the evaporating wick and glass cover surface. Hence the distillate output is more or less the same as that of the conventional wick type solar still even if the flow rate of feed water from the pond to the still is minimum. The single wick in the tilted portion is not enough to withstand for the amount of preheated water to flow across it which leads to the release of large amount of waste hotwater during the working hours of the still.

Fig. 4 shows the variation of experimental and theoretical values of instantaneous distillate yield and efficiency of the still for the flow rate of 2.310 l/30 minutes. The results are in good agreement. The experiment has been repeated for different flow rates smaller than 2.310 l/30 minutes and tested. It has been found that the still has not shown any significant change in the thermal behaviour inspite of the preheated saline water from the pond.

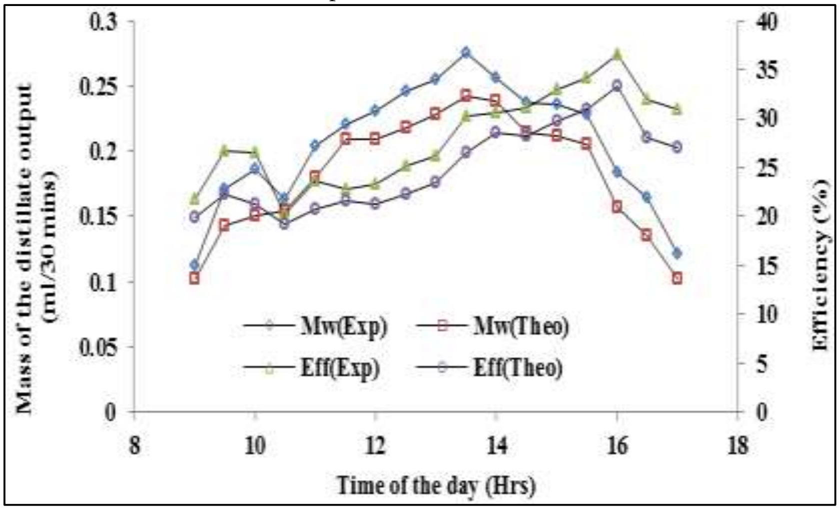

Fig. 4: Experimental and theoretical values of instantaneous distillate output and Efficiency of the solarstill with single wick

The maximum amount of distillate yield for 30 minutes interval was found to be 0.275ml at 13:30 hrs and decreases gradually till evening hours. The total daytime collection during 9:00 hrs to 17:00 hrs with single wick in the tilted portion is 3.499 litres and night time collection is 0.670 liters. Over 24 hr cycle the total collection is 4.169 liters/day. The output of the proposed still resembles the output of ordinary conventional wick-type solar still and it may be concluded that the integration of still (with single wick) with the shallow solar pond has no significant effect on the performance of the still. The overall average efficiency of the still is found to be 27.93% respectively.

Experiments have been repeated for the proposed still with multiple wicks in the tilted portion of the still. The optimized flow rate of preheated saline water from the shallow solar pond to the still is fixed as 1.560 l/30 minutes after repeating the experiments with varying flow rate. Fig. 5 shows the variation of solar radiation intensity and ambient temperature for one of the typical experimental days with multiple wick in the still. From the graph, it is clear that the intensity of solar radiation increases gradually till noon and gradually decreases in the evening hours. In the case of ambient temperature, it gradually increases till noon and remains the same till the evening hours of the day.

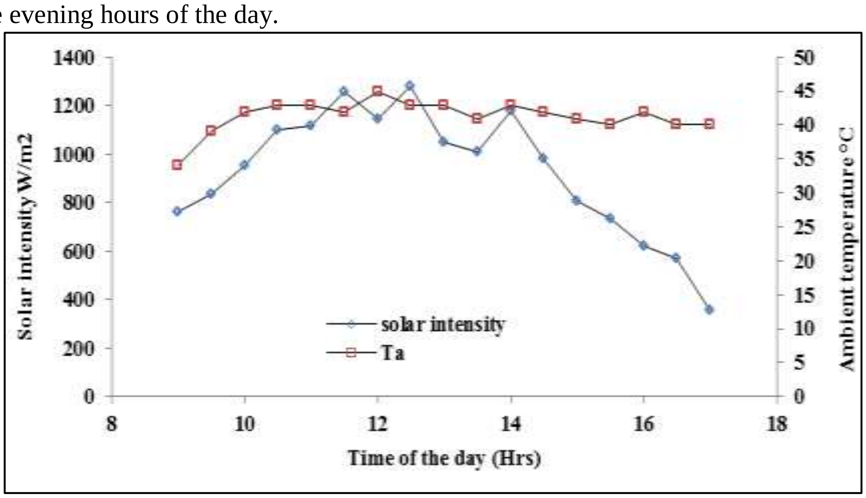

Fig. 5: Variations of solar radiation intensity and Ambient temperature with respect to time.

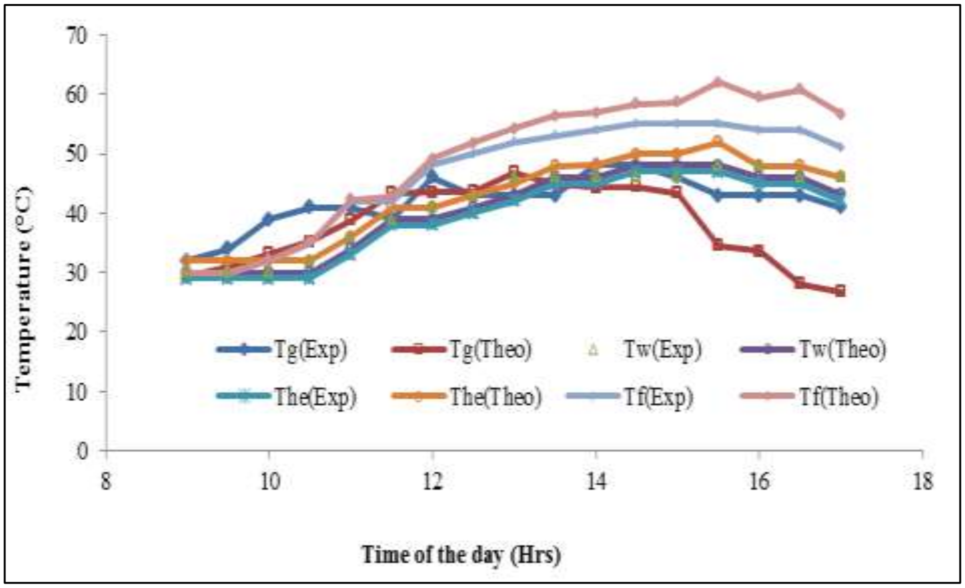

Fig. 6: Experimental and theoretical values of temperature elements of the pond.

The numerical results obtained for the analytical solutions of the temperature elements of the shallow solar pond has been validated with the experimental observations for the typical day and shown in the Fig. 6. The results have shown that, theoretical and experimental results have same trend as obtained in the typical day for the still with single wick integrated with shallow solar pond. Since the flow rate of saline water in the heat exchanger is optimized as 1.560 l/30 minutes, the maximum temperature of the saline water coming out of the pond is 61°C.

The preheated water from the pond has been fed into the tilted multiple wick portion of the still with the help of the arrangement made within the still. Since the thermal capacity of the multiple wick is high, the considered flow rate is found to be optimum to make the wick material always wet during the working hours of the day. Therefore, the amount of evaporation of saline water from the wick surface is high and results in the increased production rate. The auxillary heat energy supplied to the still has been completely utilized for the production of distilled water output. To appreciate the analytical results obtained for glass cover and wick temperature, it has been validated with the experimental observations of the corresponding typical day. A graph has been drawn for the experimental and theoretical results and depicted in the Fig. 7. It is observed that the theoretical results are in mere agreement with the experimental results.

The instantaneous distillate yield and efficiency of the still has been presented in the Fig. 8. The theoretical value of mass of the distillate yield during 13:00 to 13:30 hrs is found to be 0.241 l which in turn underestimating the experimental value of 0.275 l. In the evening hours, the experimental distillate yield is high due to the large thermal capacity of the still (multiple wicks). The total daytime collection during 9:00 to 17:00 hrs is found to be 3.999 l and night time collection corresponds to 1.700 l. Over 24hr cycle, the output of the still is found to be 5.699 l/day. The total output per day is higher than the output obtained with single wick material in the still. The instantaneous efficiency of the still throughout the day for multiple wick in the still is always higher than the still with single wick material. The maximum instantanoes efficiency of the still is obtained during 16:30 and 17:00 hrs and is 54.53%. Especially in the evening hours, the efficiency gradually increases eventhough the intensity of solar radiation is low. This is due to the fact that, the auxillary heat supplied by the pond has been completely stored as thermal energy in the multiple wick and utllized in the evening hours when the intensity of radiation is low. Hence the waste hot water from the still during working hours of the still is less when compared with the still with single wick material. The average efficiency of the still with multiple wick is 35.05% and it is found to be 8% higher than the still with single wick material. The proposed still with multiple wick integrated with shallow solar pond is fascinating with increased amount of distillate yield and efficiency.

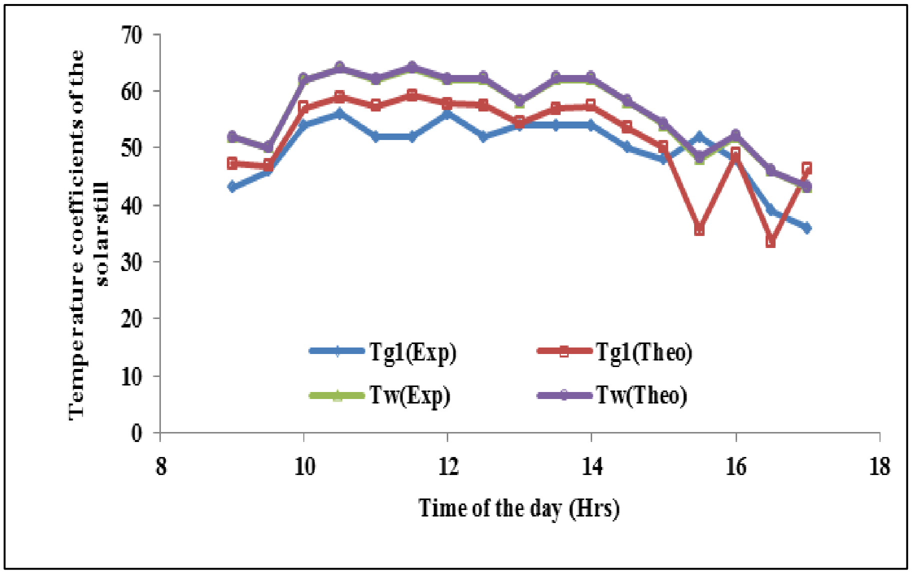

Fig. 7: Experimental and theoretical validation of temperature elements of the solarstill with multiple-wick materials.

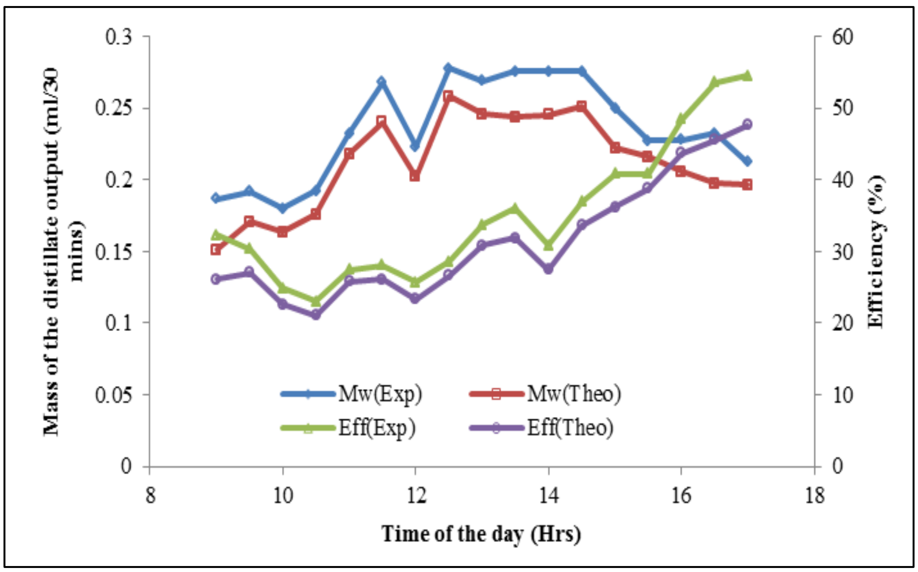

Fig. 8: Experimental and theoretical values of instantaneous distillate output and Efficiency of the solarstill with multiple-wick.

VI. CONCLUSION

The following inferences have been drawn from the experiments conducted with the proposed still integrated with shallow solar pond.

The proposed still with single wick in the tilted portion integrated with shallow solar pond has not shown significant impact on the productivity of the still.

1) The performance of the proposed still with single wick integrated with shallow solar pond is similar to that of the conventional wick type solar still.
2) The still integrated with the shallow solar pond with multiple wick shows improvement in the productivity and efficiency.
3) The flow rate of preheated saline water of 1.560 l/30 minutes to the still from the pond is optimum.
4) When wick type solar still is integrated with the pond, multiple wick in the still is recommended for the enhancement of productivity and efficiency of the still.
5) The total daily distilled water output over 24 hrs cycle and efficiency of the still (multiple wick) integrated with the pond are 5.699 l/day and 35.05%.

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