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Theoretical Analysis of Solar Distillation Using Active Solar Still

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Abstract

The performance of active single slope solar still using different operational parameters is studied theoretically and compared with the experimental data for validation purposes, to find out best factors enhancing still productivity. The thermal performance of a single slope solar still coupled with collector is evaluated through implementing the following effective parameters; a) different insulation thicknesses of 1, 2.5 and 5 cm, b) solar intensity, c) overall heat loss coefficient d) effective absorptivity and transmissivity, and e) temperature differences between the still cover and water and f) wind speed. It can be concluded from this study that active solar stills can be one of the options for enhancing the productivity of stills, while wind speed and insulation thickness can contribute to the enhancement of the overall yield.

Keywords: *Still Performance, Solar still. Solar Energy, Active Solar Systems*

1. Introduction

The availability of potable water is an important problem for the communities who will be lived in the desert regions or especially for people in arid region. These regions are recognized by a high intensity of solar radiation, which makes the direct use of solar energy represents a promising option for these communities to reduce the major operating cost for pumping drinking water.

Most third world countries are suffering from the incapability of supplying pure drinking water to their communities living in the arid regions. Also the availability of clean water is a necessity for reducing the spread of diseases in these countries.

Clean water availability is one of the services that consume power, Distillation of waste-water or sea water is one of the steps to get the clean water, while the traditional way to get the water is using fuel. Renewable energy that scores the two advantage of reducing the oil usage and distillation of the waste water is the main target of this research; this will present the chances and measures for the appropriate usage of renewable sources and highlighting the importance of achieving distillate water to be used for drinking, industrial processes and medication. In this research the focus on utilization of the solar energy in distillation is the target.

Solar distillation has the advantage of cost saving over other types of distillation such as reverse osmosis, because solar energy is limitless and easily available and likewise seawater is readily available, there is an abundance of these sources. Solar distillation has proved to be highly effective in cleaning up water supplies to provide safe drinking water [1]. As energy requirement to produce 1 litre (i.e. 1kg since the density of water is 1kg/litre) of pure water by distilling brackish water requires a heat input of 2260kJ. Distillation is therefore normally considered only where there is no local source of fresh water that can be easily offered [2].

There are various methods of solar distillation, in addition to the original single basin solar still, For example double basin solar still, multiple basin solar still, chimney solar still, etc. Although the productivity of those methods was improved compared to that of the single basin solar still, but this improvement was obtained with increase in complexity, cost and maintenance, [3- 13].

From the several types of solar stills, the simplest of which is the single basin still. But the yield of this is low and falls in the range of (3-7) liters per day per m2 [7, 9, 12, 14-16].

Recently different designs of solar still have emerged. The single effect solar still is a relatively simple device to construct and operate. However, the low productivity of such solar still leads one to look for ways to improve its productivity, and efficiency. In this study a solar collector coupled with solar still to augment its productivity is studied theoretically with the help of experimental data availability for validation purposes.

Many experimental and numerical studies have been done on the single slope solar stills, such as those of [2, 12- 14, 17-22]. Many parameters can be used to improve the operating efficiencies of various types of solar distillation devices. Forced air circulation is one of many parameters that can be used to enhance the vapor condensation rate inside stills. Several investigators have attempted to make use of the latent heat of evaporation in either multiple-effect systems or for preheating the brine to increase the output of still [16, 23, and 24]. Several large-scale distillation plants and integrated

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schemes for combining electric power generation and desalination of water have also been suggested as a way of improving the overall operating efficiency of the plant [2, 4, 25].
Other studies [8, 9, 13, 14, 15, 26, 27] have investigated the effects of climatic, operational and design parameters on the performance of single, double and multi-effect active and passive solar stills. They have concluded that the productivity increases with the increase of solar radiation, ambient temperature and wind speed. While [24, 27, 28, 29, 30] have concluded that the increase in wind speed causes increase in productivity.
Tiwari et al [28] recommend that only passive solar stills can be economical to provide pure water. An active solar distillation system can be economical from a commercial point of view

This research work aims to build a theoretical model for active solar still to test the thermal performance behavior under the Jordanian climate. The active still with different operational conditions is proposed to improve its productivity. All the results are compared together to reach to the best operating conditions that can be used in future for solar still augmentation for the production of drinking water and industrial use to arid regions in the Jordanian desert.

2. Theoretical analysis for solar still

The theoretical analysis is performed using the energy balance mode on various components of the still system with the help of the MATLAB software. To simplify the analysis, the following assumptions are made:

There is no vapor leakage in the still, and this is important to increase the productivity and efficiency.

There is no temperature gradient along the glass cover thickness and in water depth. Also the absorbed energy by the glass cover is negligible.

The condensation that occurs at the glass cover is a film – type.

When conducting energy balance in terms of (W/m2) for active still, the following assumptions are taken into consideration [2]:

An optimum Inclination of the glass cover

The heat capacity of the glass cover, the absorbing material and the Insulation (bottom and sides) are negligible.

Performance is steady state.

Construction is of sheet and parallel tube type.

The headers cover a small area of collector and can be neglected.

The headers provide uniform flow to tubes.

Heat flow through a cover is one dimensional.

There is a negligible temperature drop through a cover.

There is one-dimensional heat flow through back insulation.

Temperature gradients around tubes can be neglected.

The temperature gradients in the direction of flow and between the tubes can be treated independently.

Dust and dirt on the collector are negligible.

Shading of the collector absorber plate is negligible.

The objective of this research is to study the theoretical performance of a passive solar still that is augmented by a conventional type collector.

In solar distillation systems, the heat transfer can be classified in terms of external and internal heat transfer. The external heat transfer are mainly governed by conduction, convection and radiation processes, which are independent of each other, these are, the heat of the glass cover and the bottom and sides insulation. Heat transfer within the solar still is referred to as internal heat transfer who mainly consists of radiation, convection and Evaporation.

External heat transfer covers exchanges between the outside of the solar still and the surrounding for example heat transfer from the glass to the ambient, and the heat transfer from water that exist in the basin to the ambient. The theoretical model analysis can be made by dividing the heat transfer process that occurs on the still into two types, External and Internal heat transfer [1, 2].

Energy balance for passive still.

The energy balance for different components of the still is as follows [1, 2]: -

A) Glass cover

$$\alpha_g I(t) + [q_{rw} + q_{cw} + q_{ew}] = [q_{rg} + q_{cg}] \ldots\ldots\ldots (1)$$

B) Basin bottom plate (basin liner)

$$\alpha_b I(t) = q_b + \left[q_{bg} + q_s\left(A_s / A_{ss}\right)\right] \ldots\ldots (2)$$

C) Water mass

$$\alpha_w I(t) + q_b = (MC)_w \frac{dT_w}{dt} + [q_{rw} + q_{cw} + q_{ew}] \ldots\ldots\ldots (3)$$

2.1 Top loss coefficient

Due to the small thickness of the glass cover (4mm), the temperature of the glass may be assumed to be uniform (temperature gradient along the glass thickness is negligible). Then external radiation and convection Losses from the glass cover to out atmosphere can be expressed as [11, 29];

$$q_g = q_{rg} + q_{cg} \ldots\ldots\ldots\ldots (4)$$

And

$$q_{rg} = h_{rg}[T_g - T_a] \ldots\ldots\ldots\ldots (5)$$

$$q_{cg} = h_{cg}[T_g - T_a] \ldots\ldots\ldots\ldots (6)$$

$$h_{rg} = \frac{\varepsilon_g \sigma \left[T_g^{\,4} - T_{sky}^{\,4}\right]}{\left(T_g - T_a\right)} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where

$$T_{sky} = T_a - 6 \ldots\ldots\ldots\ldots\ldots (8)$$

Substituting qcg and qrg in equation (4) then

$$q_g = h_{1g}[T_g - T_a] \dots\dots\dots (9)$$

Where

h1g is the convection and radiation heat transfer coefficient from glass to the ambient:

$$h_{1g} = h_{rg} + h_{cg} \dots\dots\dots (10)$$

$$h_{1g} = 5.7 + 3.8V \dots\dots\dots (11)$$

2.2 Bottom and sides' loss coefficient

Heat is also transferred or lost from the water in the basin to the ambient through the insulation and subsequently by convection and radiation and conduction from the bottom or side surface of the basin.

Hence the bottom loss coefficient (Ub) can be written as

$$U_b = \frac{1}{\left[\frac{1}{h_w} + \frac{1}{\left(\frac{K_i}{L_i}\right)} + \frac{1}{(h_{cb} + h_{rb})}\right]} \dots\dots\dots (12)$$

$$h_b = \frac{1}{\left[\frac{1}{\left(\frac{K_i}{L_i}\right)} + \frac{1}{(h_{cb} + h_{rb})}\right]} \dots\dots\dots (13)$$

The value of *(hcb + hrb)* can be found from equation (10).

Similarly, the side heat loss coefficient (Ue) can be approximated as:

$$U_e = U_b \bullet \frac{A_{ss}}{A_s} \dots\dots\dots (14)$$

If the side still area (Ass) is very small comparing with basin liner still area (As) then the overall side heat loss coefficient (Ue) can be neglected [10]

2.3 Internal heat transfer.

Internal heat transfer is that occur between water surface and the glass cover [10]. There are three methods of heat transfer from water surface to the glass cover, radiation, convection and evaporation and hence these heat transfer methods are discussed separately.

I) Radiation loss coefficient.

Between any two bodies there are differences in temperature, and then there are a radiation heat transfer will occur between them. In this case, the water surface and glass cover are considered as infinite parallel planes [28]. Radiation between the water and the glass is given by:

$$q_{rw} = h_{rw}(T_w - T_g) = .96\sigma\left(T_w^4 - T_g^4\right) \dots\dots\dots (15)$$

Where hrw may be obtained from equation:

$$h_{rw} = \varepsilon_{eff}\sigma\left[\left[(T_w)^2 + (T_g)^2\right](T_w + T_g)\right] \dots\dots\dots (16)$$

The effective emittance between the water surface and the glass cover will be

$$\varepsilon_{eff} = \frac{1}{\left[\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right]} \dots\dots\dots (17)$$

II) Convective loss coefficient.

Convection occurs across the humid air in the enclosure by free convection, due to the temperature difference of humid air between the water surface and the glass cover. It may be obtained from the equation: -

$$q_{cw} = h_{cw}(T_w - T_g) \dots\dots\dots (18)$$

Where heat loss coefficient by convection from water hcw may be obtained from the expression of

$$h_{cw} = \left[T_w - T_g + \frac{(P_w - P_g)(T_w)}{268.9\times 10^3 - P_w}\right]^{1/3} \dots\dots\dots (19)$$

Partial pressure of the glass can be expressed by the following equation:

$$P_g = e^{\left(25.327 - \frac{5144}{T_g}\right)}$$

Partial pressure of the water can express by the following equation:

$$P_w = e^{\left(25.317 - \frac{25.317}{T_w}\right)}$$

iii) Evaporation loss coefficient.

Due to condensation of the rising vapor on the glass cover, there are heat loss by evaporation between the water surface and the glass cover, this can express as the following: [11]

$$q_{ew} = h_{ew}(T_w - T_g) \dots\dots\dots (20)$$

Where

$$h_{ew} = 16.273\times 10^{-3} h_{cw} \frac{(P_w - P_g)}{(T_w - T_g)} \dots\dots\dots (21)$$

Equations (19) and (21) are evaluated at initial water and glass temperature.

Then the total internal heat transfer coefficient between water surface and glass cover can be express as [4]:

$$h_{1w} = h_{rw} + h_{cw} + h_{ew} \dots\dots\dots (22)$$

Substituting equations from (4 – 22) in equations (1), (2) and (3) then the energy balance equations become [11]:

$$\alpha_g I(t) + h_{1w}(T_w - T_g) = h_{1g}(T_g - Ta) \dots (23)$$

$$\alpha_{w+} I(t) + h_{1w}(T_b - T_w) = (MC)_w \frac{dT_w}{dt} + h_{1w}(T_w - T_g) \dots (24)$$

$$\alpha_b I(t) = h_{1w}(T_b - T_w) + h_b(T_b - T_a) \dots (25)$$

Calculations of the heat balance for passive solar still

The following data are extracted from the simulation:

Vw = 4.5 m/s, Tw0 =58.8 °C = 331.8K, Tg0 =49.7°C = 322.7K, Tw=60°C

Ta = 31°C = 304 K, I =.72 kW/m2, I (t) = .95*720 = 684 W/m2 (.05 that absorbed by glass, αg = .05), Tb = 60 °C = 333K,

[hew = 29.517W/m2*K, h1g = 19.32 W/m2*K, hrw =3.649 W/m2*K

hcw =2.597 W/m2*K, UL = 19.51 W/m2*K, these values were taken From Computer Program]

$$h_{1w} = h_{rw} + h_{cw} + h_{ew} = 35.76 W / m^2 * K$$

$$\alpha_g I(t) + h_{1w}(T_w - T_g) = h_{1g}(T_g - Ta)$$

.05*720 + 35.76 * (58.8- 49.7) = 19.32 * (49.2 – 31)

361.4 W/m2 ≈ 361.28 W/m2 First equation was applied.

(MC)w = .81*.035*4180 = 118503 J/m2 *K

$$\alpha_{w+} I(t) + h_{1w}(T_b - T_w) = (MC)_w \frac{dT_w}{dt} + h_{1w}(T_w - T_g)$$

.518* 684 + 35.76 (60 – 58.8) = 118503 *(2 .2/3600) +35.76 (58.8- 49.7)

397.22 W/m2 ≈ 397.83 W/m2

$$\alpha_b I(t) = h_{1w}(T_b - T_w) + h_b(T_b - T_a)$$

.8* 684 = 35.76 * (60 – 58.8) +17.38 (60 – 31)

547.2 = 42.912 + 504

547.2 W/m2 ≈ 546.93 W/m2

Substituting the values for Tg and Tb from equation (22) and equation (24) in equation (23) the result is

$$\frac{dTw}{dt} + aTw = f(t).....(26)$$

Where

$$a = \frac{U_l}{(MC)_w}........(27)$$

$$f(t) = \frac{(\alpha\tau)_{eff} I(t) + U_l T_a}{(MC)_w}.........(28)$$

$$(\alpha\tau)_{eff} = \alpha_b \frac{h_w}{h_w + h_b} + \alpha_w + \alpha_g \frac{h_{1w}}{h_{1w} + h_{1g}}.........(29)$$

$$U_l = U_b + U_t..........(30)$$

$$R_t = \frac{1}{h_{1w}} + \frac{1}{h_{1g}} = \frac{h_{1w} + h_{1g}}{h_{1w} h_{1g}}$$

$$U_t = \frac{1}{R_t} = \frac{h_{1w} h_{1g}}{h_{1w} + h_{1g}}........(31)$$

To solve equation (25) to get approximate solution for Tw: -

At Tw (t = 0) = Two ………… (32)

Tg (t = 0) = Tgo . . . . (33)

In order to obtain an approximate analytical solution with the above initial conditions, the following assumptions have been made [4].

1) The time interval Δt (o< t <Δt) is small

2) a is constant during the time interval Δt.

3) The function f (t) is constant i.e. f (t) =$\overline{f(t)}$ for the time Interval Δt.

Then the solution of equation (26) will become as:

$$T_w = \frac{\overline{f(t)}}{a}(1 - \exp(-at)) + T_{wo}\exp(-at)...(34)$$

Where Two is the temperature of basin water and $\overline{f(t)}$ is the average value of f (t) for time interval Δt. [11]

The average glass temperature can be found from equation (22) as follows:

$$\overline{T_g} = \frac{\alpha_g I(t) + h_{1w}\overline{T_w} + h_{1g}\overline{T_a}}{(h_{1w} + h_{1g})}.......(35)$$

So the instantaneous efficiency for passive solar still is [11]:

$$\eta_i = \frac{q_{ew}}{I(t)} = \frac{h_{ew} h_{1g}}{h_{1w} + h_{1g}}(T_w - T_a)........(36)$$

Substitute equation (34) in equation (36), then

$$\eta_i = \frac{h_{ew} h_{1g}}{h_{1w} + h_{1g}} \cdot \frac{1}{U_l}\left[(\alpha\tau)_{eff}(1 - Exp(-at)) + U_l \frac{(T_{w0} - T_a)}{I(t)} Exp(-at)\right]........(37a)$$

We can find the volumetric efficiency by the following equation:

$$\eta_V = \frac{h_{fg} * \sum M}{\sum A * I}.........................(37b)$$

Where I the daily solar radiation, M is the total productivity of the day,

hfg is the latent heat of vapor, A is the still area.

There are two cases [11]:

For (at) << 1 ,i.e. the water mass in the basin large and time interval is small then,

$$\eta_i = \left[\frac{h_{ew} h_{1g}}{h_{1g} + h_{1w}}\right]\left[\frac{T_{wo} - T_a}{I(t)}\right].......(38)$$

For (at)>> 1. i.e. the water mass in the basin is small and time interval is large then,

$$\eta_i = \left[\frac{h_{ew} h_{1g}}{(h_{1g} + h_{1w})}\right]\left[\frac{(\alpha\tau)_{eff}}{U_l}\right]......(39)$$

2.4 Theoretical analysis of the active solar still.

When using a flat –plate collector, the energy balance on the whole system becomes as given by the equation:

$$\alpha_w I(t) + h_w(T_b - T_w) + q_u = (MC)_w \frac{dT_w}{dt} + h_{1w}(T_w - T_g).........(40)$$

Where qu is given by

$$q_u = FA_c[(\alpha\tau)I_c(t) - U_l(T_w - T_a)].......(41)$$

Equation (38) may be solved for Tw with the help of equation (39) for the initial condition [1,2, and 11].

Tw (t=0) = Two …………………… (42)

And the solution is:

$$Tw = \frac{\overline{f(t)}}{a}(1 - Exp(-at)) + TwoExp(-at) ......(43)$$

Where

$$\overline{f(t)} = \frac{[(\alpha\tau)_{eff} I(t) + F(\alpha\tau)A_c\overline{I_c(t)}] + [U_l + U_l F A_c]\overline{T_a}}{(MC)_w} .....(44)$$

$$a = \frac{U_l + FU_l A`_c}{(MC)_w} .....(45)$$

A`c = [Ac /As] > 1. ………………………………… (46)

Then by the help of equation (46) the instantaneous efficiency is:

$$\eta_i = \frac{h_{ew}h_{1g}}{h_{1w}+h_{1g}} \cdot \frac{1}{1+A_c} \cdot \left[\frac{(\alpha\tau)_{eff} + F(\alpha\tau)A_c}{U_l + FU_lA_c}(1 - Exp(-at)) + \frac{T_{wo} - T_a}{I(t)}Exp(-at)\right] ....(47)$$

Also there are two cases:

For at >>1

$$\eta_i = \frac{h_{ew}h_{1g}}{h_{1w}+h_{1g}} \cdot \frac{1}{1+A_c} \left[\frac{(\alpha\tau)_{eff} + F(\alpha\tau)A_c}{U_l + FU_lA_c}\right] ....(48)$$

For at << 1

$$\eta_i = \frac{h_{ew}h_{1g}}{h_{1w}+h_{1g}} \cdot \frac{1}{1+A_c} \cdot \frac{T_{wo} - T_a}{I(t)} ....(49)$$

Also the hourly-distilled water production is:

$$m_w = \frac{A_s h_{ew}(T_w - T_g)}{h_{fg}} \times 3600........(50)$$

If the comparison is made between the efficiency of the active still and passive still for two cases, it's shown that the efficiency of the active still is less than the efficiency of the passive still [1].

The reason is that, comparing equation (36) with equation (47) yields:

ηI (active) = ηI (passive) x [1/(1+ A`c)]…………..(51)

And since A`c, which is the ratio of the collector area to the still area, is positive number, then from this equation it obvious that: ηi (active) < ηi (passive).

3. Solar still specifications

The technical specifications of the solar still used in the computer model are shown in Table1.

Table 1. Technical specifications of the solar still

Specification	Dimensions
Basin area , m^2	**1**
Glass area , m^2	**1.46**
Glass thickness , mm	**4**
Number of glass	**1**
Slope of glass	**32°**

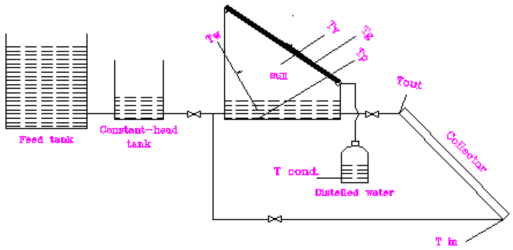

Fig. 1. Schematic diagram of the active solar still components

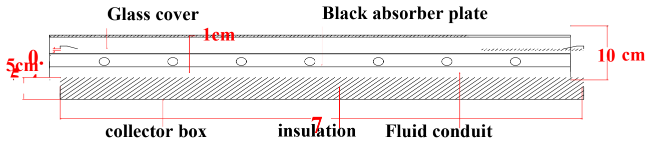

Fig. 2. Cross section of a basic flat - plate collector

Description of flat- plate collectors

The important parts of a typical liquid heating flat-plate solar collector, as shown in Figure 2, are: the "black" solar energy-absorbing surface for transferring the absorbed energy to a fluid, enveloped by glass transparent to solar Radiation over the solar absorber surface that reduces convection and radiation losses to the atmosphere; and back insulation to reduce conduction losses. Figure 1 depicts a complete water heater coupled with solar still, and most of the analysis of this study is concerned with this geometry. Flat-plate collectors are almost always mounted in a stationary position with an orientation optimized for the particular location in question for the time of year in which the solar device is intended to operate [13, 15].

Water circulation

In this method we used digital timer to operate the pump for 15 min, then stop it for another 15 min (on series), then operate it for 15 min and so on, to heat the water of the basin (four times per hour). This method gave productivity equal twice the productivity of the still alone. This method gave higher productivity due to the increase in the heat capacity of water. All water depth in the basin was kept at 3.5 cm depth for all experimental work data and the theoretical model input.

4. RESULTS

In the present study the variables affect the still productivity (Pr) have been considered. Also for the theoretical data validation, the data from the related experimental work [13,14, 15] was used for comparison and verification purposes, different variables such as : Tg,in , Tg,out ,Ta , Tw , Tb ,Tv (vapor temperature), I , Vw , Pr and Tin , Tout in active solar still, were measured hourly, the total productivity and solar Intensity (I) for each day were measured also.

Figure 3 represent the measured solar intensities. From figure 3 it can be noticed that the solar intensity increases until it reaches the maximum in the solar noon, then it decreases with time after this maximum value in the after noon. Also from figure 3, we can highlight the importance of solar intensity on the productivity, when the solar intensity increases, the productivity should increase. It is one of the main input elements needed for the mathematical modeling.

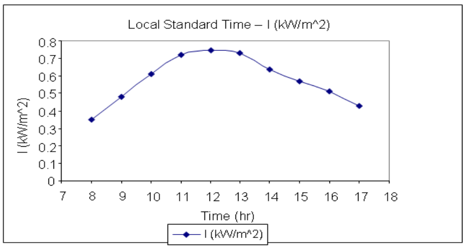

Fig. 3. Relation between the solar intensity and local standard time

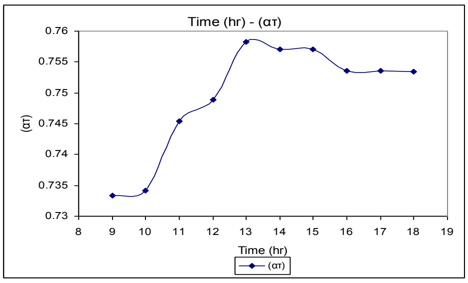

Fig. 4. Figure shows the relation between (ατ) and the local standard time

From figure 4 it can be seen that the absorptivity and transmissivity are increasing until they reach to maximum in the solar noon, then they decrease in the after noon. These results proved to be correct as they are in the same trend as the solar intensity. The absorptivity of the black plate of the still basin which are filled with water increases with the radiation intensity till noon and then decreases with the decrease of the radiation intensity in the afternoon.

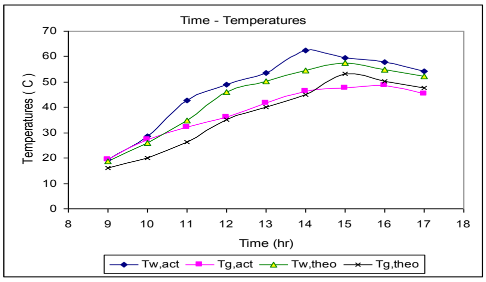

Fig. 5. Comparison between theoretical and experimental temperatures for water and glass

From Figure (5), we noted that the theoretical results from the present mathematical model gave good indication of accuracy after the comparison with the experimental data, as they show same trend with an average deviation of 5% which attributed to the measuring error in the experimental data and also the experimental data didn't consider the thermal losses as the theoretical model consider in the calculations. The temperature of water is higher than the temperature of glass (neglected absorbency), this due to solar radiation absorbed by basin black plate filled with water during the day, so the heat will transfer to water by convection from the heated plate. Also Figure 5 shows the relation between ambient temperature and productivity, these shows that when the ambient temperature increases the productivity increases (directly proportional) throughout the day, hence the ambient temperature has a very important effect on the productivity through the increase of water temperature which will increase the evaporation process inside the still.

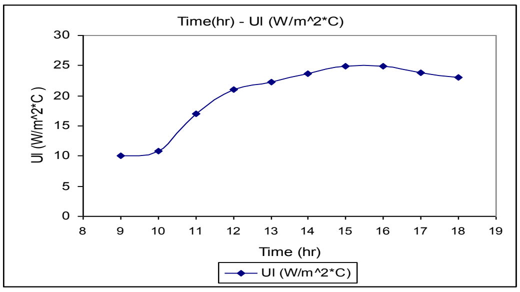

Fig. 6. Relation between overall heat loss coefficient and local standard time

Figure 6, shows the overall heat loss coefficient increases until it reach's the maximum in the solar noon due to high temperature difference between the inside still and the ambient temperature at this time, then it decrease in the after noon.

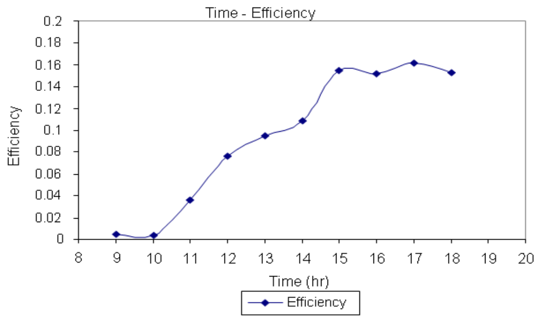

Fig. 7. The efficiency change with local standard time

From figure 7 it can be seen that the efficiency increases with time until it reaches the maximum value in the solar afternoon, at this period the incident solar radiation is larger than heat losses. Thereafter, with a time the heat losses start overcomes the incident solar radiation (which decreases the efficiency with time). Figure 7 shows that the maximum efficiency occurred in the solar afternoon. Due to the high solar radiation in this time, the high solar radiation will overcome the heat losses from the still to the ambient. It is noted that the maximum efficiency of active solar still equal to (16 %), that is lower than the efficiency of the passive solar still (38%). Normally the efficiency of active solar still is less than the efficiency of the passive solar still due to high temperature difference between the glass and water in the active still and the effective heat transfer area of the active still is larger than that in passive still. So there is more thermal losses occur in the active still.

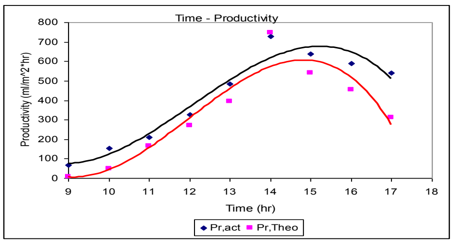

Fig. 8. Comparison between theoretical and experimental productivity of active solar still

Figure 8 shows the theoretical and actual productivity of the active solar still. They are increasing with the day time till they reach the maxima at the maximum solar radiation period, and then decreasing in the afternoon. The theoretical result shows same trend and behavior but with lower quantities, this due to the proper consideration of the losses more adequately than actual productivity taken from experimental data.

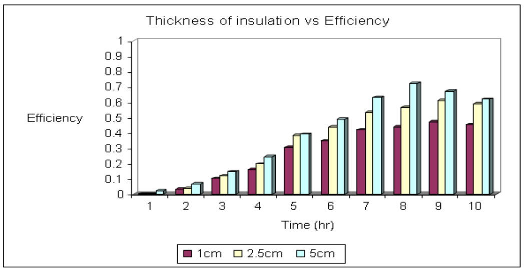

Fig. 9. Relation between the local standard time and efficiency

Figure 9 shows the insulation thickness effect on the efficiency of the active solar still system. From figure (9) it can be seen that the efficiency increases when the insulation thickness increases, this is due to the decrease in the overall heat loss coefficient from the still to the ambient when the insulation thickness increases.

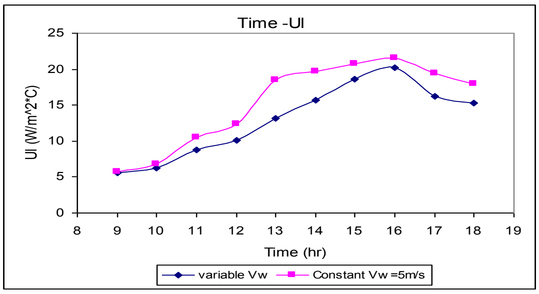

Fig. 10. Relation between local standard time and overall heat loss coefficient at different wind speeds

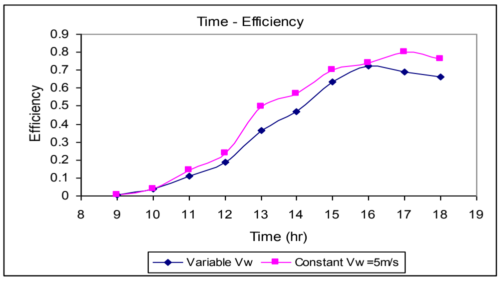

Fig. 11. Relation between local standard time and efficiency at different wind speeds

Figures (10, 11) show the effect of wind speed on the efficiency, and overall heat loss coefficient, these two variables increase when the wind speed increase. Overall heat loss coefficient increase due to the increase in the heat loss by convection from the glass cover to ambient (h_{cg}) which called wind heat transfer coefficient (h_w), which they are considered in the theoretical model calculations. While the efficiency increases due to the increase of the top heat loss coefficient when the wind speed increases.

From figures (10 and 11) we can see the importance of wind speed on the efficiency of the still, when the wind speed increases the productivity increase (directly proportional), this may be explained by the fact that increasing the wind speed results in a higher heat transfer coefficient which result in a lower cover temperature and higher condensation rate inside the still. Cooper [32] concluded that the output increases by 11.5% when increasing the wind speed from 0 to 2.15 m/s. However, the output increased by 1.5% when the wind speed increase from 2.15 m/s to 8.81 m/s. In our theoretical calculations we have taken the wind speed of 2.5m/s, which is the average wind speed in Jordan. Badran [12] and Al-Hayek and Badran [13] found experimentally that when the wind speed increases from 3.1 m/s to 5 m/s the productivity increased by 16.1 %.

5. Conclusions

A theoretical work is constructed to predict the performance and productivity of active single slope solar still using different operational parameters. The ambient conditions (i.e. wind and solar intensity) are considered to have an effect on the overall still productivity. It has been established that the overall system efficiency in terms of daily distillate output will increase by increasing the basin water temperature and the use of latent heat of condensation for further distillation. Further, increasing the temperature difference between the evaporating and the condensing surface can increase the daily distillate output. The condition can be achieved either by increasing the evaporating surface temperature (using circulated hot water from the collector) and/or decreasing the condensing surface temperature (through wind speed) or combination of both. It can be concluded that feeding the thermal energy into the basin from external source (collector) can increase the evaporating surface temperature. The water can be heated during sunshine hours and most of the thermal energy is stored in water mass. The comparisons between the theoretical model and experimental data showed that the model is predicting accurately the thermal behavior of the active still and can be used in future for testing performances of different solar still systems.

Nomenclature

α , τ	Absorptivity, Transmissivity
q_b	Rate of energy convection from basin liner, (W/m^2)
$(\alpha\tau)$ eff	Effective product of absorptivity and transmissivity
ε_w	Water emissivity
ε_g	Glass emissivity
Δt	Time interval (second)
U_b	Overall bottom heat lost coefficient (W/m^2.c°)
U_l	Overall heat loss coefficient (W/m^2.c°)

Greek Symbols

σ	Stephan-Boltzmann coefficient(5.67x10^{-8})w/m^{2}k^4
β	collector tilt angle (degrees)

Subscripts

g	glass
b	Basin plate
a	ambient
w	water

Notations

V_W	Velocity of wind; m/s
$(MC)_w$	Heat capacity of water mass per(m^2)in basin; J/m^2.C

Non-dimensional Numbers

η	Efficiency of the system

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