Proceedings of the 3rd IASME/WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING AND ENVIRONMENT, Corfu, Greece, August 20-22, 2005 (pp191-197)

Performance of A Solar Collector Augmented Still

H. Al-Tahaineh
Al Balqa' Applied university, Faculty of Engineering Technology, Department of Mechanical Engineering, PO Box 15008, Amman, Jordan.

ABSTRACT

A single stage basin solar still was connected to a conventional solar collector (finned-tube type) to study the effect of the augmentation on the still performance. The outlet was fed to the still basin instead of the usual storage tank. Measurements of various temperatures, solar intensity, and distilled water production were performed for various days at various weather and operational conditions and then compared with the predicted results. The maximum distilled water produced from the collector augmented still is 2762.5 ml/day which is 37.5% larger than that when the still worked without collector (2008.5 ml/day).

Key words: solar energy, solar still, solar collector, distilled water.

1. INTRODUCTION

Solar distillation is one of many processes available for water purification, and solar radiation is one of several forms of heat energy that can be used to power that process. The basic concept of using solar energy to obtain drinkable fresh water from salty, brackish or contaminated water is really quite simple. Water left in an open container in the backyard will evaporate into the air. The purpose of a solar still is to capture this evaporated (or distilled) water by condensing it onto a cool surface using solar energy to accelerate the evaporation, increasing the water temperature and the area of water in contact with the air can accelerate the rate of evaporation. To capture and condense evaporated fresh water, we need some kind of surface close to the heated salt water, which are several degrees cooler than the water. A means is then needed to carry this fresh water to a storage tank or vessel.

Extensive work has been done in this field to design and construct large-scale stills [1-8]. These investigations were mostly experimental but some theoretical ones have been done as well. All of these publications include references to the very famous basin type solar stills which have received the most attention because of their relative simplicity and low cost.

Copper [1] formulated a mathematical model for an ideal basin type solar still using the equations proposed by Dunkle [2] to describe the system. The convection, evaporation, and radiation between the water surface and cover glass have been approximated as that between infinite parallel planes. He suggested that ideal solar still is one which has no conductive losses and the water depth is sufficiently small so that the sensible heat stored is negligible compared to the energy transfer rates to and from the water. To test this model he used a basin type still with internal dimensions of 0.743 x.962 m, the cover slope was 10 degrees and water level at a present depth of 9.5 mm. He concluded that, it is most unlikely that a 24 hr. efficiency greater than 60% could be achieved in practice because of the various factors which limit the approach to ideal operations. The experimental conclusion was that, the maximum efficiency rarely exceeds 50%.

Datta et al. [3] studied the effect of water depth on the efficiency of a basin type solar still. They reported that for water depth 2.54 to 15.54 cm. the average efficiency of utilizing solar
radiation for evaporation was 29.6% for still with angle of 30 degrees and 26.8% for that with cover angle of 50 degrees. They suggested that large cover angle resulted in a higher reflection of solar energy by the cover and lower thermal radiation from the basin to the cover.

Mustafa et al. [4] investigated two separate types of multi basin solar still. Both are with similar stepped shelves but the second still was with a condenser reservoir. The cover angles and the depth of the water were constant being 45 degrees and 5 cm respectively. The measured efficiency for the first and second systems were 24.51% and 23.2% respectively.

The present work investigates the effect of adding conventional type solar collector to single basin solar still fabricated from the available material in Jordan market under Jordan climatic conditions. The results of this augmentation on still performance, productivity and efficiency was reported. Also, the efficiency of single basin still was compared to the efficiency of the solar still coupled with a flat–plate collector, and makes comparison between produced quantities of distilled water in each case.

2. Energy analysis:

Energy Analysis for the still without a collector (passive still)

Following the analysis of Raj kamal [5,13], the theoretical analysis can be made by performing energy balances on various components of the still. The following assumptions have been made for writing the energy balance in terms (W/m^2):

1. Inclination of the glass cover is very small.

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

3. The solar distiller unit is vapor – leakage – proof.

The energy balance for each component of the still is as follow:

a) Glass cover

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

b) Basin bottom plate (basin liner)

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

c) Water mass

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

The analysis can be made by dividing the heat transfer process that occurs on the still into two types , External and Internal .

External heat transfer

This process covers exchanges between the external heat at surfaces of the still and the surroundings. They are related to the following coefficients:

1. **Top loss coefficient**

Due to the small thickness of the glass cover, the temperature in the glass may be assumed to be uniform. Then external radiation and convection Losses from the glass cover to out side atmosphere can be expressed as:

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

And

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

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

Where

$$h_{rg} = \frac{\varepsilon_g \sigma \left[(T_g + 273)^4 - (T_{sky} + 273)^4 \right]}{(T_g - T_a)} \quad (7)$$

$$T_{sky} = T_a - 6$$

Substituting q_{cg} and q_{rg} in equation (4) then

$$q_g = h_{1g} [T_g - T_a] \quad (8)$$

Where

$$h_{1g} = h_{rg} + h_{cg} \quad (9)$$

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 from the bottom or side surface of the basin.

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

$$U_b = \frac{1}{\left[\frac{1}{h_w} + \frac{1}{(K_i / L_i)} + \frac{1}{(h_{cb} + h_{rb})} \right]} \quad (10)$$

$$h_b = \frac{1}{\left[\frac{1}{(K_i / L_i)} + \frac{1}{(h_{cb} + h_{rb})} \right]} \quad (11)$$

The value of ($h_{cb} + h_{rb}$) is found from equation (10).

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

$$U_e = U_b \frac{A_{ss}}{A_s} \quad (12)$$

Note that (U_e) can be neglected for ($A_{ss} << A_s$).

Internal heat transfer.

The mode of heat exchange from the water surface to glass cover inside the distillation unit is mainly governed by radiation, convection and evaporation and hence these heat transfer modes are discussed separately.

2. **Radiative loss coefficient.**

In this case, the water surface and glass cover are considered as infinite parallel planes. Radiation between the water and the glass is given by:

$$q_{rw} = h_{rw} (T_w - T_g) \quad (13)$$

Where h_{rw} may be obtained from equation[1]:

$$h_{rw} = \varepsilon_{eff} \sigma \left[\frac{\left[(T_w + 273)^2 + (T_g + 273)^2 \right]}{(T_w + T_g + 546)} \right] \quad (14)$$

And

$$\varepsilon_{eff} = \frac{1}{\left[\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1 \right]} \quad (15)$$

4. Convective loss coefficient

Convection occurs a cross the humid air in the enclosure by free convection. It may be obtained from the equation:

$$q_{cw} = h_{cw}\left(T_w - T_g\right) \quad (16)$$

Where h_{cw} may be obtained [1] from the expression

$$h_{cw} = \left[T_w - T_g + \frac{\left(P_w - P_g\right)\left(T_w + 273\right)}{268.9\times 10^3 - P_w}\right]^{\left(\frac{1}{3}\right)} \quad (17)$$

5. Evaporative loss coefficient

Although evaporation is desired as it ends up as condensate, but it may be also considered as a loss from the water basin.

$$q_{ew} = h_{ew}\left(T_w - T_s\right) \quad (18)$$

Where

$$h_{gw} = 16.273\times 10^{-3}\times h_{cw}\frac{(p_w - p_g)}{(T_w - T_g)} \quad (19)$$

Equations (17) and (19) are evaluated at initial water and glass temperatures. Then the total internal heat transfer coefficient is

$$h_{1w} = h_{rw} + h_{cw} + h_{ew} \quad (20)$$

Substituting equations from (4-20) in equations (1), (2) and (3) then the energy balance equations become

$$\alpha_g I(t) + h_{1w}(T_w - T_g) = h_{1g}(T_g - T_a) \quad (21)$$

$$\alpha_w I(t) + h_{1w}(T_b - T_w) = (MC)_w\frac{dT_w}{dt} + h_{1w}(T_w - T_g) \quad (22)$$

$$\alpha_b I(t) = h_{1w}(T_b - T_w) + h_b(T_b - T_a) \quad (23)$$

Substituting the values for T_g and T_b from equation (21) and equation (23) in equation (22) will give

$$\frac{dT_w}{dt} + aT_w = f(t) \quad (24)$$

Where

$$a = \frac{U_l}{(MC)_w} \quad (25)$$

$$f(t) = \frac{(\alpha\tau)_{eff} I(t) + U_l T_a}{(MC)_w} \quad (26)$$

$$(\alpha\tau)_{eff} = \alpha_b\frac{h_w}{h_w + h_b} + \alpha_w + \alpha_g\frac{h_{1w}}{h_{1w} + h_{1g}} \quad (27)$$

$$U_l = U_b + U_t \quad (28)$$

$$U_t = \frac{h_{1w}h_{1g}}{h_{1w} + h_{1g}} \quad (29)$$

Equation (24) with T_w (t = 0) = T_{wo} and T_g (t = 0) = T_{go} can be solved for T_w. In order to obtain an approximate analytical solution with the above initial conditions, the following assumptions have been made.

1) The time interval Δt is small.

2) a is constant during the time interval Δt.

3) The function f (t) is constant for the time interval Δt.

Then the solution of equation (24) is:

$$T_w = \frac{f(t)}{a}\left(1 - (-at)\right) + T_{w0}\exp(-at) \quad (30)$$

Where T_{wo} is the temperature of basin water and f (t) is the average value of f (t) for time interval Δt. The average glass temperature can be found from equation (19) as follows:

$$T_g = \frac{\alpha_g I(t) + h_{1w}T_w + h_{1g}T_g}{\left(h_{1w} + h_{1g}\right)} \quad (31)$$

Then the instantaneous efficiency is:

$$\eta_i = \frac{q_{ew}}{I(t)} = \frac{h_{ew}h_{1g}}{h_{1w} + h_{1g}}(T_w - T_a) \quad (32)$$

Substitute equation (30) in equation (32), then

$$\eta_i = \frac{h_{ew}h_{1g}}{h_{1w} + h_{1g}}\cdot\frac{1}{U_l}\left[\begin{array}{l}(\alpha\tau)_{eff}\left(1 - Exp(-at)\right) + \\ U_l\frac{(T_{wo} - T_a)}{I(t)}Exp(-at)\end{array}\right] \quad (33)$$

There are two cases

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

$$\eta_i = \left[\frac{h_{ew}h_{1g}}{h_{1g} + h_{1w}}\right]\left[\frac{T_{wo} - T_a}{I(t)}\right] \quad (34)$$

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

$$\eta_i = \left[\frac{h_{ew}h_{1g}}{\left(h_{1g} + h_{1w}\right)}\right]\left[\frac{(\alpha\tau)_{eff}}{U_l}\right] \quad (35)$$

Now similar expressions for ηi will be found for active still case.

Energy Analysis of the still with collector (active still)

When using a flat–plate collector as shown in figure (1) The energy balance on the whole system becomes as given by the equation:

$$\alpha_w I(t) + hw(Tb - Tw) + q_u = (MC)_w \frac{dTw}{dt} + h1w(Tw - Tg) \quad (36)$$

Where q_u is given by

$$q_u = FA_c\left[(\alpha\tau)I_c(t) - U_l(Tw - Ta)\right] \quad (37)$$

Equation (36) may be solved [1] for T_w with the help of equation (37) for the initial condition.

$T_{w\,(t=0)} = T_{wo}$ and the solution is:

$$T_w = \frac{\overline{f(t)}}{a}\left[1 - Exp(-at)\right] + T_{wo} Exp(-at) \quad (38)$$

Where

$$\overline{f(t)} = \frac{\left((\alpha\tau)eff\,\overline{I(t)} + F(\alpha\tau)A_c\overline{I_c(t)}\right) + \left(U_l + U_l F A_c\right)\overline{T_a}}{(MC)_w}$$

$$a = \frac{U_l + FU_l A'_c}{(MC)w}$$

$$A'_c = (A_c / A_s)$$

Then by help of the previous equation the instantaneous efficiency is:

$$\eta_i = \frac{hewh1g}{h1w + h1g}\cdot\frac{1}{1+Ac}\cdot\left[\begin{matrix}\frac{(\alpha\tau)eff + F(\alpha\tau)Ac}{Ul + FUlAc}(1 - Exp(-at)) + \\ \frac{Two - Ta}{I(t)}Exp(-at)\end{matrix}\right] \quad (39)$$

Also there are two cases:

For *at* >>1

$$\eta_i = \frac{hewh1g}{h1w + h1g}\cdot\frac{1}{1+Ac}\cdot\left[\frac{(\alpha\tau)eff + F(\alpha\tau)Ac}{Ul + FUlAc}\right] \quad (40)$$

For ***at*** << 1

$$\eta_i = \frac{hewh1g}{h1w + h1g}\cdot\frac{1}{1+Ac}\cdot\frac{Two - Ta}{I(t)} \quad (41)$$

Also the hourly-distilled water production is:

$$m_w = \frac{A_s h_{ew}(Tw - Tg)}{hfg} \times 3600 \quad (42)$$

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. The reason is that, comparing equation (32) with equation (41) yields:

$$\eta_i(\text{active}) = \eta_i(\text{passive}) \times [1/(1 + A'_c)] \quad (43)$$

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

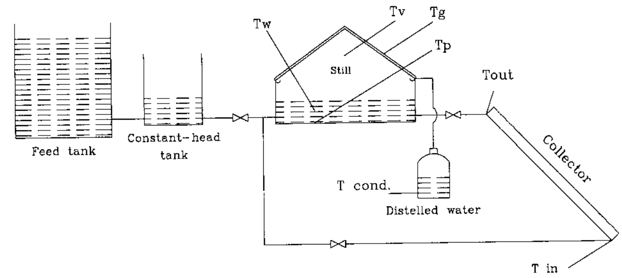

Figure 1:A schematic diagram of the solar collector augmented still

3. Numerical Model:

In order to have a numerical appreciation of results the following system parameters have been used [1,9-11].

- $R_g = R_w = \acute{\alpha}_g = 0.05$; $\acute{\alpha}_b$=o.8, $\acute{\alpha}_w$= 0.0.
- The value of (h_{rw}) is almost independent of temperature for normal operating temperature range (<80ºC) and its value varies between 7-10W/m^{2}ºC [Kumar and Tiwari, 1988; Lawrence and Tiwari, 1990 and Sharma and Malik, 1991]. Due to this the value of (h_{rw}) used in calculations is 8.5W/m^{2}ºC.
- The value of h_b=135W/m^{2}ºC.it is necessary to mention here that changes in the value of h_w have no significant effect on the performance of the still.

The value of hcw can be calculated by using eq.(18)under normal operating conditions the rise in temperature of the top cover and the saline water in the still is small and within this temperature range the vapor pressure inside the still may be approximately written as a linear function of temperature (sodha et al ,1978) $P = R_1T + R_2$. Then eq.(18) become

$$h_{cw} = 0.884\left[T_w - T_g + \frac{R1(T_w - T_g)(T_w + 273.15)}{268.9\,10^3 - R1 - R2(T_w + 273.15)}\right]^{\left(\frac{1}{3}\right)} \quad (47)$$

In the range of temperature variation observed in the experiment, the usual least square curve fitting (linear regression) yielded the following linear relationship for the saturated vapor pressure, P, inside the still

$$P = 293.3T - 84026.4 \quad (48)$$

Data for curve fitting was taken from steam table.

Collector parameters: (ατ)=0.8; F = 0.77; A_C=1.3m^2; U_l=8W/m^{2}ºc, $(\alpha\tau)_{eff}$ is evaluated using the equation (28) at water depth 2.5cm. By using the values of I(t) and T_a measured at each hour from 8:00AM to 5:PM and the initial glass and water temperatures ,the average water and glass temperatures could be calculated by integrating equation (33) for time interval of 0 to t.

Then the average temperature of water is given by:

$$\overline{T_w} = \frac{1}{t}\int_0^t T_w dt = \frac{\overline{f(t)}}{a}\left[1 - \frac{(1 - \exp(-a\Delta t)}{a\Delta t}\right] + T_{wo}\left[\frac{(1 - \exp(-a\Delta t))}{a\Delta t}\right] \quad (49)$$

The average glass temperature in terms of water temperature can be obtained from equation (34) and are then used to evaluate the internal heat transfer coefficient (h_{1w}). The values of T_w at the end of an interval become the initial condition for the second interval and so on. The most important parameters that affect on the performance of the still are the glass and water temperatures, due to this reason they were calculated following the previous steps mentioned above. A computer program written using(c++) language was built to carry out the numerical computations.

4. Results

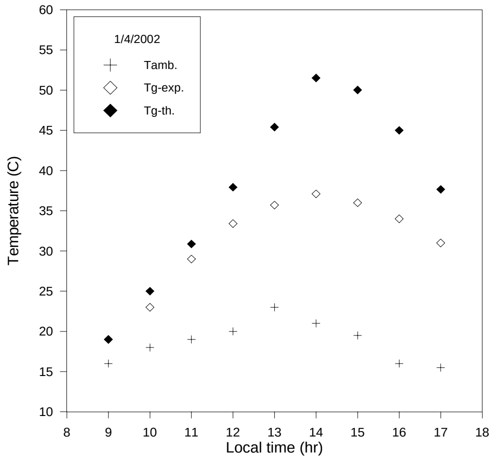

Figure (2) Variation of ambient, measured glass, and theoretical glass temperatures with local time during the day of experiment.

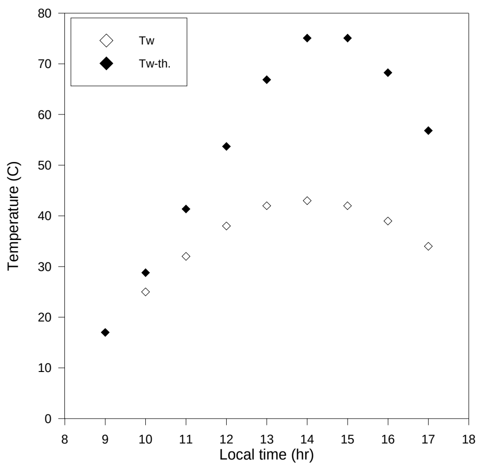

Figure (3) Variation of measured and theoretical water temperatures with local time during the day of experiment.

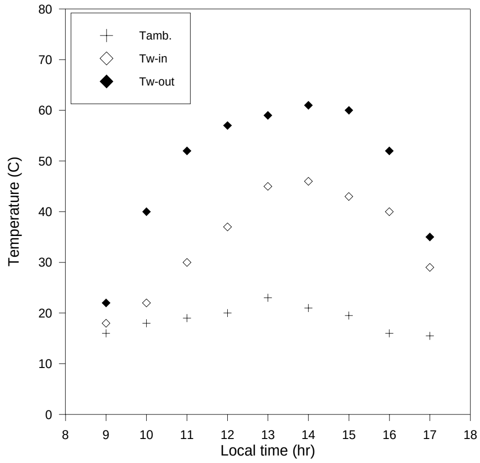

Figure (4) Variation of solar collector inlet and outlet temperatures with local time during the day of experiment.

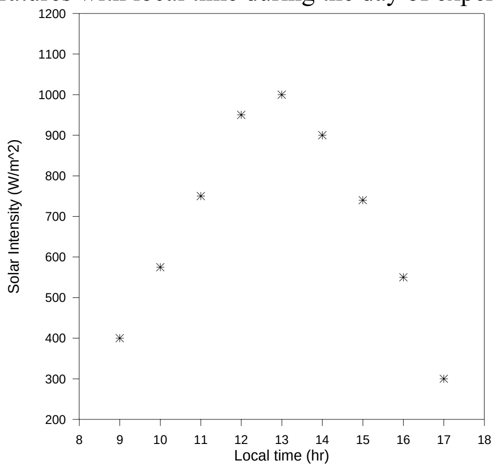

Figure (5) Variation of solar intensity with local time during the day of experiment.

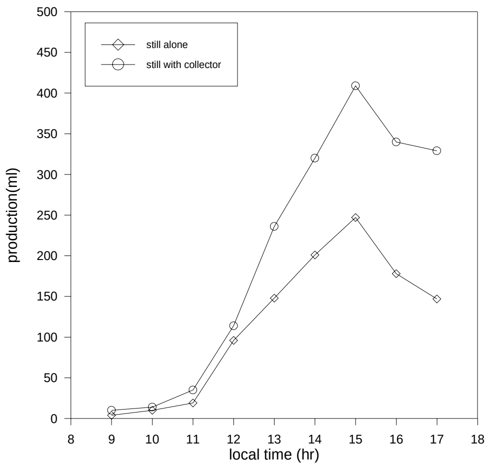

Figure (6) Condensed water production with local time for both still alone and a collector augmented still.

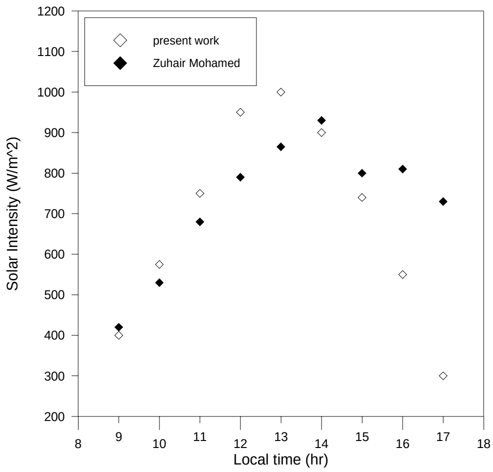

Figure (7) Variation of solar intensity of present work as compared to others work with local time.

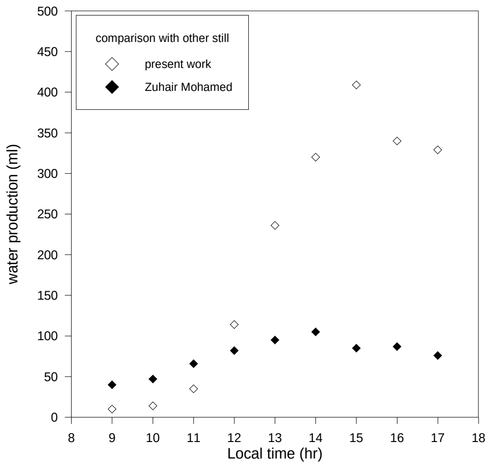

Figure (8) Variation of water production of present work as compared to others work with local time.

Table (1) Still operation conditions and efficiency

Setup	Weather conditions	Production (ml)	Efficiency, %
Still alone			
16/4/2002	Hazy and partially cloudy	1388	21.13
18/4/2002	Clear sky	2008.5	20.8
Collector augmented still			
17/4/2002	Clear sky	2403	12.4
10/4/2002	Clear sky	2762.5	13.53
9/4/2002	Clear sky	2561	12.17

5. Discussion:

Results obtained in this study show good agreement between theoretical model and the experimental measured data obtained by performing experiments on the solar collector augmented still. Figure 2 show the variation of ambient, theoretical and experimental glass temperatures. The difference between theoretical and experimental glass temperature increase with time because solar intensity increase and energy losses increase. The same thing for theoretical and experimental water temperatures inside the still as shown in figure 3.

The benefit of solar collector augmentation was show clearly in figure 4. The temperature of water enters the still increase by about 25% with adding collector to the system and this results in increasing distilled water production. The distilled water produced when the collector is augmented with still for 24 hour is 2762.5 ml/day which is 14.9% larger than when it closed at night (2410ml/day), and 37.5% larger than when the still worked alone (2008.5 ml/day) and the difference between the two cases, with and without collector, is clearly shown in figure 6 under the same average solar intensity of figure 5. This is because that the thermal energy taken by the still when it's augmented by the collector is larger than when it worked alone and also because of increase in the difference between the glass and water produced at night was mainly due to release of stored heat in the water which results from thermal heat capacity effect.

The performance of the developed still under investigation was compared with other's still [2] and the results presented in figures 7 and 8 show that the average amount of distilled water production is 55% much larger than that of ref. [6] even though there is no big difference in solar intensity.

The daily efficiency of the passive still was larger than for active still as shown in table (1), this is due to the fact that in active still the difference between glass temperature and water temperature in the still is higher and the effective are of the active still is larger than the effective area of passive still. So there is more thermal losses occur in the active still. The efficiency from 8AM to 5PM of the passive still was (53.73%) larger than the efficiency of active still.

6. Conclusions:

From the results of this work, the following may be concluded:

1. Regarding fresh water case, the distilled water production for a solar still augmented with a collector for 24hr was (2762.5ml), while it is for a still connected with collector from 8:00am to 5:pm was (2410); and for still worked alone the mass production was (2008.5), all these operations are performed at clear sky weather condition.
2. Whenever fresh water is used as a feed, the daily-distillate production of the still augmented with collector for 24hr is higher than that of still alone.
3. The efficiency for passive still is (53.73%)higher than the efficiency of the active still. This applies weather fresh or salt water was used to feed the still. Experimental evidence supports the theory and this condition is expected because of higher operating temperature range in active solar still system due to the additional thermal energy available from the collector thermal energy losses increase. Hence, despite the higher yield, the efficiency of active solar distillation decreases.

The conventional single basin solar still is the simplest and most practical design for an installation and less complexity than the other types [11,12].

7. References

[1] Copper,P.I., 1973, Solar Energy 15, P. 205-217.
[2] Dunkle, R.V., 1961, Solar water distillation; the roof type still and a multiple effect diffusion still,

International development in heat transfer, A.S.M.E., Proc. International of heat transfer, Part V, U. of Colorado, P. 895.
[3] Datta, R.I., Gomkale, S.D., Ahxned, S.Y., and Datar, D. S., Oct.1965, Evaporation of sea water in solar stills and its development for desalination, Proc.1st. Int. Symp. Water Desalination, Washington, D.C.
[4] Moustafa, S.M.A., Brusewits, G.H., and Farmer, D. M., 1979, Solar Energy, 22, P. 141-148.
[5] Kamal, R., Maheshwari,K.P.,and Sawhney ,"Solar Energy and Conservation" ,Wiley Eastern Limited , 1992.
[6] Zuhair M., M. Alhusein, and T. Alkhamis, "Experimental and Theoretical Evaluation of A basin Type Solar Still", Jordan, 1993.
[7] Copper, P.I. 1969, Digital simulation of transient solar still processes, Solar Energy, 12, p. 313.
[8] Report No. 190 prepared by the office of saline Water, U.S.A., 1966.
[9] Morse, R. N., and Read, W.R.W., 1968, A rational basis for the engineering development of a solar still, Solar energy, 12(1), P. 5-17.
[10] Delyannis, A.A., and Piperoglou, E., 1965, Solar distillation in Greece, 1st Int. Sympo. On Water Distillation, Washington, D.C., Oct.
[11] Bloemer, J. W., Collins, R.A., and Eibling, J. A. 1960, Field evaluation of solar sea water stills, Advance in chemistry, Series No. 27 (saline water conversion), P. 166-177.
[12] Datta, R.I., Gomkale, S.D., Ahxned, S.Y., and Datar, D. S., Oct.1965, Evaporation of sea water in solar stills and its development for desalination, Proc.1st. Int. Symp. Water Desalination, Washington, D.C.
[13] Llolman, J. P., 1986, Heat transfer, 6th edition, McGraw Hill.

Nomenclature

Colle collector Area,(m^2) ,A_c
Basin liner still area, (m^2) ,A_s
Side still area, (m^2) ,A_{ss}
Differential equation constant ,a
Collector efficiency factor ,F'
Basin liner convection heat transfer coefficient, ($W/m^2.^oC$) , h_{cb}
Glass cover convection heat transfer coefficient, ($W/m^2.^oC$) , h_{cg}
Heat loss coefficient by convection from water surface to the glass cover, ($W/m^2.^oC$) ,h_{cw}
Heat loss coefficient by evaporation from water surface to the glass cover, ($W/m^2.^oC$) ,h_{ew}
Time (hour) ,hr
Basin liner radiative heat transfer coefficient, ($W/m^2.^oC$) ,h_{rb}
Glass cover radiative heat transfer coefficient, ($W/m^2.^oC$) ,h_{rg}
Basin water radiative heat transfer coefficient from basin from basin to water to glass cover, ($W/m^2.^oC$) ,h_{rw}
Convective heat transfer coefficient from basin liner to water, ($W/m^2.^oC$) ,h_w
Total glass heat transfer loss coefficient from glass cover to ambient, ($W/m^2.^oC$) ,h_{1g}
Total heat transfer loss coefficient from water surface to the glass cover, ($W/m^2.^oC$) ,h_{1w}
Solar intensity, (W/m^2) ,I
Insulation thermal conductivity, ($W/m^2.^oC$) ,K_i
Insulation Length of heat exchanger, (m) ,L_i
Heat capacity of water mass per (m^2) in basin, ($J/m^2.^oC$) , $(MC)_w$
Hourly distillate water out put, ($kg/m^2.hr$) ,m_w
Glass saturated Partial Pressure, (N/m^2) ,P_g
Water saturated partial pressure, (N/m^2) ,P_g
Rate of energy convection from basin liner, (W/m^2) ,q_b
Rate of energy lost from basin liner to the ground, (W/m^2) , q_{bg}
Rate of energy lost to ambient air from the glass cover by convective, (W/m^2) ,q_{cg}
Rate of energy lost from water to the glass cover by convection, (W/m^2) ,q_{cw}
Rate of energy lost by radiation from the glass cover to the ambient air, (W/m^2) ,q_{rg}
Rate of energy lost by radiation from water surface the glass cover by, (W/m^2) ,q_{rw}
Rate of energy lost from the basin liner through the side of the still, (W/m^2) ,q_s
Ambient temperature, (^oC) ,T_a
Basin liner temperature, (^oC) ,T_b
Still glass cover, (^oC) ,T_g
Collector inlet water temperature, (^oC) ,T_{in}
Collector outlet water temperature, (^oC) ,T_{out}
Plate temperature, (^oC) ,T_p
Sky temperature, (^oC) ,T_{sky}
Still vapor temperature, (^oC) ,T_v
Still water temperature, (^oC) ,T_w
Water that inlet to the still from the tank temperature, (^oC) , T_{wi}
Water temperature at t=0, (^oC) ,T_{wo}
Time, (sec.) ,t
Overall bottom heat lost coefficient, ($W/m^2.^oC$) ,U_b
Overall side heat loss coefficient, ($W/m^2.^oC$) ,U_e
Overall heat transfer coefficient, ($W/m^2.^oC$) ,U_1
Wind speed, (m/s) ,V

Greek symbols

Absortivity ,α
Fraction of energy absorbed of the basin liner ,α_b
Fraction of energy absorbed of the glass ,α_g
Fraction of energy absorbed of the water ,α_w
Product of absorbtivity and transmissivity ,$(\alpha\tau)$
Effective product of absorbtivity and transmissivity ,$(\alpha\tau)_{eff}$
Transmissivity ,τ
Glass emissivity ,ε_g
Water emissivity ,ε_w
Stephan-poltzman coefficient ($5.67x10^{-8}$), ($W/m^2.K^4$) ,σ
Time interval (sec.) ,Δt