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Experimental Investigation of Single Basin Solar Still Coupled with Evacuated Tube Heat Pipe

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***Abstract*— the present work is an experimental investigation of single basin solar still coupled with evacuated tube heat pipe. The work carried out in Baghdad city (in Iraq 33.2456º latitude and 44.3337º longitude) during certain days from many months of the year 2016 to examine the effect of using evacuated tube heat pipe on the daily distillate output and efficiency of the system under outdoor climatic conditions. The results show that the maximum amount of exergy destruction takes place in the basin of solar still. It was found that using 10 evacuated tube heat pipes will enhance the still daily productivity from 3.4725 to 7.0375 kg/m² per day (102.66 % Increase) for sunny days. Besides, the daily energy efficiency increased from 36.029 % to 71.098 % for sunny days as well. Moreover, the solar radiation and ambient temperature found to be the most effective climatic parameters in the still's performance.**

Keywords— Solar stills, Single basin solar still, Solar distillation, Evacuated tube heat pipe.

I. INTRODUCTION

The saline water fed to the basin in the traditional solar desalination, there is a diaphanous sloping surface to solar radiation cover the basin and the water condenses on that surface and collected by a trough. The major cost is in the initial finance. A solar still can be classified into two main groups: A-Passive: which means direct solar desalination. The passive solar still is a traditional system in which the solar energy is used as an individual cause of thermal energy [1]. B-Active: in this kind, a supplementary thermal power is attached to the negative solar still for hurry up evaporation. This additional power may be acquired from a solar collector or from any recovered power from plants, such as power plant [2]. Solar power can be used by three technological methods [3]: chemical, electrical and thermal. Another form of transform solar energy is mechanical power as wind and water steam [4].

A lot of studies are made to investigate the productivity of solar still. Panchal et.al. [5] studied comparison between the solar still coupled with Flat Plate Collector as well as Passive Solar still. One year study shows that solar still coupled with Flat Plate collector increases the productivity of solar still of 35%. Lower the water depth increases the productivity of solar still and solar radiation can also produce considerable effect on productivity. Khalifa [6] studied the effect of the cover tilt angle on productivity and the value of the optimum tilt angle. A relation between the cover tilt angle and productivity of simple solar still-basin type in various seasons is established together with a relation between the optimum tilt angle and the latitude angle by an extensive review of the literature. The conclusions of this study should assist in choosing the proper cover tilt angle in various seasons and latitudes. It concluded that the cover tilt angle should be large in winter and small in summer and increasing the tilt angle would increase the productivity throughout the year. The trend obtained suggests an optimum cover tilt angle that is close to the latitude angle of the site and for maximum productivity, the cover tilt angle should be increased as the latitude angle of the test site becomes large. Panchal and Shah [7] studied the effect of different thicknesses glass cover on passive single-slope single basin solar still in winter climatic conditions of Mehsana in India (23°12' N, 72°30') from September, 2010 to Feb. 2011. Experiment used three identical size solar stills having three different thicknesses of glass cover of 4 mm, 8 mm and 12 mm. The objective of the present paper is to evaluate the behavioral variation in various parameters on solar still. Six month study shows that, lower glass cover thickness increases the distillate water output, water temperature, evaporative heat transfer coefficient, convective heat transfer coefficient as well as efficiency of solar still. Hence, 4 mm glass cover thickness is most prominent thickness of present experiment. Teltumbadeand and Walke [8] studied the effect of using different absorbing materials in a solar still. Experimental result show that the productivity of distilled water was enhance for some materials. It concluded that the water productivity in a solar still can be increased with the presence of some absorbing material such as rubber mat, black ink, sponge. Increasing the productivity of water would reduce the effective insulation area of a solar still, and compare manual and mathematical result show on graph and concluded result analysis. Vendra Singh et.al. [9] presented a comparative energy and exergy analysis of various conventional solar distillation systems . The study includes passive solar distillation systems such as single and double slope solar stills. In a single slope solar still category, three solar stills with inclination angles 15º, 30º and 45º and a 15º inclined single slope multi wick solar still have been considered. Whereas one double slope solar stills and one double slope multi wick solar still, both inclined at 15º with east-west orientation, have been considered in double slope solar still category. The embodied energy is an important factor which depends on locally available materials and their manufacturing technologies. Materials like concrete, wood, steel etc are considered to calculate the embodied energy for the solar still equivalent to the fiber reinforced plastic after deriving the formulae. It has been found that the energy, exergy and embodied energy of single slope solar still are found higher than that of double slope solar still. Those materials which have lower thermal conductivity and low embodied energy than that of FRP such as concrete, PVC, wood can replace the FRP to save the embodied energy for similar performance. The metals have high embodied energy hence these cannot be considered in terms of embodied energy despite the use of insulation. Khalifa and Hamood [10] studied the effect of brine depth in still productivity by developing a correlation from the data reported by previous studies. The correlation showed a decreasing trend in the productivity with the increase in the brine depth. An experimental study was subsequently conducted to verify this trend by an experimental investigation on a solar still that was constructed and tested with five different brine depths, namely 1, 4, 6, 8 and 10 cm. The present study validated the decreasing trend in productivity with the increase of brine depth and showed that the still productivity could be influenced by the brine depth by up to 48%. Shobha et. al. [11] studied using of the solar water heater with solar still which works as a hybrid system. The evacuated tube collector model solar water heater was coupled to a solar still, and the performance study was conducted at various timings with different operating conditions like Solar still operated alone and Hybrid Still operated during daytime with various water depths and various water samples. Both Theoretical and Experimental analysis were conducted and the results were compared. It concluded that productivity of solar still increases from 39 to 59% with hybrid unit. Raed [12] studied experimentally the effect of variable weather conditions(solar radiation, ambient temperatures and wind speed) of Baghdad city (33.3°N – latitude)on the productivity and the performance of the basin type solar still to specify the optimum values of the climatic parameters that give the higher production . Also studied experimentally the improvement in the productivity of the still by adding a thin layer of paraffin wax as a PCM. The results were shown that the productivity of the still is directly related to the intensity of the solar radiation received, where as the solar radiation received increases the productivity of the basin type solar still increases. The productivity of the still could be influenced by the solar radiation alone by up to 90% under Baghdad climatic conditions. Also the experiments illustrate that the still productivity increases with the increase of ambient temperature around the still. From the experimental data of research it was found that the still productivity could be influenced by the wind speed, where as the wind speed increases the productivity of the basin type solar still increases and it was found that the still productivity could be influenced by alone up to 25 %. Also it was noticed that the still with PCM is superior in productivity (35% improvement) compared with still without PCM where, the daily productivity of the still is found to be 3.98 (kg/m² .day) with using 3 cm of paraffin wax under the still absorber. Rajesh and Bharath [13] studied experimentally the performance of a single basin still compared with FPC (Flat Plate Collector) coupled one. Test were carried out for different water samples bore well water, sea water and river water ,for a water depth of 20 mm .The study shows that single basin still productivity enhances by 42% for borewell water, 40% for sea water and 45 % for river water when the still coupled with FPC. The various other tests like chlorine content, total hardness, calcium content, electrical conductivity, TDS, PH value, were carried out in the laboratory and found that water is safe and pure for drinking. Akash et. al. [14] studied experimentally the effect of using different absorbing materials in a basin type solar still on the productivity of fresh water. Experimental results showed that the productivity of distilled water was enhanced for some materials. For example using an absorbing black rubber mat increased the daily water productivity by 38%,but black ink increased it by 45%. Black dye was the best absorbing material used in terms of water productivity, it resulted in an enhancement of about 60%. The still used in the study was a single-basin solar still with double slopes. Khalifa and Hamood [15] studied experimentally the effect of insulation on the productivity of a basin type solar still . Solar stills with Styrofoam insulation thickness of 30, 60 and 100 mm were investigated and the results are compared with those obtained for a still without insulation. It was found that the insulation thickness has a significant impact on the productivity of the still up to a thickness of 60 mm. The insulation thickness could influence the productivity of the still by over 80%. A performance correlation for the effect of insulation on productivity is also developed. The experimental investigation on the effect of insulation on the productivity of basin type single slop solar still verified that the increasing trend in the productivity with the increase in the insulation thickness. The productivity (y) as a function of insulation thickness (t) may be given by the following correlation:($y = 1023t^3 - 408.8t^2 + 45.34t + 1.81$.).

II. Experimental Facilities and Still Description

The basin still was constructed from a variety of local materials, which are selected based on previous literatures results to get optimum design of still components (basin, glass cover, insulation, piping) that verify the enhancement in still productivity with other effects (using evacuated tube heat pipe, operation parameters and climate conditions). A schematic diagram of the test rig as shown in Figure 1.In present work the basin was made of GI sheet (galvanized iron) (1mm thickness) with dimension (0.8x0.5x0.63m) which can verify the desired requirement as shown in Table 1 and Figures 1. The basin painted by black color at bottom to increase the solar absorptivity and painted white on the inside surfaces of the walls in order to reflect the incoming solar radiation to the feed water with an attempt to increase the water temperature and at the same time keep the temperature of the condensing surface low [16], [17] which will increase the evaporation rate due to increasing the temperature different between brackish water and glass. The glass used with thickness, (4mm) because the condensation temperature for 4 mm glass cover thickness is lower as compared with 8 mm as well as12 mm thickness [7] which cause increasing in productivity with tilt angle 33° close to latitude of experiment location to verify maximum production [6]. As shown in Figures 1. The trough used in present work is a half circle cross sectional area with dimensions (50 x 10 x 5 cm) made from GI sheet (1mm thickness) as shown in Figure 1. In the present work a Cork Board is used (6 cm thickness and 0.043 W ⁄ m. K˚ thermal conductivity). Two pipes (10 cm long & 1.27cm diameter for feeding brackish water and 10 cm long & 0.25cm diameter for distillated water) and fitting were used to connect devices that hold pipe segments together is used, one for draining the distillated water from trough and the other for feeding brackish water to the still as shown in Figure 1.

The evacuated tube heat pipe used in the present work are made up of two components; an evacuated glass tube and a heat pipe inside the glass tube. The evaporator section of the heat pipe was placed inside the evacuated glass tube whereas the condenser section was placed in the storage tank, as shown in Figure 2 while Table 2 shows design specifications of the evacuated tube heat pipe solar water heating. It's better from connect the evacuated tube glass with still basin for two reasons: the first glass tube will be far from the salt water and thus prevents the deposition of salts inside the glass tube causing decrease the efficiency of the glass tube. Second, the amount of thermal energy instead of being used to raise the temperature of the amount of water in the distilled and the amount of water inside glass tube, it will be used to raise the temperature of the water inside the distilled only and increase the productivity.

By using calibrated thermocouples (type-k) we recorded the temperatures, the calibration certificates are shown in appendix E, in combination 8 channel temperature recorder with SD card data logger manufactured by (Lutron Company of Taiwan model BTM - 4208SD). Thermocouple for ambient temperature was mounted in an open ended white (to shield it against solar radiation) PVC flexible tube (internal diameter = 5 cm, wall thickness = 0.2 cm and length = 20 cm) to allow free air circulation. The tube was mounted horizontally on the underside of a table located close to the solar stills above the plane of a horizontal roof, as shown in Figure 3. The temperature of water is measured by a thermocouple located into still, this thermocouple was guarded against solar radiation via white tube by the same previous way of using PVC pipe. The tube was supported by suitable ultra epoxy (weather resistance and water proof) against a GI strip constructed vertically into basin (thickness = 0.1 cm, length = 3 cm) with many grooves to allow to the water to enter to the thermocouple. The water completely surrounded the junction of the thermocouple which was well secured, it suspended in the middle between both the bottom and top of the saline water layer. The basin thermocouple was fixed on the still basin and well secured from basin water and sun ray by the same previous type of white tube and same ultra epoxy but without any groove to avoid any water to touch the thermocouple and by putting another white PVC around the previous tube (thickness = 0.3 cm, length = 10 cm) with ultra epoxy to avoid any water enter to the thermocouple, as shown in Figure 4. The temperature of the glass cover was measured using thermocouple. It was glued on outer surface of glass cover and shielded against solar rays by using the same previous procedure, as shown in Figure 5. The location of thermocouples for the still are shown in Figure 6, and as shown in Figure 7. While Figure 8 shows the evacuated tube heat pipe coupled with the still.

Table 1. Design specifications of the still distillation, evacuated solar collector and heat exchanger.

Still Design	Basin	GI sheet Height 669.5 mm Length 800 mm Width 500 mm Thickness 1 mm
	Basin Cover	Glass Thickness 4 mm Tilt angle 33°
	Insulation	Cork board Thickness 60 mm and 0.043 W/m . K˚ thermal conductivity

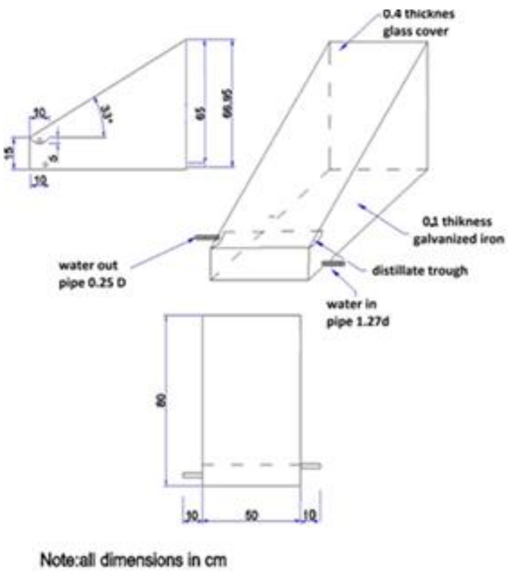

Figure 1. Schematic of the System.

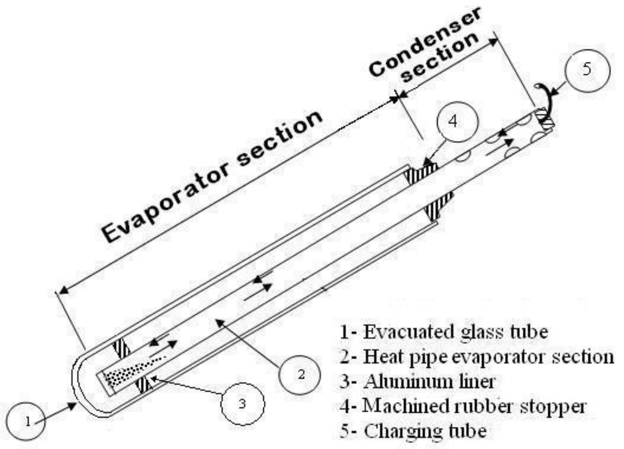

Figure 2. Assembly of the evacuated tube heat pipe solar collector

Table 2. Design specifications of the evacuated tube heat pipe solar water heating system using four HP7 heat pipes.

Evacuated tube heat pipe solar collector array	Number of Evacuated tube heat pipes	10
	Total absorber area	2.578 m^2
	Orientation	33^o , south facing
Heat pipes (HP7)	Evaporator length	1800 mm
	Condenser length	200 mm
	Diameter	22 mm
	Working fluid, charge	Ethanol, 50%
Evacuated glass tube	Material	High quality boro-silicate glass
	Length	1800 mm
	Outer tube diameter	58 mm
	Inner tube diameter	47 mm
	Glass thickness	1.6 mm

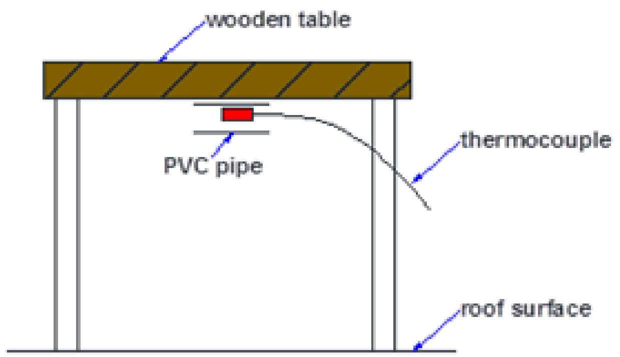

Figure 3. Installation of a thermocouple for measuring the ambient air temperature

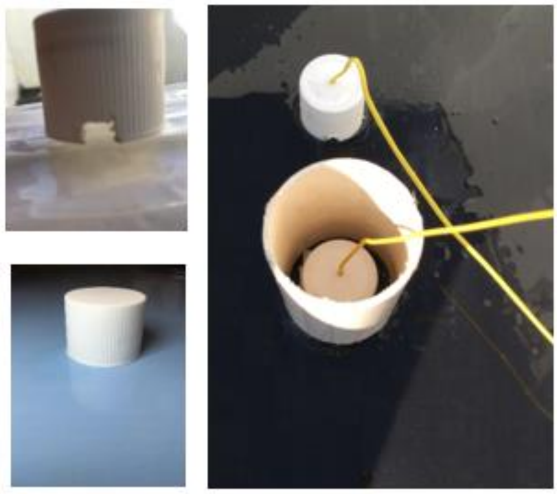

Figure 4. Basin and water thermocouples installation

Plate 5.Glass cover thermocouples installation.

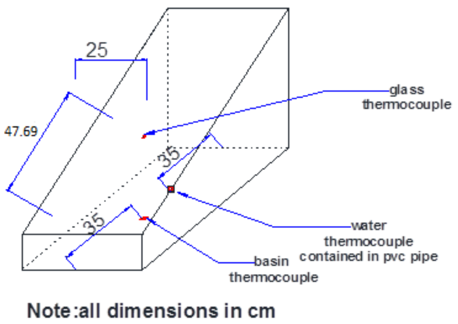

Figure 6. Thermocouples Distribution of the Experimental Solar Still Prototype.

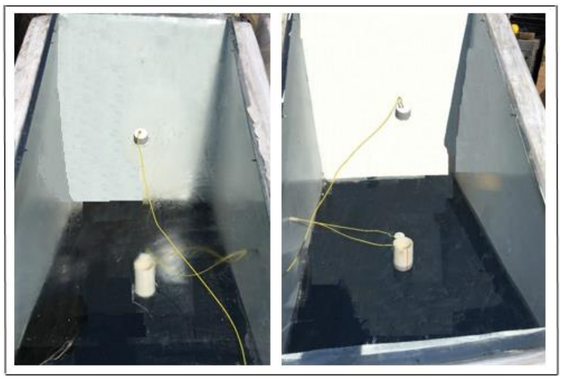

Plate 7.Glass cover, water and basin thermocouples installation.

Figure 8.The evacuated tube heat pipes coupled with the still.

III. ANALYSIS WORK

Solar on the glass lid of the solar still is partially reflected and absorbed by the cover and remaining amount of it is transmitting through the cover. The large amount of this transmitted solar radiation is absorbed by brackish water in the still basin and remaining part of radiation will loss from sides and bottom of still basin. Heat gained by glass cover, brackish water ...etc. will transfer by different heat modes. The new source of solar energy was constructed from a heat pipe inside the evacuated tube, where the temperature inside the evacuated tube very high and the end of this heat pipes enter to the basin and contact the water inside the basin, and by this way the solar energy will be transferred to the water inside the basin. So, it will provide the water inside the basin with additional thermal energy in addition to the thermal energy received by basin directly from the sun.

During the analysis, the following assumptions have been adopted:

1. The heat capacity for the glass, basin and insulated material was neglected because of the small values of these material as compared with the values of water.
2. There is no leakage of vapor from system.
3. Water vapor ideal gas.
4. No heat losses from the sides and bottom of still.
5. The area of basin equal the area of glass ($A_b = A_g = A$).
6. Due to small thickness of glass cover, it assumed no temperature gradient through glass ($T_{gin} = T_{out} = T_g$).
7. Working pressure is atmospheric pressure inside and outside of still (1 bar).
8. The thickness of water flow is regarded to be constant during each experiment.

The Efficiency and Productivity of the Solar Still
The daily and hourly productivity of still can be found as:

The Hourly Productivity and Energy Efficiency

$$\dot{m}=\frac{h_{e,wg}(T_w-T_g)*3600}{h_{fg,w}} \quad (kg/m^2.\ hr)\ [15] \qquad (1)$$

The instantaneous energy efficiency of the solar still in charging mode is:

$$\eta_{energy} = \frac{h_{e,wg}(T_w-T_g)}{I(t)}*100\% = \frac{\dot{m}*h_{fg,w}}{I(t)*3600}*100\%\ [16] \qquad (2)$$

The Daily Productivity and Efficiency

$$\dot{m}_{day} = \sum_1^{24}\dot{m} \quad (kg/m^2.day) \qquad (3)$$

Then the daily efficiency can be calculated by:

$$\eta_{energy,d\%} = \frac{\dot{m}_{day}*h_{fg,ave}}{(\sum_1^{24} I(t))*3600}*100\% \qquad (4)$$

The values of ($h_{fg,ave}$) is the average daily latent heat and (Δt) is the time interval through sunlight measuring. The value of (h_{fg}) can be taken from the vapor tables or by the following relation [17]:

$$h_{fg}=3044205.5-1679.1109T_f-1.14258T_f^2 \quad (J/kg) \qquad (5)$$

Where

$$T_f = \frac{(T_w+T_g)}{2}+273.15 \quad (k^{\circ}) \qquad (6)$$

Exergy balance of single basin single slope still

A- Exergy destruction in the glass cover

The amount of exergy received by the glass cover (from both the sun and brine) can be express as [18];

$$IR_g = \alpha_g Ex_{sun} + Ex_{e,wg} + Ex_{c,wg} + Ex_{r,wg} - (Ex_{c,ga} + Ex_{r,gs}) \qquad (7)$$

Where
$IR_g =$ glass cover irreversbility.

$Ex_{c,ga}$ = exergy due cnovection heat transfer for glass and ambient.
$Ex_{r,ga}$ = exergy due raditave heat transfer for glass and ambient.
Ex_{sun} = exergy due to solar radiation.
$Ex_{e,wg}$ = exergy due evaporative heat transfer for water and glass.
$Ex_{c,wg}$ = exergy due free cnovection heat transfer for water and glass.
$Ex_{r,wg}$ = exergy due raditave heat transfer for water and glass.

$$Ex_{c,ga} = h_{c,ga}A(T_g - T_a)\left(1 - \frac{T_a+273.15}{T_g+273.15}\right) \quad (8)$$

$$Ex_{r,gs} = h_{r,gs}A(T_g - T_s)\left(1 - \frac{T_a+273.15}{T_g+273.15}\right) \quad (9)$$

$$Ex_{e,wg} = h_{e,wg}A(T_w - T_g)\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (10)$$

$$Ex_{c,wg} = h_{c,wg}A(T_w - T_g)\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (11)$$

$$Ex_{r,wg} = h_{r,wg}A(T_w - T_g)\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (12)$$

Exergy of solar radiation (Ex_{sun}) can be calculated by multiplying the energy of solar radiation (I_{tilt}), by the Petela expression $\left[1 + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 - \frac{4}{3}\left(\frac{T_a}{T_s}\right)\right]$ [19];

$$Ex_{sun} = I_{tilt}A\left[1 + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 - \frac{4}{3}\left(\frac{T_a}{T_s}\right)\right] \quad (13)$$

where T_s is the solar radiation temperature, i.e. sun temperature at 6000 K.

B- Exergy Destruction in Water Mass

Exergy balance of water mass can be write as [18]:

$$IR_w = \alpha_w \tau_g Ex_{sun} + Ex_w \text{-} (Ex_{e,wg} + Ex_{c,wg} + Ex_{r,wg}) \quad (14)$$

Where

IR_w = water mass irreversbility.
$Ex_{c,bw}$ = exergy due to free convection heat transfer from basin to water,
Ex_w = accumulated exergy within the brine.

$$Ex_{c,bw} = h_{c,bw}(T_b - T_w)\left(1 - \frac{T_a+273.15}{T_b+273.15}\right) \quad (15)$$

$$Ex_w = \frac{m_w C_w}{A}\left(\frac{T_w - T_a}{t}\right)\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (16)$$

C- Exergy Destruction in the Basin Liner

$$IR_b = \alpha_b \tau_g \tau_w Ex_{sun} - (EX\_w + Ex_{bws)}\ [18] \quad (17)$$

$$Ex_{bws} = U_{ins}(T_b - T_{ws})\left(1 - \frac{T_a+273.15}{T_b+273.15}\right)\ [18] \quad (18)$$

Exergy Efficiency

To get the exergy efficiency, it used exergy output to the exergy input, exergy output associated with the productivity while radiation exergy from the sun refers to the exergy input, as shown in the next expression [20]:

$$\eta_{exergy} = \frac{\text{Exergy output from passive solar still}}{\text{Exergy input to passive solar still}} = \frac{Ex_{out}}{Ex_{in}} \quad (19)$$

$$\eta_{exergy} = \frac{Ex_{ew}}{Ex_{sun}} \quad (20)$$

Where Ex_{ew} is the exergy due to evaporation of water in still and it can calculated as:

$$Ex_{e,wg} = h_{e,wg}A(T_w - T_g)\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (21)$$

Or

$$Ex_{e,wg} = m \cdot h_{fg,w}\left(1 - \frac{T_a+273.15}{T_w+273.15}\right) \quad (22)$$

Sub. eqs. (13 & 21) in eq. (20);

$$\eta_{exergy} = \frac{h_{e,wg}A(T_w - T_g)}{I_{tilt}A} \text{x} \frac{\left(1 - \frac{T_a+273.15}{T_w+273.15}\right)}{\left[1 + \frac{1}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)^4 - \frac{4}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)\right]} \quad (23)$$

Or

$$\eta_{exergy} = \frac{\dot{m} h_{fg,w}}{I_{tilt}A} \text{x} \frac{\left(1 - \frac{T_a+273.15}{T_w+273.15}\right)}{\left[1 + \frac{1}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)^4 - \frac{4}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)\right]} \quad (24)$$

$$= \eta_{energy} \text{x} \frac{\left(1 - \frac{T_a+273.15}{T_w+273.15}\right)}{\left[1 + \frac{1}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)^4 - \frac{4}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)\right]} \quad (25)$$

$$\therefore \eta_{exergy} = \eta_{energy} \text{x} \frac{(T_w - T_a)}{T_w\left[1 + \frac{1}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)^4 - \frac{4}{3}\left(\frac{T_a+273.15}{T_s+273.15}\right)\right]} \quad (26)$$

The equations were solved by using the design parameters of the solar stills, as shown in Tables 3 [21].

Table 3. Relevant parameters used for calculations [21].

Relevant parameter	Value	Relevant parameter	Value	Relevant parameter	Value
ε_w	0.95	k_{ins} (W/m. K°)	0.045	A_b (m^2)	0.4
ε_g	0.88	x_{ins} (m)	0.03	k_b (W/m. C	73
τ_w	0.95	C_b (J/Kg. K°)	896	x_b (m)	0.001
α_b	0.9	C_g (J/Kg. K°)	800	σ (W/m^2. k	5.67 $*10^{-8}$
α_w	0.05	C_w (J/Kg. K°)	4190		

IV. Results and Discussion

To study the effect of evacuated tube heat pipe on the productivity of single basin solar still, two stills were constructed with same design and they have been tested under outdoor conditions. The results were showed that the productivity of solar still during day time with evacuated tube heat pipe (7.0375 Kg/m²) (during August month) is more than the still without evacuated tube heat pipe (3.4725 Kg/m²), that mean (102.66 %) enhancement in still productivity, as shown in Figures (9&10).

Figures (11) shows the variation of hourly thermal efficiency of the two stills during day time. The reasons behind this enhancement is some of incident solar energy on the evacuated tube heat pipe will be used to increase the temperature of raw water in the still coupled with that evacuated tube heat pipe in addition to the incident solar energy on the still directly.

Figure (12) shows that the exergy rate varies with solar radiation. The exergies increase with increase the solar intensity

Figure (13) show that the exergy efficiency is much smaller than the energy efficiency. The daily energy efficiency by using 10 evacuated tube heat pipe increased from 36.029 without 10 evacuated tube heat pipe to 71.098 with the 10 evacuated tube heat pipe.

Figure (14) shows that the irreversibility or exergy destruction of solar still directly proportional with solar intensity, so it increases with increasing solar intensity, this increasing is faster in the basin than other solar components. This large amount of exergy destruction in still basin is due to the large difference between the ambient and basin temperature because the basin temperature is the highest temperature of the solar still components, as shown in Figure (16).

Figure (15&16) explains that $T_w$stared rise with increasing of solar radiation I and ambient temperature T_a from 8 AM and it stay rising continuously until reach to maximum value then it will be decreasing while the sun moving towards sunset and so on for T_g and T_b. As it is clear that T_w, T_g and T_b stared with close value (small difference) between them, but that difference will be increase when the solar energy increase, and when the solar energy decrease the difference between T_w, T_g and T_b will be decrease and the productivity is continuing because of continuation of water evaporation due to the difference between T_w and T_g , as shown in Figure (17&18).

Figure (19&20) shows comparison of average experimental variation of temperatures with time for glass and water with & without 10 evacuated tube heat pipe. As it is clear that , T_g and T_w for still with 10 heat pipe rise more than for still without 10 heat pipe caused more productivity and stared with close value (small difference) between them, but that difference will be increase when the solar energy increase, and when the solar energy decrease. Figures (21) show that the difference $(T_w - T_g)$ with 10 evacuated tube heat pipe is more that without evacuated tube heat pipe and that will lead to increase the productivity.

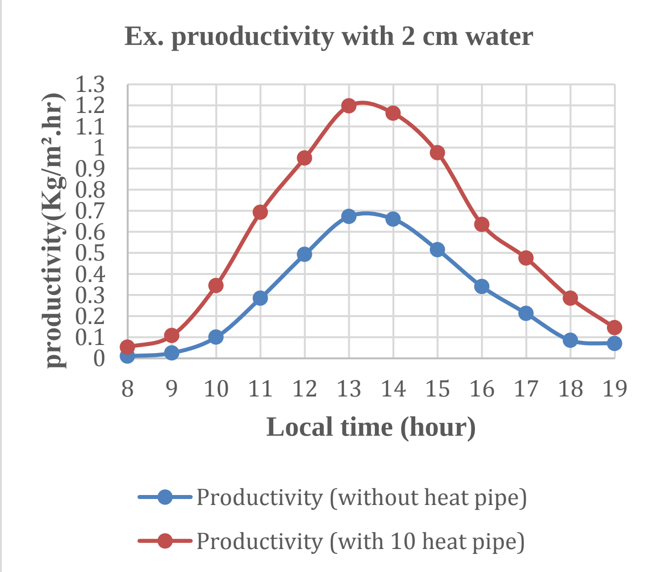

Figure 9. Comparison of average the hourly variation of the experimental still productivity with & without 10 evacuated tube heat pipe from 8 AM to 7 PM (Aug.-2016).

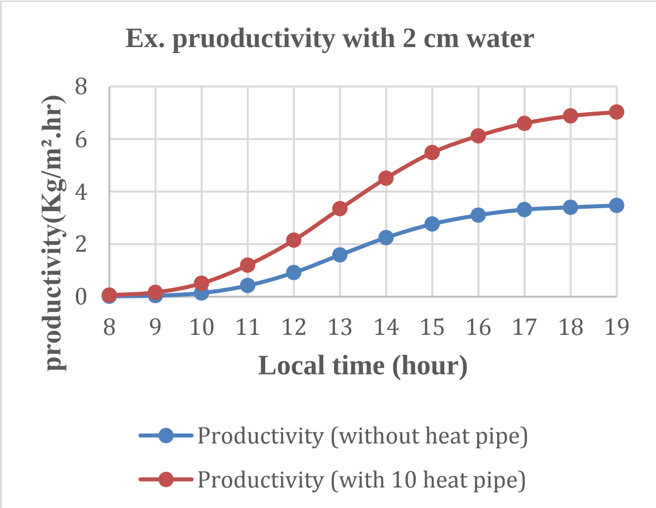

Figure 10.Comparison of the average productivity of stills productivity with and without 10 evacuated tube heat pipe from 8 AM to 7 PM (Aug-2016).

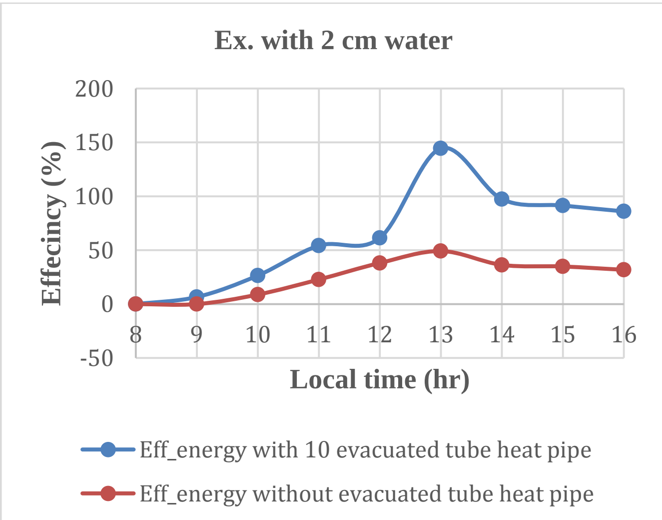

Figure 11. Comparison of the average hourly stills efficiency with and without10 evacuated tube heat pipe for a certain day (Aug-2016)

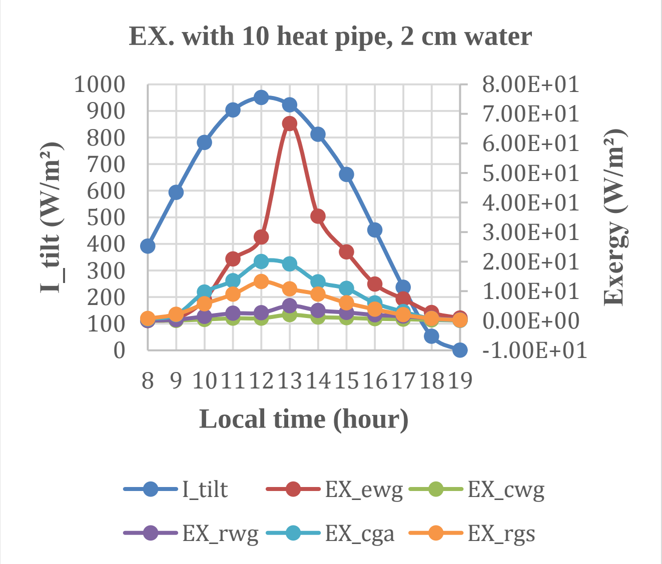

Figure 12. Average hourly variation in exergy rates for still with 10 evacuated tube heat pipe for a certain day (Aug-2016).

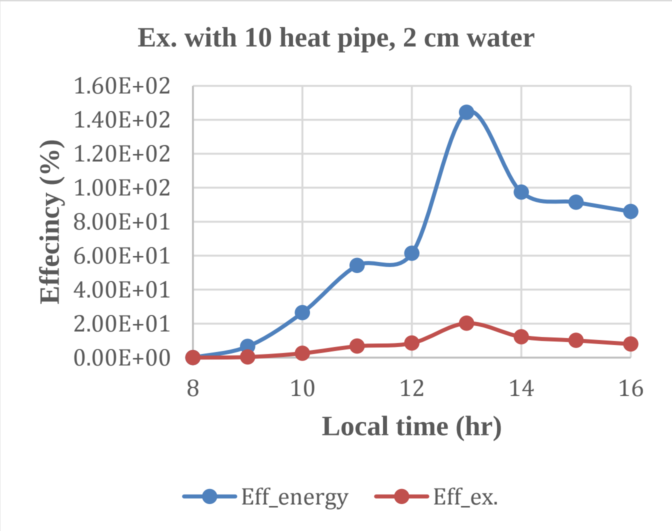

Figure 13. Comparison of average energy and exergy efficiency of still with 10 evacuated tube heat pipe for a certain day (Aug.-2016).

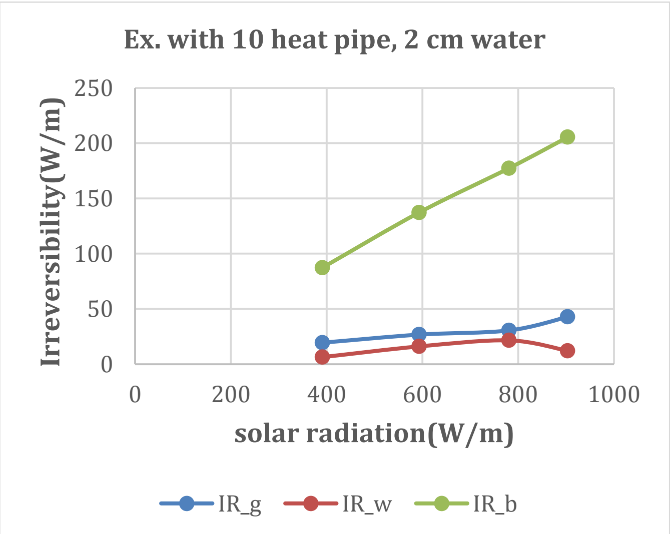

Figure 14. Average hourly variation in irreversibility rates of the solar still with 10 evacuated tube heat pipe (Aug-2016).

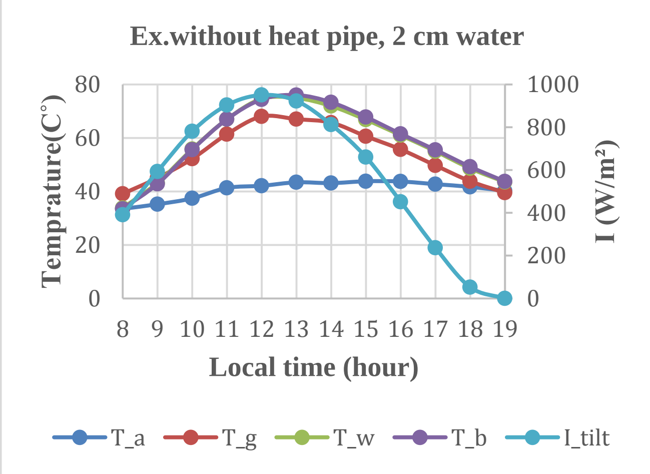

Figure 15. The average experimental variation of temperatures with time for solar still without evacuated tube heat pipe from 8 AM to 7 PM (Aug.-2016).

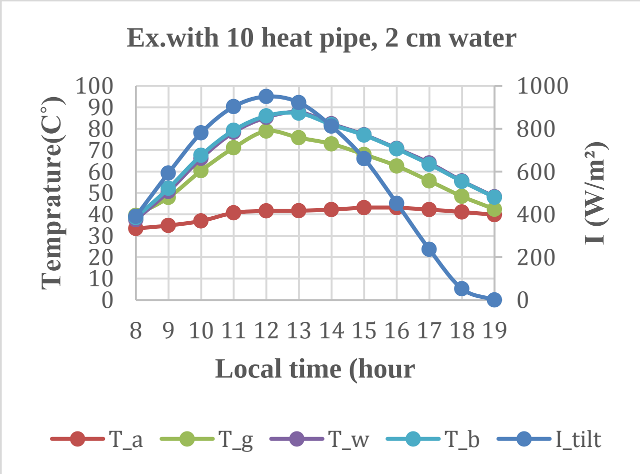

Figure 16. The average experimental variation of temperatures with time for solar still with 10 heat pipe from 8 AM to 7 PM (Aug.-2016).

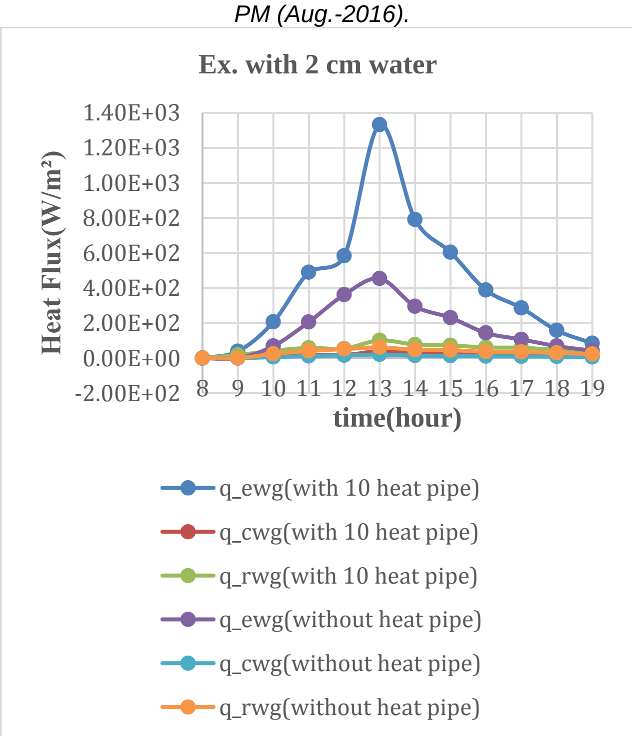

Figure 17. Average hourly variation of heat flux with time for certain days from 8AM to7PM (Aug-2016).

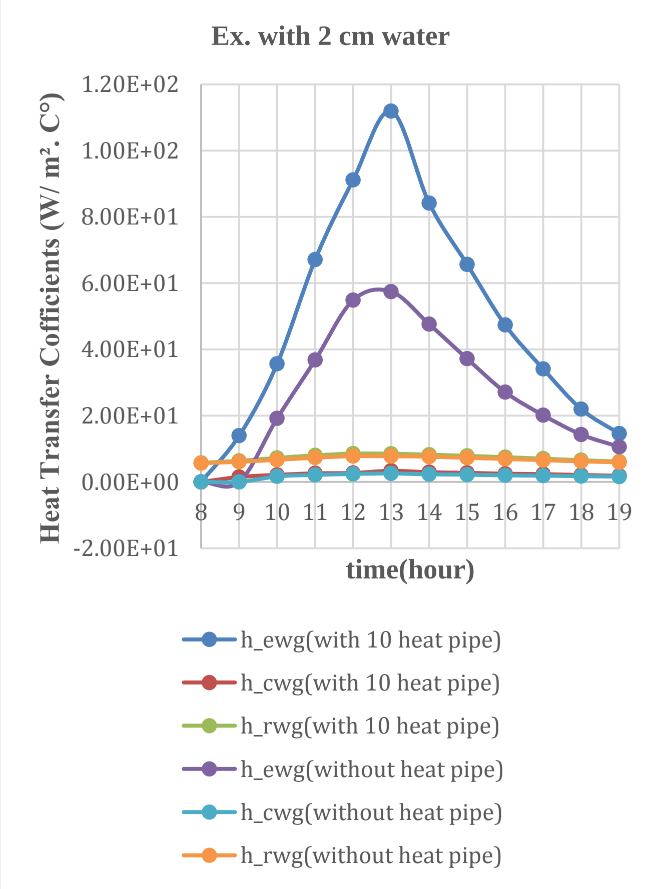

Figure 18. Average hourly variation of heat transfer coefficients with time for certain days from 8AM to7PM (Aug-2016).

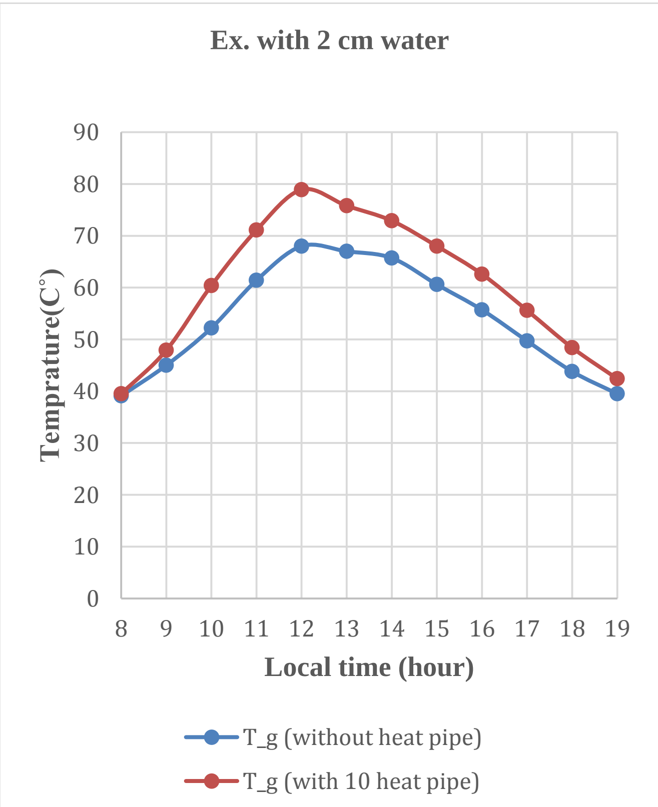

Figure 19. Comparison of average experimental variation of temperatures with time for glass with & without 10 evacuated tube heat pipe from 8 AM to 7 PM (Aug.-2016).

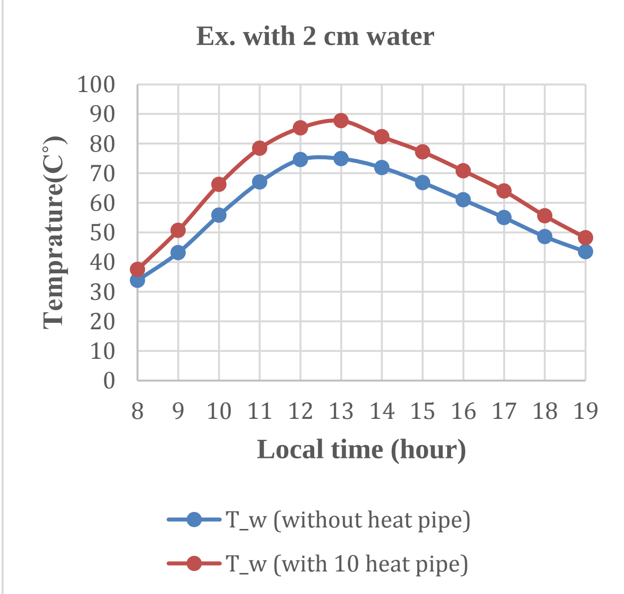

Figure 20. Comparison of average experimental variation of temperatures with time for water with & without 10 evacuated tube heat pipe from 8 AM to 7 PM (Aug.-2016).

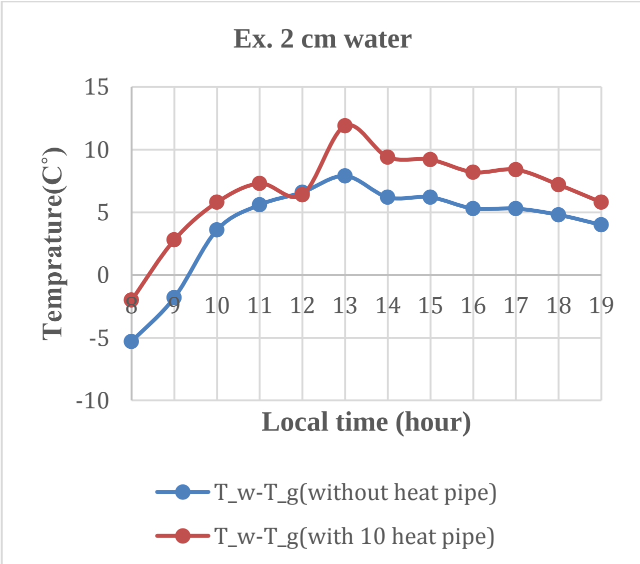

Figure 21. Comparison of the difference temperatures ($T_w - T_g$) with time for solar still with and without evacuate tube heat pipe from 8 AM to 7 PM (Aug.-2016).

V. CONCLUSIONS

From the present work the following conclusions can be extracted:

1. The most amount of exergy in solar still is destructing in the basin of solar still, thus effort must take to reduce this destruction by good design of the solar still basin and glass cover.
2. Using the new technique of evacuated tube heat pipe is the best method to enhance the still performance. The productivity enhancement of single basin solar still was found (102.66 %) for sunny weather for still with evacuated tube heat pipe as compared with still without evacuated tube heat pipe.

3. The solar distillation is a good, easy and economic method for enhancement the quality of saline water and keep it within the acceptable range of drinking water.
4. The solar still consist of single basin, single slope with evacuated tube heat pipe is a good method for save a drinking water for rural communities in Baghdad where brackish and contaminated water is found as marshes, because of a good weather conditions over there (high solar radiation, high ambient temperature, long duration of sunshine and plenty of sunny days during the year) and for economic advantage.

References

[1] Hazim M. Qiblawey and Fawzi Banat," Solar thermal desalination technologies", Desalination 220 (2008) 633–644.

[2] Foster,Ghassemi and Cota," Solar Energy (Renewable Energy and the Environment)", International Standard Book Number: 978-1-4200-7566-3,2010.

[3] Tiwari G.N. Solar Energy. Fundamentals, Design, Modeling and Applications. – New Dehli: Alpha Science International Ltd, 2006. – p. 525.

[4] Weiss W., Themessl A. Training Course – Solar Water Heating. Latvia – Baltic States. –Helsinki: Solpros AY, 1996. – p. 55.

[5] Hitesh N. Panchal, Mitesh I. Patel, Bakul Patel, Ranvirgiri Goswami & Manish Doshi," A comparative analysis of single slope solar still coupled with plate collector and passive solar still", IJRRAS 7 (2), May 2011. [3]H. S. Wang and J. W. Rose, "Theory of heat transfer during condensation in microchannels," *Int. J. Heat Mass Transf.*, vol. 54, no. 11–12, pp. 2525–2534, May 2011.

[6] Abdul Jabbar N. Khalifa, " On The Effect of Cover Tilt Angle of The Simple Solar Still On Its Productivity In Different Seasons And Latitudes", Energy Conversion And Management 52 (2011) 431–436.

[7] Hitesh N Panchal, Dr. P. K. Shah," Effect of Varying Glass cover thickness on Performance of Solar still: in a Winter Climate Conditions", International Journal Of Renewable Energy Research, IJRER H.N.Panchal, PK.Shah, Vol.1, No.4, pp.212-223 ,2011.

[8] T.R.Teltumbade and P.V.Walke ," Experimental Evaluation Of A Single-basin Solar Still Using Different Absorbing Materials: An Overview", International Journal of Engineering Science and Technology (IJEST) Vol. 3 No. 4 Apr 2011.

[9] Ragh V. Singh, Rahul Dev, M. M. Hasan, G. N. Tiwari," Comparative Energy and Exergy Analysis of Various Passive Solar Distillation Systems",world renewable energy congress 2011-Sweden 8-13 May 2011.

[10] Abdul Jabbar N. Khalifa, Ahmad M. Hamood, "On the verification of the effect of water depth on the performance of basin type solar stills", Solar Energy 83 (2009) 1312–1321.

[11] Shobha.B.S ,Vilas Watwen ,Rajesh .A.M," Performance Evaluation of A Solar Still Coupled to an Evacuated Tube Collector type Solar Water Heater", (IJIET), Vol. 1 Issue 1 June 2012.

[12] Raed F. Abdul Lateef," Performance evaluation of solar desalination under Baghdad climatic conditions", M.Sc. thesis, collage of engineering-university of Baghdad,2012.

[13] Rajesh. A.M, Bharath.K.N," Solar Still Coupled With Solar Collector and Storage Tank", InterJRI Science and Technology, Vol. 1, Issue 2, July 2009.

[14] B. A. Akash, M. S. Mohsen, O. Osta and Y. Elayan, "Experimental Evaluation of a Single-Basin Solar Still Under Different Absorbing Materials", Renewable Energy, Vol. 14, Nos, 1-4, pp. 307-310,1998.

[15] A. N. Khalifa and A. M. Hamood, " Effect of Insulation Thickness On the Productivity of Basin Type Solar Stills: An Experimental Verification Under Local Climate", Energy Conversion and Management 50 (2009) 2457–2461.

[16] C. Tenthani, A. Madhlopa1 and C.Z. Kimambo," Improved Solar Still for Water Purification", Journal of Sustainable Energy & Environment 3 (2012) 111-113 Copyright.

[17] Pankaj K. Srivastava, S. K. Agrawal," Experimental Investigation of some Design and Operating Parameters of Basin Type Solar Still", International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, Volume 2, Issue 5, May 2012).

[18] K.R. Ranjan1,2*, S.C. Kaushik1 and N.L. Panwar," Energy and exergy analysis of passive solar distillation systems ", International Journal of Low-Carbon Technologies, 11, 211–221, 2016.

[19] Mark G. Lawrence,"The relationship between relative humidity and the dew point temperature in moist air", junior research group, February 2005-BAMS 225-233.

[20] S.D. Sharma and Kazunobu Sagara," Latent Heat Storage materials and systems: a review", International Journal of Green Energy, 2: 1–56, 2005.

[21] A.E. Kabeela, Mofreh H. Hamedb, Z.M. Omara," Augmentation of the basin type solar still using photovoltaic powered turbulence system", Desalination and Water Treatment, 48 (2012) 182–190October.