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The Performance of Solar Still Using Heating Pipe Evacuated Tubes at Basrah climate

Ahmed Sh. Sadiq and Ala'a A. Jassim

Department of chemical engineering, Basrah University Basrah – Iraq

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Abstract: The performance of active double slope solar still using heating pipe evacuated tube was studied theoretically and compared with the experimental result relative to Basrah climate. These tests were extended for the period of January to August 2013; a computer program was used to calculate the water productivity and other parameters such as heat transfer coefficient and heat flux of the system theoretically then compared with the experimental results relative to local Basrah climate. The results showed the water productivity has increased with the increasing of solar intensity and wind velocity. On1st July 2013, the water productivity of the solar still system with evacuated tubes has about 11.23 kg for the period between 800: AM to 17:00 PM. The values results of system with evacuated tubes have compared with the conversional solar system. The results show the value of water productivity has increased about 43.5%.

Keywords: desalination, solar still basin, heating pipe evacuated tube.

1. INTRODUCTION

It is very important to find new, cheap, clean and simple methods for producing the drinkable water. The nature of live and population growth makes the rate of water consumption is be very high also, the operating cost of the conventional methods of desalination process are very expensive and unfriendly relative to environment. So it is very important to find and apply another method such as solar desalination systems.

Solar desalination system has the advantage of cost saving over other types of distillation because solar energy is limitless and easily available and likewise seawater is readily available[1] Solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate[2].the system consists of a basin, in which a constant amount of raw water is enclosed in a v-shaped glass envelope. Sunlight heats the water in the basin. This heated water evaporates and recompenses on the underside of the sloping transparent cover and runs down into collecting through along the inside lower edges of the transparent cover[3].The basin is covered with a thin black plastic film, like black gravel and insulated against the heat losses Heating pipe evacuated tube is one of the clean and modern methods for the exploitation of solar energy for water heating in homes and residential buildings, it can work in different weather factors, it heated the water quickly even on cold day

Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass with high chemical and thermal shock resistance. The outer tube is transparent allowing light rays to pass through with minimal reflection. The outer side of the inner tube is coated with a sputtered solar selective coating (Al-N/Al or AlN/AlN-SS/Cu) which features excellent solar radiation absorption and minimal reflection properties[4]. The ends of the tubes connected to the copper header are fused together and a vacuum is created between them. This process is called as evacuation, as by definition, it means that the air is pumped out from the cavity. The vacuum is created to recreate the thermos flask effect as vacuum acts as an insulator and does not allow short wave radiation to escape through the glass tube[5]

The material of heat pipe from copper, the advantage of heat pipe to transfer the heat to the manifold the copper heat pipe is hollow and contains a small amount of fluid The hollow center of the heat pipe is a vacuum so that even at low temperature .The fluid will vaporize the vapor rises to the tip (condenser) of the heat pipe where the heat is transferred to the water flowing through the manifold.

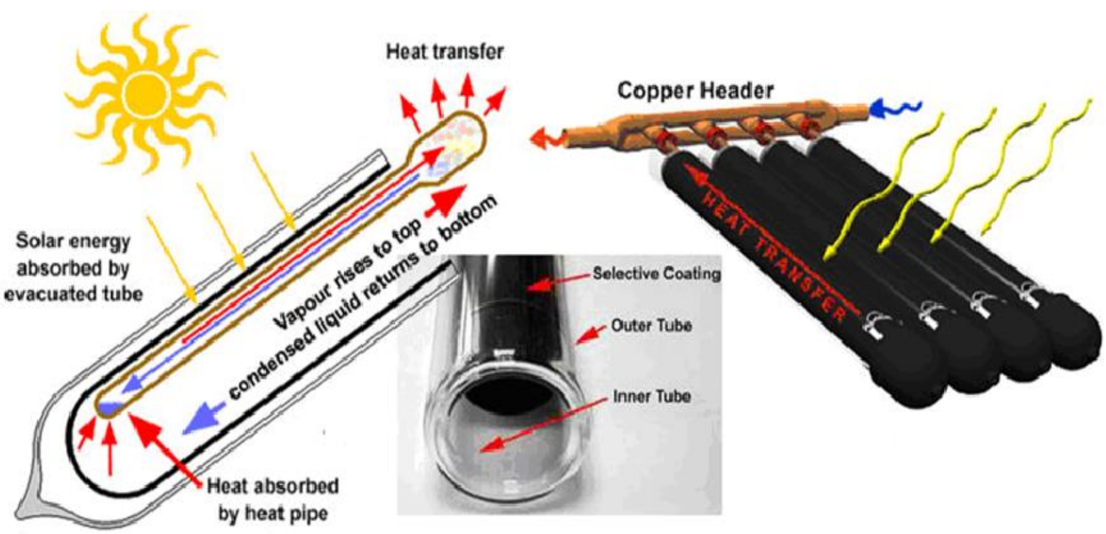

Figure 1: Heating pipe evacuated tube[5]

2.EXPERIMENTAL WORK

The work was conducted on the small rig solar desalination unit in different days and different weathers. The values of the different temperatures and solar intensity and wind velocity are measured by various gauge and props. This measurement is used to calculate the productivity. Its double slope solar still used to intercept the maximum insolation the still was oriented toward the sun so as to ensure the arrival of the largest solar energy. A frame was fixed at the middle of the using which the glass covers on either side. The area of basin was $1m^2$(1 length, 1m width). The distillate channel was provided at each side of the basin for the collection of distillate output. A hole was drilled in each of the side. Fiberglass was fixed all along of the edges of the still. The saline water feed from one side of this fiberglass. The glass panes of 3 mm thickness were used as covers for the still, and it's a hole in the middle of the basin use it to clean the still basin from mud and salts accumulated. It's a 8 of heating pipe evacuated tube are used in the present work.

Figure 2: shows the total system of solar desalination

In fact the interest of this tube to increase the vapour in the system leading that to increase productivity. Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass; the ends of the tubes connected to the copper header are fused together. On the internal surface of the inner borosilicate glass tube there is a black absorber plate .The heat is collect in the head of the copper pipe which it contact with the manifold. The length of this tube is 180cm, the diameter is 18 cm and the length of the copper pipe is 130 cm the end bottom of the evacuated tube contain a predictive cap from the silicone rubber.

The manifold is contact the still basin and the head of pipes copper of the evacuated tubes makes the system as a circle the saline water flow from the still to the manifold as a liquid and comeback to the still basin as the vapour by helping evacuated tube. The pipe of the manifold from the copper and it's containing 8 holes to the heads of copper pipes of evacuated tube.

A various types of props, gauges and measuring instrument have used such as A Solar Power Meter Digital to measure solar intensity , An anemometer to measure wind velocity and thermocouple which is a sensor used to measure temperatures.

3.THEORETICAL ANALYSIS

In the present work, the mathematical models of solar basin developed by previous researches [1, 6, 7, and 8] are applied and tested the experimental results of desalination by solar still relative to Basrah climate after modification. The mathematical models with the results of experimental rig is modified by connection heating pipes evacuated tubes in the solar system then the productivity is measured and recorded relative to Basrah climate.

To simplify the analysis, the following assumptions are made:

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

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

3-Performance is steady state.

4-The heat capacity of the glass cover, the absorbing material and the Insulation (bottom and sides) are negligible**.** The energy balance for loss cover can be calculated

$$\alpha_g I(t) + [qrw + qcw + qew] = [qrg + qcg] \quad (1)$$

And the energy balance for basin bottom plate (basin liner) can be calculated from:

$$\alpha_b I(t) = qb + [qbg + qs(A_s/Ass)] \quad (2)$$

Also The energy balance for water mass can be calculated from:

$$\alpha_w I(t) + qb = (MC)_w \left(\frac{dTw}{dt}\right) + [qrw + qcw + qew] \quad (3)$$

3.1.Top loss coefficient: The external radiation and convection losses from the glass cover to out atmosphere can be expressed. The total heat loss from glass to ambient can be calculated from:

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

The radiative heat loss from glass to ambient is

$$q_{rg} = h_{rg}\,(Tg\text{-}Ta) \qquad (5)$$

$$h_{rg} = \frac{\varepsilon\sigma(Tg^4 - Tsky^4)}{(Tg - Ta)} \qquad (6)$$

The sky temperature can be calculated

$$T_{sky} = Ta - 6 \qquad (7)$$

The convective heat loss from glass to ambient can be calculated:

$$q_{cg} = h_{cg}\,(Tg - Ta) \qquad (8)$$

$$h_{cg} = 2.8 + 3.0v \qquad (9)$$

By substituting equations (5) and (8) into equation (4) gives

$$q_g = h_{rg} + h_{cg}(Tg\text{-}Ta) = h_g(Tg\text{-}Ta) \qquad (10)$$

Where h_g is the convection and radiation heat transfer coefficient from glass to the air

$$h_g = h_{rg} + h_{cg} \qquad (11)$$

3.2. 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. The bottom loss coefficient (U_b) can be written as

$$Ub = \frac{1}{\left(\frac{1}{hw} + \frac{1}{\frac{Ki}{Li}} + \frac{1}{hcb+hrb}\right)} \qquad (12)$$

Where Ki and Li are the thermal conductivity of air and the insulation thickness respectively ,The side heat loss coefficient can be approximated as:

The rate of heat loss per m^2 from the basin liner to ambient can be written as;

$$q_b = h_b\,(Tb - Ta) \qquad (13)$$

$$h_b = \left[\frac{Li}{Ki} + \frac{1}{hcb+hrb}\right] \qquad (14)$$

3.3. Internal Heat Transfer.

3.3.1. Radiation loss coefficient: The rate of radiative heat transfer, *qrw* from the water surface to the glass cover:

$$qrw=hrw\,(Tw-Tg)=\varepsilon\sigma(Tw^4-Tg^4) \qquad (15)$$

$$hrw=\mathcal{E}_{eff}\,\sigma[(Tw^2+Tg^2)(Tw+Tg+546)] \qquad (16)$$

ε_{eff} is the effective emittance between the water surface and the glass Cover, it can be described by the following equation

$$\varepsilon_{eff}=\frac{1}{\frac{1}{\varepsilon w}+\frac{1}{\varepsilon g}-1} \qquad (17)$$

3.3.2. Convective loss coefficient: Heat transfer occurs across humid area in the distillation unit by free convection, which is caused by the effect of buoyancy, due to density variation in the humid fluid,

which occurs due to the Temperature gradient in the fluid [11].The rate of heat transfer from the water surface to the glass cover, *qcw* by convection is the upward direction through the humid fluid and can be estimated

$$qcw=hcw(Tw-Tg) \qquad (18)$$

$$hcw=o.884[Tw-Tg+\frac{(Pw-Pg)(Tw+273)}{268.9*1o3-Pw}]^{0.333334} \qquad (19)$$

Where; Pw and Pg are the saturation partial pressures of water at water temperature and glass temperature, respectively

$$Pg=e^{(25.327-\frac{5144}{Tg+273})} \qquad (20)$$

$$Pw=e^{(25.327-\frac{5144}{Tw+273})} \qquad (21)$$

3.3.3. 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

$$q_{ew}=h_{ew}[Tw-Tg] \qquad (22)$$

$$h_{ew}=16.273*10^{-3}\,h_{cw}\,\frac{Pw-Pg}{Tw-Tg} \qquad (23)$$

$$q_{ev}=m_l\,cp_l\,(Tin-Tout) \qquad (24)$$

To calculate the hourly productivity of the total system is

$$Mw= \frac{qew+qev}{L} *3600 \quad (25)$$

$$Mw=\frac{[hew(Tw-Tg)]+[ml* cpl\ (Tin-Tout)]}{L}*3600 \quad (26)$$

Where L is latent heat, the thermal efficiency of the total system can be calculated:

$$\eta= \frac{\sum Mw*L}{\sum (I*Ac*3600)+(I*As*3600)} *100 \quad (27)$$

4. RESULT AND DISCUSSION

The experimental rig was used for investigating the effect of operating parameters Such as solar intensity, air velocity and air, glass and water temperatures on the performance of sola still with evacuated tube. The experimental results of water productivity for the period between 8:00 AM to 17:00 PM on 1st July

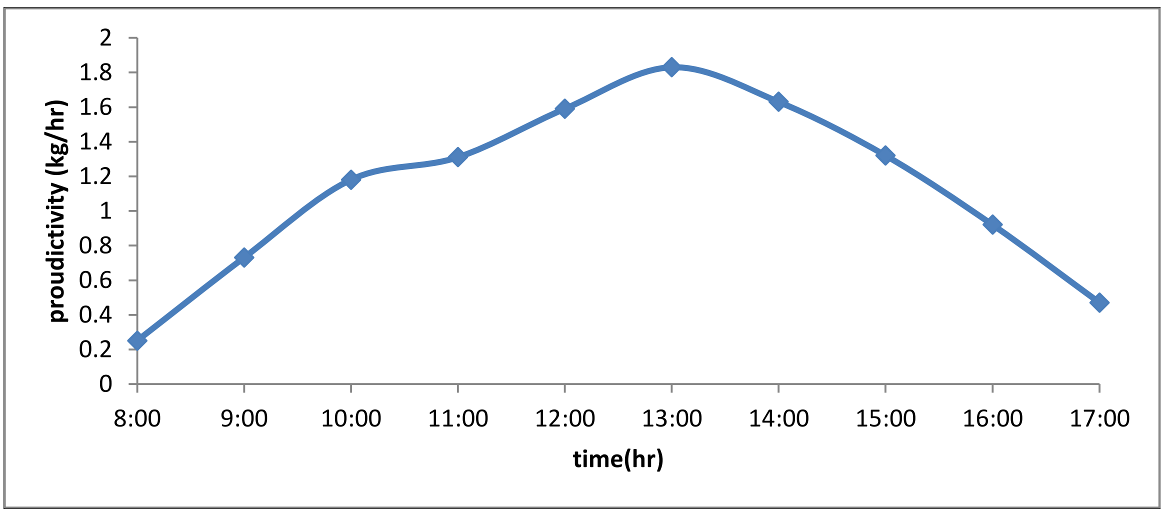

Figure 3: Shows the productivity as a function of time on 1st July 2013

The results show the productivity of solar still with evacuated tube is about 11.23 kg for the period between 8:00 AM to 17:00PM. The production rate of still has increased gradually for the period between 8:00 AM to 13:00 then decreased during the next period 13:00 PM to 17:00 PM due to the reduction of solar intensity.

The difference between experimental and theoretical results due to fluctuations of hourly climate parameters such as the solar intensity and the air velocity. However the degree of agreement between theoretical and experimental results is about 90%

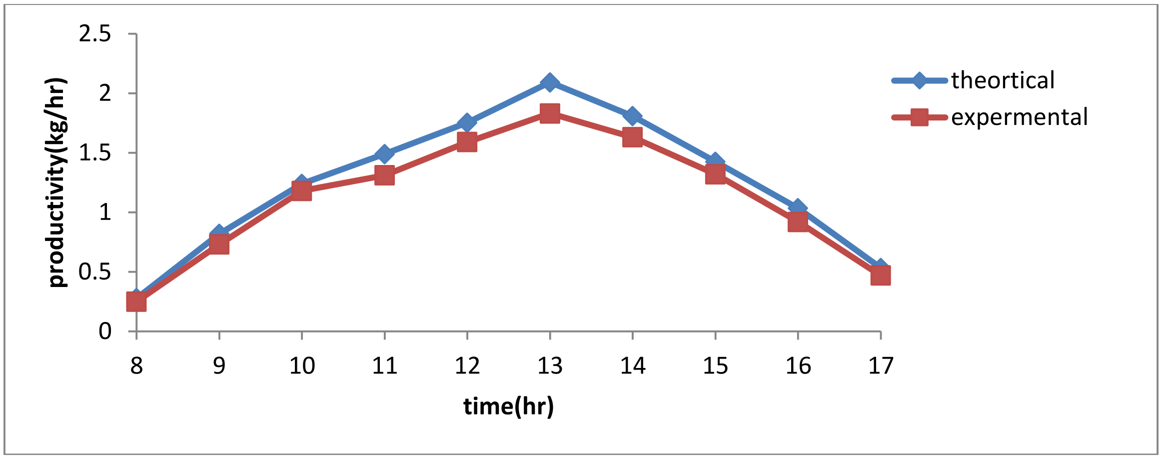

Figure 4: shows the comparison between theoretical and experimental results of water productivity on1st July 2013

For investigating the effect of solar intensity on the water productivity of solar still it has recorded by using solar intensity meter for the period between 8:00AM and 17:00 PM on 1st July 2013 the values of solar still productivity have measured and presented as shown in table (1) The results show that an increasing in the rate of water productivity during the early hours of the day until it reached a maximum value at mid noon due to higher solar radiation is contributed to increase the amount of water vaporization After this time, the rate of water production is decreased with time due to the reductions of solar intensity and ambient temperature.

Table-1: shows the solar intensity and water productivity as a function of time on1st July 2013

Time (hr)	Solar intensity(w/m^2)	Productivity (kg/hr)
8:00 AM	279	0.25
9:00 AM	519	0.73
10:00 AM	917	1.18
11:00 AM	1186	1.31
12:00 PM	1205	1.59
13:00 PM	1237	1.83
14:00 PM	1210	1.63
15:00 PM	1033	1.32
16:00 PM	758	0.92
17:00 PM	405	0.47

The variation of air velocity is contributed to change the rate of water production , air velocity is contributes to dispersed the solar intensity make that to decrease the air and glass temperature so ,the rate of vapor condensation inside the solar still has increased and reaches the maximum value at 13:00 PM .

Table-2: shows the air velocity and water productivity as a function of time on1st July 2013

Time (hr)	Air velocity(m/s)	Productivity (kg/hr)
8:00 AM	0.5	0.25
9:00 AM	0.72	0.73
10:00 AM	0.7	1.18
11:00 AM	1.27	1.31
12:00 PM	2.5	1.59
13:00 PM	2.75	1.83
14:00 PM	2	1.63
15:00 PM	1.55	1.32
16:00 PM	0.79	0.92
17:00 PM	0.55	0.47

Figure 5 shows the temperatures profile of air (T_a), glass (T_g), water (T_w), and the outlet water temperature of collector (T_{outc}). The black basin is absorbed the solar intensity makes the temperature of water is higher than the temperature of glass. Also, the increase of the air temperature is contributed to increase the temperature of glass .The decrease of the glass temperature is participated to increase the rate of water condensation inside the solar still. The large difference between the Tw and Tg is made the evaporative heat transfer (q evaporation) as high as Possible, leads that to the increase of water productivity **.**The temperature of water in the solar still has the same value of temperature enters to the collector so, the evacuated tubes make the outlet water temperature from the collector as high as possible, more than 100C.This increasing in the outlet water temperature of collector has contributed to increase the rate of evaporation in the still basin**.**

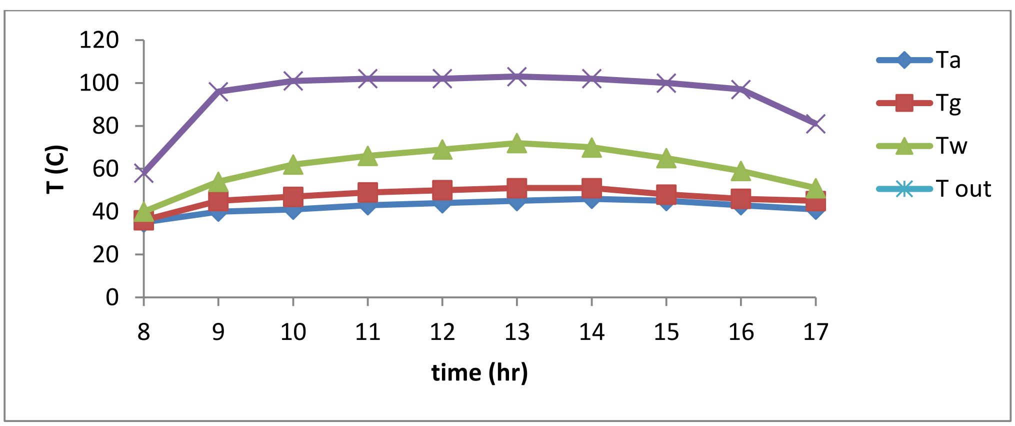

Figure 5 Shows the temperatures profile on 1st July 2013.

The effect of evacuated tubes on the amount of water productivity has described and discussed .The results have calculated for both solar still, with and without evacuated tubes.

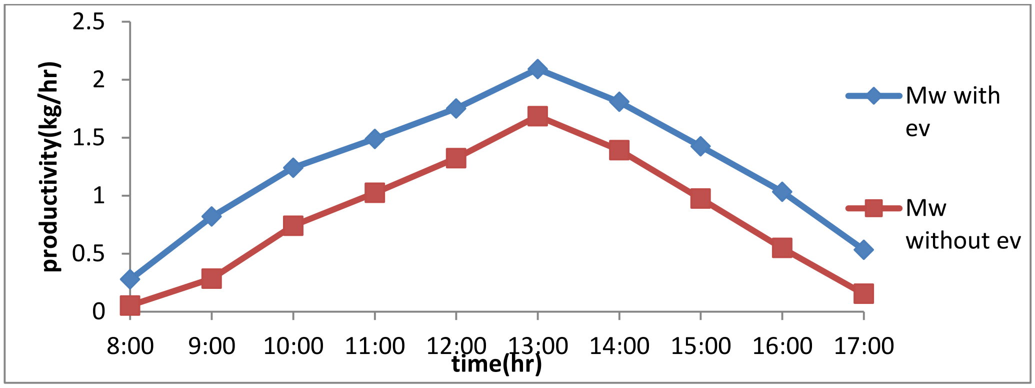

Figure 6: Shows the productivity for the system with and without evacuated tubes

It is very to see the performance of solar still with evacuated tubes is larger than the conversional system without evacuated tube, this is due to the effect of the heat transfer of water through evacuated tubes.

The percentage of increasing in the solar productivity due to the using of evacuated tubes is 43.5 % Figure (7) shows the hourly water productivity for 7 months. These measurements have record for the period between 9:00AM and 14:00PM at 10th day in every month. The results show the maximum productivity was about 8.41 kg in July while the minimum water productivity was about 2.53 in January. The maximum water productivity was about 1.9kg /hr at 13:00AM in July.

Also table (3) shows the total water productivity recording for the period between 9:00AM and 14:00PM on 10th day in every month.

Table-3: The productivity (kg) from 8.00 AM to 14:00 PM

day	10th Jan	10th Feb	10th Ma	10th Apr	9th May	10th Jun	10th Jul
productivity	2.53	4.35	4.73	5.33	6.16	7.45	8.41

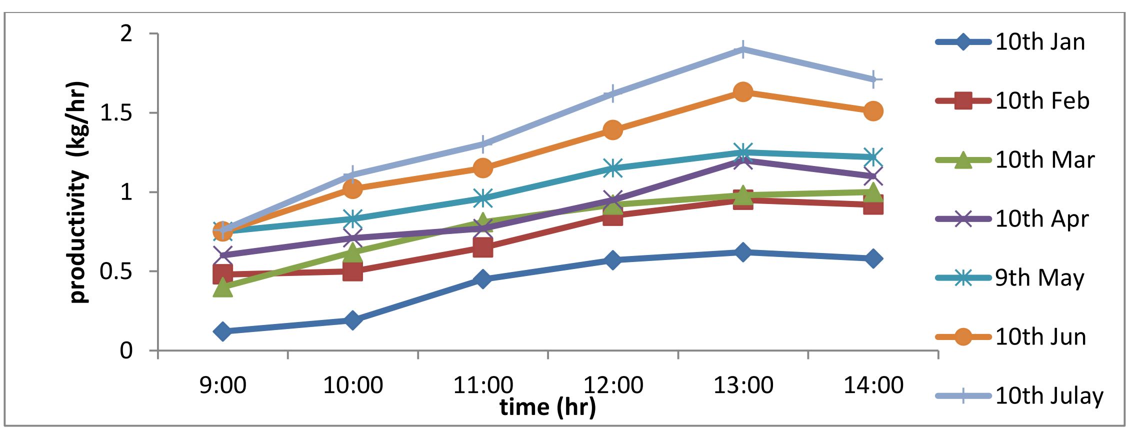

Figure 7 shows the water he productivity on the 10th day iv every month

5. CONCLUTION

- The ability of using the solar still with evacuated tubes especially in the regions suffering from water scarcity. The nature of weather in Basrah city is supported the ability of using the solar still with acceptable rate of productivity especially during the crises or emergency periods.
- The mathematical model prediction of productivity of solar still with evacuated tubes has given a high accuracy relative to the experimental results. The degree of agreement is 90%
- The water productivity of solar still system with evacuated tubes on1st July 2013 is about 11.23 kg for the period between 800: AM to 17:00PM
- he relation between water productivity and solar intensity and air velocity is proportional
- The maximum productivity was at 13:00PM, while the minimum productivity was at 8:00AM.
- The productivity is increased at July month comparing with others months due to the increase of solar intensity and ambient temperature.
- The productivity is increased when using heating pipe evacuated tubes about 43.5% compared without using heating pipe evacuated tubes.

Symbols	Description	Unit
A_c	Area of the collector	m^2
A_s	Area of basin still	m^2
A_{ss}	Area of solar still sides	m^2
Cp_l	Specific heat capacity of water	$J.kg^{-1}.c^{-1}$
h_{cb}	Convective heat transfer coefficient from basin	$W.m^{-2}.c^{-1}$
h_{cg}	Convective heat transfer coefficient from glass	$W.m^{-2}.c^{-1}$
h_{cw}	Convective heat transfer coefficient from water	$W.m^{-2}.c^{-1}$
h_{ew}	Evaporative heat transfer coefficient from water	$W.m^{-2}.c^{-1}$
h_{rb}	Radiative heat transfer coefficient from basin	$W.m^{-2}.c^{-1}$
h_{rg}	Radiative heat transfer coefficient from glass	$W.m^{-2}.c^{-1}$
h_{rw}	Radiative heat transfer coefficient from water	$W.m^{-2}.c^{-1}$
h_{tg}	Total heat transfer coefficient from glass	$W.m^{-2}.c^{-1}$
h_{tw}	Total heat transfer coefficient from water	$W.m^{-2}.c^{-1}$
I	Solar intensity	$W.m^{-2}$

K_i	Thermal Conductivity of air	$W.m^{-1}.c^{-1}$
L	latent heat of evaporation	$J.kg^{-1}$
L_i	Insulated thickness	m
m_l	Mass flow rate of water transfer in the collector	$kg.sec^{-1}$
Mw	Hourly yield	$kg.hr^{-1}$
$(Mw)_{exp}$	Experimental hourly yield	$kg.hr^{-1}$
P_g	partial vapour pressure at glass temperature	$N.m^{-2}$
P_w	partial vapour pressure at water temperature	$N.m^{-2}$
q_b	Heat flux to basin	$W.m^{-2}$
q_{bg}	Heat loss from basin to insulation material	$W.m^{-2}$
q_{cg}	Convective heat loss from cover to ambient	$W.m^{-2}$
q_{cw}	Convective heat transfer from water	$W.m^{-2}$
q_{ev}	heat transfer of water through the evacuated tube	W
q_{ew}	Evaporative heat transfer	$W.m^{-2}$
q_g	Heat flux to glass	$W.m^{-2}$
q_{rg}	Radiative heat loss from cover to ambient	$W.m^{-2}$
q_{rw}	Radiative heat transfer from water	$W.m^{-2}$
q_s	Side heat loss to ambient by conduction	$W.m^{-2}$
t	Time	hr
T_a	air Temperature	℃
T_g	glass Temperature	℃
T_w	water Temperature	℃
T_{inc}	Inlet temperature of the collector	℃
T_{outc}	Outlet temperature of the collector	℃
T_{sky}	sky temperature	℃
U_b	Total bottom heat transfer coefficient	$W.m^{-2}.c^{-1}$
V	air velocity	$m.sec^{-1}$

Greek Symbols	Description
α_b	Absorption coefficient of the basin
α_g	Absorption coefficient of the glass
α_w	Absorption coefficient of the water
ε_{eff}	Effective emissivity
ε_g	The emissivity of glass
ε_W	The emissivity of water
η	Thermal efficiency
σ	Stefan-Boltzman's constant (= $5.6697*10^{-8}$)

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Corresponding author: Ahmed Sh. sadiq ;

Department of chemical engineering, Basrah University Basrah – Iraq

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