Experimental Study of the Effect of Reflection Mirrors Orientation on the Performance of Solar Still

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Abstract

The present experimental work is a study of solar still with reflected mirrors. The solar radiation was calculated mathematically for angles ranging from 9o to 30o with 15o increment for reflected mirrors and from 0-45o with 5o increment for glass cover. Experimental analysis showed that the best angle that intercept the maximum amount for solar radiation at the angle 85o for reflected mirrors at the south-north orientation of solar still which indicates that as the slop of mirrors increase the average solar radiation decreases. Also the glass cover is inclined about 40o. The study included the experimented test for the angle which may not permit the condensate to drip back into the basin. It was found to be 11^o.

Keywords: Solar energy, Reflected mirrors, Solar still, Performance, Efficiency

الخلاصة

العمل التجريبي اجري على مقطر شمسي باستخدام المرايا العاكسة. الاشعاع الشمسي تم حسابة رياضيا بزوايا من 9 الى 30 درجة مع زاوية ميل 15 درجة للمرايا العاكسة ومن 0 الى 45 درجة وبزاوية ميل 5 درجة للغطاء الزجاجي. تحليل التجارب اظهرت ان افضل زاوية للحصول على اكبر اشعاع شمسي عند زاوية 85 درجة للمرايا العاكسة عند اتجاة محور الجنوب الشمالي للمقطر الشمسي التي تشير الى ان زيادة ميل المرايا يقلل معدل الاشعاع الشمسي . الدراسة تظمنت اختبار تجربة للزاوية التي لا تسمح بتتكثيف القطرات في الحوض. وقد حددت ب 11 درجة .

Introduction

Solar distillation has been used for many years, usually for comparatively small plant outputs. Over the years, substantial research has been carried out to find out ways into improving the efficiency of the process. Research work has been carried out in many parts of the world. Solar distillation uses, in common with all distillation processes, the evaporation and condensation modes, but unlike other processes energy consumption is not a recurrent cost but is incorporated in the capital cost of the solar collector. The solar still therefore, is of a simple design, construction and maintenance with ease of operation. It is best suitable for regions of the world with high solar intensities. The mechanism of operation is based on the transmitting, absorption and reflective properties of glass and other transparent materials. The glass has the property of transmitting incident short-wave solar radiation which passes through the glass, the glass being a medium of transfer of heat, into the still to heat the brine.

The purpose from using the reflected mirrors is to improve the performance of solar still. Solar radiation enters the still through the glass cover and is converted to thermal energy at the water basin. This heat is transferred to the water which evaporates. The vapor produced rises and condenses on the underside of the glass cover. The fresh water flows along the glass surface by gravity into troughs. There are many designs for solar stills. 95 percent of functioning solar stills are of the basin type solar still. The performance of basin still depends on the basin, transparent glazing cover, evaporation surface, insulation material and climatic condition. A lot of researcher works on design, fabrication methods, and testing and performance evaluation etc. of solar distillations have been carried out various researchers throughout the world since ancient time. The research works in passive solar stills were carried out by Cipollina et.al. [1] and in this case the water in the basin is directly heated by solar energy. Satcumanathan and Hansen [2] showed that the effect of the cover slope is more pronounced for a small gap distance between the water surface and the cover than for a large distance. Also, reducing the gap distance between the evaporating surfaces and condensing surface improves the still performance. H.Hinai et.al.[3] reported that the shallow water basin, 230 cover tilt angle , 0.1 m insulation thickness and asphalt coating of solar still were found to be the optimum design parameters of simple solar still that produce an average annual solar still yield of 4.15 kg/m2.day. Abdul Jabbar et.al. [4] developed a concluding correlation from all brine depth data the correlation showed a decreasing trend in the productivity with the increasing in brine depth and showed that the still productivity could be influenced by the brine depth by up to 48 %. Salah Abdullah et.al.[5] modified conventional solar still, it involves the installation of reflecting mirror on all sides, replacing the flat basin by a step-wise basin, and coupling the conventional solar still with a sun tracking system it improves the system thermal performance up to 30 %, 180 %, 380 % respectively.S. Nijmeh et.al.[6] , Bilal A.Akash et.al. [7] Studied the effect of different absorbing material in a solar still and shows that the productivity of distilled water was enhanced for some materials. M. El-sayed et al. [8] showed that the productivity of solar still reaches its maximum value at an optimum cover slope. An average slope of 20^o to 25^o from the horizontal shows satisfactory results for a wide range of wide range of stills .Abdulrahman Ghoneyem [9] were designed, constructed and tested four single effect basin type solar still, three still had a glass cover of different thickness 3, 5, 6 mm and fourth cover plastic reported that the thinnest glass cover had shown the highest production rates up by 15.5 %.. Abdul Jabbar N. et.al. [10] In his study the effect of insulation on the production of a basin type solar still is verified. Solar still with insulation thickness of 30, 60,& 100 mm are investigated and the result are compared with those obtained for a still without insulation and found that the insulation thickness could influence the productivity of the still by 80 %.. Mohammed Farid, Faik Hamad [11] fabricated the solar still from galvanized steel sheet, found that the efficiency of the still to be independent of solar radiation. An increase in still productivity was observed with the increase in ambient temperature and decrease in wind velocity. Singh et al. [12] showed that east-west orientation of a double slope solar still gives the maximum productivity for a glass cover inclination at around 55^o at Delhi, India. Trist at al. [13] made experimental measurements to determine condition necessary for efficient solar desalination. The effects on performance of using various different absorber materials in basin type solar still are investigated. Jadhav Madhav

V. [14] studies the effect of using two different basin materials in solar still and thus enhances the productivity of water, the experimental results show that the productivity of distilled water was enhanced for black granite basin solar still as compared to iron steel basin solar still.

The present investigation is intended to provide further theoretical and experimental evidence on the reflection mirrors orientation with different tilt angles.

The experimental work is carried out in Energy and Fuel Research Center, Technology University, Baghdad .Figure 1.

Mathematical Models

The theoretical mathematical model includes for the solar still prediction of the still performance basically developed by Dunkle [15]. Figure 3 shows the heat fluxes in the solar still, the figure 3 indicates the direction of the heat flows which can be used as the basis for the heat balance equations, as follows:

Heat balance on the glass cover with reflection mirrors:

$$Q_g = \alpha_g I + Q_c + Q_r + Q_e \qquad (1)$$

Heat balance in the water basin:

$$\alpha_g \tau_g I = C_s(\frac{dT_w}{dt}) + Q_b + Q_c + Q_r + Q_e + Q_f \qquad (2)$$

Heat balance on the entire still:

$$\alpha_g I + \alpha_w \tau_g I = C_s(\frac{dT_w}{dt}) + Q_b + Q_r + Q_g \qquad (3)$$

The appropriate thermal coefficients [15] used were $\alpha_W = 0.90$ $\alpha_g = 0.94$ $\tau_g = 0.90$ $C_s = 174.44$

The solution of these equations can be achieved by numerical solutions. Heat quantities in the above equations can be calculated from the heat transfer principles [15], as follows:

The heat transmitted by evaporation (Q_e), [15] is given by:

$$Q_e = 0.0061[(T_W - T_g) + T_W(P_W - P_g)/(0.265 - P_W)]^{1/3}(P_w - P_g)L_W \qquad (4)$$

Where L_W is calculated [15]

$$L_w = 316.10^3 - 2407.4T_W \qquad (5)$$

The heat transmitted by convection (Q_c), [15] is given by:

$$Q_c = 0.883\left[(T_w - T_g) + \frac{T_w(P_w - P_g)}{0.265 - P_W}\right]^{1/3}.(T_W - T_g) \qquad (6)$$

Where P_w is calculated [16]

$$P_W = Exp\left[25.3 - 5144T_W^{-1}\right]/10^6 \qquad (7)$$

The heat transmitted by radiation (Q_r), is determined from the following equation as follows [16]:

$$Q_r = 0.9\sigma[T_W^{\ 4} - T_g^{\ 4}] \qquad (8)$$

Heat lost from glass cover to ambient (Q_g), is given by:

$$Q_g = Q_c + Q_r \qquad (9)$$

Where Q_c ، Q_r are the external convection and radiative modes, expressed as[17]:

$$Q_r = F_{g\,sky} = 0.055(T_a)^{1.5} \qquad (10)$$

And $F_{g\,sky}$ is the configuration factor of diffuse radiation between cover and sky, calculated as follows [18]:

$$F_{g\,sky} = [\frac{1-\varepsilon_g}{\varepsilon_g} + (\frac{1}{F_{gs}})]^{-1} \qquad (11)$$

Where F_{gs} is the view factor between the glass cover and the sky, it is determined from the following equation [18]

$$F_{gs} = 0.5(1+\cos\beta) \qquad (12)$$

Q_c is calculated as follows [19]

$$Q_c = h_c(T_g - T_a) \qquad (13)$$

Where h_a is calculated as follows [19]

$$h_c = 2.64V^{0.78} \qquad 18 \le V \le 110$$

Heat lost from base and periphery to ambient is calculated as follows [20]

$$Q_b = h_s(T_W - T_a) = 1.11(T_w - T_a) \qquad (14)$$

Heat added to the feed water to increase its temperature to that in the still [20], is

Calculated as follows

$$Q_f = F.C_p(T_w - T_{fi}) \qquad (15)$$

The instantaneous rate of distillate (D) produced by the still is given [21] as follows

$$D = \frac{Q_e}{L_g} \qquad (16)$$

The efficiency of the still is estimated using the relation [21]:

$$\eta = Q_e / I \qquad (17)$$

Experimental Work

Since the solar still performance depend on the amount of solar radiation intercepted inside the still. The experimental work is carried out on the solar still with reflected mirrors. The solar radiation was calculated mathematically for angles ranging from 9^o to 30^o with 15^o increment for reflected mirrors and from 0-45^o with 5^o increment for glass cover. Thus, a solar analysis study was conducted to find out the best tilting angle for the solar still with reflection mirrors that intercepts the maximum amount of solar radiation. In Fig.2, the solar radiation was calculated mathematically for 7 tilt angles ranging from 0^o to 45^o with 5^o increment. Calculations for solar radiation were presented for 12 days. The values calculated represents the total daily amount of total solar radiation from 8 A. M. to 16 P. M. for every tilt angle on south and north orientations. This value represents the total value of the 12 selected days. Experimental analysis showed that the best angle that intercept the maximum amount for solar radiation at the angle 85^o for reflected mirrors at the south-north orientation of solar still which indicates that as the slop of mirrors increase the average solar radiation decreases.

Also the glass cover is inclined about 40°. The study included the experimental test for the angle which may not permit the condensate to drip back into the basin. It was found to be 11°.

The solar still is shown in Fig.1. It consists of a wood frame covered by a galvanized steel rectangular body, 2.5 m long, 1.5 m wide and 0.5 m high, and is covered with a high purity glass panes.(1x2) m^2 and four reflected mirrors with dimension 0.8 m long ,0.7 wide for the two frontal mirrors and 0.9 m, 0.6 m for the side mirrors. Water basin is painted internally with a layer of a special light and heat resistant matte black paint, and covered externally with 25 mm polystyrene sheets as insulator, with conductivity of 0.040 W/m K. The still should be insulated to minimize the unproductive conductive loss through the sides and base. The distilled water is collected through a trough fixed at the basin water periphery. The glass cover which could be readily removed when desired is placed 50mm away from basin plate. Rubber gaskets all over the set – up prevent leakage of vapor and therefore heat. The apparatus is finally placed on a steel frame made such that the base of the set-up fits into it exactly.

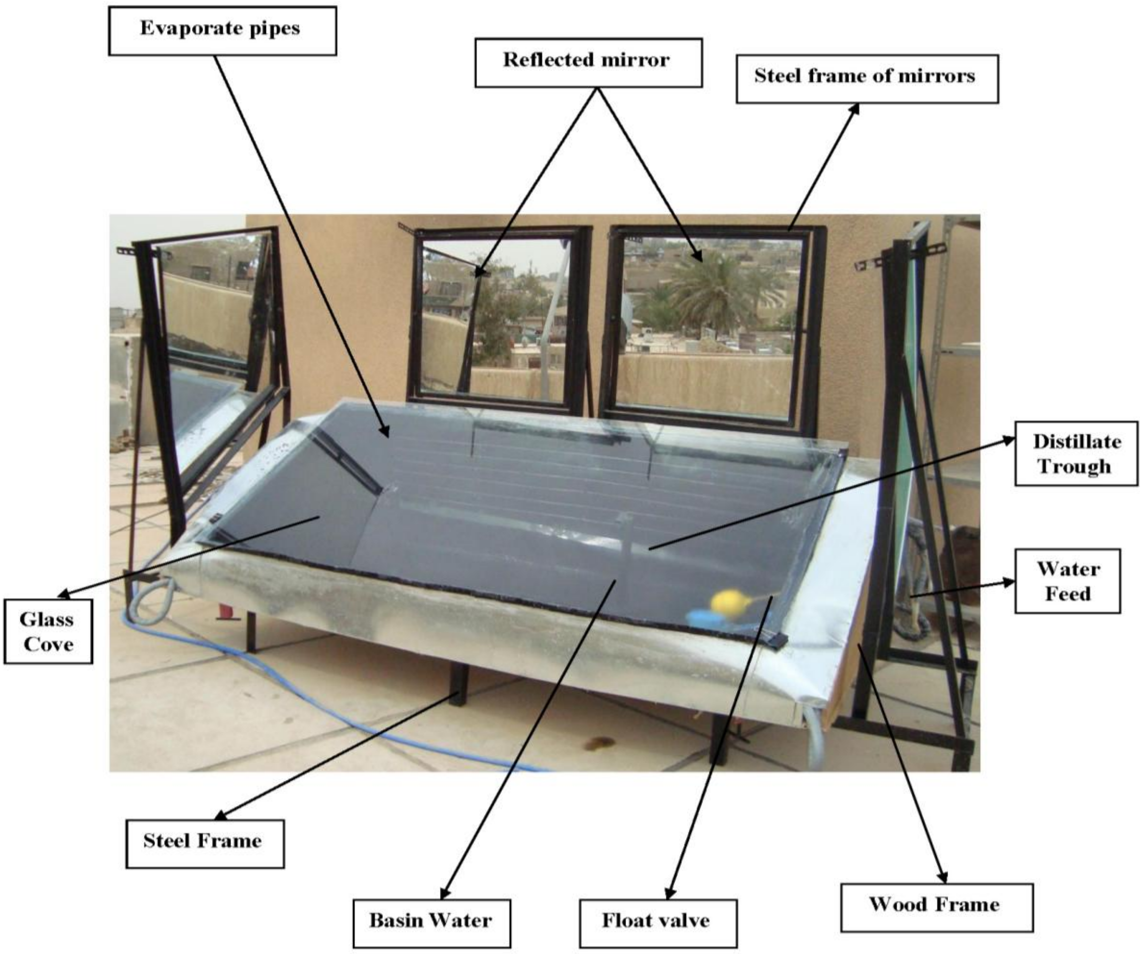

Fig.1. Solar water distillation of solar still with reflection mirrors

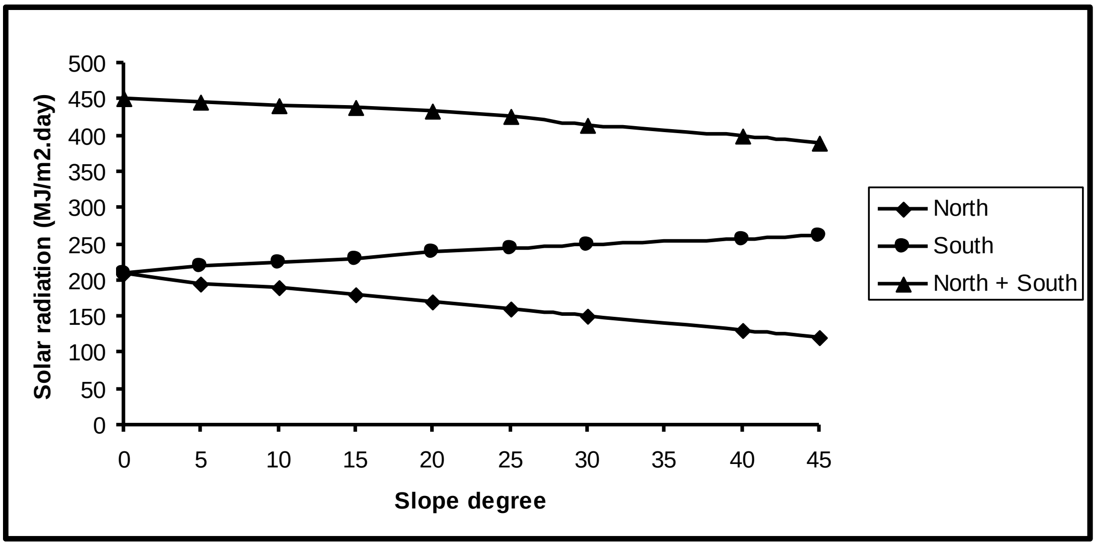

Fig.2. Average daily total solar radiation for surfaces facing south and north for different tilt angels [15].

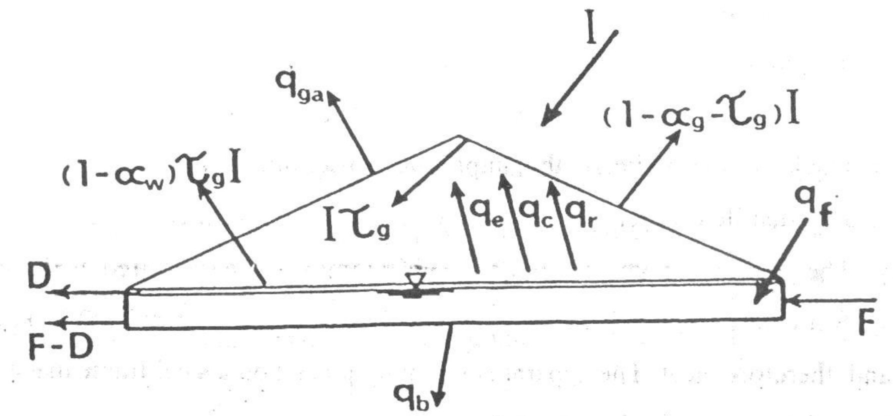

Fig.3. Direction of heat flow in the solar stil [15]

Results and Discussion

Figure 4 show the variation of the average solar radiation at a horizontal surface which estimated in May month according to Iraqi weather and note that the value of solar amount radiation and heat transfer rate between (8-9) hour is very small and may be negligible, theoretical calculation and experimental work begin at (9-17) hour of the time days .

Figure 5 shows the variation of heat transfer rates by evaporation, radiation and convection during the time of the day in May 2009. The average maximum values heat transfer rates for convection, radiation and evaporation are 32, 74, 550 (Watt/m2) respectively at (13-14) hours afternoon and shows that the evaporation is very greater than the convection and radiation.

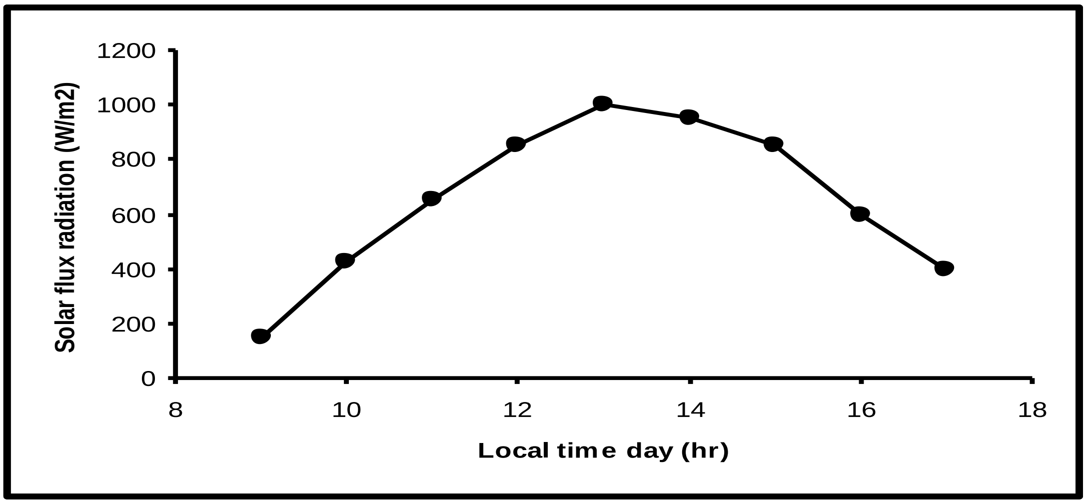

Fig.4. Average history solar radiation on May month 2009

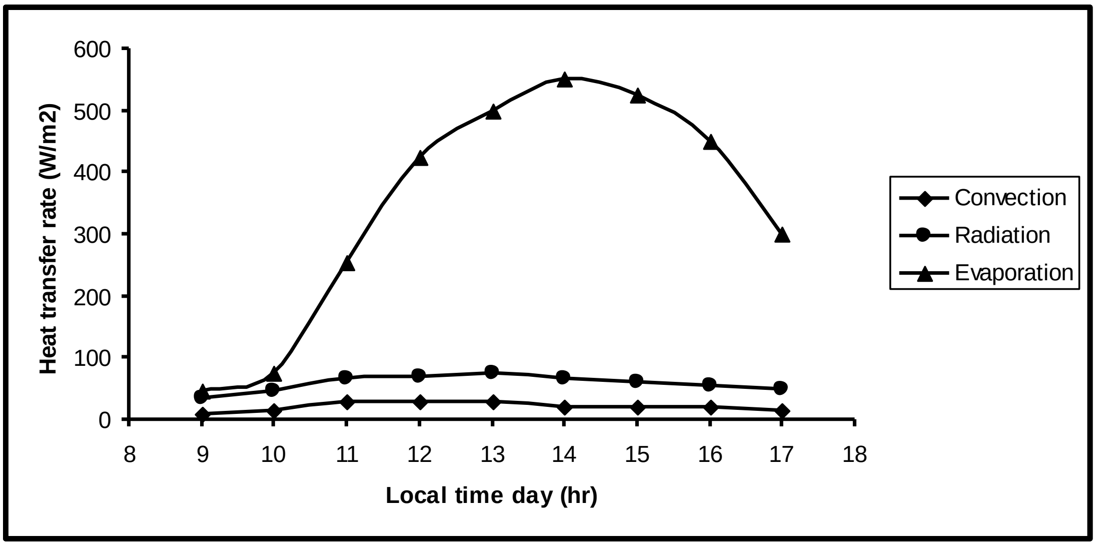

Fig.5 Heat transfer rates by evaporation, radiation, and convection
from the solar still with reflection mirrors .

Figure 6 shows the theoretical calculation analysis of the solar still for reflection mirrors temperature. The reflection mirrors on glass cover temperature were made after every 60 minutes maximum and compared with experimental measurement of reflected temperature on glass covers temperature 60^0 between (13-14) hours is gave a good agreement between the measured and theoretical 65^0 at the same time predicted reflection mirrors temperature on glass cover temperature. We note from the figure a gradual rise of temperature of the glass cover and reach maximum temperature and after 14 hour begin the temperature of the glass cover down and by the lack of solar radiation falling on the solar still and a shadow effect due to a decrease of energy.

Figure 7 show the variation of the experimental ambient temperature, reflection mirrors temperature of the glass cover and the basin water temperature as function of the variation of the solar flux on horizontal surface during the time of the day. The maximum solar flux value is recorded between (13-14) hour, while the ambient temperature 36, reflection mirrors temperature the glass cover temperature 60^0 and the basin water temperature 70^0 reach their maximum values and after 14 hour the temperature of the glass cover begin decrease as a result of decreasing the amount of solar radiation falling on the solar still a shadow effect due to a decrease of energy.

Figure 8 shows the variation of the efficiency, for the still provided with the black cotton wick materials. The maximum efficiency is recorded between (15-16) hours approximately 65%. . After it start decrease gradually to reach a minimum value when increased emission of radiation infrared as a result of high surface temperature of the absorber solar still and increasing loss of heat from solar still and causing falling efficiency of the solar still.

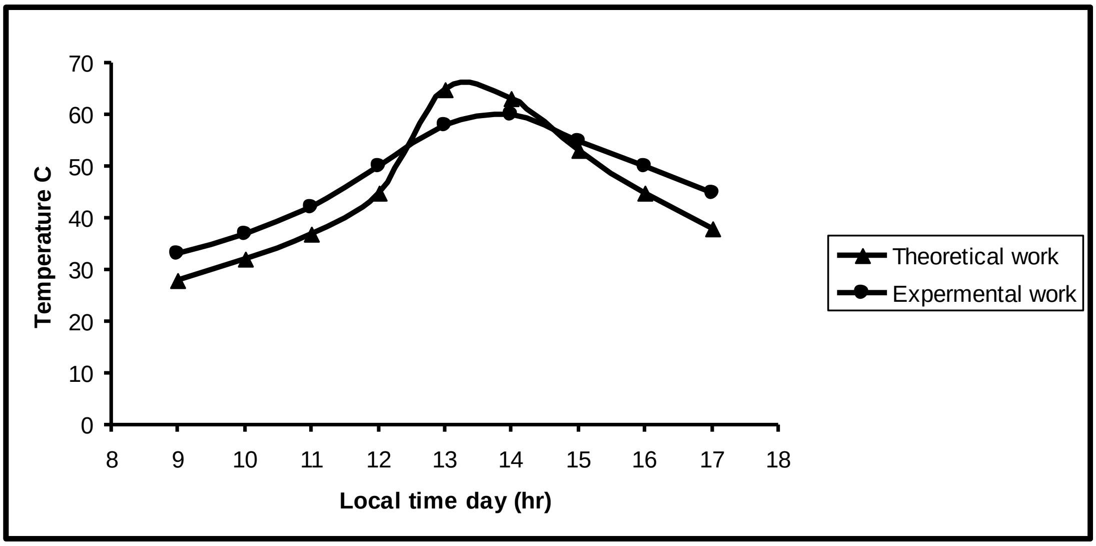

Fig.6. Glass covers temperature for theoretical and experimental work

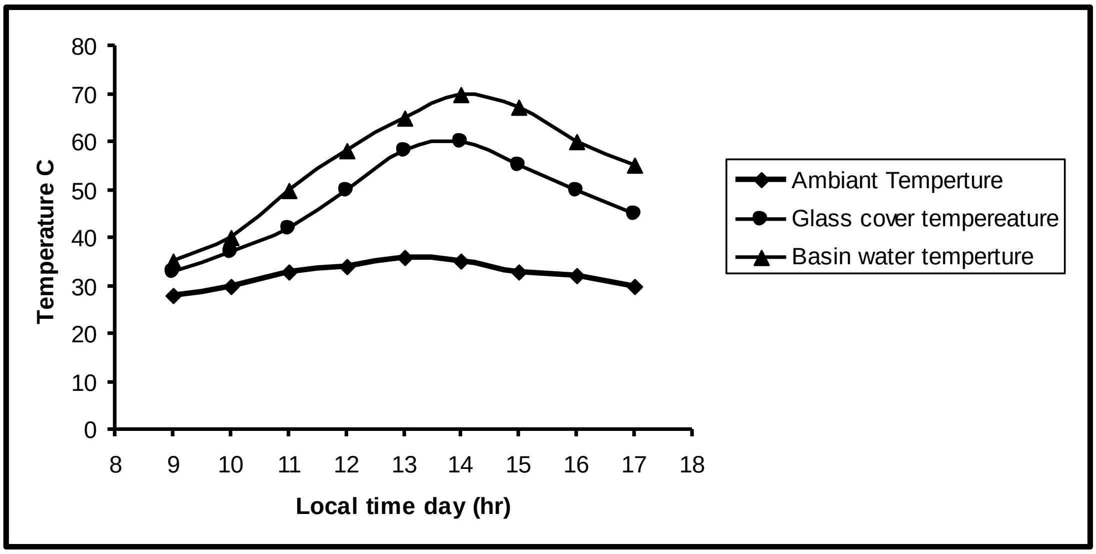

Fig.7. Glass and Basin temperature from the solar still with reflection mirrors with ambient temperature on May month 2009

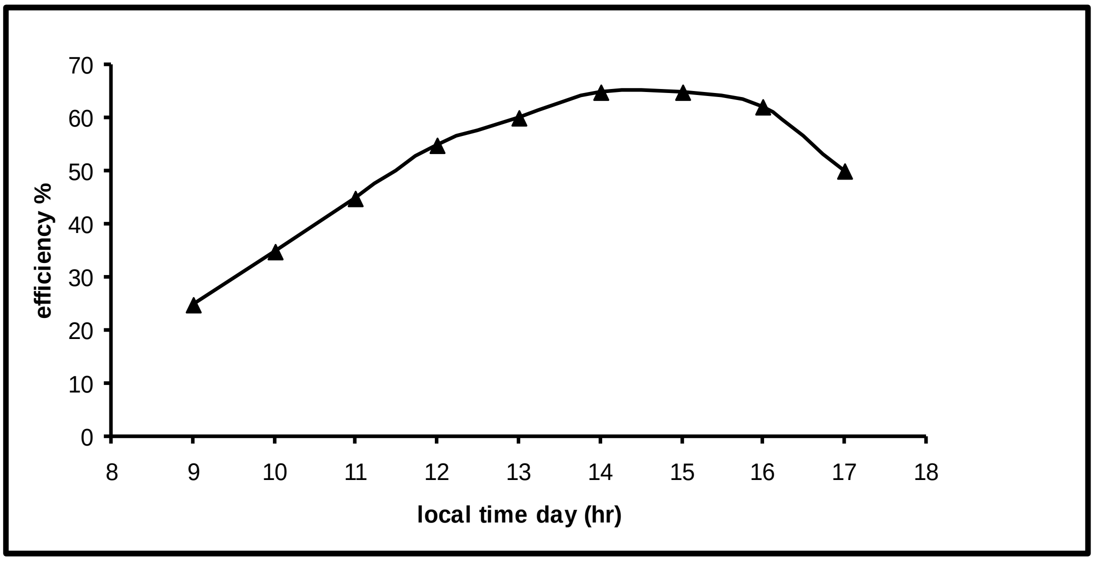

Fig.8. Variation of the efficiency during the local time of the day.

Conclusions

1- The total daily solar radiation, for 12 days representing slope of the reflection mirror angle, facing to south and north, increases and has maximum value for 85^o of reflection mirror.

2- Experimentally work indicated that the minimum angle, which may not permit the condensate to drip back into the basin, is 11^o.

3- The value heat transfer rates of evaporation are very greater than heat transfer of convection and radiation.

4- The temperature of glass cover ,basin water and efficiency of system solar still increases gradually from (9-14) hours, and after 14 hour begin the temperature and efficiency of the solar still decreases due to the lack of solar radiation falling on the solar still and a shadow effect .

5- The difference between theoretical calculation and experimental work due to quality of workmanship, materials for thermal insulation and accuracy of solar radiation incident on the surface of the solar still system.

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LIST OF SYMPOLS

C_S	Heat capacity of water and still	$kJ/^0C.m^2$
C_p	Specific heat of water at constant pressure	J/kg K
D	Rate of distillate production	$kg/s.m^2$
F	Rate of the feed water	$kg/s.m^2$
h_c	Convective heat transfer coefficient between cover and ambient	W/m^2 K
h_s	Heat transfer coefficient between still and surrounding	W/m^2 K
I	Solar radiation on a horizontal surface	W/m^2
L_g	Latent heat of evaporation of water at saturation temperature T_g	J/kg
L_w	Latent heat of evaporation of water at saturation temperature T_w	J/kg
P_g	Saturation pressure of water at T_g	MN/m^2
P_w	Saturation pressure of water at T_w	MN/m^2
Q_b	Rate of heat flux transferred from base and periphery to ambient	W/m^2
Q_c	Rate of heat flux transferred by convection from water to glass cover	W/m^2
Q_e	Rate of heat flux transferred by evaporation from water to glass cover	W/m^2
Q_f	Rate of heat added to the feed to increase its temperature to that in	W/m^2

	the still	
Q_g	Rate of heat flux transferred from glass cover to ambient	W/m^2
Q_r	Rate of heat flux transferred by radiation from water to glass cover	W/m^2
β	The tilt angle of the glass cover with the horizontal	Degree
T	Temperature	^0C
t	Time	S
T_g	Average temperature of the inner side of the glass cover	^0C
T_{go}	Average temperature of the outer side of the glass cover	^0C
T_w	Average water temperature in the basin	^0C
V	Wind velocity	Km/hr
ε_g	Emissivity of the glass cover.	
ε_w	Emissivity of the water liner.	
α_g	Absorpitivity of the glass cover.	
α_w	Absorpitivity of water and basin.	
τ_g	Transmisivity of the glass cover.	
σ	Stefan – Boltzman constant, - 56.7 X 10^{-9}	$W/m^2\ k^4$
η	Efficiency	
ΔT_w	Temperature difference between water basin and glass cover	^0C

Subscripts

a	ambient
fi	inlet feed
g	glass
i	inner
o	outer