THERMAL PERFORMANCE OF FLAT PLATE SOLAR COLLECTOR WITH REFLECTORS IN SOUTH ALGERIA

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Abstract: In this paper, a theoretical and experimental studyof flat platesolar water collector with reflectors.A mathematical model based on energy balance equations saw the thermal behavior of the collector is investigated. The experimental test was made at the unit research applies in renewable energy (URAER) located in southern Algeria.An increase of 23% for solar radiation incident on the collector surface with the addition of the planers reflectors in the day of May, this increase causes an improvement of the performance of the collector,the fluid temperature increases with an average of 5%. Thetests conducted on the flat plate solar water collector in open circuit enabled the determination of thermal performance of the collector by estimating the daily output
The thermal efficiency of the collector ranges from 1% - 63% during the day, a mean value of 36%obtained.

Keywords: flat plate collector, thermal efficiency, reflectors

1. INTRODUCTION

Solar energy is becoming an alternative to limited fossil fuel resources. One of the simplest applications of this energy is the conversion of solar radiation into heat; the essential element for capturing this energy is the solar collector. A flat plate solar collector is the most commonly used because of their effectiveness of conversation and low manufacturing costs, therefore a lot of research has been conducted to analyze the functioning of the collector and improve the efficiency [1-2].

The adding of the planers reflectors on the flat plate solar collector increase the amount of solar radiation incident on the surface of the collector and consequently improved their performance, for this reason, several studies made on the solar collectors with planers reflectors.Ljiljana T. Kosti' et al[3]. Investigated the influence of the position of the planers reflectors with Aluminum on the thermal efficiency of the solar collector,it showed the positive effect of reflectors, an energy gain in the range 35-44% during the summer period to thermal collector with reflectors, which should reduce costs for return time.Zoran T et al [4]. Analyzed the impact of planers reflectors (bottom, top, left and right) in Aluminum, on the total solar radiation on a collector in a day for a whole year,they found that the intensity of solar radiation on the collector increases by about 80% during the summer period (June September) with reflectors optimally, relative to the collector without reflectors.Hiroshi Tanaka [5]. Made a theoretical analysis of the flat plate solar collector and the reflector at the bottom with a space between them, the solar radiation absorbed at the collector decreases rapidly with an increase in the length of the space when the reflector and/or the collector are not attached to a suitable angle.Another study done by Mr. Hiroshi Tanaka [6],[7]. A solar collector with upper and lower reflector,an increase in the daily solar radiation absorbed on the absorber plate on a solar plan would average about 19%, 26% and 33% throughout the year using planer reflector.When the length ratio of the reflector and the collector is 0.5, 1.0 and 2.0. JOSEPH W. BOLLENTIN and all. [8] Developed an analytical model used to determine the solar radiation on flat platesolar collectors increased with planers reflectors.

The aim of this work, a modeling, numerical simulation and experimental validation of a flat plate solar water collector with planers reflectors,the mathematical model based on energy balance equations to see the thermal behavior of the collector.We will present the temperatures of the essential elements of the flat plat solar, the thermal efficiency and effect of the reflectors on the performance of the collector,and we will explain the different tests on the solar collector.

2. MATERIAL AND METHOD

Estimation of solar radiation incident on the collector surface

The total solar radiation absorbed by the flat plate solar water collector is equal to the sum of direct radiation on the surface of collector"I_b,"the diffuse radiation by sky "I_{ds}," the radiation reflected from the ground "I_s".The radiation reflected by the side reflector "I_{lr}" left towards the collector with an inclined angle "γ_1" and, the radiation reflected by the reflector on the right side toward the collector I_{rr} with tilted angle "γ_2".The schematic of the falt plate solar water collector with reflectors is shown in Figure 1.

$$I_t = I_b + I_{dc} + I_s + I_{rr} + I_{lr} \quad (1)$$

Where the components are given by [3, 9]

$$I_b = I_{nb}\cos(\theta) \quad (2)$$

$$I_d = I_{dh}(1+\cos(\beta))/2 \quad (3)$$

$$I_s = I_{gh}\rho_g(1-\cos(\beta))/2 \quad (4)$$

$$I_{rr} = I_{nb}\rho\cos(\alpha_s+\beta+\gamma_2)\sin(2\gamma_2+\alpha_s+\beta-180) \quad (5)$$

$$I_{lr} = I_{nb}\rho\sin(\alpha_s+\beta-\gamma_1)\sin(2\gamma_1-\alpha_s-\beta) \quad (6)$$

Were I_{nb}, I_{dh}, I_{gh} are direct solar radiation at normal surface, horizontal and diffuse global horizontal respectively [W/m²] [10-11].

θ: It is the angle of incidence of solar radiation for an inclined surface with angle β, the angle of incidence is equal [12].

$$\cos(\theta) = \cos(\delta)\sin(\omega-\beta)\cos(\phi-\beta)+\sin(\delta)\sin(\phi-\beta) \quad (7)$$

δ: solar declination, ω: time angle, ϕ: attitude, α_s: solar height

$$\sin(\alpha_s) = \cos(\phi)\cos(\delta)\cos(\omega)+\sin(\phi)\sin(\delta) \quad (8)$$

The solar radiation absorbed by the glass and the absorber are given as a result

$$q_c = \alpha_c I_t \quad (9)$$

$$q_c = \tau_c\alpha_r I_t \quad (10)$$

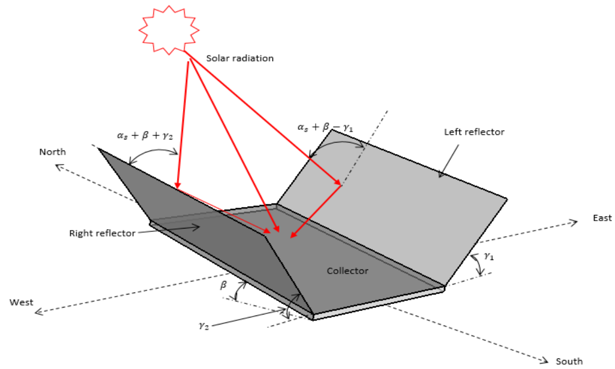

Fig.1 - Schematic diagram of the flat plate collector with reflector

Mathematical Model of flat plate solar collector

A detailed mathematical model for a flat plate solar water collector was developed. This model described by the written energy balance equations for all components of the collector (glazing, air gap,absorber, fluid and, insulation).TheFigure 2 illustrate the heat transfers that take place between the different elements of flat plate solar water collector.

Before starting the calculations, it is necessary to specify certain calculation assumptions:
- Heat transfer in one dimension through the layers of the system.
- The mass flow fluid uniform in the collector pipe.
- The heat transfer from the edges of the collector is negligible.
- The wind speed on the face collector assumed constant.
- The heat flux received by the collector is a function of time.
- The physical properties of the materials are not depending on the temperature.
- The physical properties of the fluid are a function of temperature.
- The temperature of the collector components are a function of time.

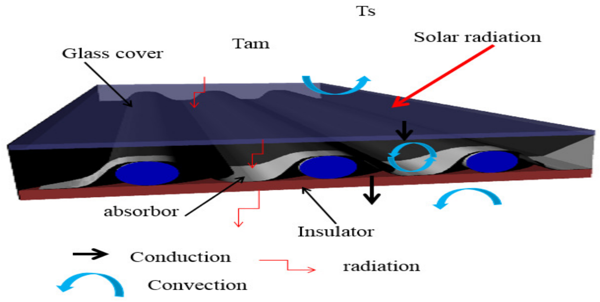

Fig.2 - Flat plate solar water collector

The energy balance equation of the glass cover expressed as follows

$$M_c c_{pc}\frac{dT_c}{dt} = q_c(t) - h^r_{c-r}A_c(T_c - T_r) - h^c_{c-a}A_c(T_c - T_a) - h^r_{c-a}A_c(T_c - T_s) - h^c_{c-a}A_c(T_c - T_a) \quad (11)$$

The energy balance equation of the air layer expressed as follows

$$M_a c_{pa}\frac{dT_a}{dt} = h^c_{a-r}A_a(T_r - T_a) - h^c_{a-c}A_a(T_c - T_a) \quad (12)$$

The energy balance equation of the absorber expressed as follows

$$M_r c_{pr}\frac{dT_r}{dt} = q_r(t) + h^r_{c-r}A_r(T_c - T_r) + h^c_{a-r}A_r(T_a - T_r) - h^c_{f-r}A_r(T_r - T_f) - \frac{\lambda_{in}}{e_{in}}A_r(T_r - T_{in}) \quad (13)$$

The energy balance equation of the fluid expressed as follows:

$$c_{pf}\left(\rho_f\frac{D_{in}}{4}\frac{dT_f}{dt} + \frac{\dot{m}}{\pi D_{in}}\frac{dT_f}{dx}\right) = h^c_{f-r}(T_r - T_f) \quad (14)$$

The energy balance equation of the insulation expressed as follows

$$M_{in}c_{pin}\frac{dT_{in}}{dt} = \frac{\lambda_{in}}{e_{in}}A_{in}(T_r - T_{in}) - h^r_{in-a}A_{in}(T_{in} - T_s) - h^c_{in-a}A_{in}(T_{in} - T_a) \quad (15)$$

Expression of heat transfer coefficients

In the above equations, the radiation transfer coefficients and convection heat are calculated using the relationship as reported in the references.

The coefficient of heat transfer by convection, from the wind to the airflow on the outer surface of the collector depends primarily on the wind speed v and defined as follows [13]:

$$h^c_{c-a} = 5.7 + 3.8v \quad (16)$$

The radiation heat transfer coefficient between the glass cover and the sky is given by the following relationship [14].

$$h^r_{g-a} = \varepsilon_g\sigma\left(T_g^2 + T_s^2\right)\left(T_g + T_s\right) \quad (17)$$

The equivalent air temperature is calculated by the following correlation equation [12].

$$T_s = T_a - 6 \quad (18)$$

The radiation heat transfer coefficient between the glass cover and the absorber is given by the following relationship [15]:

$$h^r_{g-r} = \sigma\left(T_g^2 + T_r^2\right)\left(T_g + T_r\right)\left(\left(1/\varepsilon_g\right) + \left(1/\varepsilon_r\right) - 1\right) \quad (19)$$

The convection heat transfer between the transparent cover and the air layer is calculated by the correlation proposed by **Duffie and Beckman** [12] on the natural convection between two flat plates as follows:

$$h^c_{g-a} = h^c_{r-a} = \frac{N_u \lambda_a}{e_a} \quad (20)$$

With λ_a and e_a are the thermal conductivity and the thickness of the air layer respectively
The Nusselt number (Nu) is calculated using the following equation [12, 16]:

$$Nu = 1 + 1.44\left[1 - \frac{1708\left(\sin 1.8\beta\right)^{1.6}}{Ra\cos(\beta)}\right]\left[1 - \frac{1708}{Ra\cos(\beta)}\right]^{+} + \left[\left(\frac{Ra\cos(\beta)}{5830}\right)^{1/3} - 1\right]^{+} \quad (21)$$

Where β collector inclination angle

In natural convection, Nusselt number depends on the Rayleigh number Ra is a function of the numbers of Grashof "Gr ", and Prandtl "Pr".

$$R_a = G_r \times Pr \quad (22)$$

$$G_r = \frac{g \times (T_r - T_g) \times e_a^3}{T_a \upsilon_a^2} \quad (23)$$

$$P_r = \frac{\mu_a \times cp_a}{\lambda_a} \quad (24)$$

υ_a, μ_a are the kinematic and dynamic viscosity of air respectively

The heat transfer coefficient by convection between the water and the tube expressed by the correlation proposed by Incropera et al [17-18].

$$h^c_{f-r} = \frac{N_u \lambda_f}{D_h} \quad (25)$$

$$N_u = 0.023 \times R_e^{4/5} \times P_r^{0.4} \quad (26)$$

With "Re" Reynolds number

$$R_e = \frac{v D_h}{\upsilon} \quad (27)$$

D_h is the hydraulic diameter for a tube $D_h = D_{in}$
The thermal efficiency of the water level sensor is given by the following equation [17-19]

$$\eta_{th} = \frac{Q_u}{A_g I_t} = \frac{\dot{m}\, cp_f \int \left(T_{fout} - T_{fin}\right) dt}{A_g \int I_t\, dt} \quad (28)$$

The model is composed of a system of the equations, which shows the heat exchange at the flat plate solar water collector. We chose the Runge-Kutta fourth order method to solve this equation system on FORTRAN 90 environment.The equations and the heat transfer coefficients are solved with system initial temperatures. The thermo-physical parameters used in the calculation are shown in Table 1.

Table 1 - Simulation input parameter

Parametre	Value
β	32,39 degree
D_{int}	0.022 m
L	1.5 m
W	0.12 m
e_c	0.001m
e_r	0.001m
v	1 m/s
e_i	0.04m
ε_r	0.05
ε_i	0.05
ε_g	0.85
λ_i	0.045 W/mK
c_{pg}	840 j/kgk
c_{pr}	383 j/kgk
c_{pin}	1500 j/kgk
ρ_g	2700 kg/m^3
ρ_r	8954 kg/m^3

Equation (14) is an equation to the partial derivative (EDP) can be discretized by the finite difference method of implicit schemes.

$$\frac{dT_f}{dt} = \frac{T_{f\,j}^{\,i+1} - T_{f\,j}^{\,i}}{\Delta T} \quad (29)$$

$$\frac{dT_f}{dx} = \frac{T_{f\,j}^{\,i+1} - T_{f\,j-1}^{\,i+1}}{\Delta X} \quad (30)$$

$$\Delta x = \frac{L}{n} \quad (31)$$

For the initial conditions of the simulation

$$T_{fin} = T_a \quad (32)$$

Finally, equation (5) is written in the following way

$$T_{f\,j}^{\,i+1} = \left[A_1 T_{f\,j-1}^{\,i+1} + A_2 T_{f\,j}^{\,i} + A_3 T_r\right] / A_4 \quad (33)$$

A_1, A_2, A_3, A_4, these are constant obtained after mathematical calculation made

Experimental study

We show in the Figure 3, the prototype of flat plate solar water collector or we did experimental tests,two reflectors are placed on the sides of the collector, the prototype placed on a roof of a building of the unit research applied in renewable energy located in southern Algeria near the town of Ghardaia about 18 km . Longitude and altitude of the unit are respectively + 32.37 °, 3.77 ° and + 450 m above sea level.The tests carried out in a clear day less mail in 2015.we studied the thermal behavior of the collector and the reflector effect on the performance. Where we measured the fluid temperature at outlet and inlet of the collector.The dimensions of the different elements of the flat plate solar water collector are given in Table 2.

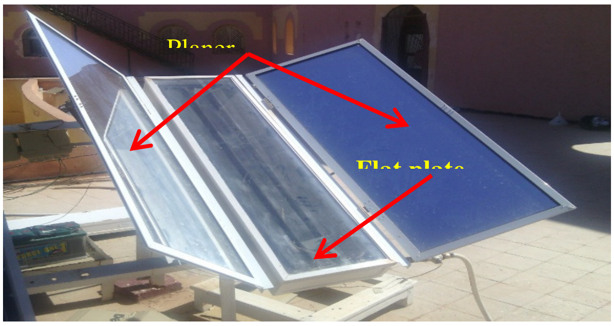

Fig.3 - Image of the prototype flat plate solar water collector with reflectors

Table 2 - Different componentsof flat plate solar water collector

Nom	Material	Dimension	Number
Tube	Galvanized steel	0.02×1.5×0.001 (m)	3
Metal plate	Galvanized steel	0.5×1.5×0.001 (m)	1
cover	Ordinary glass	0.5×1.5×0.004 (m)	1
Metal box	Galvanized steel	0. 5×1.5×0.1 (m)	1
Insulation	lain glass	0. 5×1.5×0.1 (m) 0. 1×1.5×0.1 (m)	1
Planer reflector	mirror	0.5×1.5×0.004 (m)	2

3. RESULTS AND DISCUSSION

Numerical Results

We present in the Figures 4-7, the results of the numerical simulation obtained from flat plate solar water collector,the temperatures of the inlet of fluid and the ambient temperature taken into constant throughout the day. To investigate the effect of several operating and design parameters on the transient performance of the collector.

Figure 4 shows the hourly variation in the total solar irradiance "It" global "Ig," and reflected "Ir", these values are obtained by the equations shown above. Maximum values reached at noon.The total solar irradiance varies from 0 W/m^2 -1500 W/m^2 in a time interval between 8: 00 and 17:00.In noon "I_t" reaches 1507 W/ m^2, in 10: 00; "I_t" =974.44 W / m^2, in 15:00; "I_t" =1127.20 W/m^2, these high values are due to solar reflectors adding in the collector.The solar radiation com by two lateral reflector (left and right) ranges from 0 to 311 W/m^2 and 0-230 W/m^2 respectively,the left reflector on placing the collector with an optimal angle " γ_1 " =82.76 degree, and the reflector on the right place on the collector with an optimal angle " γ_2 " = 27.18 "degree.The adding of planers reflectors causes a 23% increase for incident on the collector surface in the day.

The Figure 5 shows the hourly variation of the temperature components of flat plate solar collector (glass cover, air layer, the absorber fluid, and insulation),temperatures follow the same manners in the day due to solar radiation incident (maximum values between 10: 00 and 14: 00). The temperature of the absorber made of high values, this finding is due to their optical parametric and geometric characteristics (high absorption capacity, and thin).The temperature of the absorber is from 24 ° C to 79 ° C in the time interval between 8: 00 and 17: 00. At 8:00; Tr = 24.51 ° C, 12: 00; Tr = 79 ° C, and 15: 00; Tr = 64.66 ° C.Increasing the temperature of the air layer located in between the absorber and the cover glass and the absorber because of the greenhouse effect.

The outlet temperature of fluid ranges from 22 °C to 36°C, the water absorbs the heat generated by the absorber, which causes an increase in its temperature.In 12:00; T_{fout} = 36.68 ° C, in 15: 00; T_{fout} = 33.47 °C.The temperatures of the cover and isolation have taken interesting values due to their poor physical properties.

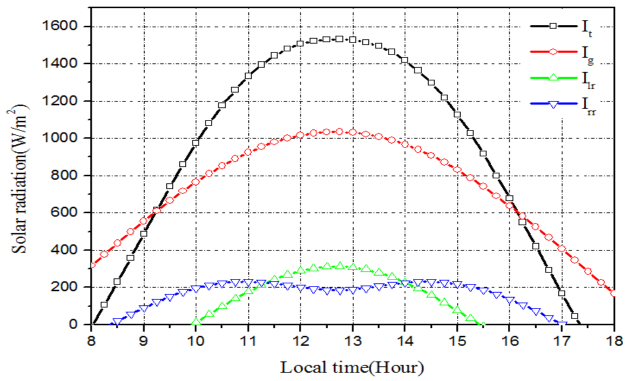

Fig.4 - Hourly variation of solar radiation

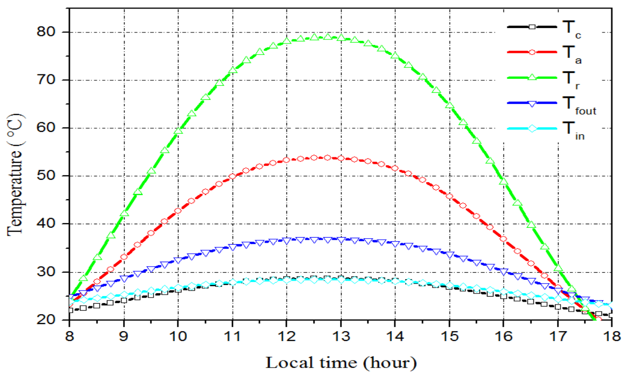

Fig.5 - Hourly variation of temperature elements

Figure 6 shows the variation with time of the thermal efficiency of the collector, the yield is calculated by the equation (28),the mass flow rate value and the ambient temperature is equal to 0.0055 k /s, 24 ° C respectively,To a constant mass flow, thermal efficiency of the collector depends on the water temperature difference. When the temperature difference increases, the increase of the thermal efficiency, the yield reached 71.33% to 12: 00.

Figure 7 shows the hourly variation in the case where the collector with and without reflectors, the addition of the reflectors cause an increase in the amount of solar radiation incident on the collector surface, the absorber temperature increase and consequently an increase in the water temperature. The fluid temperature increases with an average of 5%.

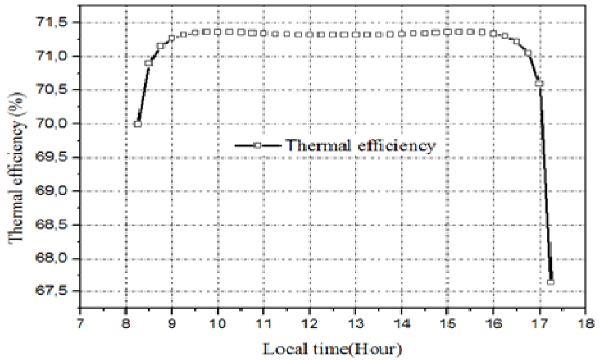

Fig.6 - Hourly variation of thermal efficiency

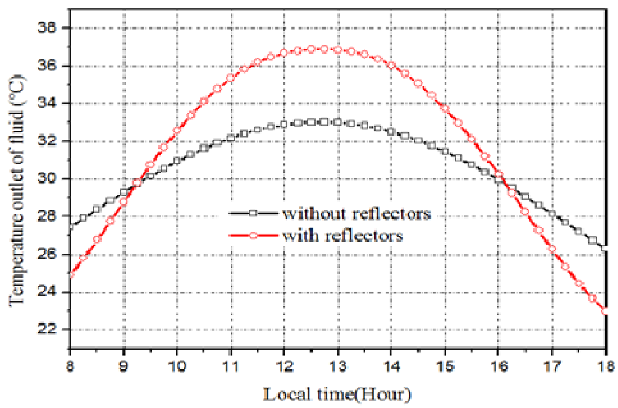

Fig.7 - Hourly variation of fluid temperature

Experimental results

Figures 8-13 present the experimental results of tests on the flat plate solar water collector with reflectors in May 13, 2015. The time variation of the direct normal solar radiation, diffuse horizontal, and global horizontal solar radiation, ambient temperature and wind speed are plotted in Figures 8-9.These data and the different climatic conditions (humidity, air pressure, sun, etc.) were obtained by the meteorological and radiometric station in the research unit applied in renewable energy (Ghardaia). The curves show that the sky was clear on the day. The solar radiation varied to 0-638 W / m^2, in the day, the room temperature reaches 25 °C at noon , and the wind speed varied from 0-4 m /s in the day.

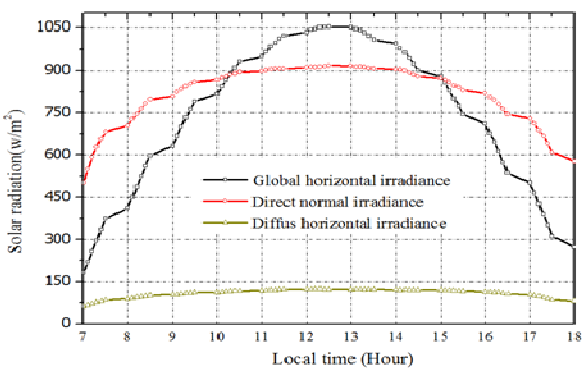

Fig.9 - Hourly variation of solar radiation in the test day

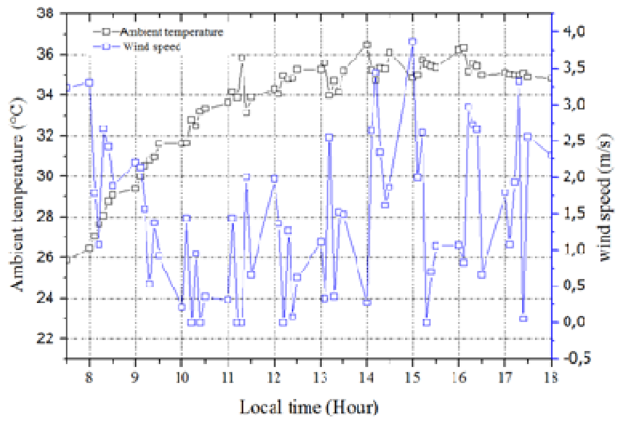

Fig. 10 - Hourly variation wind speed and ambient temperature in the test day

Figure 10 shows the evolution of the water temperature at the inlet and at the outlet of the collector with reflector, the fluid flows in the collector with mass flow rate is equal to 0006 kg/s . The fluid temperature at the collector output reaches 35 °C, a fluid temperature difference at the inlet and the collector output with 8 °C.The maximum difference coincides with the maximum values of solar radiation incident on the collector surface.

The time variation of the thermal power of the collector in the day of the experiment is shown in the Figure 11. The thermal power ranges from 31 W to 199 W. This power reached maximum values between 10: 00-14: 00 due to the solar radiation incident during this interval time, the heating power was 112 w in 10:30, 199 W in 13: 00, 138W in 14: 00.

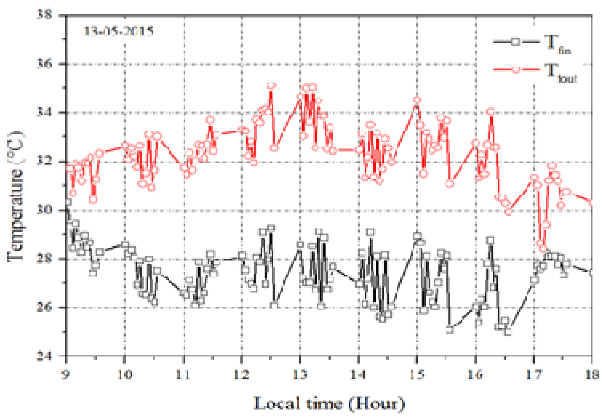

Fig.10 - Hourly variation of water temperature

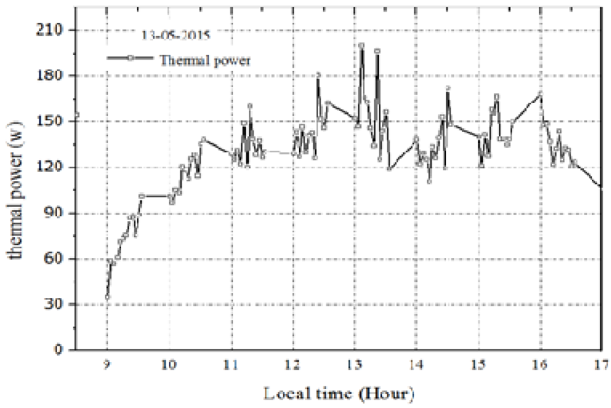

Fig. 11 - Hourly variation of thermal power

Figure 12 illustrate the hourly evolution of the thermal efficiency of the collector with reflectors, the mass flow rate equal to 0.006 k / s, the yield varies from 1% to 63% in the time between 9: 00 -17: 00, in 10: 00 η_{th} = 33.32%, in 12: 00; η_{th} = 32.04%, in 17: 00; η_{th} = 56.54% average daily value is about 38%.

Figure 13 illustrates the thermal performance variation based on the reduced temperature $T^*=(T_{fin}-Tam)$ / Ig .This curve shows the relationship between the performance of the collector and the environment,the thermal efficiency can be correlated with the reduced temperature using linear $\eta = \eta_0$-a1T *.Experimental data obtained show good linear correlation (R^2 = 0.98) for the flat detector, linear correlations these are simpler and more useful in engineering applications.

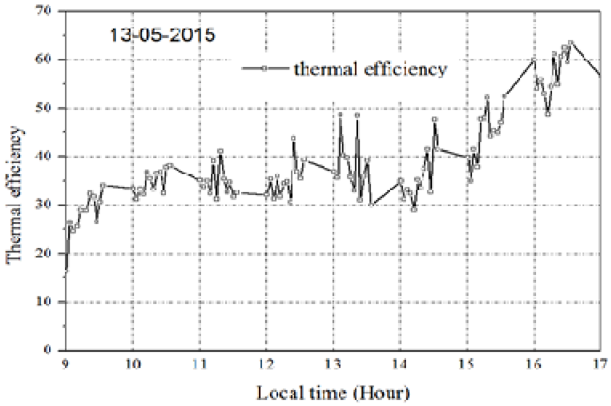

Fig. 12 - Hourly variation of thermal efficiency

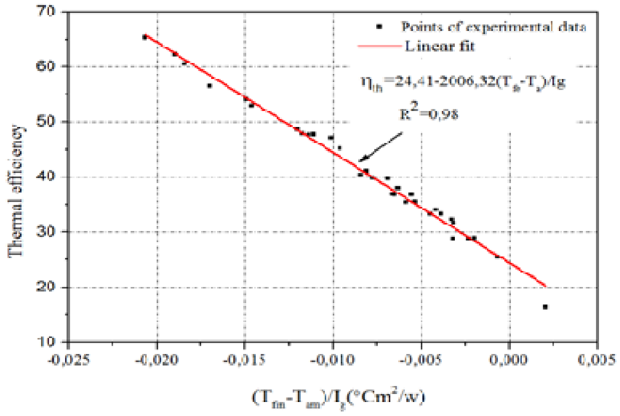

Fig. 13 - Variation thermal efficiency with (t_{fin}-T_{am}) / Ig

4. CONCLUSION

In this work, modeling, numerical simulation and experimental study of a flat plate solar water collector with reflectors were treated and designed,the mathematical model based on energy balance equations to see the thermal behavior of the collector. We presented the temperatures of the essential elements of the collector,thermal efficiency and the effect of the reflectors on the performance of the collector, the tests were conducted in the summers of the month of May 2015, we measured some parameters related with the performance of the collector, as the fluid temperature in input and output . For a mass flow of 0006 kg/s, the thermal efficiency of the collector ranges from 1% to 63% during the day, a mean value of 36% is obtained.

5. Nomenclature

A	surface (m^2)	α_s	solar height (degree)
e	thickness, (m)	ϕ	altitude (degree)
h^c	convective-exchange coefficient (W m^{-2} k^{-1})	θ	incidence angle
h^r	radiative-exchange coefficient (W m^{-2} k^{-1})	am	ambient
I	solar radiation (w m^{-2})	r	absorbor
l	length of the collector (m)	c	cover
$\dot{m}$	mass flow (Kg.s^{-1})	f	fluid
m	mass (kg)	a	air gap
q	heat flow (w)	in	insulator
c_p	specific heat(j Kg^{-1} K^{-1})	out	outlet
T	temperature (°C)	s	sky
D_h	hydraulic diameter(m)	t	total
α	absorbance	th	thermal
η	efficiency	R^2	coefficient of determination
τ	transmittance	t	time (s)
λ	thermal conductivity (W m^{-1} k^{-1})	rr	right reflector
ρ	density (kg m^{-3})	lr	left reflector
β	tilt angle of collector (degree)	g	ground
γ	tilt angle of reflector(degree)		
ω	hour angle (degree)		
δ	declination (degree)		

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