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Experimental Study and Modeling the Behavior of a Solar Water Heater Tested At the Region of Adrar, Algeria

S. Bannaceur[1], B. Draoui[1], M. Benhamou[2], L. Bennamoun[3]

[1]Department of Mechanical Engineering, University of Béchar, Algeria
[2]Research unit in renewable Energies for Saharan
[3]Department of Chemical Engineering, University of Liège, Belgium
[*]Corresponding Author Email's Address: *Lyes.Bennamoun@ulg.ac.be*

***Abstract*— We presented in this study an experimental and theoretical study of a solar water heater (SWH), tested at the hot region of Adrar (Algeria). The SWH was composed essentially with a solar collector and a water storage tank. The experimental work allowed following the variation of the temperatures of the most important components of the SWH, which are the glass and the absorber. The results have shown that 80°C are reached with around 2 hours of inertia. The theoretical study focused on the effect of withdrawal. The efficiency of the system was: 32.89%.**

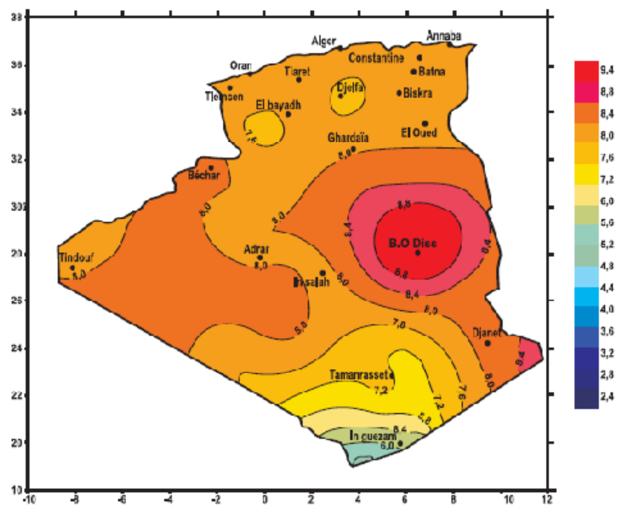
***Index Terms*— Solar water heater, solar collector, modeling, Sahara climate, temperature**

I. INTRODUCTION

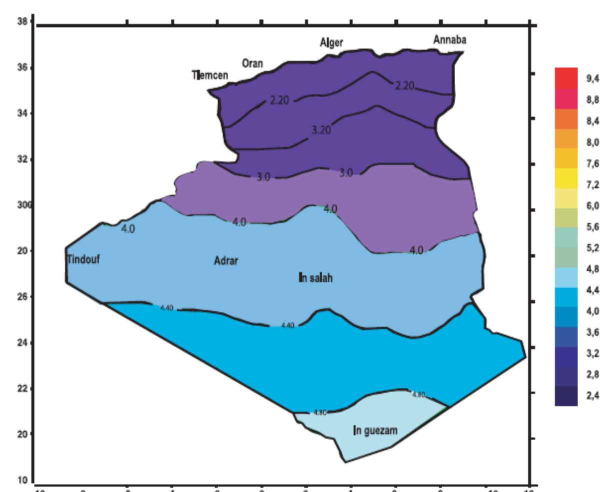
As reported by several references [1-4], Algeria disposes of an important potential of renewable energies in particular solar energy, it plays the most important role. The insolation duration in Algeria is around 2650 hours per year for the coastal regions, 3000 hours for the high plateau regions and increases to 3500 hours per year for the Sahara. In other terms, the coastal regions receive around 1700 kWhm^{-2} per year, 1900 kWhm^{-2} for the high plateau and 2650 kWhm^{-2} for the Sahara. Accordingly, the total solar potential of Algeria is estimated to 169440TWh per year which represents 60 times the energy consumed by the European community. In this study, a particular attention is given to the region of Adrar, where the experimental work was done.

Adrar region is situated in the south west of Algeria. It has a high rate of sunshine, as shown in the following figure (Figure1a and figure 1b). Therefore, the average horizontal radiations in summer are near 8 kW.m^{-2} per day and around 4 kW.m^{-2} in winter. The region is characterized by a continental climate with low temperatures in winter (-4°C) and a hot summer with temperatures that can reach 51°C [5]. Generally precipitation in Sahara varies between 0 and 150 mm par year.

Solar water heater (SWH) is almost one of the most important applications of solar energy that find domestic use. We present in this study the performances of a SWH tested in the region of Adrar.



(a)

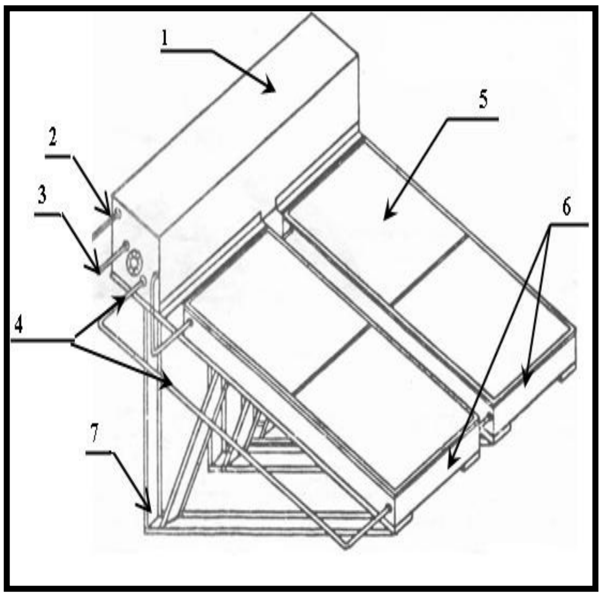


(b)

Figure 1. Global radiations received in Algeria in an horizontal plane. (a) In July. (b) In December [2]

II. Materials And Methods

We used a solar water heater thermosiphon which was subject to series of tests and measures to determine its performances. The SWH was tested in the Research Unit of Renewable Energy in the middle of Adrar. The site coordinates are: latitude 27.88 °, 0.28 ° longitude, altitude 264 m, albedo 0.2. The collector is inclined at 27 degrees to the horizontal and oriented to the south. A storage tank that has 220 l capacity is placed as shown in the figure 2.



1. Storage tank 2. Hot water outlet 3. Cold water
4. Hydraulic connections 5. Glass cover 6. Two collectors
7. Support

Figure 2. General diagram of the solar water heater

The specifications of each part of the SWH are resumed in table 1 for the solar collector and table 2 for the storage tank. We measure, water temperature at the entrance and the exit of the collector, also the temperature of the absorption plate, the glass and the outside temperature, using seven thermocouples type K (alumel-Cromel). They are located as follows:

Two at the surface of the absorber (we note them positions 3 and 4), two at the surface of the glass (note positions 5 and 6), at the entrance (position 1) and the output of the collector (position 2). The ambient temperature is also measured (note position7).

The system allows to effectuate a withdrawal of 50l during 3 periods; from 9h to 10h, 14h to 15h and 18h to 19h

TABLE 1. Specifications of the solar collector

Elements	Size and characteristics	Material
Ferry	Length: 1,930 m Width: 0.9 m Height: 0.08m	Aluminium
Glass	Thickness: 0.004 m Transmission: 0.88 Refractive index: 1.52	White glass
Absorber tube	Type of absorber Thickness: 0.6 .10 $^{-3}$ m Emissivity: 0.2 Conductivity: 240 W / m ° C Absorptivity: 0.95 Diameter: 0012 / 0014 m Number of tubes: 9	Tube-fin Aluminium Copper
Collector	Length: 1m Diameter: 0020 / 0022 m Number: 2	Copper
insulation	Rear thickness: 0.03m Side Thickness: 0.03m Conductivity: 0.0027 W / m ° C	Polyurethane foam

TABLE 2. Specifications of the storage tank

Ferrule	Length Radius Thickness Volume Thermal conductivity Material	1.77m 0.4 0.002m 220 l 46 W / m ° C Re × 42
Lid	Length Width Thickness Thermal conductivity Material	1.96m 0.49m 0.0011m 46 W / m ° C Galvanized
Insulation	Material Thickness Thermal conductivity	Foam Polyurethane 0.044m 0.0027 W / m ° C

III. Mathematical Modeling

The modeling of heat transfer in a solar water heater natural circulation remains a difficult and complex problem. To simplify, we have divided the solar water heater system into two namely the plan collector and the storage tank.

A. Solar collector

The power recovered by the coolant is defined as the difference between the incident solar energy and heat loss. It is given by the following equation [6]:

$$Q_u = A_c F_r \left[(\tau\alpha)_{eff} G_t - U_L (T_{fe} - T_a) \right] \quad (1)$$

In order to calculate the parameters of the collector F_r, U_L, F_r and Q_u, the average temperature of the plate T_{pm} the average temperature of the fluid in the collector T_{fm} and mass flow $\dot{m}$ are initialized the calculation is repeated iteratively until obtaining the wanted error. The average temperature of the plate shall given by [6]

$$T_{pm} = T_{fe} + \frac{Q_u}{A_c U_L F_r}(1 - F_r) \quad (2)$$

With:

$$F_r = \frac{\dot{M} C_p}{U_L}\left[1 - \exp\left(\frac{-F_c U_L}{\dot{M} C_p}\right)\right] \quad (3)$$

$\dot{M}$ is the mass flow per surface ($\dot{M} = \frac{\dot{m}}{A_c}$)

The fluid temperature at the collector output is given by [7]

$$\frac{T_{fs} - (T_a + \frac{(\alpha\tau)_{eff} G_t}{U_L})}{T_{fe} - (T_a + \frac{(\alpha\tau)_{eff} G_t}{U_L})} = \exp\left(\frac{-F_c U_L Ac}{\dot{m} C_p}\right) \quad (4)$$

The fluid temperature at the collector output is given by the average temperature of the fluid in the sensor and calculated using Klein's equation

$$T_{fm} = T_{fe} + \frac{Q_u}{A_C U_L F_r}\left(1 - \frac{F_r}{F_C}\right) \quad (5)$$

The efficiency of a solar water heater in a given period by the following equation:

$$\eta_{c.e.s} = \frac{w_{wt}(T_m^* - T_m)}{A_c \int_0^t G_t \, dt} \quad (6)$$

$$w_{wt} = C_P M_S \quad (7)$$

B. Tank storage

To calculate the temperature of water in the storage tank, we applied the stirred model which considers the transitional regime represented by a uniform temperature of the storage tank. The application of energy balance we can write:

$$(MC_p)_S \frac{dT_S}{dt} = A_c F_r [S - U_L(T_S - T_a)]^+ - (UA)_S (T_S - T_a) - \dot{m}_p C_{PS}(T_S - T_{Re}) \quad (8)$$

And:

$$S = (\alpha\tau)_{eff} \quad (9)$$

One of the most important that could be calculated is the mass flow rate of water in the system. It dependents on several parameters, such as the geometry of the system, nature of the flow and the received radiations during the use of the SWH.

IV. Results And Discussion

The experiments are done under clear sky and wind velocity varying between 0.1 and 2m/s. The interpretation of our results is divided into two parts first measure the temperature gradient in several positions (glass, absorber plate, the input and output of the collector) in our system Secondly is to study theoretically the influence of hot water withdrawn from storage tank on temperature of the absorber, the fluid and the storage tank. Figure 3 represents the theoretical and experimental developments of the global solar irradiance during the day. We observe that in the interval of 09h30 to 19h 30 both curves are almost similar. However, we observe the existence of a gap at the beginning and middle of the day probably due to the cloudy weather registered at this period of registration. The maximum values are reached between 12h and 14h.

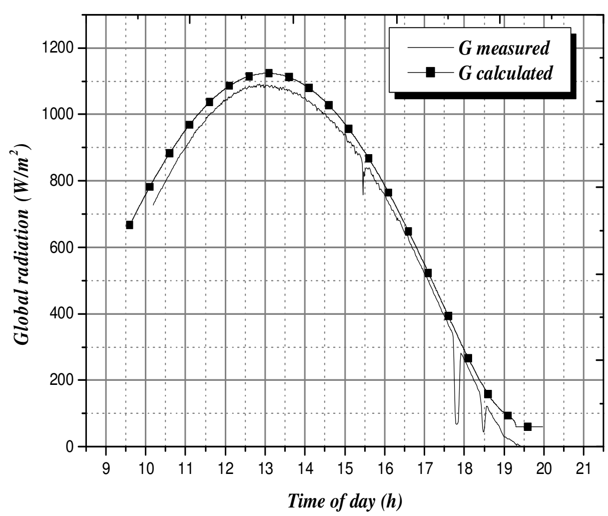


Figure 3. Evolution of global radiation on inclined

It was shown that before 8h it is not necessary to study the behaviour of the collector and the required energy serves essentially to warm up the solar collector, until reaching the temperature of 35°C [7].

Figure 4 shows the variation of inlet temperature and collector output at 9h until 20h30. But it should be noted that there are two distinct phases: First stage starts at 9h to 17h. At this interval, the figure shows a temperature difference between input and sensor output. It varies from 20 ° C to 30 ° C at midday. This difference is due to the gain in energy and delivered to water. In this lap of time the maximum values are attained between 14h and 16h, which mean that the collector presents an inertia effect. In the second phase begins at 17h and there the two curves are almost superposed because of the low energy difference between input and output of the sensor caused by the low absorbed radiations in this period.

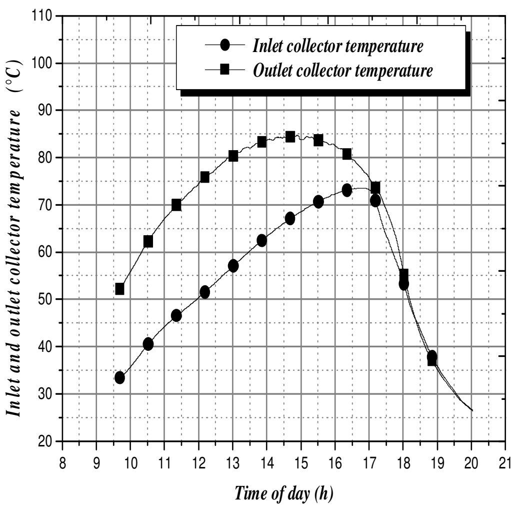


Figure 4. Evolution of Temperature measured of outlet and inlet collector

Figure 5 presents the temperature variation of the upper and lower glass sides and ambient temperature. The three curves have uniform allure reaching the maximum around 14 h 30 after what they decrease. There is a difference in temperature between the top lower sides of the glass of about 3 ° C. This difference grows to a maximum of 7 ° C around 14 h and the difference is zero at 19h. We have shown in Figure 6 a comparison of local temperatures. These are measured in the middle of two adjacent passages (y = 0), using thermocouples in the direction of the flow at: x = 0.467 m and x = 1.402 m. We note that the temperature of the top position is higher than the lower one with a difference of 25 ° C at 15h This difference is reported to that results depend on temperature of the fluid and the higher face is closer to the fluid than lower one.

Figure 7 shows the change in average temperature of the fluid with and without the extraction. We register three phases:

Phase 1: The first draw-off has been a small change in temperature of the fluid which is corroborated by a tiny difference between the two curves because of the continuous sunshine that causes a permanent heating.

Phase 2: We observe that in this phase is between 14 h and 17h30. The temperature drop to fluid temperature due to the second withdrawal because of the amount of water received by the network which caused a collapse in the heat sensor, leading to a decrease in the temperature of the second curve between 14 h and 15 h despite the insignificant increase in temperature after the scheduled aroused.

Phase 3: We notice a superposition of the two curves which indicates no significant change in the temperature of the fluid despite the third bailing caused by the inactivity of t

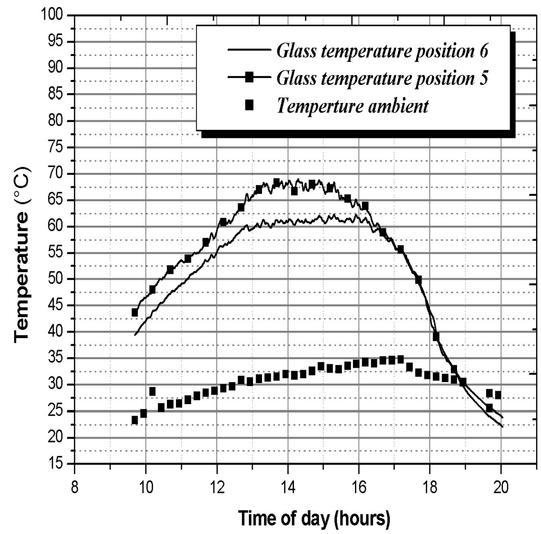


Figure 5. Measurement of the glass and ambient temperatures

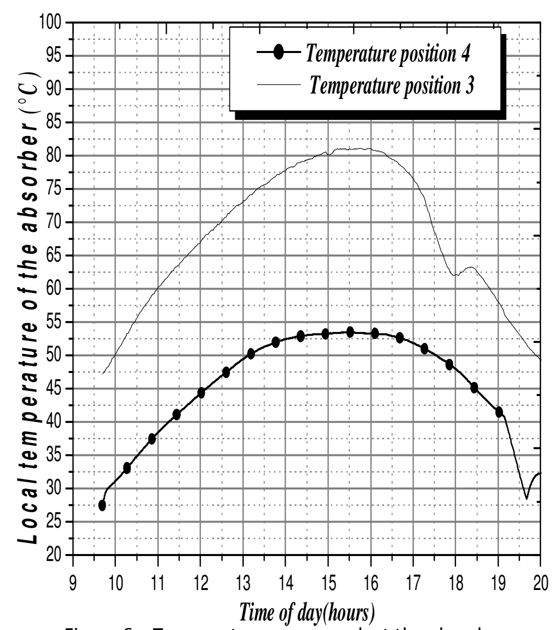


Figure 6. Temperature measured at the absorber

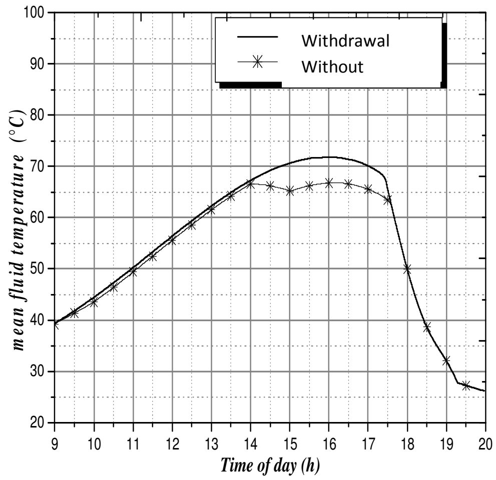


Figure 7. Variation of the average temperature of the fluid with and without water extraction

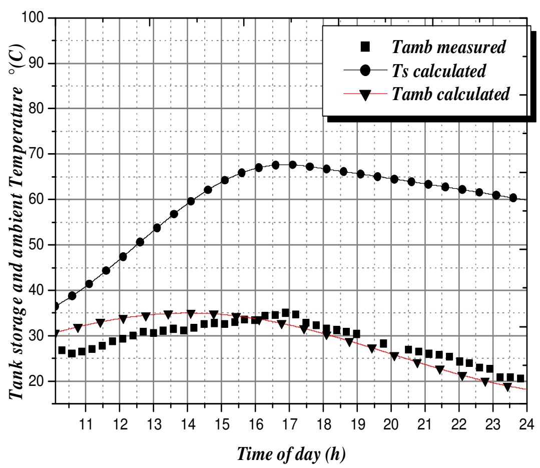


Figure 8. Variation of ambient and storage temperatures

We have shown in figure 8 changes in storage temperature. The curve shows a rapid rise between 10h and 16h due to the important radiations received by the tank which can be stored and then transferred to stored water. As demonstrated by the difference in temperature measured in the range of times cited above. After 16h, the flux received by the solar system register an important decrease; however the temperature of the stored water in the tank is still important with a small decrease less than 10°C after 6hours during the lap time of 18h-24h.

The calculated efficiency of the presented system using equation 6 and the different registered temperatures has given a value of: 32.89%.

V. Conclusions

This study was mainly divided into two parts. Regarding the first, this study focused on testing a solar water heater located in the city of Adrar. The experimental results were reasonably well, it gave an idea about the evolution of the temperature through the different components of solar water heater and presented the effectiveness and performance of each part. In second part, we focused our work on the theoretical study to determine the influence on water temperatures of the storage tank extraction called in the study withdrawal and to compare the results with and without water extraction. A low amelioration in the results at high radiations period was registered.

Nomenclature

A_c area of collector, m^2
C_P specific heat capacity, J/kg.°C
D diameter, m
F_C collector efficiency factor
F_R collector heat removal factor
$h_{1....6}$ the different heights of solar water heater
H_f total force due load losses in the system, m
h_t driving force generated by the collector , m
L length , m
M mass of water stored in the tank, Kg
n_p passage number
P pressure , N/m^2
Q_u heat gained in the collectors, W
S curvilinear abscissa, m
t time, s
T temperature, °C
T_a ambiant temperature, °C
T_s tank storage temperature, °C
u flow velocity of the fluid, m/s
U_L coefficient of thermal losses, W/m^2°C
W_{Wt} thermal capacity of water stored in the tank, J/°C
ν kinematic viscosity of the fluid
$(\alpha\tau)_{eff}$ effective transmittance-absorptance product
ρ density, Kg/m^3
$\eta_{c.e.s}$ the efficiency of a solar water heater
ζ_c singular pressure loss coefficient for elbows
ζ_T singular pressure loss coefficient for branch tee

indices
cc tank-collector
cv tank
m average
p passage

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