EXPERIMENTATION OF A SOLAR WATER HEATER WITH INTEGRATED STORAGE TANK

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ABSTRACT

An integrated collector storage (ICS) solar water heater was constructed in 2004 and studied its optical and thermal performance. It was revealed that it has some thermal shortcomings of thermal performances. The ICS system consists of one cylindrical horizontal tank properly mounted in a stationary symmetrical Compound Parabolic Concentrating (CPC) reflector trough. The main objective was to delimit the causes of these deficiencies and trying to diagnose them. A rigorous experimentation of the solar water heater has been done over its daily energetic output as well as the evolution of the nocturnal thermal losses. In fact, three successive days, including nights, of operation have permitted to obtain diagrams describing the variations of mean temperature in the tank and the thermal loss coefficient during night of our installation. The experimental results, compared with those obtained by simulation, showed a perfecting of thermal performances of system which approach from those of other models introduced on the international market.

Keywords: solar water heater, integrated collector storage, thermal performances, thermal losses.

INTRODUCTION

The increasing price of fossil fuels and awareness of environmental issues have caused growing interest towards renewable energy. In the past 20 years, interest has been growing to adopt new methodologies to utilize effectively renewable sources of energy. Free, clean and intermittent, solar energy is the greatest hope for an inexhaustible energy source in particular for the countries equipped with a strong sunning such as Tunisia.
[Didier 2007] shows that the feasibility of using low cost solar collection and storage technology to provide energy for residential units is investigated. Solar energy has known a tremendous progression in his use in the field of heating especially the solar water heater.

Solar water heating in the low-temperature range (40–70 °C) can be achieved by Flat Plate Thermosiphonic Units (FPTU) and Integrated Collector Storage (ICS) units, as well. These solar devices cover domestic needs of hot water of about 100–200 l per day [Tripanagnostopoulos 2007]**.**

In separated storage systems with forced circulation, heat transfer fluid is forced through the collector either by mechanical means or by externally generated pressure. His major disadvantage is that it uses electrical energy which is expensive.

Worldwide, more than 90% of all solar domestic water heating system is based on thermosiphonic principle.

Nomenclature

A_{ap}	aperture area of the system (m^2)
A_c	absorber area (m^2)
$C_{p,w}$	water specific heat (kJ kg^{-1} K^{-1})
CPC	compound parabolic collector (-)
CR	concentration ratio (-)
D_t	cylindrical storage tank diameter (m)
G	total incoming solar radiation intensity on aperture area (Wm^{-2})
Q_a	absorbed heat on system aperture (J)
Q_p	total heat lost (J)
Q_u	useful heat (J)
M_w	water mass in the storage tank (kg)
Ta;m	mean ambient temperature (°C)
Ti;m	Initial mean water temperature in the storage tank (°C)
$T_{f,m}$	final mean water temperature in the storage tank (°C)
T_m	medium water temperature in the storage tank (°C)
Us	thermal loss coefficient during the night ($W.K^{-1}$)
V_T	storage tank volume (m^3)
Δt	time interval (s)

Greek symbols

η	mean daily efficiency
ρ	water density ($kg.m^{-3}$)
θ θ	acceptance angle

These systems use only density changes of heat transfer fluid to achieve circulation between collector and storage. They supply hot water at a temperature of about 60°C and consist of a collector, storage tank, and connecting pipes. The main advantage of the FPTU units is their ability to preserve effectively the temperature of the stored water.

The integrated collector storage (ICS) systems are the simplest type solar water heaters that can be used for the supply of hot water for domestic purposes, as alternative devices to the well known flat plate thermosiphonic units (FPTU).

This type is a direct heating solar system [Gertos 2008]. The service water lies in direct contact to the tank surfaces and heated by. The ICS heaters are a popular, inexpensive and a maintenance-free means of solar water heating. They have more sophisticated counterparts because of design simplicity and lower cost**.**

The earliest evidence of their deployment dates back to the late 19th century. These systems consist of one or more water storage tanks which perform dual function of absorbing solar radiation and preserving heat of water. They are suitable for direct connection to the water mains and can be effectively used in combination with curved reflectors. Thermal protection of storage tanks is less effective in ICS systems compared to FPTU systems and several methods are suggested to keep water temperature at a satisfactory level. Among them, the use of a selective absorber reduces radiation thermal losses and double glazing, transparent insulation and inverted or evacuated absorber to suppress convection thermal losses.

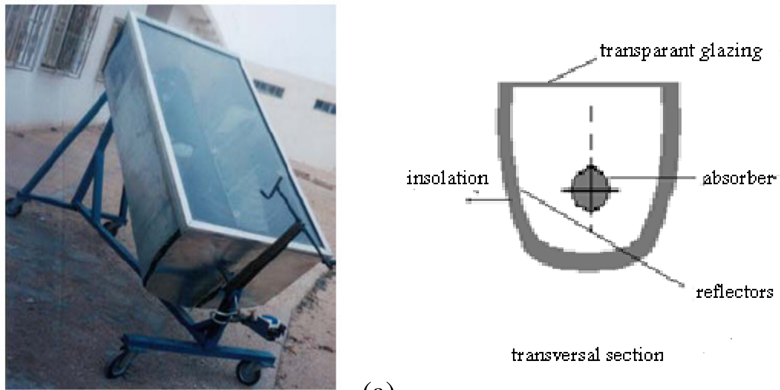
Thermal performance of ICS systems during both day and night depends on the design principles and the used materials, as well as the weather conditions. The improvement of the thermal

performance of ICS systems is a long time research activity where several new systems, based on specific design principles were proposed.
In the literature, few works are referred to ICS systems with cylindrical water storage tanks mounted in curved reflector troughs [Varghese 2007]. The use of compound parabolic collector (CPC) symmetric reflectors can result in ICS solar systems with effective water heating by using the non-uniform distribution of solar radiation on the cylindrical absorber surface. In most of the above systems the part of the cylindrical absorber is thermally insulated in order to reduce storage tank thermal losses.
The concentration ratio of CPC solar collectors depends on the acceptance angle of the reflectors and in the case of $\theta = 47°$ the reflectors can be stationary with concentration ratio CR= 2.5. These reflectors contribute to the collection of a significant part of the diffuse solar radiation, which corresponds to 1/CR [Tripanagnostopoulos 2004] . CPC type solar collectors with an acceptance angle in the range of $60° < \theta < 90°$ are more practical and combine effective collection of the diffuse solar radiation, moderate system depth and satisfactory concentration ratio.
In order to cover the demand of 100-200l of hot water, Tripanagnostopoulos [Tripanagnostopoulos 2004] proposed an ICS system mounted in an asymmetric CPC reflector, which the diameter of the cylindrical tank $D_t = 0.32$m. The CPC reflector depends on the acceptance angle and the truncation level.

The purpose of this study is to carry out a rigorous experimentation of the solar water heater consisting of ICS system with single storage tank as an absorber mounting inside curved reflector trough has been carried out, by following its daily energetic output as well as the evolution of the nocturnal thermal losses, in order to look for thermal performances of this system.

DESIGN CONCEPTS OF THE CPC SOLAR WATER HEATER

It consists of a solar-water heater with integrated storage and without a heat exchanger, made up of a cylindrical stainless tank (inert stainless steel with respect to domestic water) of 95 liters. This tank is placed inside a thermally insulated trunk and with a reflector made up of three parabolic branches. The unit is closed by an opaque and selective glass whose surface is 1.92 m^2 [Yousfi 2008]. The storage tank or the absorber is placed in the focal line of a concentrated system or solar collector by means of a support allowing it a free rotation around the axis of the absorber and a variable slope of the unit. Thanks to this system of support, it is possible to choose a horizontal or tilted position water-heater according to the sunning and the consumption of hot water. The surface of concentration of the solar rays (A_c) is 1.4 m^2 and collecting surfaces (A_{ap}) is 3.7 m2 hat gives a concentration factor equal to 2.6.



(a) (b)

Figure. 1**.** (a) Model of CPC system, (b) cross section model of CPC system

The thermal tests of performances of this solar-water heater will be carried out according to the European norms EN 12976.

Assembly and emplacement of the collector

The system is titled with a fixed angle of 36°. It should be noted that according to the European norm EN 12976 the collector must be submitted for testing with slopes such as the factor of angle of incidence of the collector varies from less than 2 % compared to the normal incidence. The thermal performances of the collector will be judged according to three different orientations: South-east, South and South-west. Another approach consists in moving the collector in order to follow the azimuth trajectory of the sun thanks to a manual system what allows a comparative study of the thermal efficiency of the fixed position and that of the mobile position.
The framework of assembly of the collector should not in no case block the opening of the sensor and does not have to affect the back or side insulation [Sutter]. A metal support of fixing to open sky is used in order to make it possible to the air to circulate freely all around the parts of the collector. The collector must be assembled so that its lower edge is located at least at 0.5 m above the surface of the ground.
The performances of many collectors are sensitive to the air velocities. Indeed, in order to ensure a maximum reproducibility of the results, the collector is assembled so that the air can circulate freely above the aperture surface, the back part and the coatings.

Instrumentation

Thanks to a local weather station equipped with a unit of data acquisition Testo 950, the different measurements of various climatic parameters: wind speed, ambient temperature and solar flow were directly taken on a computer.
For analysis and testing purpose, K-thermocouples were located at different positions in the heater. According to this norm, the thermocouples should not be assembled to more than 200 mm of the aperture surface of the collector.
Four measuring of temperature are necessary for the collector tests. They are the temperatures of water at the inlet, the medium and the outlet side of the tank as well as the ambient temperature.

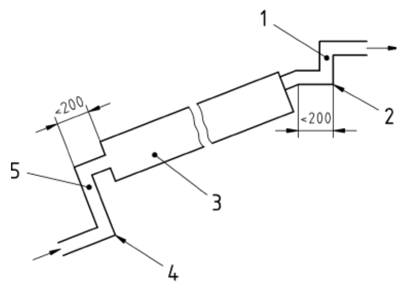


Figure. 2. Assembly of the thermocouples

1- Ts thermocouple
2- Elbow of the tube
3- Solar collector
4- Elbow of the tube
5- Te thermocouple

This type of compact solar water heater is simple in design, low in cost, easy in operation and maintenance, easy to install and of high efficiency compared to flat plate collectors and tubular type ICS systems.

SETTING PROCEDURE

The measurements were done under clear sky four days. According the norm, a maximum temperature all about 80°C and maximum $\frac{\Delta T_{m,d}}{G_m}$ (standardized profit) at least 0.09 are recommended. For every orientation of the collector, the measurements begin at 6h until 18h by taking every 30 minutes the values of the inlet, medium and of outlet temperatures of the tank.

In order to estimate overall loss coefficient during the night and to forward after its variation with the wind velocity, tank's medium temperature difference and the ambient temperature, successive three nights by taking the different temperatures every 30 minutes.

These parameters were measured simultaneously under steady-state conditions.

The useful heat received by the water is calculated by the equation [CHAOUACHI 2006]:

$$Qu = M_w \, C_{pw} \, (T_{fm} - T_{im})$$

In the permanent regime, the useful heat can be calculated as the difference between the total heat absorbed Qa by the system and the lost one Qp:

$$Qu = Q_a - Q_p$$

The mean ambient temperature is determined as:

$$T_m = \frac{T_e + T_{mi} + T_s}{3}$$

Where Te, T_{mi}, Ts are respectively the down, the middle and the up temperatures in the tank.

The calculation of the mean daily efficiency of each system is based on the formula [Hamdi 2005]:

$$\eta = \frac{Qu}{C.Qa}$$

The total solar radiation intercepted by the aperture surface A_c of the system during the interval Δt from the start point t_i in the morning to final point t_f in the afternoon is:

$$Qa = Ac\int_{ti}^{tf} G(t).dt$$

As the coefficient U_s is extracted by operating during the night as a system behavior from the afternoon until the next morning, it will not be affected by solar radiation. U_s is calculated by the relation:

$$U_s = \frac{\rho C_{pw} Vt}{\Delta t} \ln \frac{(T_{im} - T_{am})}{T_{fm} - T_{am})}$$

Where V_t is the water volume of the system storage, $\rho * C_{p,w}$ =4180 kJ m^{-3} $K^{-1}$for water. So, the heat lost by the whole system is written as

$$Q_p = Aa\ Up(Tm - Tam)\Delta t$$

And T_m is the mean temperature

$$T_m = \frac{T_{f,m} + T_{i,m}}{2}$$

EXPERIMENTAL RESULTS

The results of the few characteristic experiments among the plenty of the conducted tests have been presented as below.

Temperature's evolution in the storage tank

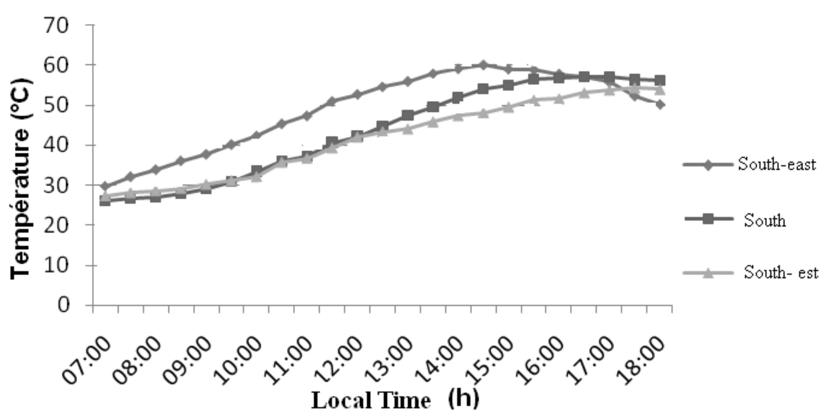


Figure. 4. Variation of mean water temperature for different orientations

The measurements were done on 5th Mai 2008 which corresponds to a clear sky day with a medium wind speed. After making a comparison between the three orientations, we concluded that the South-East orientation is the best. At this orientation, the maximum mean temperature reaches 54°C at 15:00. This can be explained by the fact that, in this moment, the solar radiations come directly and perpendicularly to the aperture surface so the temperature will be increasing.

Evolution of the thermal efficiency

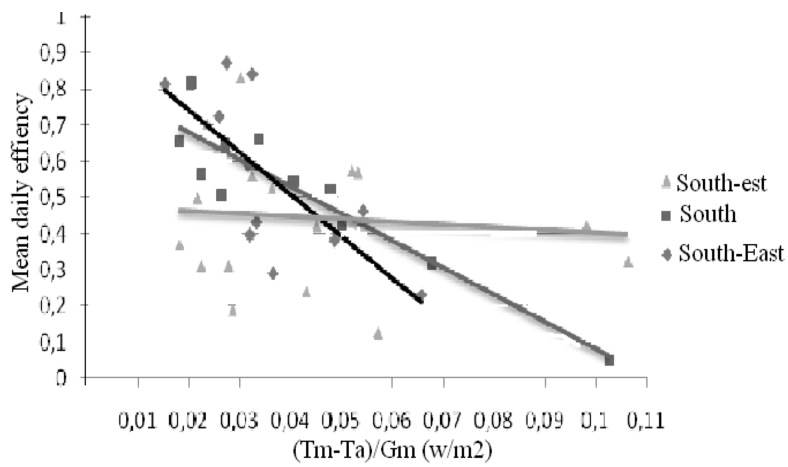


Figure. 5. Evolution of thermal efficiency for different orientations

This figure shows the evolution of the thermal efficiency for different orientations. For the south-east orientation, hot water can be obtained from the morning until mid-day. For the south orientation, the necessity for hot water is covered from mid-day until 16:00. In order to obtain hot water in the evening, the south- west will be suitable.

As remarked, the thermal efficiency is a linear function with the $\frac{\Delta T_{m,d}}{G_m}$. In the beginning of the day and for weak solar radiations, the thermal efficiency can reache 80% and decreases until 20%. This can be explained by the difference between the mean temperature of tank and the ambient temperature is bigger as the thermal losses are bigger.

The evolution of thermal loss coefficient

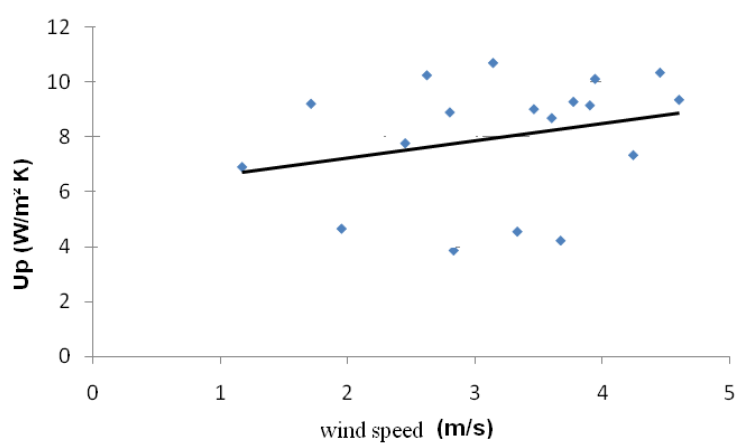


Figure. 6 . The influence of the wind speed on the evolution of thermal loss coefficient

The thermal loss coefficient increases with the wind speed. A very high speedy wind increases the thermal loss through the solar collector. It is a characteristic parameter for the solar heater. This irregular points' distribution can be explained by the fact of the instantaneous sky clearness as well as the weather conditions.

The thermal loss during the night

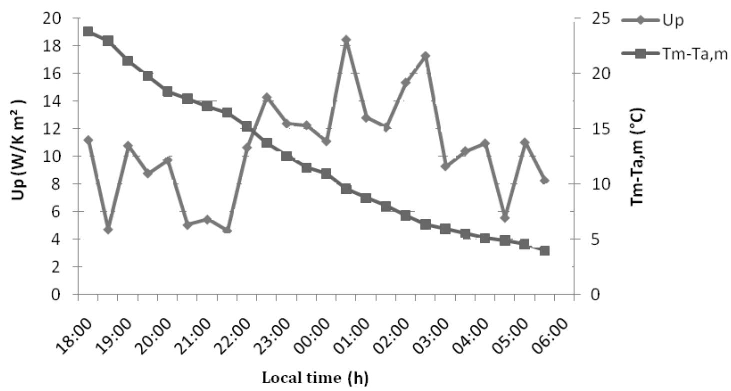


Figure 7. Evolution of thermal loss coefficient and $(T_m - T_{a,m})$ during the night.

The overall loss coefficient of the system presents several fluctuations. We notice that from midnight, the loss coefficient U_p is maximum (19 W/K.m^2) between 1h and 4h. By the night hours, the overall heat loss coefficient is increasing where the temperature difference is decreasing. This is can be explained by the fact the outlet temperature is decreasing during the night; so, the difference between it and the ambient temperature is decreasing, too.

In addition, all this can be as a result of the effect of humidity on the collector's glass and coatings during this period.

CONCLUSION

After an experimental, theoretical study, it's clear that the solar water heater with integrated storage tank, designed and constructed in National engineering school in Gabes, Tunisia, is a performing, profitable heater in comparison with the others existing in the world. In fact, it can provide hot water at a temperature of 60°C, a quotient of $\frac{\Delta T_{m,d}}{G_m}$ of 0.1 which are close to models introduced in the market. The improvements of the thermal performance occurred in the system are caused by an improvement of insulation, black and selective glass and a black painted absorber.

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