Le 2ème Séminaire International sur les Energies Nouvelles et Renouvelables
The 2nd International Seminar on New and Renewable Energies
Unité de Recherche Appliquée en Energies Renouvelables,
Ghardaïa – Algérie 15, 16 et 17 Octobre 2012

Experimental Study of an ICS Solar Water Heater with CPC Reflectors in Ghardaïa

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***Abstract*— Integrated collector storage (ICS) solar water heater with stationary compound parabolic concentrating (CPC) reflectors is designed at Ghardaïa and test results are presented. The system consists of one cylindrical horizontal tank properly mounted in a stationary symmetrical compound parabolic concentrating reflector through. The suggested designs aim to achieve low cost domestic solar water heater, we used high emittance absorber surface, low cost curved reflectors and single glass cover, the underside of the reflector is covered in insulation to reduce heat losses to the ambient. Experimental results are used to determine the maximum useful efficiency and thermal losses during the night.**

***Keywords*— Include at least 5 keywords or phrases**

I. Introduction

The flat plate thermosiphonic units (FPTU) and Integrated Collector Storage (ICS) systems are solar water heaters that cover about 100-200 litres per day of the domestic hot water needs in the low-temperature range (40-70 °C). ICS solar water heaters are not frequently used systems because of storage tank high thermal losses during the night, although they are cheaper and more aesthetically attractive than the FPTU in building integration [1]. The cylindrical storage tank of ICS system can be mounted in a horizontal or vertical position inside the collector trough. Many researchers have studied the thermal performance of several types of ICS systems. Tripanagnostopoulos et al. [2] investigated some ICS systems which consisted of single and double cylindrical tanks horizontally placed in truncated CPC reflector troughs in order to achieve efficient, practical and low cost solar water heater.

II. Description of the System

The CPC type reflector is the ideal non-imaging light collector which allows useful concentration without tracking and collects direct and substantial fraction of diffuse radiation. Only two parameters are needed to specify the complete geometry of a fully developed (i.e., non-truncated) CPC namely, the radius R of the cylindrical absorber and the acceptance angle, θ_c. Any solar radiation incidence within the acceptance angle, with the help of parabolic reflector can reach the absorber. Based on the above referenced parameters R and θ_c, the analytic equations of the reflector parts, based on the rectangular axis system O, x, y, are as follows [3]:

$$x = R\sin(\varphi) - \rho\cos(\varphi)$$
$$y = -R\cos(\varphi) - \rho\sin(\varphi) \qquad (1)$$

With

$$\rho(\varphi) = R\varphi \qquad for \qquad |\varphi| \le \theta_c + \pi/2$$
$$and$$
$$\rho(\varphi) = R\,\frac{\varphi + \theta_c + (\pi/2) - \cos(\varphi - \theta_c)}{1 + \sin(\varphi - \theta_c)} \qquad (2)$$
$$for \qquad \theta_c + \pi/2 < \varphi < -\theta_c + 3\pi/2$$

The geometric concentration ratio is defined as follows:

$$C_a = A_c / A_r \qquad (3)$$

Where Ac is the aperture surface area of the system and Ar is the cylindrical tank surface area
The basic design of the proposed ICS system is shown below in figure 1. The prototype consists of symmetrical CPC reflector whose line focus is a cylindrical tank of radius R. The tank is covered with a selective surface of high solar absorption and low thermal emission. A transparent cover may be fitted across the aperture of the concentrator to protect the reflecting film from deteriorating and to reduce the rate of heat loss from the absorber. The underside of the reflector is thermally insulated to reduce heat losses to the ambient temperature. The angle θ_c represents the acceptance angle. The prototype geometrical dimensions are length L and width 2w.

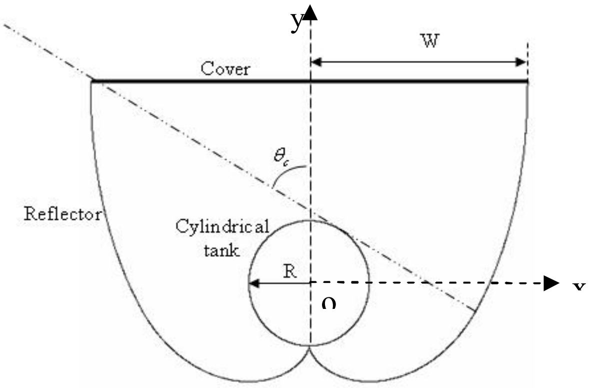

Fig. 1 Cross section of ICS system

The cylindrical storage tank has radius R = 0.2 m and length L = 1 m which gives a water storage volume Vt = 125 l. The design of the curved reflector parts was based on the acceptance angle θc = 90°, this gives longer operation time to the system, absorbing all the incoming solar radiation. We used polished stainless steel (reflectivity ρ= 0.68) to form the designed reflectors and the absorbing surface is painted matt black ($\alpha_r = 0.9$; ε_r=0.9).

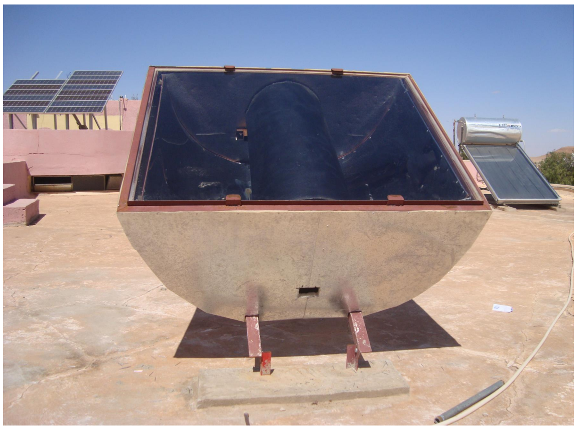

Fig. 2 view of experimental system

III. Experimental results

In this part, we have adopted the MUE 'maximum useful efficiency' formalism, developed by, [4] for the determination of the day time thermal (and optical) proprieties of this integrated collector storage with experimental temperatures. The MUE of such a system can be cast in a mathematical form which is similar to the familiar Hottel–Whillier–Bliss equation, [7] for a low-mass flat-plate collector, but where the variables take on time averaged values, specifically [5], In Eq.

$$\eta = \overline{K} F_E \eta_o - \frac{F_E U_L \left(\overline{T_f} - \overline{T_a}\right)}{\overline{I}} \tag{4}$$

In Eq. (4), T is the temperature of the water in storage, Ta is the ambient temperature and I is the irradiance on the aperture plane of the collector. ηo is the optical efficiency and U the heat loss coefficient of the collector–storage unit. K is the incidence angle modifier and FE is an enthalpy retrieval factor defined as:

$$F_E = \frac{M_w C_w}{M_w C_w + M_{cs} C_{cs}} \tag{5}$$

where M_w and C_w are, respectively, the mass and heat capacity of the water and Mcs and Ccs are the respective mass and heat capacity of the material from which the collector–storage unit is fabricated.

Most important of all, the bars indicate time average over the daily heating period, from sunrise until the time the water reaches its maximum daily temperature. That is to say, we use daily average, rather than instantaneous, values of the variables in Eq. (4). The bar over K indicates a daily energy average, which is fairly constant on a monthly basis, [5]. MUE is defined as:

$$\eta = \frac{M_w C_w \left(T_{\max} - T_{sunrise}\right)}{A_c \int I(t)dt} \tag{6}$$

Where Ac is the collector aperture area, and the integral is taken over the time from sunrise until the water reaches its maximum temperature. We remark that, in contrast to a semi-empirical test method that was subsequently developed for testing integrated collector–storage systems, [8, 9], the MUE method is not empirical, and in that all of its parameters have a clear physics-based interpretation. It follows directly the fundamental heat flow equation, as a consequence of the long relaxation time of the system, [5]. The results obtained by the application of the Eq. 4 are presented in Figure 3 and Figure 4.

In order to compute the night time heat loss coefficient, we use data between sunset and sunrise of the next day. For each 5 minutes, we calculate the difference between the mean water temperature and ambient, then averaging the results over Δt= tsunrise-tsunset. This average, (T_f-T_a) was then divided into the temperature difference, (T_i-T_f), between the water's initial temperature and final temperature during this time. The heat loss coefficient can be calculated as follow,[4]:

$$U_L = \frac{(M_w C_w + M_{cs} C_{cs})(T_i - T_f)}{A \Delta t (T_f - T_a)} \quad (7)$$

The table 1 summarized results of the maximum useful efficiency and heat loss coefficient during the night respectively. The result show that the system has a satisfactory efficiency

TABLE I
EXPERIMENTAL RESULTS OF THE SYSTEM

Period	Equation of the storage internal energy	MUE equation
19/11/10 to 28/12/10	$MC\frac{\partial T_f}{\partial t} = -5.36\langle \overline{T} - Ta \rangle$ ULAC=5.36 (W/°C) UL =6.306 (W/m2°C)	$\eta = 0.5732 - 5{,}319(\overline{T_f} - \overline{T_a})/\overline{I}$ $\overline{K} F_E \eta_0 = 0.5732$ $F_E U_L$ = 5,319 W/m²°C F_E = 0.979 U_L = 5.433 W/m²°C

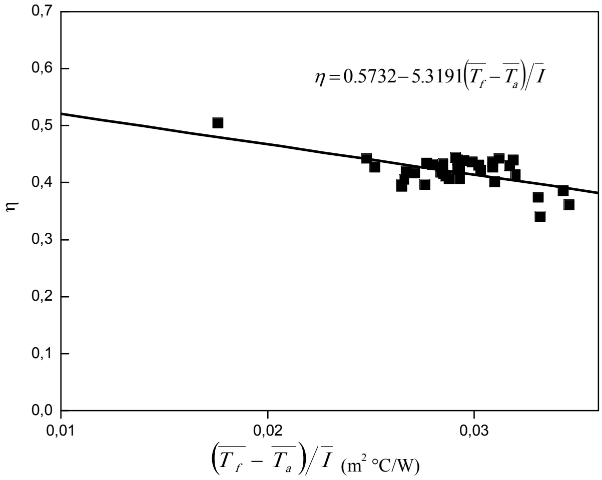

Fig. 3 Characteristic graph of the Maximum useful efficiency of the system

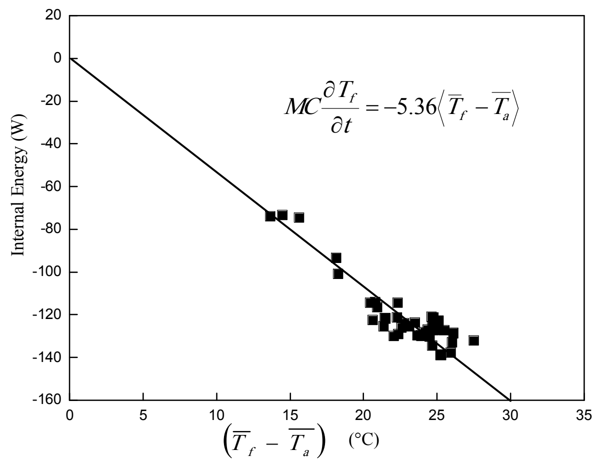

Fig. 4 Variation of the internal energy at night as function of $(\overline{T_f} - \overline{T_a})$

IV. CONCLUSIONS

Integrated collector storage solar water heater based on vertical cylindrical storage tank and reflector of CPC were designed, constructed and tested. The MUE 'maximum useful efficiency' and thermal losses of the system was computed by using experimental data, it show satisfactory results. This domestic SWH system with a capacity of 120 liter per day is capable of achieving significant energy saving in hot climate countries particularly in the present situation of acute energy shortage and most suitable to cater the needs of family of four persons.

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