Experimental Study of a Flat Plate Solar Collector Equipped with Concentrators

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Abstract- The present study focuses on the improvement of the performance of a flat plate air solar collector, fitted with mini concentrators at the absorber.
A literature review of previous work on flat plate air solar collectors allowed us to focus our research on aspects not yet covered by the literature.

The purpose of this work is to study the evolution of temperature profiles for different components of the solar collector for the case of free and forced convection.

Keywords Flat plate air solar collector; Mini-concentrator; Temperature evolution.

1. Introduction

Flate plat Solar collectors are widely used in the design of greenhouses [1] - [2] or in houses and bulding to reduce energy consumption [3] - [4]. Other applications of these solar planar air collectors exist such as solar powered adsorption refrigeration system using flat plate solar collector [5].

The performance of a flat plate air solar collector can be improved by enhancing several intrinsic parameters of the collector itself. These may be of different types. There are parameters that are related to the parts making up the collector, i.e. the top [6] - [7] - [8] or the absorber [9] - [10] - [11] – [12], those related to the site where the solar collector is installed, like the solar irradiation [13] - [14], ambient temperature [15] or even the tilt angle of the solar collector [16] - [17] – [18] , and finally, those parameters that depend on the flow of the heat transfer fluid inside the collector, like the effect of free and forced convection [19], the influence of the flow rate or speed of the flowing fluid [20], and the fluid inlet temperature [21].

The output temperature of a classical plane air solar collector does not exceed 80 °C. Different techniques have been used to increase that temperature. It has been suggested to add baffles within the test section where air flows in order to promote turbulence and improve the heat exchanges by convection between the absorber and the heat transfer fluid. With such a technique, the temperature can reach 100 °C. The mini cylindro-parabolic concentrators used in this study, which are implanted on the absorber, have a dual role. On the one hand, they play the classic role of baffles that are usually used to increase convection exchanges inside the solar collector; on the other hand, they concentrate and orient the infrared radiation towards the absorber. As a result, the temperature of the absorber increases considerably; it may exceed the value of 140 °C, in the month of May. Consequently, the air temperature at the outlet of the collector may exceed 120 °C.

Fig. 1. The solar collector studied

2. System of Equations

The improvement of the performance of the solar collector requires the prediction of the thermal losses that may take place. It is necessary to take into account the different heat exchanges when determining these losses:

$$Q_{perte} = Q_{conv} + Q_{cond} + Q_{ray} \tag{1}$$

Conduction losses are usually small compared to convection and radiation losses. In most analyses, these losses are often referred to as "Convection Losses".

$$Q_{cond} = \lambda_{cond} A_{abs} (T_{abs} - T_{amb}) \tag{2}$$

Convective losses are proportional to the absorbing surface of the solar collector and to the difference between the temperature of the solar collector surface and the ambient temperature. These losses are given by the formula:

$$Q_{conv} = \lambda_{conv} A_{abs} (T_{abs} - T_{amb}) \tag{3}$$

Radiation heat loss is important in the case of receivers operating at temperatures slightly above ambient temperature; it becomes more dominant for collectors operating at high temperatures. The radiation heat loss rate is proportional to the emittance of the surface and the difference of the temperatures T_{abs} and T_{sky} each raised to the fourth power:

$$Q_{rad} = \xi_{abs} \sigma A_{abs} \left({T_{abs}}^4 - {T_{sky}}^4 \right) \tag{4}$$

Or :

ξ_{abs}: Emissivity factor of the absorber.

σ : Stefan-Boltzmann's constant

T_{sky}: Sky temperature

3. Methodology and Procedures

The different series of experiments were carried out in an open site, far from obstacles, in order to avoid the shadowing effects.

Various measurement campaigns were conducted, depending on the solar irradiation, during the day. The measurements were carried out in 30-minute intervals.

Measurements of the different quantities were carried out between 09.00 a.m. and 4.00 p.m. This period of time is more than sufficient for taking the measurements because during that period of time the solar irradiation varies considerably. The measurements were taken on Monday, 02 May, 2016. The different quantities to be measured are given in the following table, where the number of measurement points is given for each quantity.

Table 1. Measured quantities

Measured quantities	*Number of measurement points*
Ambient temperature	01
Solar irradiation	01
Temperature of glazing	01
Temperature of absorber	15
Air temperature inside the collector	15
Air temperature at the outlet of the collector	01

The temperature of the absorber and that of air inside the collector for a given reading are, respectively, the average temperature calculated on the basis of fifteen local values, spread over the entire surface of the absorber, and the average temperature at various points of air between the glazing and the absorber, inside the collector.

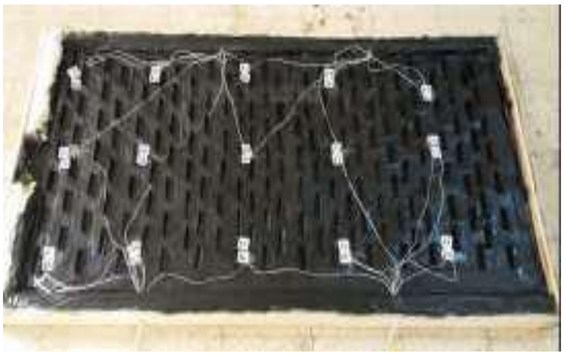

Fig. 2. Locations of thermocouples at the absorber and in the air inside the collector.

4. Results and Discussions

Figure 3 illustrates the evolution of solar irradiation. It is significant between 10 a.m. and 1 p.m., with values varying between 900 W/m2 and 1050 W/m2. The irradiation drops sharply from 900 W/m2 to 650 W/m2 between 1 p.m. and 2 p.m.

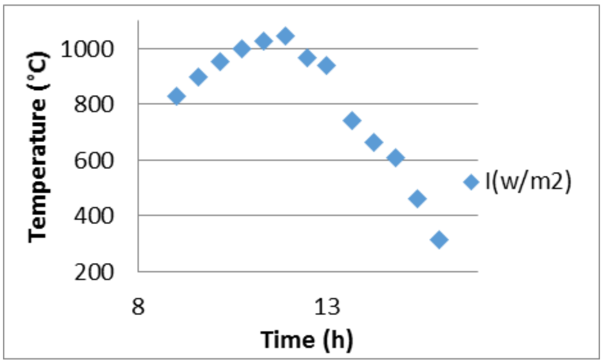

Fig. 3. Evolution of solar irradiation

Figure 4 shows the variation of the absorber's temperature; the free and forced convections are compared. It can be seen that the difference between the two convections is appreciable in the time interval between 11 a.m. and 4 p.m. An average temperature decrease of 8 °C is observed for the forced convection in the same time interval.

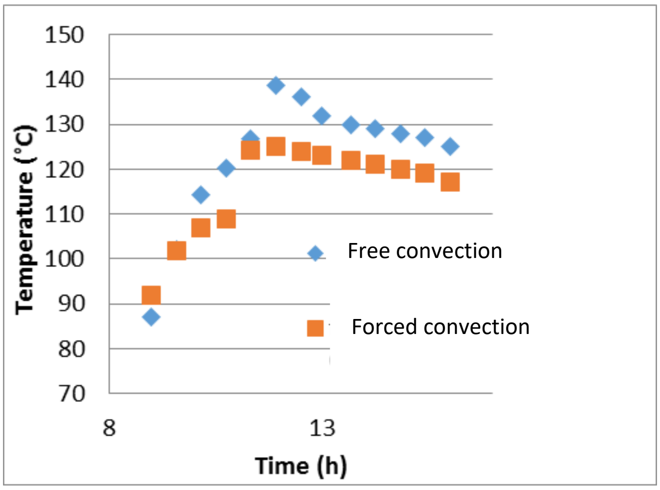

Fig. 4. Evolution of the absorber's temperature (free and forced convection)

Figure 5 shows the variation of the temperature of air inside the solar collector for the case of free and forced convection. The minimum air temperature is above 80 °C for both configurations. It is found that the difference between the two configurations is small, and the temperature decreases by 4 °C on average, for the case of forced convection.

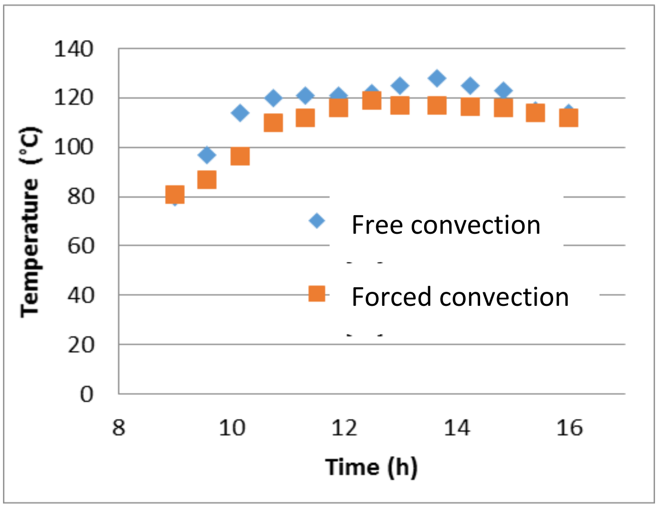

Fig. 5. Evolution of air temperature (free and forced convection)

5. Conclusions

This work is very important as it represents an important contribution to the improvement of the performance of a planar solar collector.

The temperature of the absorber in the case of free convection always remains the highest.

It reaches 140 °C (mean temperature of the absorber), and in some regions this temperature can reach 147 °C.

The air temperatures inside the solar collector, in the two cases of free and forced convection, are almost identical; they both exceed 120 °C at 12 a.m. These temperatures are above 100 °C for almost the entire measurement time interval. The air temperature inside the collector is always lower than that of the absorber (for free and forced convection); it remains almost always above 100 °C.

In the two cases of free and forced convection, the air temperature at the outlet is quite different from that inside the collector. By putting a double glazing or creating vacuum inside the collector, these losses should be considerably limited and reduced. This should improve the output temperature even more.

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