Journal of Environmental Science and Engineering, 5 (2011) 1026-1030

Theoretical and Experimental Study of a Cylindro-Parabolic Solar Collector

Y. Boukhchana, A. Fellah and A. Ben Brahim

Engineers National School, University of Gabes, Gabes 6072, Tunisia

Received: January 15, 2011 / Accepted: April 25, 2011 / Published: August 20, 2011.

Abstract: This article outlines the theoretical and experimental performance studies of a cylindro-parabolic solar collector. The theoretical study consists on the establishment, through mass and energy balances, of a mathematical model to control the exiting temperature of the heating fluid as well as the temperatures of the absorber and the glass. The experimental level investigates the influence of the solar absorber tube diameter on the performances of the driving device. Several experiments were made in order to know the possibility to reach temperatures being able to ensure for example the ammonia vaporization in the generator of a solar absorption refrigeration system. These experiments were carried out under various operating and climatic conditions. The results are presented and discussed.

Key words: Solar energy, experimentation, absorption refrigeration, solar collector.

1. Introduction

Ever increasing attention is focused on the research field of renewable energies. This occurs for several reasons which can be mainly summarized, on one hand, by the increased growth of the world demand for conventional energy and its provisioning problems, and on the other hand, by the increase of its cost and the eventually caused pollution. Therefore solar energy appears to be the energy of the future [1, 2]. It will have a great role to play while it provides a way to set up a decentralized and energetically autonomous cold chain [3].

One of the advantages of this energy is its aptitude to be transformed into heat. The solar collector constitutes the major component of any solar system [4]. For the collection of energy there are two techniques [4, 5]. The first is the flat-plate collectors used for the transformation of solar energy into thermal energy directly useful. However, the use and the applicability of this type of solar collector are very restricted. It presents moreover a certain number of disadvantages and the manufacturers were brought to design other more profitable models of configuration using the principle of concentration.

The cylindro-parabolic solar concentrator is one of the concentrators often used with systems for solar absorption refrigeration that can achieve temperatures over than 100 °C [6, 7]. It consists in a module having a parabolic reflectors laid out in a cylindrical way. This geometry enables it to focus incident solar radiation, according to a linear receiving tube, called solar absorber in which the heating fluid circulates. This tube is, often, covered with an air empty glass tube to reduce heat losses [4].

The principal objective of this work is to present the theoretical and experimental studies of a cylindro-parabolic solar collector. This prototype is an experimental ammonia-water system which has been designed and modeling in dynamic state, in the Applied Thermodynamics Research Unit in the Engineers National School of Gabes in Tunisia [8, 9]. For the theoretical study, a mathematical model which combines mass and energy balances for the

Corresponding author: Y. Boukhchana, Ph.D., main research field: absorption refrigeration system. E-mail: Yasmine_Boukhchana@yahoo.fr.

cylindro-parabolic collector is developed to control the output temperature of fluid as well as the absorber and glass temperatures. And at the experimental level, the influence of the absorber tube diameter of the collector on the performances of the driving device which made object of investigation. For that, several experiments were made in order to know the possibility to reach temperatures being able to ensure the ammonia vaporization in the generator. These experiments were carried out under various operating and climatic conditions.

2. Theoretical Study of the Cylindro-Parabolic Concentrator

2.1 Presentation of the Solar Collector

It is a parabolic stainless reflector and Plexiglas panels (Fig. 1). The collector is orientated in a north-south direction and tracking the sun from east to west. The mirror surface of 0.92 m^2 focuses the sun radiation onto a receiver tube, called a solar absorber, located along the focal line of reflector length of 4.1 m. The absorbent tube is made of copper covered with a selective layer. It is surrounded by a transparent glass envelope. In Table 1 are noted the characteristics of the various elements.

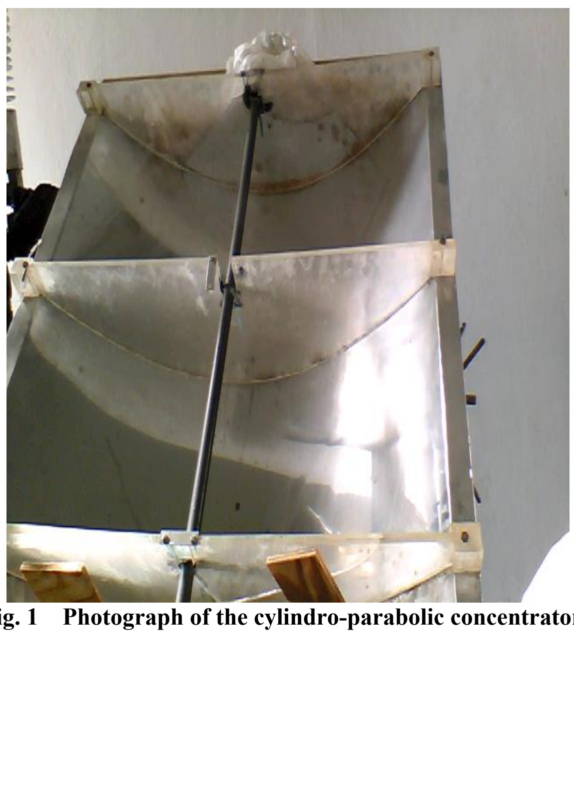

Fig. 1 Photograph of the cylindro-parabolic concentrator.

2.2 Mathematical Model

The solar absorber receives the total solar radiation expressed as:

$$G^* = D^* + S^* \quad (1)$$

Where, S^* and D^* are the direct and the diffuse solar radiations expressed as follow [8]:

$$S^* = 1370\exp\left[\frac{-F}{0.9+9.4\sin\left(h_{sun}\right)}\right]\sin\left(h_{sun}\right) \quad (2)$$

$$D^* = 54.8\sqrt{\sin\left(h_{sun}\right)}\left[F\text{-}0.5\text{-}\sqrt{\sin\left(h_{sun}\right)}\right] \quad (3)$$

With F is factor of disorder of Linke and h_{sun} is height of the sun.

Taking into account the thermal losses, the energy balances on the solar absorber and the glass cover are given by:

$$\left(MC\right)_{Abs}\frac{dT_{Abs}}{dt} = \rho_{co}\tau_v\alpha_{Abs}G^*C_gA_{Abs} - C_{app}A_{Abs}\left(T_{Abs}-T_a\right) - U_{Abs\text{-}fl}A_{Abs}\left(T_{Abs}-T_{fl}\right) \quad (4)$$

$$\left(MC\right)_v\frac{dT_v}{dt} = AG^*\rho\alpha_v + \varepsilon_v\sigma A_{Abs}\left(T_{Abs}^4 - T_{fl}^4\right) + h'_{cn}A_v\left(T_{Abs}-T_v\right) - \varepsilon_v\sigma A_v\left(T_v^4 - T_a^4\right) - h''_{cn}A_v\left(T_v - T_a\right) \quad (5)$$

In which the geometrical concentration (C_g) and overall heat loss coefficient (C_{app}) have as the respective expressions [8, 10]:

$$C_g = \frac{A_0}{A_{Abs}} \quad (6)$$

$$C_{app} = h_{rd} + h_{cn} = \frac{1}{\dfrac{1}{h'_{cn}+h'_{rd}} + \dfrac{1}{h''_{rd}+h''_{cf}}} \quad (7)$$

Where, the internal and external irradiative and natural convective thermal conductance are given by the following relations:

$$h'_{rd} = \frac{\varepsilon_{Abs\text{-}v}\sigma\left(T_{Abs}^4 - T_v^4\right)}{T_{Abs}-T_v} \quad (8)$$

$$h'_{cn} = 3.30\,W/m^2\,°C \quad (9)$$

$$h''_{rd} = \frac{\varepsilon_v\sigma\left(T_v^4 - T_a^4\right)}{T_v - T_a} \quad (10)$$

$$\begin{aligned} h''_{cf} &= 7.5 + 4\times S && \text{Pour } 0 < S < 4\,m/s \\ h''_{cf} &= 7.3\times S^{0.8} && \text{Pour } 4 < S < 40\,m/s \end{aligned} \quad (11)$$

Mass and energy balances for the heating fluid in the solar collector are written as follow:

$$\frac{dM_{fl}^{Abs}}{dt} = \dot{M}_{in-Abs} - \dot{M}_{out-Abs} = V_{Abs}\frac{d\rho_{fl}^{Abs}\left(T_{fl}^{Abs}\right)}{dt} \quad (12)$$

Table 1 The cylindro-parabolic concentrator characteristic.

Component	Dimension (m)	Heat-transfer area (m^2)	Physical properties
Concentrator	W = 0.88 L = 1.04	0.92	p = 0.8
Solar absorber	L = 1.04 Φ_{in} = 0.0111 Φ_{ex} = 0.01465	A_{in} = 0.036 A_{ex} = 0.048	α = 0.95 ε = 0.95
Glass tube	L = 1.04 Φ_{in} = 0.0243 Φ_{ex} = 0.0283	A_{in} = 0.08 A_{ex} = 0.093	α = 0.1 τ = 0.8 ε = 0.1

$$\frac{d\left[M_{fl}^{Abs}H\left(T_{fl}^{Abs}\right)\right]}{dt} = \dot{M}_{in-Abs}\int_{T_{rf}}^{T_{in-Abs}} Cp_{fl}dT - \dot{M}_{out-Abs}\int_{T_{rf}}^{T_{out-Abs}} Cp_{fl}dT + h_{cf}A_{Abs}\left(T_{Abs} - T_{fl}^{Abs}\right) \quad (13)$$

2.3 Theoretical Results

The solar radiation, received by a collector, varies typically as it's shown on Fig. 2 during a sunny day. It increases from the sun rising to reach a maximum at mid-day before decreasing again until cancelling with fallen the night. Thus, the use of solar energy is well adapted to the applications for which the needs coincide with the day sunniest hours.

The variation of the input and output fluid temperature of the solar absorber is shown on Fig. 3. The difference in temperature at the inlet and the outlet increases before cancelling with sunset.

The profiles of the temperature in the solar absorber and the average temperature of fluid are illustrated on Fig. 4. Both temperatures increase typically from the beginning of the day before being the same at the end of solar control.

Fig. 5 shows the temperature variation of the absorber and the glass cover versus the time. Given the low absorptivity of the glass α = 0.1, the variation of its temperature is low compared to that of the solar absorber which reaches temperatures well elevated up to 205 °C, as it has a greater absorptivity α = 0.85.

It is obvious to note that the variation of the temperatures depends particularly on the incidental solar power and of the surrounding climatic conditions.

3. Experimental Performances of the Concentrating System

In order to study the influence of the absorber tube diameter of the collector on the performances of the

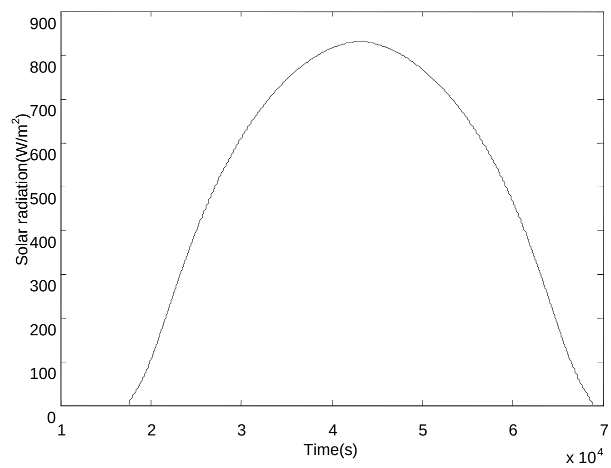

Fig. 2 Variation of the density of the solar flow for June 21.

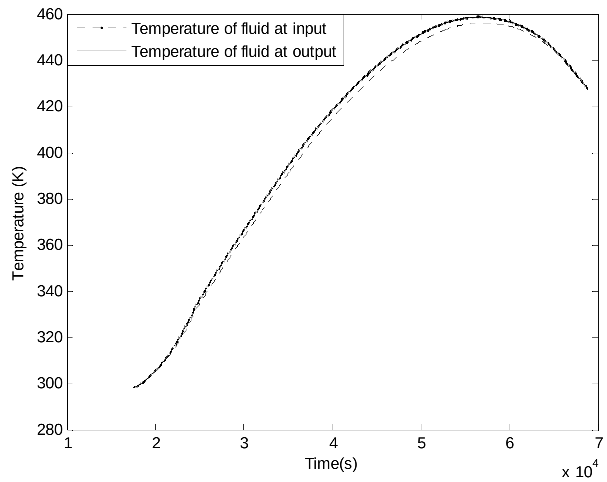

Fig. 3 Variation of the temperature of fluid at input and output.

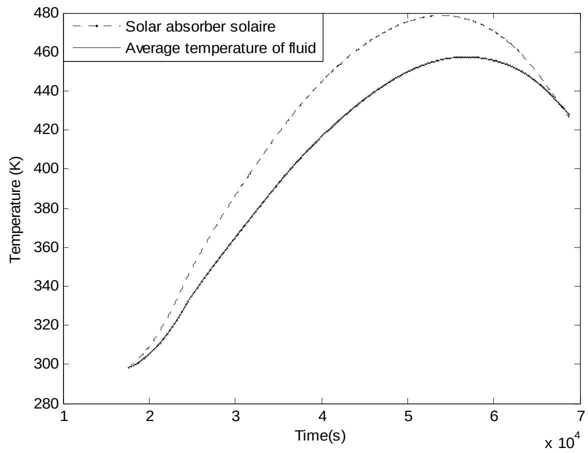

Fig. 4 Variation of the temperature and the average temperature of the heating fluid in the solar absorber.

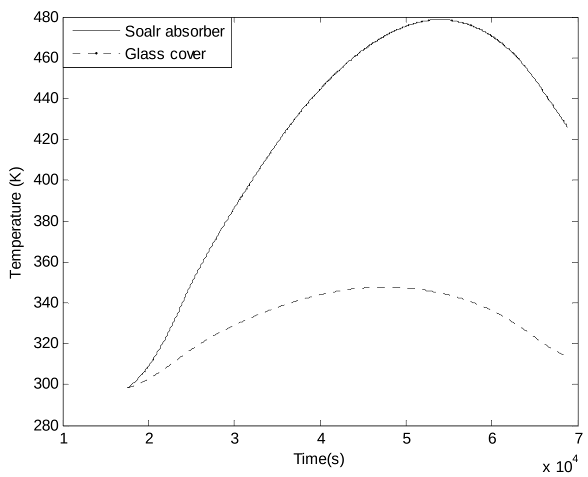

Fig. 5 Variation of the temperature of the solar absorber and the glass cover.

driving device, several experiments were made. Two different tube diameters, 10 mm and 20 mm, were used as solar absorber. These experiments were carried out under various operating and climatic conditions.

3.1 Theoretical Results

Fig. 6 represents the test results carried out in 11/06/2009. There were an ambient temperature of 29 °C and absence of wind. At the beginning the temperatures are very close. After, Ts increases very quickly and reaches 98.7 °C. The presences of thermostat in the oil ejection pump caused the engine shut-down, which of its share stops the cycle of heating of ethylene glycol. In this time the

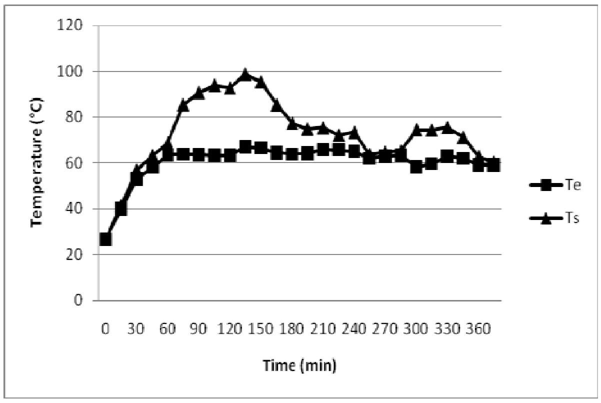

Fig. 6 Variation of the temperature of fluid at input and output in 11/06/2009 with an absorber of 10 mm.

temperatures drops at least 70 °C then increases again with the new starting of the engine. Table 2 summarizes the results of the tests carried out.

According to these results by using a cylindro-parabolic solar collector with an absorber diameter of 10 mm, one notices that the temperature of fluid at output can reach 100 °C but it decreases even below 70 °C.

3.2 Testing Performance with an Absorber Tube Diameter 20 mm

For these tests the change of the absorber diameter of 10 mm by another of 20 mm is to increase the quantity of oil in the copper tube. Fig. 7 shows the experimental results carried out in 16/06/2009. It was a very sunny day and the ambient temperature measured at 08 h 30 min is 27 °C.

The exiting fluid temperature increases very quickly as soon as the installation is started. It continues its progression up to a value limits Tout = 112.7 °C. After, it undergoes a fall of a few degrees and is stabilized in the vicinity of 97 °C during one hour. This fall of temperature is due to the stopping of the pump. Table 3 summarizes the results of the tests carried out.

Table 2 Experimental results for Φ = 10 mm.

Day	T_{in} (°C)		T_{out} (°C)	
	Max	Final	Max	Final
05/06/2009	64.7	57.3	85.6	62
10/06/2009	62.1	60.8	74.6	71.3
11/06/2009	66.5	59	98.7	60.3

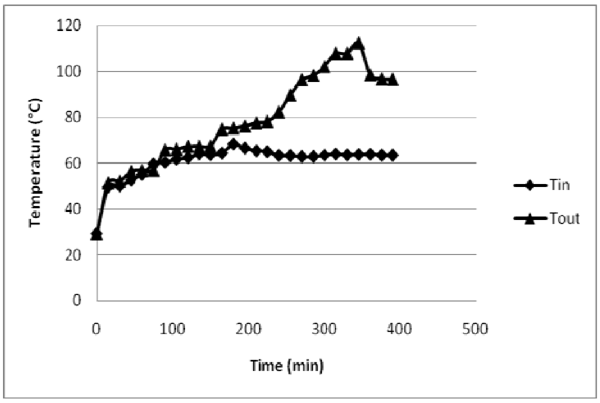

Fig. 7 Variation of the temperature of fluid at input and output in 16/06/2009 with an absorber of 20 mm.

Table 3 Experimental results for Φ = 20 mm.

Day	T_{in} (°C)		T_{out} (°C)	
	Max	Final	Max	Final
16/06/2009	68.2	63.4	112.5	96.6
22/06/2009	72.7	65.4	106.9	83.2
23/06/2009	67.5	66.3	94.5	75.8

According to the experimental results with an absorber diameter of 20 mm the exiting fluid temperature rises enormously and reaches a maximum of 112.5 °C, then it decreases and stabilizes towards 80 °C.

4. Conclusions

This work proposes a theoretical and an experimental study of a solar collector with effect of concentration of the cylindro-parabolic type. The theoretical study based on mass and energy balances enable us to develop a mathematical model to control the temperature of fluid at output tube as well as the temperatures of the absorber and the glass cover. The experimental study allows of the suitable choose absorber tube diameter with which higher temperatures superior to 100 °C were reached. Considering than the correct operation of the absorption machines requires a level of useful temperature often higher than 80 °C.

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