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Design, construction and evaluation of parabolic trough collector as demonstrative prototype

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Abstract

Thestages of design, modeling, and evaluation of a parabolic trough collector (PTC) for heating water as a demonstrative prototype are presented. In the design it was considered the parabolic aperture of 0.5 m wide and 0.95 m long. The design was done using computer-aided design and manufacturing. The results of the evaluation to determine the thermal performance of the parabolic trough collector have a maximum outlet temperature of 47.3 °C for a direct solar radiation of 783 W/m^2 at a flow rate of 0.200 L / min.

Keywords: solar collector; parabolic through, demonstrative prototype.

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1. Introduction

Parabolic trough collectors (PTC) are frequently used for steam generation due reaching temperatures up to 300ºC [1-3]. Radiant energy from de Sun is focused by the PTC surface on an absorber pipe and this is transmitted to thermal

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fluid. In the case of direct steam generation, solar energy concentrated onto absorber pipe is transferred to liquid water changing its phase to steam.

The most important applications of PTC technology for power generation can be seen in Kramer Junction California, that has an installed capacity of 354 MW; and in Boulder City Nevada, where there is a solar thermal plant of 64 MW capacity, owned by the ACCIONA Group [4]. Another power generation plant (DISS, Direct Solar Steam), which has great importance in research are located in Plataforma Solar de Almería, Spain. In DISS plant it is possible to study, under real conditions, the processes to obtain two-phases fluid (steam-liquid water) in a PTC. Furthermore, the control system to manage the PTC field and its optimization performance are possible to study [5].

The operation of these solar plants depends strongly on the solar resource available in the region where these plants are located. Is well known that solar radiation varies according to the geographic location; therefore, it is necessary take into account the above in design, construction and operation of PTC.

In Mexico, the high costs of construction, operation and maintenance of solar thermal systems have prevented their widespread application, without forgetting that one of the most significant barriers to the development of solar concentrating technologies is the lack of public policies that gives support to these technologies.

The construction of a light, rigid and low cost parabolic trough collector is presented. The goal is diversify the use of PTC due its low cost and installation and operation ease in industrial processes like laundries, nursery (soil sterilization) and child food among others. The demonstrative prototype is based on previous work reported by our research group [6-8].

2. Experimental

2.1. PTC DESIGN

The dimensions of the PTC were based on a compact and easily transported design for advertising purposes of the Engineering in Energy Systems career at the Universidad de Quintana Roo. Theinput parameters in collector design were width aperture of PTC (*Wa*)and rim angle (φ_r). (Figure 1).

A 96º rim angle was used in order to maintain a space between the glass cover and the absorber pipe, as well as a *Wa* of 50 cm.

Considering the parameters above, and according to the design reported in [9], the length of the parabola (Eq. 1), the focal length (Eq. 2), the radius of the parabola (Eq. 3), and the diameter of the receptor (Eq. 4) were calculated.

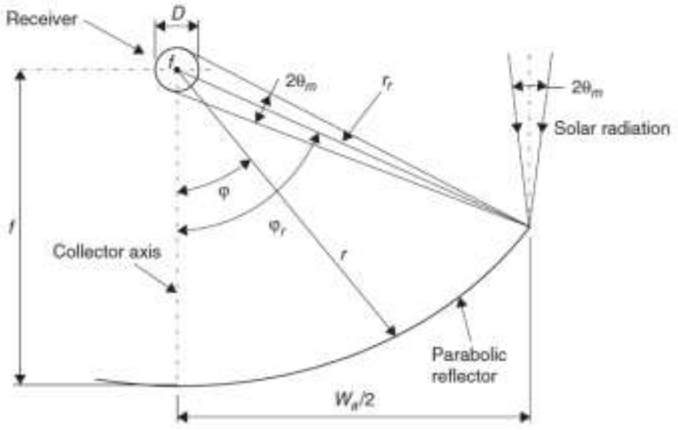

Fig. 1. Transversal cut of the solar collector.[9]

$$f = \frac{Wa}{tan(\frac{\varphi}{2})} \tag{1}$$

$$S = \frac{Hp}{2}\left\{\sec\left(\frac{\varphi}{2}\right)\tan\left(\frac{\varphi}{2}\right) + ln\left[\sec\left(\frac{\varphi}{2}\right) + \tan\left(\frac{\varphi}{2}\right)\right]\right\} \tag{2}$$

$$r = \frac{2f}{1+\cos{(\varphi)}} \tag{3}$$

$$D = 2r\sin{(\theta)} \tag{4}$$

The dimensions of the collector can be seen on Table 1.

Table 1. Parabolic collector dimensions

Description	Dimensions (m)
Width aperture of PTC	0.50
Length of parabola	59.8
Parabola focal distance	0.112
Radius of the parabola	0.25
Theoretical diameter of the receptor	0.0023
PTC length	0.95
PTC width	0.58

Finally, using Eq. 5 [3], a concentration ratio of 67.17 was obtained for the PTC; this means that the PTC receptor theoretically has a concentration of 67 Suns.

$$C = \frac{Wa}{\pi D} \tag{5}$$

2.2. CONSTRUCTION OF PTC.

All components of the PTC were design using a commercial software (Inventor Professional 2013), based on the dimensions shown in Table 1.

The edge and central ribs (Figures 2 and 3, respectively) were joined with three beams up to form a PTC structure. The Figure 2 shown that the edge rib has a circular hole to hold the cylindrical receptor, and a parabolic cut of 1 mm width, where the anodized aluminum reflective sheet is placed. It is also observed in Figure 3, that the central ribs are used to give stiffness to the PTC structure and to give parabolic form to the reflective aluminum sheet along the structure.

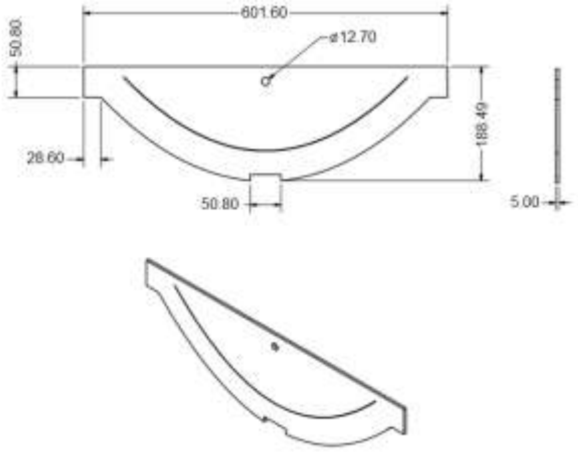

Fig. 2.Edge rib [Dimensions in mm].

At the top of the PTC, a transparent glass cover (0.58 m width x 0.95 m length x 0.006 m thick) is placed to minimize convective losses on the absorber pipe, increasing the thermal gain on the thermal fluid and consequently its thermal efficiency. Figure 4 shows the base supports where the parabolic trough collector PTC will be installed. The hole at the top of the base is concentric with the hole placed in the edge ribs and in this point the parabola focus coincides with rotation axis of PTC structure, maintaining the absorber tube only en rotation without translational.

Figure 5 showsan explosion rendering of the PTC assembly, where all components can be observed. The structure is composed of two central ribs and two edge ribs, which are held together by a rectangular frame.

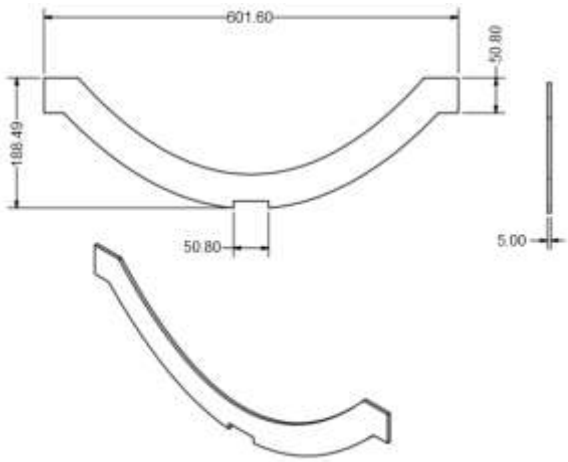

Fig. 3. Central rib [Dimensions in mm]

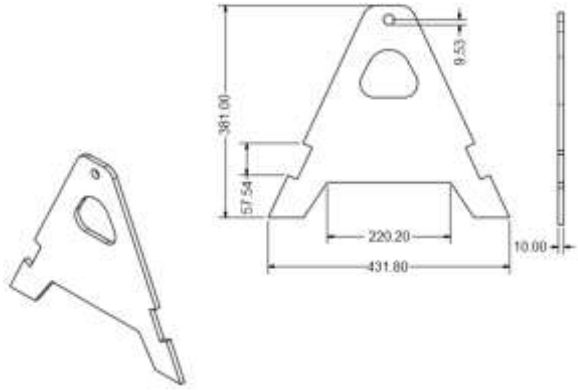

Fig. 4. Base supports [Dimensions in mm].

All the components of the PTC were made from medium density fiberboard (MDF) due to the easiness in the cutting process using the CNC (Computer Numerical Control). However, the PTC presented here is for educational purposes, in case of industrial and commercial applications, the construction material must be changed by any weatherproof material like steel or aluminum.

In order to give more stiffness to the PTC structure, twoequal leg aluminum angles (0.05 m) were used on each edge of PTC structure. The trough's surface used was a reflective aluminum anodized sheet (Alanod™) of 1mm thick and a copper tube of ½" diameter as absorber, see Figure 5.

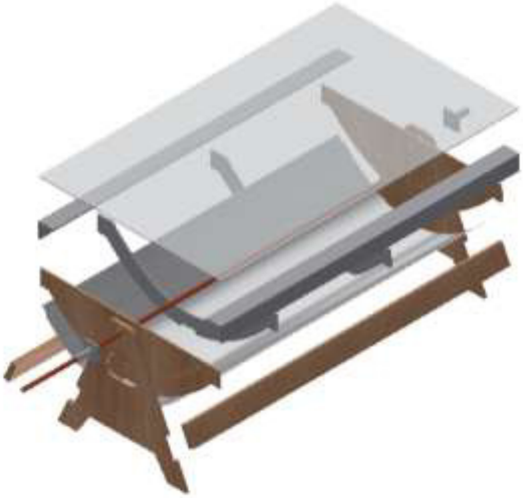

Fig. 5.Rendering of the PTC.

The reflective aluminum sheet was cut and fixed according to the dimensions of PTC initially proposed. The aluminumsheet was then polished in order to prevent the radiation from being deflected or lower the incidence radiation on the surface.

The coupling between PTC structure and the base support was made using a 1” diametersteel tube placed between the base supports for a better fastening of the collector, preventing like this the flexion of the absorber tube.

The copper absorber pipe was place through the holes from the base and structure of PTC, and then covered with carbon soot, by passing a candle along the absorber tube up to have covered the entire pipe surface. It is highly recommended the use of black paint for high temperatures (>400°C) like Solkote™.

Finally, the transparent glass 6 mm thick was placed and bonded to the aluminum frame with silicone. (Figure 6).

Fig. 6. PTC collector finished.

2.3. EXPERIMENT INSTRUMENTATION

The Figure 7 shows the diagram used for the thermal evaluation of the PTC, which includes a water container located 2 m high from PTC, a check valve, the PTC, pyrheliometer and data acquisition system. The water flow from the container, pass through the absorber pipe where it is heated, and then recollected by a glass baker to measure the flow rate. The water flow is induced through the system by gravity. The solar concentrator is oriented as seen in Figure 8, with a slope of 18° depending on the latitude of the location.

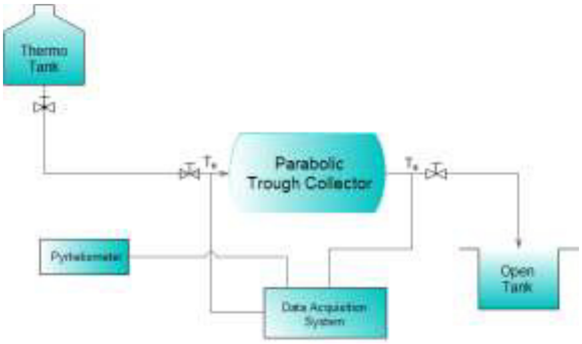

Fig. 7. Schematic diagram of the PTC evaluation

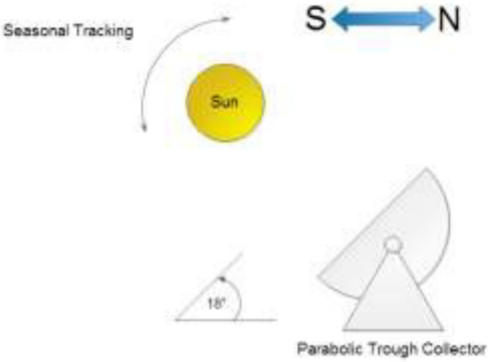

Fig. 8.Diagram of seasonal solar tracking in North-South direction. The PTC is placed along the East-West axis.

The input and output temperature of the flow was measured with type K termo couples connected to the data acquisition system (Agilent model 34970A). The experiment was carried out in two days, from 11:20 am to 2:00 pm, with a solar radiation in the range of 400-900 W/m^2, and a room temperature of 23-31°C.

3. Results and Discussion

3.1. THERMAL EVALUATION

The PTC evaluation was conducted from 12th and 14thDecember using a flowrate of 0.2 L/min.In the first day of the evaluation the sky conditions were clear, see direct solar radiation behavior in Figure 9. On the other hand, the input and output water temperatures from the PTC besides the room temperature it shown in Figure 9.

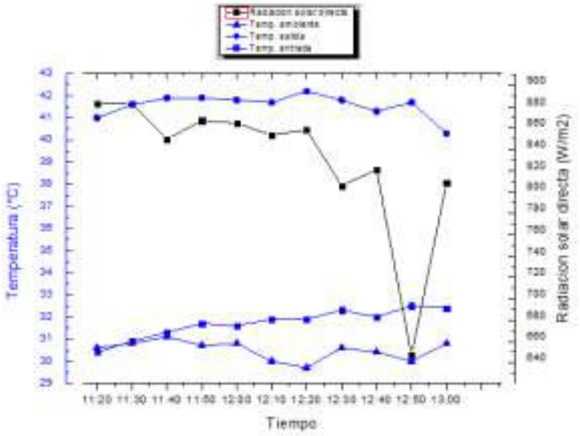

Fig. 9.Temperatures (inlet, outlet and ambient) and direct solar radiation measured in thermal evaluation of PTC, first day.

The maximum output water temperature (Ts) was 47.3°C at 1.30 p.m. with a direct solar radiation of 783.58 W/m^2 and the minimum was 34.5°C at 12.40 p.m. with a direct solar radiation of 16.17 W/m^2.

On the second day of evaluation (Figure 10) meteorological conditions were partially cloudy (4/8). Maximum temperatures of 42.2°C at 12.20 p.m. were registered, with a radiation of de 858.2 W/m^2, the minimum value recording was 30°C at 12.50 p.m. with a direct solar radiation of 646 W/m^2.

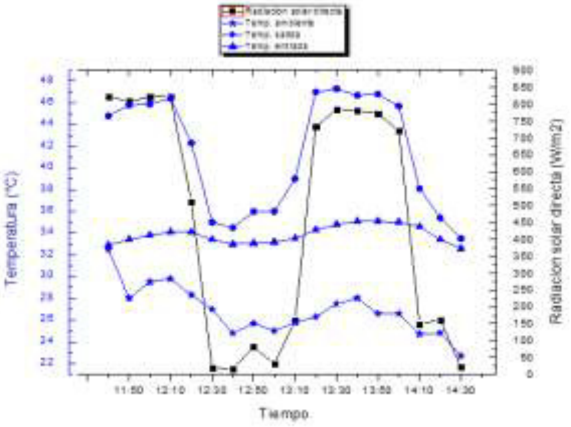

Fig. 10. Temperatures (input, output and ambient) and direct solar radiation measured in thermal evaluation of PTC, second day.

The useful energy and efficiency of PTC were calculated from equations (6) and (7), respectively. The inlet and outlet temperature were obtained from data acquisition system. On the first day of evaluation, the useful energy obtained was 152 J/s and an efficiency of 50.57%.On the other hand, an average useful energy of 136 J/s with an efficiency of 36.49% was obtained on the second day of evaluation.

$$\dot{Q} = \dot{m}Cp(\Delta T)(6)$$

$$\eta = \frac{\dot{Q}}{WA}(7)$$

4. Conclusion

The design, construction and evaluation of the PTC were presented as a demonstrative prototype. The efficiency obtained was lower than the reported investigations. This is due to the optical properties of the absorber pipe`s coating; in this case carbon soot with an absorbing capacity ˜0.90 was used. Nevertheless, the useful energy was not the one expected, due to the way it was applied; it left some irregularities on the surface.

Finally it is important to mention that the thermal efficiency of the collector is strongly related to the atmospheric conditions, like the direct solar radiation, the room temperature and the cloudiness.

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