Design and Construction of a Parabolic Trough Solar Collector for Process Heat Production

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Abstract

In this paper are presented the results of designing a parabolic trough solar collector (PTSC), and its application in a solar thermal system for the production of process heat. Implementing a series of innovations in the structural form, the material selection and the adoption of new manufacturing processes; enables a faster erection on installation site and reduction in production costs.

Drawing on the experience acquired during five years in the manufacture of PTSC modules, are identified a series of design requirements that allow to do improvements in the PTSC modules, including increased optical efficiency through the selection of materials with less weight and greater mechanical strength; the application of a new design that avoids structural deformations on the PTSC module and which are optimal to implement a motion system of low power consumption and high precision in angular positioning.

By means of a control system and data acquisition based on a Programmable Logic Controller (PLC), is possible to manipulate and record variables as temperature and angular position, in order to ensure the conditions of solar radiation incidence on the receiver and record all the variables involved in the system. This data is stored in a database for its posterior analysis.

The improvements achieved at this project generate a new method to reduce the logistics times and labor for this type of solar thermal systems as well as manufacturing costs. As a result is obtained a PTSC module with best features strength / weight and stiffness / weight, and other technical advantages.

Keywords: Parabolic Through Solar Collector; Process Heat; Motion System; Programmable Logic Controller.
1. Introduction

The need to compete in a global market involves costs improvements in every system that use renewable energy sources. The manufacture of parabolic trough solar collectors (PTSC) is no exception. As a result, it have been identified items that are able to reduce associated costs. A new system developed by the Mexican company Powergie S.A.P.I. de C.V., with the advice of Universidad Autónoma de la Ciudad de México (UACM), and financing from Instituto de Ciencia y Tecnología del Distrito Federal (ICyTDF). The place of implementation is Mexico City (19°24'09"N 99°24'36"W) at the Powergie's Solar Workbench (PSW), located near to the center of the city.

Among the features expected from a PTSC module are identified the following: easy transportation to the installation site, modular scalable design, fast installation time, low costs motion systems for solar tracking but with acceptable accuracy. The PTSC module is installed at the PSW which accomplishes all these characteristics, and its purpose is to serve as a platform for the development and testing of other concentrating solar collectors. Its erection was finished in June 2013 and consists of a hydraulic and thermal subsystem, a control subsystem, and a parabolic trough solar collector of 1.6m × 2.44m.

In order to measure the characteristics described above, it have been developed various site installation testing and it has been configured the PSW in different ways. Currently the PSW is configured in its better way, and is evaluating the thermal performance. The idea is to be able to test different concentrating technologies and for this purpose the PSW has also a modular design (figure 1).

![Figure 1. Elements of the PTSC system installed at the PSW.](image-url)
2. The PTSC system design.

The PTSC system design was performed dividing it into three subsystems: PTSC module and its motion device, hydraulic and thermal subsystem, control and monitoring equipment.

2.1. PTSC module and its motion device.

Within the construction problems of the PTSC modules, are of considerable relevance the mechanical deformation as a result of its high structural weight, in combination with the loads they are subjected as wind, gravity and thermal expansion due to the absorbion of ambient heat and solar radiation incident on them.

The proposal developed in this project, has a modular and scalable design, materials consists of high strength / weight ratio, has geometric dimensions and assembly forms that allow easy manufacturing, transportation and a quickly and safely installation, all executed by a team of three installers with basic training. The time required to erect a PTSC module is only 60 minutes.

The PTSC module has been conformed by three fundamental components: the reflector; the receiver; and the structural base. The reflector is a parabolic mirror constructed of structural aluminium where is installed the substrate surface that contains the mirror film (figure 2). All the components are made of structural aluminium in order to reduce weight and increase strength. The aluminium has the advantage of resist corrosion and absorb less heat than other metallic materials [1]. The receiver has an absorber pipe made of aluminium and a concentric cover glass that avoids reduction in the energy collected by the wind convection effect [2]. The reflector and receiver are installed on the structural base that is anchored to the floor.

Figure 2. Main elements of the PTSC module.
To determine the dimensions of the PTSC module, is used a Matlab GUI that contains the mathematical models of heat transfer for a hydraulic circuit integrated of a hot water storage tank (HWST), piping, pump, and the PTSC module (figure 3). All the parameters of the circuit can be set by the main menu for example: volume of liquid to be heated, volumetric flux that serves the pump, dimensions of the PTSC module and the materials of the reflector and the receiver.

Figure 3. Symplified diagram of the PTSC. [3]

Table 1 shows the parameters that define the PTSC module constructed by PowerGIE, based on equations of thermal efficiency on a concentrating collector, operating under steady-state conditions [4, 5]

Table 1. Parameters defined for the PTSC design.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector aperture</td>
<td>1.6m</td>
</tr>
<tr>
<td>Collector length</td>
<td>2.44m</td>
</tr>
<tr>
<td>Rim angle</td>
<td>90°</td>
</tr>
<tr>
<td>Focal distance</td>
<td>0.4m</td>
</tr>
<tr>
<td>Aperture area</td>
<td>3.7952m</td>
</tr>
<tr>
<td>Absorber diameter</td>
<td>0.02675m</td>
</tr>
<tr>
<td>Envelope diameter</td>
<td>0.0381m</td>
</tr>
<tr>
<td>Concentration ratio</td>
<td>18.98</td>
</tr>
<tr>
<td>Mirror reflectance</td>
<td>94%</td>
</tr>
<tr>
<td>Water flow rate</td>
<td>0.5l/s</td>
</tr>
<tr>
<td>HWST capacity</td>
<td>0.3m³</td>
</tr>
<tr>
<td>Pump power</td>
<td>140W</td>
</tr>
</tbody>
</table>
The motion system is designed considering mainly the reflector weight of about 50kg and its center of mass of 0.2656m measured from the focus to the vertex of the parabolic profile (figure 4).

Figure 4. Reflector’s center of mass calculated in a CAD software.

Figure 5 shows a three-dimensional drawing the motion device and their components, basically it is integrated by a gearmotor, a couple of pulleys and belt, and a traction wheel.

The traction wheel is the interface between the motion device and the reflector which is rotated on one axis located at the focal point. The advantage included at this design is the low power consumption of about 0.3W, and its precision in angular movement of 0.01°.

Figure 5. Main elements of the motion device and its components.
2.2. Hydraulic and thermal subsystem

The hydraulic and thermal subsystem is designed for heat the liquid substance (in this case water); and contains all the necessary elements to move the fluid through the PTSC module, in order to absorb the collected solar energy by forced convection and store the energy inside the HWST [6].

It allows controlling and managing the energy levels that are reached into the HWST, mainly fluid volume and temperature reached in a solar day. Figure 6 shows a simplified drawing of the hydraulic and thermal system, it is observed that contains all the measure instruments required to control the water quantity inside the HWST, and water flow rate, the pressure and the temperature.

![Figure 6. Hydraulic and thermal subsystem diagram.](image)

2.3. Control and Monitoring subsystem.

The control and monitoring system is a very important part from the PTSC system, it allows manipulating in a secure way all parts and functions of the system and also is the ideal tool to measure and record all the variables involved in the performance of the system behavior.

In this particular case has been employed a S7-1200 Programmable Logic Controller (PLC) from SIEMENS, in order to acquire all the data and send it to a PC for its posterior treatment and analysis.
3. Results

A new PTSC module has been constructed, it has a rapid integration and assembly method in site, it can be assembled by three installers of 1.6 meters high in just 60 minutes with the use of an allen wrench and a screwdriver. A complete module weighs 50kg, and can be transported in a compact car due to its modular concept and it is possible to scale the system in a series or parallel arrangement, according to user needs, see figure 7(a).

The IPN materials laboratory has tested the mechanical deformation, and has concluded that, the distortion is negligible compared to the size of the reflector module, so it meets the required accuracy in the geometry of the parabolic trough [7]. Also it has been created a new motion device of low power consumption and high accuracy, its application can be extended to various types of solar collectors, see figure 7(b).

![Figure 7. PTSC module installed on site (a) isometric view, (b) motion device, (c) lateral view.](image)

The hydraulic and thermal subsystem was implemented with a piping system of practical connection, that avoids soldering, allowing a quick erection and ensures a secure installation (figure 8).

![Figure 8. Hydraulic and thermal subsytem (a) pump and piping, (b) HWST.](image)
The control and monitoring subsystem integrates all the elements of the PTSC system through the sensors that transduce the measurements from the process to the PLC S7-1200. The implementation of this PLC helps to record all process variables for further processing on a PC, this is an important fact because it allows a stand alone solution, without the need for a PC on site (figure 9).

Furthermore, the use of solar tracking function-SIEMENS SPA which was developed based on the algorithm "Solar Position Algorithm" (SPA Calculator) of the National Renewable Laboratory [8] in collaboration with the German company Siemens for use in the new S7-1200 (figure 10).

According to the company SIEMENS, is the first application implemented in Mexico using this tool. The data recorded has been processed to determine the percentage of energy captured by the PTSC module and the energy introduced in the heated substance. In Figures 11, 12 and 13 is showed the results obtained for July 26th, which was a day free of clouds and with excellent radiation levels to increase the temperature.

Figure 9. Control and monitoring subsystem (a) Interior view of the rack that contains the control components: PLC, electrical elements, connections. (b) PLC SIEMENS S7-1200, (c) Touch Panel, (d) Front view of the rack that shows the touch panel, the emergency button, start and stop buttons.

Figure 10. The SPA by NREL, (a) Parameters in the S7-1200, (b) Diagram of SPA angles.
Figure 11. Temperature measured at the HWST for July 26th.

Figure 12. Total radiation incident over the PTSC module plane for July 26th.

Figure 13. Angular position of the PTSC module for July 26th.
4. Conclusions

A new PTSC module has been developed in order to compete in the national market. The results obtained from the construction of the PTSC system indicate that times of erection are short, and direct costs in manufacture are low, but it is necessary to compare them with other technologies with presence around the world.

It is observed a good implementation time of the hydraulic and thermal subsystem with the use of piping of practical, quick and secure connection. A motion device with lower energy consume has been developed, and with the application of the SPA-SIEMENS function is possible to eliminate the solar tracker sensor. The precision on angular movement is about 0.01°.

With regards to the control system, it has been observed the behavior of a first order system, as outlined in the mathematical design, the peak temperature has been 80°C, which coincides with the preliminary design information for solar radiation conditions above 19 MJ/m²/day, in a day with excellent weather conditions. The volume flow was 0.5 liters / second, and the water volume was 0.3m³, which means an average thermal efficiency of 60%.

The works on the evaluation of PTSC system will be continued and also the generation of design improvements to create a more competitive proposal for the national and global market. In the long term are considered STCCP’s perfecting works, as well as simplifying the tools used and developing better components compared with those used today, as this will represent improvements in costs, especially in the area of control and building materials for the PTSC modules.

Acknowledgements

This work has been funded mainly by ICyTDF (PIEMP11-24) and Powergie S.A.P.I. de C.V. All the Powergie’s Team gratefully acknowledge to ICyTDF and UACM, especially with Dr. Alvaro Lentz Herrera, for his technical and logistic support.

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