Solar Concentrator PDR with solar tracking

Concentrador Solar PDR con seguimiento solar

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Abstract

The reduction in conventional fuels consumption can be accomplished through the use of solar energy, transforming it into thermal energy throught a solar collector. There are a lot of solar collector kind, but the solar concentration way, specifically the parabolic dish reflector technology, or just PDR solar concentrator, offers one of the most efficient paths to achieve high quality thermal energy. Usually, the PDR solar concentrator are designed in big dimensions in order to generate electrical energy; nevertheless this technology could be used in minor scale in order to generate solar concentration high levels to achieve enough thermal energy to satisfy hot water demand in residential buildings, homes and even the industry. The prototype here presented was developed in four phases: The parabolic dish, the gear box and mechanical support device, the sun tracking control system and finally the system integration and operational tests. The four phases conjunction results in a totally operative prototype with the capability of achieve temperatures of 400 ºC, over a concentration focal point under partially cloudy day conditions.

Prototype, Solar energy, Thermal energy, Solar concentrator, PDR, Sun tracking, Parabolic dish.

Resumen

La reducción en el consumo de combustibles convencionales puede realizarse a través del uso de la energía solar, transformándola en energía térmica a través de un colector solar que de entre todos los tipos existentes, la tecnología del colector de concentración de disco parabólico reflector, o simplemente concentrador solar PDR, presenta una de las vías de mayor eficiencia para la obtención de energía térmica. Los concentradores solares de disco parabólico reflector, usualmente son diseñados en grandes dimensiones con el propósito de generar energía eléctrica, sin embargo esta misma tecnología, pero a pequeña escala, es capaz de alcanzar elevados niveles de concentración solar generando así energía térmica suficiente para satisfacer la demanda de agua caliente en edificios habitacionales, casas e incluso en la industria. El prototipo que en este trabajo se presenta fue desarrollado en cuatro fases: El disco parabólico, las cajas de engranes y dispositivo de soporte, el sistema de control para el seguimiento solar y finalmente la integración y pruebas de operación. La conjunción de las cuatro fases resulta en un prototipo totalmente operativo con la capacidad de llegar hasta los 400 °C de temperatura sobre el punto focal de concentración bajo condiciones de día parcialmente nublado.

Prototipo, Energía solar, Energía térmica, Concentrador solar, PDR, Seguimiento solar, Disco parabólico

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Introduction

Solar energy is a viable alternative to solve the energy problems that the use of fossil fuels entails. There is a lot of information about the behavior of this energy, in what magnitude it is received on our planet and especially in Mexico. Currently, both public and private organizations worldwide are making great efforts to generate knowledge and technological advances in order to achieve a better capture of solar energy in an increasingly economical and efficient way (Perales, 2007). They have developed a series of experimental models and from them it has been tried to improve them more and more, however, these improvements carry with them an inevitable increase in manufacturing costs.

There are various technologies of solar collectors whose efficiencies depend on the capacity to capture solar radiation, the most widely used being the flat collector type, however, its concentration is relatively low compared to other technologies used at gigantic industrial levels, such is the case concentration collectors, specifically the parabolic reflector disk. Until now, concentration technology has generally been handled only on a large scale, that is, from 5 to 7 m in diameter, thus justifying the demand for electrical energy necessary to move the collector in two rotational axes, which precisely gives it the possibility of reach high levels of concentration.

The purpose of this work is to design and build a prototype of a PDR solar concentrator, or reflector disk parabolic, with solar tracking in two axes, whose diameter is of small modularity and that provides high quality thermal energy, that is, high temperature. The reason for providing a disk of small dimensions lies in making concentrating solar technology applicable both to satisfy the needs of thermal energy for services and uses of small and medium-sized industries as well as for homes, and is no longer exclusive to the production of steam for power generation.

The design and construction process, as well as integration and testing, of the small modularity PDR solar concentrator is presented in four sections: Configuration of the concentrator disk, the design criteria and the final construction of the concentrator disk are presented.

Clamping and movement mechanisms, the elements used for the transmission of movement to the concentrator are presented; Control system for solar tracking, the form of control chosen to carry out solar tracking in two axes is disclosed; Results, the experimental data obtained once all the parts of the concentrator have been integrated are presented.

Hub Disk Configuration

The dimensions of the reflector parabolic disk are determined from the geometric relationships shown in Figure 1 in which it can be observed that there is a relationship between the diameter of the disk, a, the focal length, f, and the edge angle. , ϕr, depending on the width of the focal image, W, required so that a heat transfer device can be placed in the center of the concentrator (Kalogirou, 2009).

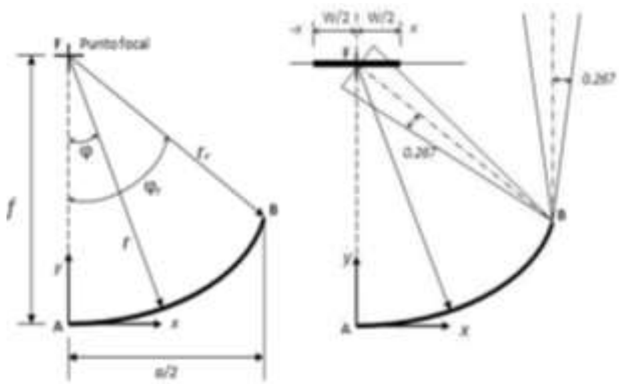


Figure 1 Geometric parameters of a reflecting parabolic disk

When designing any type of solar collector, the main objective is to obtain the best possible use of the solar radiation captured. In the case of concentration collectors, this use depends on the concentration ratio, finding that the main design criterion to be established is the maximum concentration ratio Cmax, and this value must be kept constant to carry out the sizing of both the disk and the absorber element.

This Cmax value is defined as the maximum that can be obtained, based on the interception of all the reflected specular radiation which is within the cone with angular amplitude equal to 0.534 + δ as shown in Figure 2. According to Duffie and Beckman (2009), this maximum value mathematically is obtained as follows:

$$C_{max} = \frac{sen^2\varphi_r \cos^2(\varphi_r + 0.267 + \frac{\delta}{2})}{4sen^2(0.267 + \frac{\delta}{2})} - 1 \quad (1)$$

The inclusion of the factor called scattering angle, δ, makes it possible to consider the angular errors associated with inappropriate solar tracking, roughness inherent to the reflecting surface and poorly shaped in the curvature of the disk. That is, depending on these errors, it can be known how much the radiation reflected by the concentrating element increases in amplitude. These standard errors have been obtained experimentally using statistics (Stine, 1985).

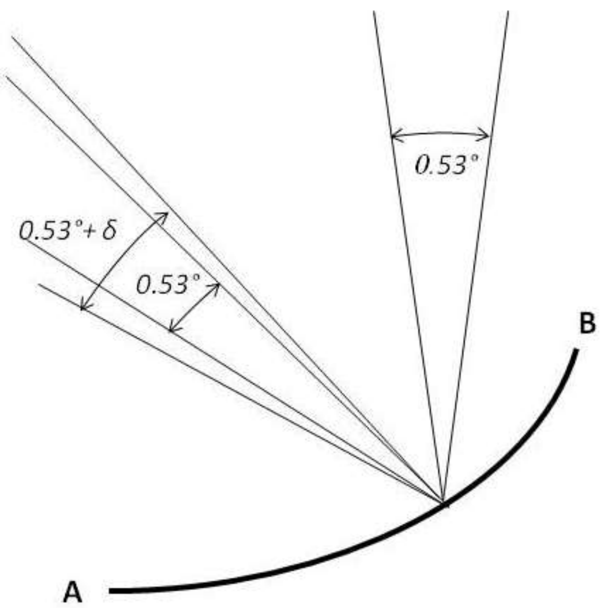
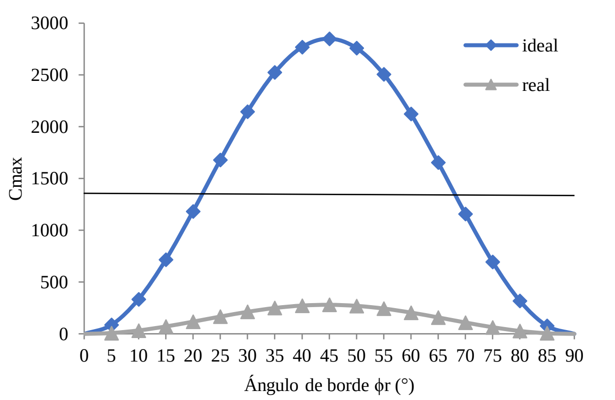


Figure 2 Schematic of a portion of a concentrator with a scattering angle δ added to the solar interception angle of 0.53 °.

From equation 1 it can be seen that the Cmax depends on the edge angle φr, in this way various values of it will have to be proposed to know the maximum value of Cmax that could be reached.



Graphic 1 Maximum concentration ratio for PDR collectors

In Graph 1 it can be seen that the maximum value of Cmax is 2850 and is reached when °r = 45 °, after 45 ° the value of Cmax begins to decline in the same proportion as it increased. However, only the ideal case has been considered, it is possible to compare the ideal case with the behavior of Cmax by including the angular deviation. According to the graph φr against Cmax, it is observed that the maximum concentration ratio decreases drastically from 2850 to 280 when including the angular dispersion, that is, it decreases almost 10 times its value.

The values of φr = 45 ° and Cmax, real = 280 are considered as the first design criteria for the reflector parabolic disk and must be kept constant to determine the geometric parameters of the disk.

The second design criterion of the parabolic disk is the fulfillment of one of the objectives of this work, the small modularity of the concentrator, which must be small to be installed in a house but large enough to be able to couple some type heat exchanger at its focal point, for example thermosiphon type.

Having the edge angle defined to achieve the highest concentration, it is now necessary to establish the edge radius and the optimal focal length to generate an image on the focal plane such that it allows satisfying the criterion of small modularity.

According to the results obtained, disc diameters less than 1 m provide very small focal images to consider the construction of a functional heat exchanger. The diameters of 1 m, 1.25 m and 1.5 m generate focal images on which thermosyphon-type heat exchangers of at least 2.54 cm in diameter could well be constructed.

Disc diameters of 1.75 m onwards are considered too large to meet the small modularity criterion (Durán, 2012).

Therefore, the diameter of the disk proposed for the construction of the parabolic disk will be defined at a value of 1.5 m since its corresponding image width will allow a thermosyphon of almost 5 cm in diameter to be placed on its focal point, allowing a better use of the radiation solar.

Table 1 summarizes the geometric characteristics and technical specifications of the concentrator and absorber and is illustrated in Figure 3.

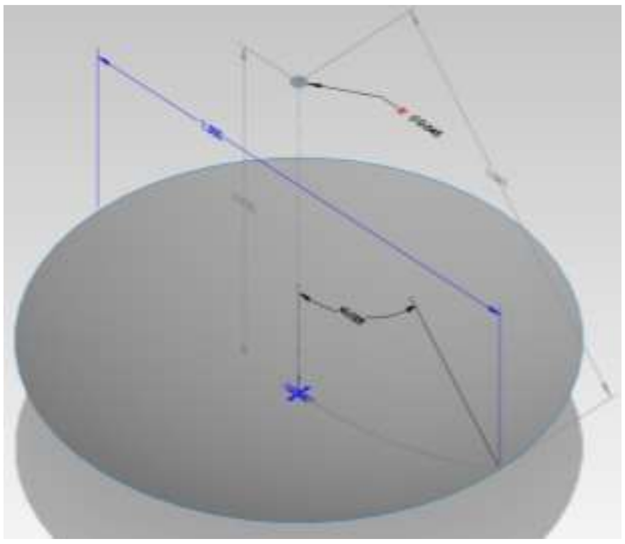


Figure 3 Graphic design of the reflector disc and absorber element

Characteristic	Specification
Collecting area	12.55 m^2
Edge angle	45°
Diameter	1.5 m
Focal distance	0.9 m
Edge Radius	1.06 m
Disc mold	Fiberglass
Reflective material	Mylar
Mylar reflectivity	0.85
Absorber diameter	0.05 m
Absorber material	Aluminum
Anodized aluminum absorptivity	0.14
Total weight	20 kg

Table 1 Technical specifications of the concentrator disc and absorber element

Mechanisms of movement and clamping

The mechanical system of the concentrator is made up of two parts. The first is a gearbox manufactured in duplicate in order to allow the transmission of motion from the motors to each axis of rotation (two-axis tracking mechanism). The second refers to the support structure to mount the rotation shafts that in turn will support the reflector disk.

The motor considered suitable for the movement of the concentrator is an automotive worm-worm type motor, since it provides high torque at low speed and a transmission of unidirectional movement from the motor to the mass of the concentrator.

The design of a gearbox or speed reducer is of great importance for the solar concentrator, since through it it is possible to obtain the precision of the angular movement in each axis.

So that for every half turn of the axis of the worm gear, the elevation or azimuth axis has an angular displacement of 1 °. In order for the box to be neither too heavy nor robust, a 4-gear design like the one shown in Figure 4 is proposed.

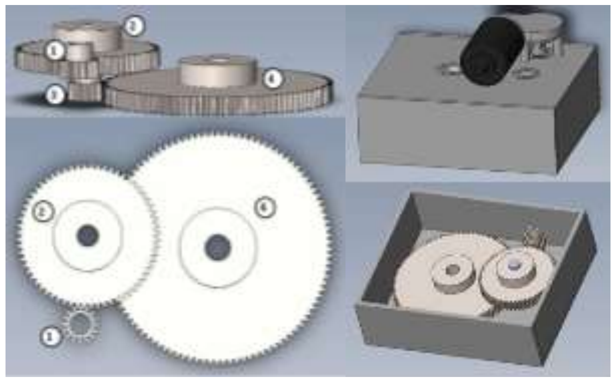


Figure 4 Gear train for transmission of motion and speed reduction

Figure 5 shows the proposed design for the support system, which tries to concentrate all the weight of the concentrator just on the vertical axis so that there is no weight imbalance during the movement of the prototype, perhaps caused by the disc itself. reflector or gearboxes, these two components being the heaviest.

As it is a solar concentrator that must be following the Sun throughout the day, it is required that the main components of the support are in a certain way resistant to corrosive effects and deterioration due to the weather, so the material of the bars that make up the shafts are made of stainless steel.

The main mechanical components are mentioned in Table 2 and are indicated in Figure 5, which corresponds to the design of the PDR solar concentrator.

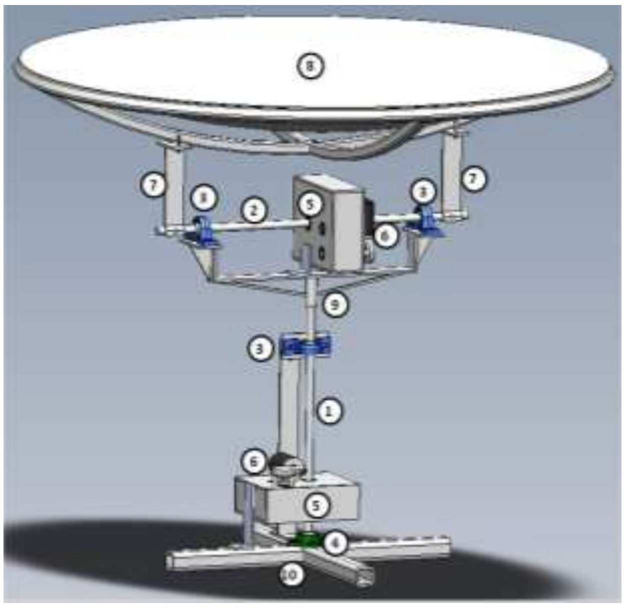


Figure 5 PDR Solar Concentrator General Design

No.	Component / Part
1	Vertical axis of rotation for azimuth.
2	Horizontal axis of rotation for lifting
3	Bearings for the two axes, vertical and horizontal.
4	Bearing for vertical axis.
5	Gear box.
6	Engine.
7	Disc support arms.
8	Reflector disk.
9	Vertical axis support.
10	Base.

Table 2 Components and main mechanical parts of the concentrator

Control system for solar tracking

When working with concentrating solar collectors, it is necessary to develop a solar tracking system in one or two axes depending on the type of collector, since they work mainly with direct solar radiation. In the case of parabolic disk concentrators, a solar tracking is managed in two axes, elevation and azimuth, with the aim that the concentrator is always oriented to the Sun at any time of the day.

According to Duffie and Beckman (2009), the position of the Sun at any time of the day can be predetermined, considering the date and geographic location of the viewing point. With this mathematical algorithm the set point signals for the elevation axis and the azimuth axis are generated.

The proposed control strategy is of the open loop type where signals are generated that allow the activation of the two direct current motors, one for elevation movement (0 to 90 °) and the other for azimuth movement (0 to 180 °). , so that to obtain a degree of movement in each axis of rotation, the corresponding motor must give half a revolution. The block diagram of the control system is shown below in Figure 6.

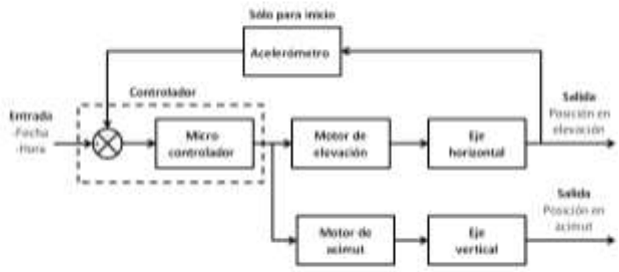


Figure 6 Control system block diagram.

The controller is the module where all the control and power electronics necessary to obtain a response from the tracking system are located, it is here where the aforementioned mathematical algorithm is housed. Physically it is a micro controller with its own software in conjunction with a minimum power system necessary for its operation. The choice of this microcontroller lies in its large memory capacity and processing speed, sufficient to carry out the trigonometric operations characteristic of the equations that determine the apparent motion of the Sun.

Obtaining the degrees of movement for the positioning of the concentrator, a core part of the microcontroller's programming, starts from the establishment of the date, time, longitude and latitude entries of the geographical place where the concentrator is installed for later perform the corresponding calculations and send two activation signals to a dual type motor speed control card, this in order to reverse the polarity of the motors so that they can be driven in both directions of rotation. This card is the one that ultimately turns the motors for elevation and azimuth on or off.

The accelerometer only acts when the system is actuated for the first time in order to establish the concentrator in a reference point and from there perform the calculations of the rotation in elevation, or when the system must be reset after a failure stop or maintenance.

The control system will ensure that the action of the motor is a gradual movement making the output values of the positioning calculations in elevation and azimuth of the Sun be geometrically reproduced as best as possible. Because the apparent movement of the Sun makes a change of approximately 15 ° every hour (Wieder, 2003), the tracking system does not make a continuous movement, instead it generates a change in the position of the concentrator every 5 min.

Results

Two experimental tests were carried out in the same geographical area under similar weather conditions, test 1 - cloudy weather, test 2 - partially cloudy weather, this by comparing the components of the total radiation that indicates a predominance of diffuse radiation over radiation. direct.

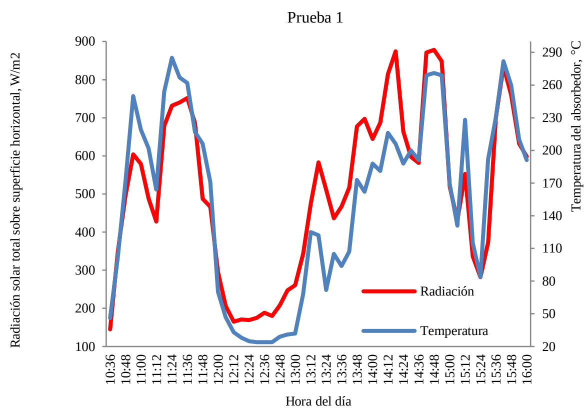
The measurement of the total radiation on a horizontal surface is carried out by means of a total radiation meter in W / m2, calibrated for the solar spectrum under normal test conditions, that is, spectrum for an air mass of 1.5, with GT = 1000 W / m2 at 25ºC, which is similar to direct sunlight at noon in central Europe. From this measurement of total radiation, the direct radiation normal to the concentrator aperture plane was obtained, from the mathematical model of the Erbs correlation (Erbs D. G., Klein S. A., & Duffie J. A., 1982).

From the radiation measurements, an estimate of the incident direct solar radiation is obtained normal to the concentrator aperture plane, from which the absorbed flux at the focal point is calculated, which in turn will serve for future estimates. useful energy which may be subject to experimental verification.

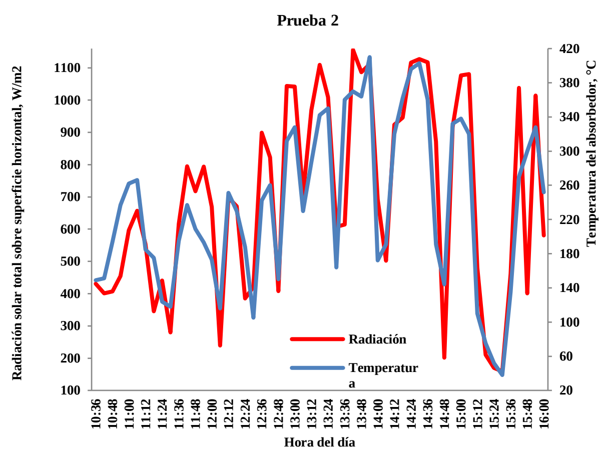
The temperature reached on the absorber element is monitored by a type J, class 2 thermocouple, calibrated for a temperature range from -40 to 750 ºC. The thermocouple at all times remains in direct contact with the absorber element without the latter having any type of thermal insulation.

Considering the experimental data, Graphs 2 and 3 clearly show a linear or proportional relationship between the total radiation and the temperature reached by the absorber at the focal point.

The peaks indicate sampling points that can be considered as instants of solar clarity, it is at these points where the maximum temperature values are reached. However, the abrupt decreases of the same are translated not only as instants where the cloud cover interferes with the passage of solar radiation but also there is the existence of air currents that accelerate the transfer of heat by convection generating heat losses in the absorber element.



Graphic 2 Graph of experimental data obtained for test 1.



Graphic 3 Graph of experimental data obtained for test 2.

Taking an average of the maximum and minimum temperature values reached in the collector absorber element, it is considered that in the tests the minimum temperature reached was 24 ° C between 12:30 and 12:42 hrs, while the maximum was 410 ° C at 1:54 PM, under partly cloudy sky conditions.

Currently the solar concentrator is in the experimentation stage with fluid loading, passing through its focal point a thermal oil whose boiling point is 300 ° C.

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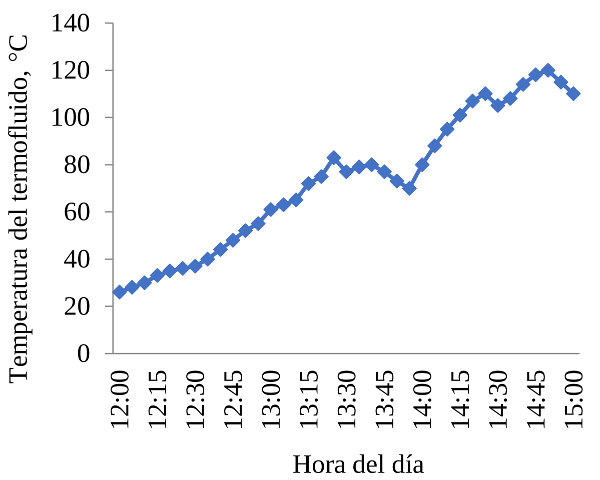
Although improvements are still being implemented in the fluid circulation system, some experimental values from preliminary tests show that the operation of the concentrator for 3 hours increases the temperature of the thermal oil from 26 ° C to 120 ° C, as shown in the Graph 4.



Graphic 4 Experimental data obtained by circulating thermal oil through the concentrator.

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Conclusions

From the information resulting from the experimental tests and the calculations obtained from them, it can be concluded that the PDR solar concentrator is functional and fully complies with the proposed objective, being applied on a smaller scale than usual, so that it can be installed in home or small business.

Choosing the right diameter depends in the first instance on knowing the edge angle that provides the maximum concentration. Once known, this angle must be kept constant to ensure maximum concentration and then the most convenient dimensions of focal length and diameter of the disk can be freely varied.

The direct solar radiation incident perpendicular or normal to the aperture plane is at all times greater than the direct radiation on a horizontal plane, this shows that the proposed control system works and that the trajectory of the apparent movement of the Sun is effectively being followed. The system will be positioned in the direction of the Sun regardless of the obstruction of solar radiation, whether by cloud cover, buildings, trees or any other object that generates shade.

The angular scattering error considered allowed dimensioning a suitable focal image width so that the solar radiation reflected by the disk is concentrated almost entirely within the absorbing area. Even so, the concentrator exhibits movement oscillations in its support structure mainly due to the torque applied by the motors at the beginning of each position change.

The minimum and maximum values of temperature reached in the absorber are directly associated with the minimum and maximum of incident solar radiation registered in the radiation meter. Therefore, it can be mentioned that the focal point has a behavior in real time that depends for the most part on the incident solar radiation.

It can be estimated that the operating range of the concentrator shows a wide range of application due to the temperatures that can be reached, registering temperature ranges of more than 400 ° C above the focal point, which makes the concentrator a source of energy of high quality according to the general objective of this study. Therefore, the prototype has a great capacity to be exploited scientifically and commercially due to its simplicity in handling, small modularity and, above all, its great capacity to generate high-quality thermal energy.

There are times when the temperature curve is above the radiation curve, meaning that the absorbing element obtains energy from a different source than the radiation reflected by the parabolic disk.

One possible explanation is that there is solar radiation that reaches the absorber from its back and at the same time receives energy by conduction heat transfer from its support device which is made of aluminum and is also exposed to solar radiation, then the sum of these two sources of energy and the low or almost zero speed of the wind so that the absorbing element gives up heat slowly contribute to the fact that at times the heat energy of said element is greater than that provided by the incident solar radiation reflected on the Focal point.

Based on the experimental data obtained by circulating the thermal oil through the concentrator, some preliminary calculations indicate that it could be achieved by increasing a temperature delta of 25 to a mass of water of 100 kg, or generating 30 kg of saturated steam. of water starting from water at 25 ° C.

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