Proceedings of COBEM 2009
Copyright © 2009 by ABCM
20th International Congress of Mechanical Engineering
November 15-20, 2009, Gramado, RS, Brazil

CENTRAL SOLAR TOWER MODEL FOR THE PRODUCTION OF STEAM

Luiz Guilherme Meira de Souza, lguilherme@dem.ufrn
Débora Damasceno Belarmino, debelarmino@yahoo.com.br
Aldo Paulino de Medeiros Júnior, aldo.paulino@yahoo.com.br
Aroldo Vieira de Melo , aroldovmelo@hotmail.com
José Ribeiro de Souza Filho, pqdrfilho@bol.com.br
Reginaldo Dias dos Santos, reginaldodias@yahoo.com.br
Universidade Federal do Rio Grande do Norte, Natal/RN

Abstract. *It is presented a model of two subsystems of Central Solar Tower to produce steam in applications to help in energy consumption. The first subsystem consists of 24 heliostats constructed of adaptive and mobile metal structures to track the apparent movement of the sun on its focus and covered by 96 layers of mirror of 150 mm at width and 220 mm at length, totaling an area of concentration of 3.2 m². Thereby obtaining optical parameters essential to reflection of sunlight by the reflector surface and absorption of this light by focus located in the light receiver, which is inserted in the second subsystem, which is at the top of a tower. The tower was built in galvanized iron able to support the absorber, and a gas cylinder to cool the equipment. The area illuminated by the sun was 9 x 10-2m2, yielding a concentration factor of 35.22. It will be shown the processes of manufacture and assembly of the Mini-Central Tower proposal, which has as main characteristics the construction and assembly facilities, in addition to reduced cost. Data of tests to produce water vapor parameters are presented and determined to diagnose the efficiency of the mini-solar central tower. It will be demonstrated the thermal, economic and material viability of the proposed system.*

Keywords*: solar oven; solar cooker; composite material; low cost; sustainable development*

1. INTRODUCTION

Depending on the energy crisis and the problem of global warming it appeared a need to pick up a power source that could minimize the problems arising from this situation. This paper demonstrates the feasibility of using a tower to a possible generation of electricity from the sun, an environmentally correct alternative, where nowadays all developed nations seek technologically and economically viable solutions to replacement of fossil fuels for meeting the energy demands of mankind.

Are present, construction, assembly and removal performance of a model of two of the four subsystems of an existing Central Tower, having low cost of manufacture and the need to operate under solar appropriate conditions, which work in periods and in regions of low or no cloudiness. This prototype was produced to convert solar energy into heat, with the future prospect of using the steam to drive a turbine that can handle an electric generator to convert, then, heat in power. It can also be used simply as heat and/or spray water for commercial, industrial and household applications in rural and urban areas.

The heliostats of the proposed system has been designed from the experimental results obtained with various models, choosing the one that had increased efficiency, and simplest manufacturing processes and assembly. The determination of geometric parameters of the system has also been through preliminary tests that took into account the optical processes in the capture and reflection of sunlight.

The proposed model presents area of reduced uptake and uses three rows of heliostats, each one with eight units, for a better guide to the reflected solar radiation on a punctual focus, which is located in an absorber painted of matte black and thermally insulated on its not illuminated part, so to avoid the loss of heat by convection and radiation.

To demonstrate the feasibility of using the central little tower were examined some parameters to show the efficiency of a solar system for the production of steam, such as: temperature of the absorber, temperature of water boiling, temperature of the thermal insulating used and of the environment, amount of steam generated and the direct solar radiation.

2. BIBLIOGRAPHIC REVISION

Concentration Thermosolars Systems (CTS) convert the direct component of solar radiation into another kind of energy, for their immediate use or storage. The CTC consists of three systems: the central receiver systems (CRS) or tower systems, the disks parabolic (PA) or discs stirlings and cylinder parabolic collectors (CPC). The first two concentrate solar radiation on a point (focus point), thereby obtaining higher temperatures compared to the last that concentrates on an axis (linear focus). These systems are used to direct radiation, clear sky and no cloud cover. They are some solar systems Terms of concentration (STC) in operation around the world. Figure (1) project shows high concentration, used in countries around the world (Filho, 2008, Lion, 2007, Queiroz, 2005):

Figure 1. High-concentration, in operation.

Among the most recent scientific work developed in the world, and which were presented at scientific events in the field of solar energy, are:

Martínez, moiá and Pujol (2008), developed a hub of average temperature, fixed reflector and mobile focus, used as a mesh of 32 evacuated tubes with a total opening of 24 m² and a maximum range of focus around 0, 8. It is hoped this project to obtain an average efficiency of around 40% (compared to a radiation incident directly to a latitude of 39 °) at temperatures between 120 and 150 ° C.

Aguilar, Calama, Acosta, Cusevas, Hernández, Jaramillo, and Rábaco Pérez-Flores, (2008), built a channel of parabolic solar collector, with a width of 1.06 m and length 2.44 m, with focal length of 0.26 and an absorber tube of 19.05 mm in diameter.

Rolim, Fraidenraich, TiBA and Vilela. (2008) developed an analytical model of a solar thermal system to generate electricity with linear focus parabolic concentrators. It is currently the technology of generating solar electricity with more experience in the world. It is being used for simulation of operation and annual snapshot of a system to be installed in the city of Ouricuri, Brazil.

Filho, (2008) built and analyzed a cylinder-parabolic concentrator for steam production, changing the curve of the prototype using conventional observations made in the processes of capture and simulation of reflection of rays. It was shown the thermal viability, and economic hub of the studied materials.

3. MATERIALS AND METHODS

The proposed central tower model has as main feature the use of a clean and inexhaustible energy, manual mechanism following the action of the sun, concentration of spot focus, adjustable concentration factor and easy assembly and manufacturing processes.

3.1. Processes of manufacture and assembly of the mini-tower system

For the manufacture and assembly of the mini central solar tower it was used the following procedures:

3.1.1. Project of size and design of the field of mirrors:

Each mirror of heliostat, with 2 mm thick, is composed of four segments of mirrors with length of 220 mm and 150 mm in width. Thus, the field to capture solar radiation comprising 96 mirrors has a catchment area of 3.2 m². The field of heliostats was designed to consist of three rows each one with 8 heliostats. The rows had distances from the tower of 2, 3 and 4 meters respectively, totaling 24 heliostats.

Using the equation described by Simmons (1925), as the field of mirrors have similarity to the geometry of plane curves, drew up in scale, the profile of the three curves heliostats that together form the catchment area of the proposed system. For distances of rows of heliostats up the tower it was determined the distances to the same focus that correspond, respectively to 3.10, 3.82, 4.65 meters. So it was determined the position of each heliostat on its focus, based on the design of concentric curves to the same axis, for subsequent construction of the field.

3.1.2. Manufacture of support structures of heliostats cutting and fixing of mirrors

The mobile pedestals, structures for setting mirrors were made by using scrap iron properly welded and adapted to allow regulations to follow the apparent movement of the sun. Areas to set the mirrors were made the same way, including four sections to facilitate the targeting of the four mirrors toward the absorber.

The mirrors were cut using a professional glass cutter. Glue was used in the setting of the contact segments of the mirror on the surfaces of iron and after the time required for drying, the mirrors were set, concluding, therefore, the assembly of the reflecting surfaces of the proposed model. The metal parts of fixed structures were painted, targeting to minimize the degradation due to its exposure to the phenomena of nature. Figure (2) shows the structure of a heliostat and Figure (3) shows the heliostat in its final form.

Figure 2. Structure of Heliostat.

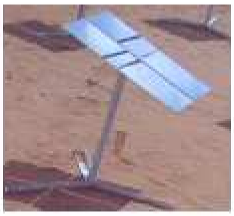

Figure 3. Heliostat mounted.

3.1.3. Targeting of heliostats

After the assembly was done a simulation on the reflecting surfaces. It was found that there were gaps in the segments of reflectivity on mirrors segments, not causing the direction of reflected rays to focus. The problem was solved for each individual heliostat. Figure (4) shows the reflection of sunlight in the four mirrors of a heliostat for a single focus.

Figure 4. Targeting of heliostats.

3.1.4. The receiver and the tower.

An empty cylinder of 240 mm diameter and 290 mm in height, was used as an absorber of the proposed system. Was cut in half and parts connected with solder at way concave-convex, to reduce its internal volume. The area was not illuminated with a thermally insulated composite produced in LES / UFRN, a basis of plaster, cement, crushed EPS, scrapings of tire and water, to minimize the thermal losses.

The cylinder was painted with matte black to better absorb the incident rays. Its alimentation was made by gravity through a hole located at the top of it.

The absorber was fixed on the tower through a metal structure. For the construction of the tower it was used a rod of galvanized iron of 2.37 m. The tower can be removed from its tripod, attached by adjustable steel cables. It is left is an area of 4.0 cm between the bottom of the absorber and the top of the tower to prevent the loss of heat by conduction.

The ground height of the center of focus was 2.70 m. The structure of the tower was painted to minimize effects of corrosion due to its exposure to phenomena of nature. Figure (5) shows the absorber positioned at the top of the tower.

Figure 5. Absorber at the top of the tower

3.1.5. Positioning of heliostats and tower

The heliostats were positioned so that the absorber were raised and that there was no blocking or shading of sunlight on each other. This evaluation was performed throughout the day, avoiding reflexive losses. The axis areas of heliostats were positioned in the north-south direction and the reflecting surfaces oriented to the east-west to follow the apparent movement of the Sun. The subsystem Tower - absorber was slightly to the south. Figure (6) shows the field even with some solar shading and Figure (7) the field already well positioned in its final format.

Figure 6. Field with solar shading

Figure 7. Solar field.

3.2. Experimental Procedure

Before being operated all heliostats, with four layers of mirrors, were previously adjusted to obtain a focus spot.

The system was tested in two configurations: with load and without load. In the loaded configuration, the system was fed through a funnel made in PET bottle attached to a hole made at the top of the absorber.

It was used four cromel-alumel thermocouples, attached to a digital thermometer to check the temperature data. A thermocouple was attached on the front of the absorber in the center of the area illuminated by the sun, another in the mediation center, inside the absorber, where the fluid was under review, the third in the insulation and fourth to check the ambient temperature. It was also used a pyranometer, built in LMHES / UFRN, which was coupled to a digital multimeter to measure solar radiation.

It was also measured the amount of water spray during five hours of operation of the test by the volume of water for replenishment. Consumption of tests performed during the verification of the amount of evaporated water, to control the flow, we used the device of measuring the time required for one liter of water to evaporate.

3.2.1. No load test

The heliostats were regulated every 15 minutes for a perfect direction of the rays reflected by the absorber. It was measured the global solar radiation and temperature of the absorber in the illuminated area and of the environment.

3.2.2. Tests with load

First the absorber was filled with 2.5 liters of water, in breaks of 15 minutes, and the heliostats were set up towards the sun, so the absorber is illuminated by rays. Right after it was measured the solar radiation and temperature of the absorber in the central part of the illuminated area and the temperature of the water. Then it was checked the temperature in the isolated area. It's understood that the water boils in the exit hole made in the front and top of the absorber, because the fluid is expanded to receive heat. The receiver was refueled approximately from 40 to 40 minutes, to maintain the level of water. Figure (8) shows the mini-tower in central test.

Figure 8. Mini-central solar tower in test.

3.3. Heat Balance

According to (Fraidenraich, 1995; Queiroz, 2005, Lyon 2007), the process of converting sunlight directly into heat passes through two stages, as follows: In the first stage the solar radiation is captured by a surface of capture and reflected to the absorber. In the second stage the solar radiation absorbed by the absorber is transferred to the working fluid by convection and the air by convection and radiation. Figure 9 shows the layout of the term conversion of solar energy.

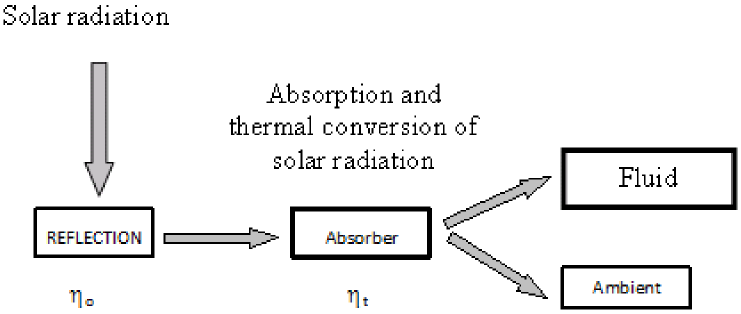

Figure 9. Schedule of the term conversion of solar energy.

Initially solar radiation is captured by means of heliostats areas and reflected to the absorber. Right after the solar radiation is absorbed by the receiver it is transferred to the inside of it where the fluid (water) of work is, and then by convection to the water and is lost to the air by convection and radiation.

So, to evaluate the efficiency of the system it is necessary to calculate the maximum absorbed power, the lost power, the net power, thermal efficiency, effectiveness and helpful optical efficiency.

3.3.1 Maximum power absorbed.

The maximum power that reaches the absorber ($_{\mathrm{Pabs}}$), given in (W) is the energy that enters the system, as determined by equation (2):

$$\boldsymbol{P_{abs} = I_d \cdot A_u \cdot \rho \cdot k_{rd} \cdot \alpha_t} \qquad (2\ )$$

Where (Id) the instantaneous direct solar radiation collected by the system of abstraction (W/m^2), (A$_u$) a floor area of the catchment area (m^2), (ρ) the reflectivity of the concentrator (%) (krd) the fraction the reflected radiation that reaches the absorber (%) and (α_t) is the absorptivity of the absorber tube (%)

3.3.2 Power loss

It's said that the total power lost (P$_{\mathrm{perdida}}$) is the energy leaving the system and is due to convection from the surface illuminated and isolated and the radiation from the surface light and isolated, so the heat losses are represented respectively by equations (3) and (4). So the power loss and represented by equation (5)

$$\mathbf{P}_{\mathbf{conv}} = \mathbf{P}_{\boldsymbol{i}\mathbf{conv}} + \mathbf{P}_{\mathbf{iso}\,\mathbf{conv}} = h\,(\mathrm{A}_i)\,(\mathrm{T}_{abs} - \mathrm{T}_\infty) + h\,(\mathrm{A}_{iso})\,(\mathrm{T}_{abs} - \mathrm{T}_\infty) \qquad (3)$$

$$\mathbf{P}_{\mathbf{rad}} = \mathbf{P}_{\boldsymbol{i}\boldsymbol{rad}} + \mathbf{P}_{\boldsymbol{iso}\,\boldsymbol{rad}} = \varepsilon\,\sigma\,(\mathrm{A}_i)\,(\mathrm{T}_{abs}{}^4 - \mathrm{T}_{viz}{}^4) + = \varepsilon\,\sigma\,(\mathrm{A}_{iso})\,(\mathrm{T}_{abs}{}^4 - \mathrm{T}_{viz}{}^4) \qquad (4)$$

$$(\mathbf{P}_{\boldsymbol{lost}}) = \mathbf{P}_{\mathbf{conv}\,+}\,\mathbf{P}_{\mathbf{rad}} \qquad (5)$$

Where ($\mathbf{P}_{\mathbf{conv})}$ is the power lost by convection (W), ($\mathbf{P}_{\boldsymbol{i}\mathbf{conv}}$) the power lost by convection by the illuminated area of the absorber (W), ($\mathbf{P}_{\mathbf{iso}\,\mathbf{conv})}$ the power lost by convection by the area isolated by the absorber (W), (***h)*** the coefficient of heat transfer (W/m^2.ºC), (A$_{i)}$ the area illuminated by the reflected radiation (m^2), (A$_{iso}$) thermally isolated area (m ^{2}), ($\mathbf{T}_{\boldsymbol{abs}}$) the absolute temperature at the focus of the absorber (K)**,** ($\mathbf{T}_\infty$) the air temperature (K), ($\mathbf{P}_{\mathbf{rad})}$ the power lost by radiation (W), ($\mathbf{P}_{\boldsymbol{i}\boldsymbol{rad})}$ the power lost by radiation by the illuminated area of the absorber (W), ($\mathbf{P}_{\boldsymbol{iso}\,\boldsymbol{rad}}$**)** the power lost by radiation the illuminated area of the absorber (W), (T$_{viz}$ = $\mathbf{T}_\infty$) the temperature of the neighborhood (K), (***ε)*** and the emissivity of the absorber (***σ)*** is the Stefan-Boltzmann constant (5,67x10^{-8}W/m^2. K)

To calculate the coefficient of heat transfer, determine the following parameters: Prandtl number (**Pr**), Reynolds number ($\boldsymbol{Re_D}$), and the Nusselt number ($\boldsymbol{Nu_D}$), because the second Incropera, (2003), with the knowledge of *Nu*, the local convection coefficient *h* can be found using equation (8) and the convective power can then be determined. *Nu* is a parameter that accounts for the thermal boundary layer which represents the coefficient of friction for coating speed limit, being determined by equation (6) and Reynolds number represented by equation (6).

$$\boldsymbol{Re_D = V.D/\,\upsilon} \qquad (6)$$

$$\boldsymbol{Nu_D} = \mathbf{0{,}3+[0{,}62(R_{\boldsymbol{eD}})^{1/2}(Pr)^{1/3}]/[1+(0{,}4/Pr)^{2/3}]^{1/4}\ .[\ 1+(\ R_{\boldsymbol{eD}}/282000)^{5/8}]^{4/5}} \qquad (7)$$

$$\boldsymbol{h = Nu_{D.}\,k/D} \qquad (8)$$

Where (***V)*** is the air speed (m/s), (***D)*** the diameter of absorber (m), (***υ***) the kinematic viscosity of air (m/s^2) and (***K***) the thermal conductivity of air (W/m. K).

3.3.3 Net power

The net power (P$_{u)}$ system is the difference between the maximum power absorbed and lost power, represented by equation (8).

$$\mathbf{P}_{\boldsymbol{u}} = \mathbf{P}_{\boldsymbol{abs}} - \mathbf{P}_{\boldsymbol{lost}} \qquad (9)$$

3.3.4 Useful Efficiency

By Figure (14), we noticed that the useful conversion efficiency (η_u) of the whole process of converting solar radiation into heat, is a parameter that determines the percentage of all the radiant solar energy that reaches the reflector surface and is transferred for the working fluid, i.e. it depends on the efficiency of the optical system for capturing solar energy (η_o), represented by equation (10) of the catchment area and the thermal conversion efficiency or thermal efficiency (η_t), given by equation (11) of the absorber, once we get the useful efficiency of the process represented by equation (12):

The optical efficiency is a parameter that calculates the percentage of radiant solar energy that reaches the reflector surface and is sent to the absorber. This is therefore a percentage of optical losses, due to the radiant energy that reaches the reflecting surface not sent to the receiver of light. The thermal efficiency is the parameter that determines the percentage of all the solar energy that reaches the absorber and is transferred to the working fluid.

$$\eta_o = \rho \,.k_{rd}.\ \alpha_t \tag{10}$$

$$\eta_t = P_u/P_{abs} \tag{11}$$

$$\eta_g = \eta_o \times \eta_t \tag{12}$$

3.3.5 Concentration Factor

The concentration factor (C) is determined by the relationship between floor area and the illuminated area, according to equation (13):

$$C = A_u/A_i \tag{13}$$

4. RESULTS AND DISCUSSIONS

Using the equations presented were certain parameters that reflect the efficiency of transformation of electromagnetic energy into heat energy, by the Central Mini-Tower, the values are presented in Table (1).

Tabela 1. Values of parameters for assessing efficiency.

Parameters	Value calculated
Power absorbed	**1463,6W**
Power lost	**499,84 W**
Net power	**963,75 W**
Optical efficiency	**77%**
Thermal efficiency	**66%**
Efficiency useful	**51%**
Factor concentration	**35,22**

Table (2) and (3) shows the average and maximum data of the general system model tower under study. Table (3) presents data obtained maximum.

Table 2. Average of three days of no-load test of the prototype.

DAY	Tmaximum absorber (°C)	Taverage absorber (°C)	Direct solar radiation (W/m²)
1	**489,3**	**467,8**	**590,4**
2	**485,1**	**460,9**	**584,0**
3	**481,5**	**460,1**	**580,8**
AVERAGE	**485,3**	**462,9**	**585,1**

Table 3. Average of three days of test with loading of the prototype.

DAY	T_{water} (°C)	$T_{absorber}$ (°C)	T_{vapor} (°C)	$T_{insulate}$ (°C)	**Direct solar radiation (W/m^2)**
1	**33,6**	**133,3**	**106,8**	**37,6**	**585,6**
2	**34,0**	**134,4**	**106,4**	**37,1**	**582,4**
3	**34,2**	**134,4**	**107,1**	**37,6**	**584,0**
AVERAGE	**33,9**	**134,0**	**106,8**	**37,4**	**584,0**

The data indicate a maximum temperature of 500.8° C for a direct solar radiation of 600.0 W/ m². The average temperature was 95.4% of the maximum temperature, which represents a significant achievement, which can be reached on the basis of appropriate solar conditions with radiation nearly constant for the period tested.

This constancy of radiation, necessary to an appropriate use of systems that convert solar energy into electric energy using the effect of concentration, is possible only in few regions of the world, among them the Brazilian Northeast. The values point to an average temperature always above 450.0 ° C, for a direct solar radiation always above 580,0 W/m².

The measured parameters show that the days selected had excellent solar conditions, nearly constant, as desired. It was only chosen days with virtually no cloud cover, ideal for operating a plant for generation of solar thermal energy and subsequently in processing power of low magnitude.

The temperature of the thermal insulation was only 12.0% above the ambient temperature, which shows a good efficiency of the material used for this purpose. The efficiency of thermal insulation provided an obtaining of a higher temperature of water steam. The absorber temperatures are significant with an average of 134.0° C, and were always above the temperature of the fluid vapor.

The average direct solar radiation corresponds to around 584.0 W/m^2, which is above the average expected in the region of northeastern Brazil, between 400.0 and 560.0 W/m².

The data suggest temperatures of water steam always above 100.0° C, with average value of 106.8° C, corresponding to 6.8% above the boiling temperature of the used fluid. The amount of vaporized water was around 7.5 liters in five hours of operation.

The graphs of Figures 10 and 11 below show the behavior given by the measured temperatures of the absorber during the tests.

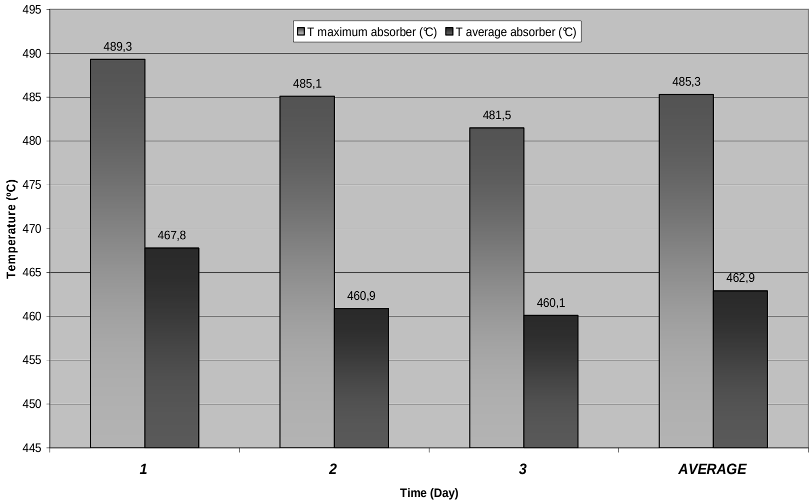

Figure 10. Behavior given and average temperatures of three days of testing without charge.

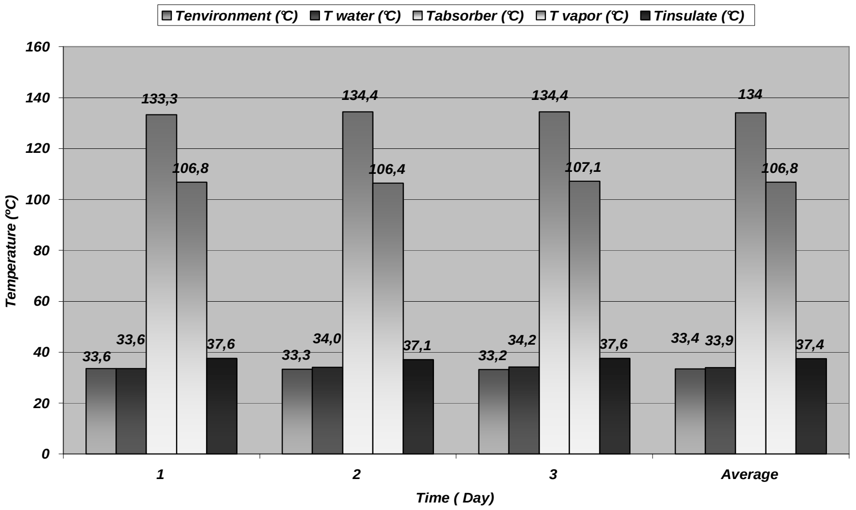

Figure 11. Behavior given and average temperatures of three days of tests with load.

The cost of the system was rather low because of using up scrap material for its construction, which helped to minimize the cost of manufacture. The materials that were purchased, mirror, glue, cable, steel, paints and welding rods, and others, amounted to R$ 250,00.

According to the data obtained, the delivery system of the working fluid corresponds to an energy 0,96 kWh. Considering the five hours of operation per day, it amounts 4,80 kW/day. Since the price of the kW/h cost is approximately R$ 0,37 it can be calculated that the economy in a year of use of the mini solar central tower corresponds to 4,80 kW/ day x 365 days x 0,37 R$ /kW = R$ 648,24.

5. CONCLUSIONS AND SUGGESTIONS

Based on the process and outcome of the model presented in this paper the conclusions below are presented.

1. It was demonstrated the feasibility of using the tower, through the study of its type, to obtain the consequent generation of steam and electricity;
2. The processes of manufacture and assembly of the central tower model was simple, not requiring significant technical-scientific knowledge to be handled;
3. The difficulty of the tracking mechanism for keeping the focus always illuminated by sunlight, requiring correction of positioning in short periods of time, in about 15 minutes, which requires a thorough job;
4. It can be observed that the heliostats provided a good concentration of rays in the absorber, in a small area, allowing to obtain a factor of considerable concentration;
5. The convective loss of the absorber were of minor magnitude, demonstrating the efficiency of the composite material used as a thermal insulator;
6. For the proper functioning of the mini-studied central tower, it can be said that this system presents a large feasible tower to be applied, especially in our region. Requiring, however, an automated tracking mechanism. This system can be deployed in the near future for electricity generation;
7. The thermal conversion subsystem comprising a turbine and an alternator, may be of conventional type, thus avoiding the need for further research;
8. It is important that more tests are performed, in all seasons of the year for a more real core of the mini-tower.

6. REFERENCES

INCROPERA, F.P.; DE WITT, D.P.**, Fundamentos de Transferência de Calor e Massa,** Guanabara Koogan, 4ª edição, Rio de Janeiro, 2003.

FILHO, J. R., **Projeto, construção e levantamento de desempenho de um concentrador solar cilíndrico parabólico com mecanismo automático de rastreamento solar,** Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN – Natal/RN,2008.

LION, C. A. P. Q.**, Construção e análise de desempenho de um fogão solar à concentração utilizando dois focos para cozimento direto**, Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN – Natal/RN, 2007.

BEZERRA, A.M., **Aplicações Térmica da Energia Solar,** Editora Universitária, João Pessoa, Pb, 2001.

QUEIRÓZ, W. F., **Construção de um fogão solar à concentração para cozimento direto e indireto**, Dissertação de MESTRADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA MECÂNICA DA UFRN – NATAL/RN, 2005.

FRAIDENREICH, N., LYRA, F., **Energia solar: Fundamentos e Tecnologias de conversão heliotérmelétrica e fotovoltaica**, Ed. Universitária, Recife, 1995.

KEMPER, J.P. the plataforma solar. Munich: M.A.N; 1981

MARTÍNEZ, V.; PUJO, L R.; MOIÁ, A., **Um concentrador solar innovador de reflector estático y foco móvil para procesos de calor**. XIV Congreso Ibérico y IX congreso Iberoamericano de Energia Solar, Vigo,Galícia, España, 2008.

AGUILAR, J.O.; CALAM, J.S.; ACOSTA, R.; CUSEVAS, J.D.; HERNÁNDEZ, J.; JARAMILLO, O.A.; PÉREZ-RÁBACO, C.; FLORES, J.J., **Diseño y construcción de um colector solar de canal parabólico**. XIV Congreso Ibérico y IX congreso Iberoamericano de Energia Solar, Vigo, Galícia, España, 2008.

ROLIM, M.M.; FRAIDENRAICH, N.; TIBA, C.; VILELA O.C., **Dimensionamento e simulação anual de uma central heliotérmica com coletores parabólicos lineares utilizando solução analítica**. XIV Congreso Ibérico y IX congreso Iberoamericano de Energia Solar, Vigo,Galícia, España, 2008.

SIMMONS, F. G., **Cálculo com Geometria analítica,** Makron Books, Volume 2, São Paulo, 1987, Brasil.

Censolar (Centro de Estudios de la Energia Solar) **Avances em Energías Solar**, PROGENSA, Sevilha, 2001, Espana.

7. RESPONSIBILITY NOTICE