# DIMENSIONING OF A CPC FOR USING AS A BI-FACIALLY IRRADIATED SOLAR COLLECTOR

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**Abstract.** This paper presents the dimensioning of a compound parabolic concentrator (CPC) as a component of an adsorptive solar refrigerator prototype. The solar collector is composed by a series of tubes, placed side-by-side and painted in matt black. Inside the tubes, in an annular space, an adsorbent material is confined; it interacts with a working fluid (the adsorbate) in the cooling process. The external surface of the tubes, upper and under, is the solar radiation absorber surface; they are covered with transparent insulation material of high efficiency (TIM covers). The actual concentrators are made of polishing aluminum and are installed in such a way that makes possible the incidence of solar rays also on the lower part of the absorbing surface. During the daytime, it is necessary to concentrate energy for obtaining high temperatures inside the tubes; in the nighttime, the collector shall be cooled to allow a release of the heat dissipated from the adsorption – an exothermic process –, in which the fluid (methanol) is transferred to the adsorbent (activated carbon). Field tests had been carried through with concentrators of cylindrical-circular geometry installed below the tubes; temperatures in the different surfaces of a cavity formed by the reflectors and the tubes had been measured for one entire day. The cylindrical-parabolic geometry is proposed for the reflectors in order to increase the efficiency of the solar collector, by concentrating the radiation on the lower and upper surfaces. We expect that with this kind of concentrator the solar collector can operate at suitable temperatures without TIM covers, improving the adsorber cooling during the nighttime. Analytical model for dimensioning the CPC concentrator have been developed, and the resulting geometric and optical properties are compared with the original configuration. All calculations were made for an incidence angle of $0^o$.

***Keywords***: *solar concentrator, bi-facial collector, low concentration CPC.*

## 1. INTRODUTION

The use of the compound parabolic concentrator (CPC) in solar refrigeration applications is not innovation. In general, these systems need to reach high regeneration temperatures in the solar collector during the day, and to release heat during the night. As larger the received and released heat, higher is the coefficient of performance of the refrigeration system.

The main raison to use concentrators in solar refrigeration is to increase the temperature of the absorbing surface, which is reached by the incidence of the solar radiation also on the lower face of the receiver.

Headley *et al*. (1994) (cited in Anyanwu, 2003) built an activated carbon-methanol adsorption refrigerator with a cylindrical-parabolic reflector to concentrate the solar radiation into an adsorbent copper tube at the focal line. Tamainot-Telto and Critoph (1999) used two CPC solar collectors with tubular absorbers and a single glazing cover to compose the solar collector of an ammonia-carbon refrigeration solar refrigerator.

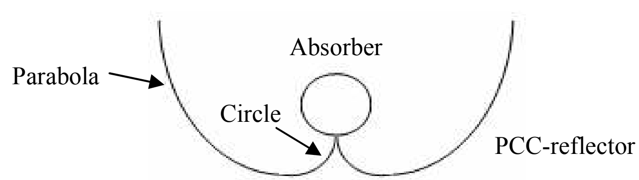



Figure 1. Design of parabolic circle concentrators (PCC). Adapted from Niemann *et al*. (1997).

Niemann *et al*. (1997) developed and investigated shape concentrators made by segments of parabolas and circles, because of its easiness manufacturing. This kind of collector consists of an evacuated tubular collector with external parabolic circle concentrators (PCC) (Fig. 1). The non-tracking PCC-collector is integrated to an ammonia-carbon adsorption ice maker.

Leite *et al*. (2004, 2005a, 2005b) has used a semi-cylindrical concentrator (as suggested by Goetzberger *et al*., 1992) in an adsorptive solar refrigerator that uses the pair activated carbon-methanol. The solar collector is formed by a series of tubes painted in matt black, of low reflectivity. Inside of tubes, in an annular space, is confined an adsorbent material that it interacts with a fluid of work in the refrigeration process. The external surface of tubes, upper and under, is the absorber surface of solar radiation of collector, they are used coverings with transparent insulation material of high efficiency (TIM covers). The actual concentrators are made of polishing aluminum and are installed in such a way that makes possible the incidence of solar rays also in the lower part of the collector. The Figure 2 shows the collector with the TIM covers and the concentrator.

Figure 2. Lateral view of the collector, TIM covers and the concentrator.

For obtaining an increase in the efficiency of solar conversion, we have proposed the use of a compound parabolic concentrator (CPC) instead of the cylindrical one originally considered. The great advantage of the cylindrical-parabolic geometry lies in the fact that the solar radiation can be concentrated also on the upper side of the absorbing surface. In this way, the solar collector can operates without TIM covers, and, thus, improves the night cooling.

The analytical expressions for the two concentrators and some geometric properties are shown in the section 4. In section 5 the main optical properties are determined and compared. Finally, in the section 6, the found results are discussed and the last section is the conclusion.

This work presents a proposal of compound parabolic concentrator (CPC) with the objective of increasing the efficiency of the adsorptive refrigerator. The cylindrical-parabolic geometry concentrates the solar energy on the lower and upper surface of the collector. This concentration on the upper surface can make possible the use of the solar collector without TIM covers, also contributing to a better night cooling.

In the following section the dimensions of collector was presented. The analytical expressions for the two concentrators and some geometric properties are shown in the section 3. In section 4 the main optical properties are determined and compared. Finally, in the section 5, the found results are discussed and the last section is the conclusion.

## 2. ADSORPTION REFRIGERATOR

The adsorption icemaker is based on an intermittent cycle, which occurs without heat recovering. This cycle consists of two typical stages: one is characterized by the adsorption process, when the evaporation of the working fluid (the adsorbate) takes place; and another consists of the solid medium (the adsorbent) regeneration by solar energy, when the adsorbate is condensed. The adsorbent-adsorbate pair is the activated carbon-methanol. The solar-powered refrigerator is mainly composed of an integrated adsorber-solar collector, connected to a condenser and an evaporator (Fig. 3). The direction of the gaseous flow is altered, according to the cycle stage; it goes from the adsorber towards the condenser during the regeneration, and from the evaporator towards the adsorber, during the adsorption phase. The TIM covers are in place during regeneration, and retracted otherwise to improve cooling, as shown in Fig. 3.

The refrigeration stage begins by the end of the afternoon, when the temperature and the pressure of the adsorber decrease, following an isosteric process, i.e., a process in which the adsorbed phase concentration ($a$) is constant. The evaporation takes place when the gaseous adsorbate flows to the adsorber throughout the night, producing the refrigeration effect until the adsorber temperature reaches a minimum value. In another isosteric process (Fig. 3b), the adsorber is heated by the solar radiation incidence, increasing the temperature and pressure until they reach the condenser pressure. Then condensation takes place and the adsorbate is transferred to the condenser until the adsorber reaches a maximum temperature, which means the end of the cycle. The ideal thermodynamic cycle can be represented by two isosters (iso-lines with constant adsorbed phase concentration) and two intercalated isobars, as shown in Fig. 4. Processes 1-2 and 2-3 represent the cooling of the adsorbent and the adsorption, respectively, and processes 3-4 and 4-1 describe the regeneration stage of the adsorbent (heating and desorption). A complete thermodynamic analysis of the adsorption refrigeration system is given by Leite (1998).

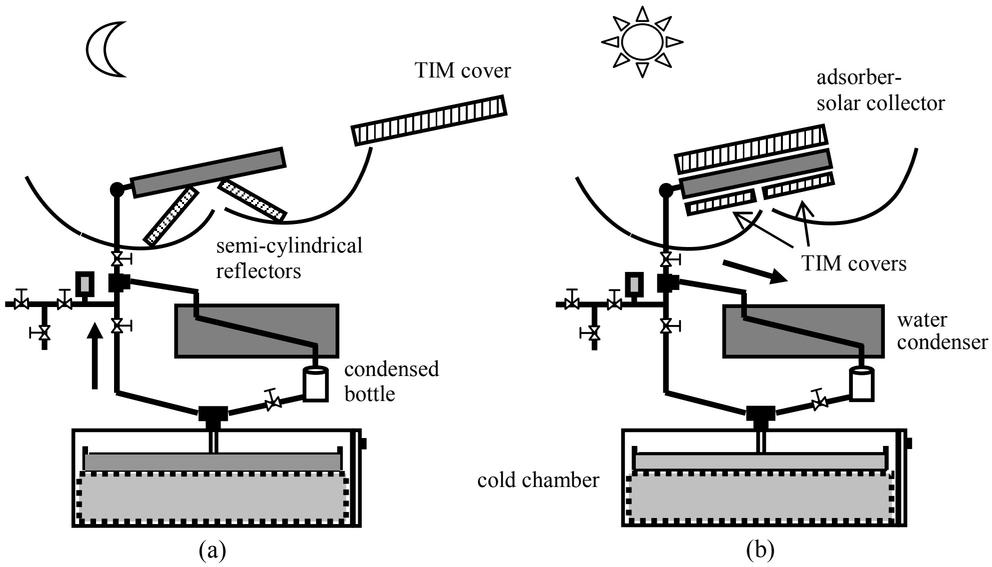



Figure 3. Scheme of the adsorptive icemaker and its operation: (a) Stage of refrigeration; (b) Stage of regeneration.

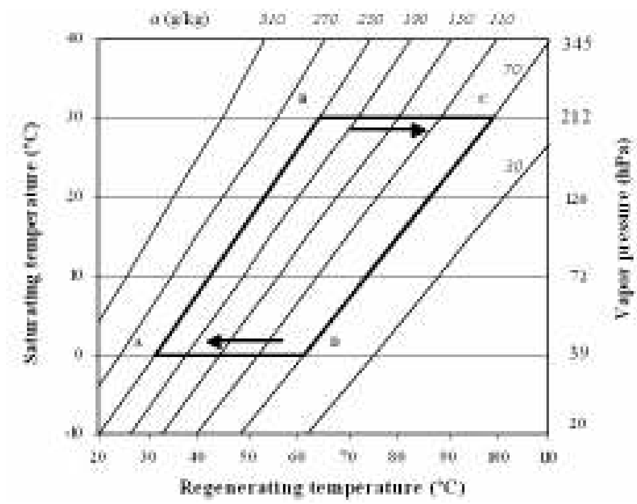


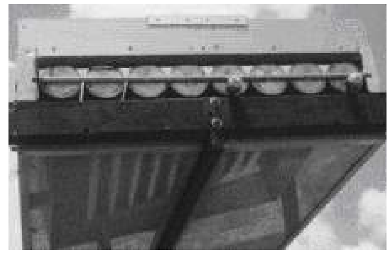

Figure 4. Network of activated carbon-methanol isosters and theoretical cycle.

The dimensioning parameters and a thermal efficiency analysis based on experimental data of the actual prototype have been recently published by Leite *et al*. (2004).

## 3. DIMENSIONS OF THE SOLAR COLLECTOR

The absorber is composed by 8 tubes placed side-by-side, having a projected collector area 0.61 x 1.65 $m^2$ (Fig. 5a). The TIM covers installed in the absorber have the dimensions, respectively, 1.78 x 0.71 x 0.09 $m^3$, for the upper cover, and 1.67 x 0.34 x 0.07 $m^3$, for the lower cover (Leite *et al*., 2004). The lower TIM cover was made in two identical parts (Fig. 5b), articulated around a central and longitudinal axis, in order to be movable, which improves the heat dissipation from the absorber, during night.

(a)



(b)

Figure 5. View of the absorber plane (a) and the TIM covers over and under the adsorber (b).

The semi-cylindrical concentrators are installed below the absorber, as shown in Fig. 2. They have a radius of 0.35 m, 1.65 m of length, 0.001 m of thickness and the arc of the circle has 1.1 m. Figure 6 shows the dimensions of the concentrator.

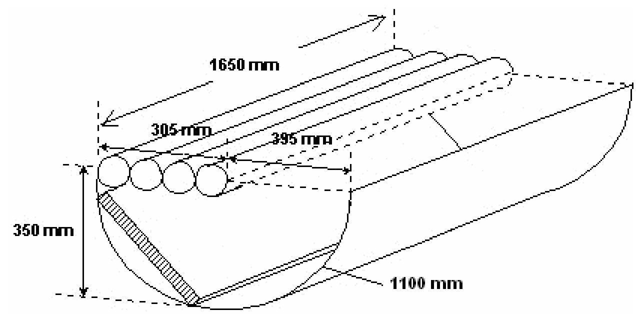



Figure 6. Schematic of the half solar collector with the dimensions.

## 4. GEOMETRY OF CONCENTRATORS

In this section, some geometric properties of the concentrator are presented, as the geometry of the cavity, the concentration ratio and the length of the reflector. The equations of the concentrators are found using the Cartesian coordinate system and presented in it parametric form.. The first concentrator is a formed by a simple involute and the second concentrator, a CPC, is formed by three parts, an involute and two parabolic segments.

### 4.1. Involute and CPC equations

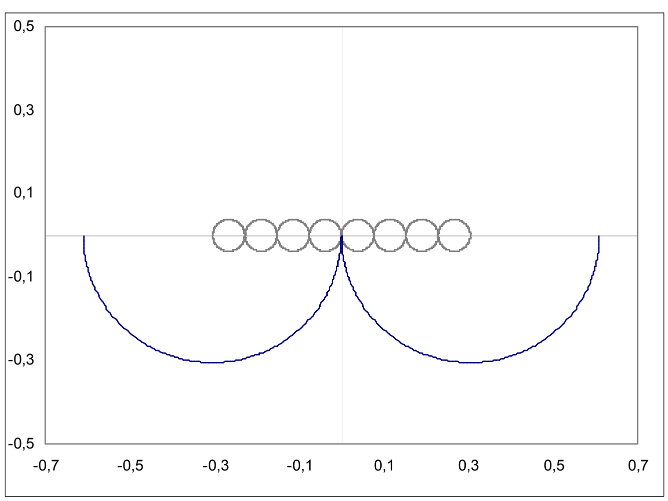



Figure 7. The solar collector with the absorber multi-tubular and the circular concentrators generated starting from the Eqs. (1) and (2).

For involute the equations are as following:

$$x = x_0 + r\cos\phi \tag{1}$$

$$y = y_0 + r\sin\phi \tag{2}$$

where $r$ is the radius of involute, has the value of 0.35 m. The angle $\phi$ is measured in the counterclockwise with center at point $x_0$ = 0.35 m, $y_0$ = 0 m, and it varies among $\pi \le \phi \le 2\pi$ (Fig. 7).

The CPC is formed for three segments, as seen in Fig. 8. The first part is circular, with radius equal to 0.269 m centered at point $x_0$ = 0.266 m, $y_0$ = 0 m. The equations are the same of the involute of the first concentrator (Eqs. (1) and (2)), but the angle $\phi$ varies among $\pi + \alpha \le \phi \le 3\pi/2 + \theta_a$. The angle $\alpha$, seen in Figure 7 is a acute angle. The involute doesn't begin in the origin of the Cartesian system, but it suffers a displacement in the axis y equal to the ray of the tubes (Fig. 9) forming a small acute angle, $\alpha$, with the axis x. The angle $\theta_a$ is the half-acceptance angle, which has the value of 30º.

Second segment is formed by a parabola with the focus moved until the point $F_1$, which is the same point of involute center. The distance $f_1$ is equal to radius of first segment and the symmetry axis is rotated of $\theta_a$.

The equations are following:

$$x = x_0 + \frac{2 f_1 \cos\phi}{1 - \sin(\phi - \theta_a)} \tag{3}$$

$$y = y_0 + \frac{2 f_1 \sin\phi}{1 - \sin(\phi - \theta_a)} \tag{4}$$

The angle $\phi$ is measured in the same way that in the involute and varies among $3\pi/2 + \theta_a \le \phi \le 2\pi$.

The last segment also is parabolic and their equations are identical the Eqs. (3) and (4), substituting $f_1$ for $f_2$. The value of the focus coordinates is $x_0 = -0.266$ m, $y_0$ = 0 m, and the distance $f_2$ is given for $f_2 = f_1 + x_0[1 - \sin(2\pi - \theta_a)]$ = 0.669 m. The angle $\phi$ varies among $2\pi \le \phi \le \pi/2 - \theta_a$.

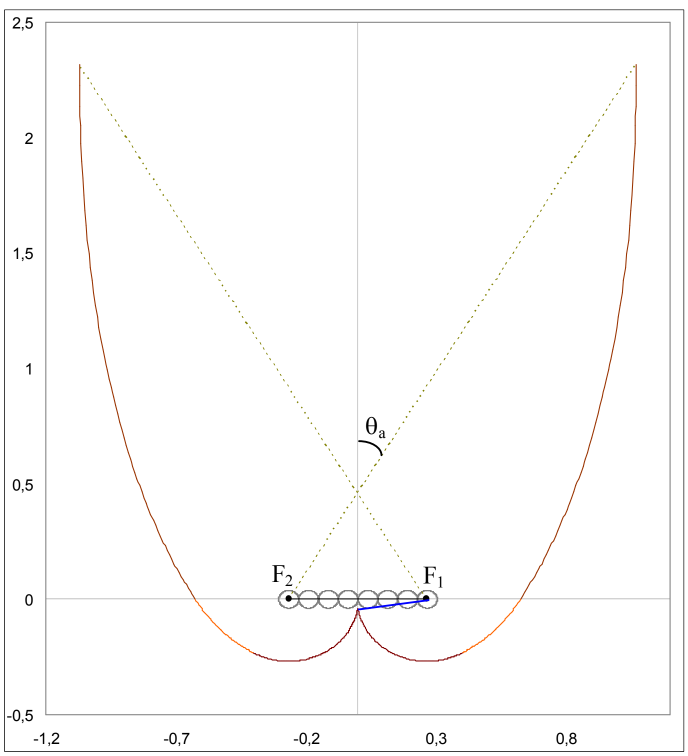



Figure 8. The solar collector with the absorber multi-tubular and the CPC generated starting from the Eqs. (1) to (4).

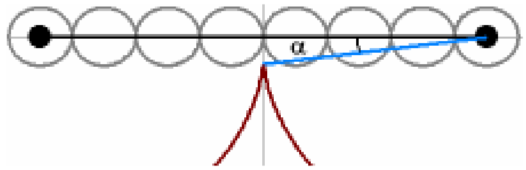



Figure 9. Detail of the acute angle α.

### 4.2. Concentration ratio of concentrators

The concentration ratio is defined as the ratio of the area of aperture to the area of the receiver (Duffie and Beckman, 1991):

$$C = \frac{A_a}{A_r} \tag{5}$$

For the linear concentrators, the highest possible concentration ratio can be given for:

$$C = \frac{1}{\sin\theta_a} \tag{6}$$

The circular concentrator has a C = 2 and the CPC untruncated was projected to have the same concentration ratio.

### 4.3. Length of concentrators

The length of circular concentrator can be calculated by:

$$L_{circ} = 2r\phi \tag{7}$$

with $\phi = \pi$, totaling a length of 2.2 m.

The length of the CPC is the sum of the perimeter of each segment that forms the concentrator. The circular section can be calculated by Eq. (9), with the angle $\phi = 2\pi/3 - 0.142$, what results in the value of 1.05 m.

The parabolic section of the concentrator it can be calculated by equation found in Fraidenraich *et al.*, (2007):

$$L_{parab,i} = 2^{5/2} f_i \frac{1}{(1+\cos\phi_i)^{3/2}} \cdot \left\{ \cos^3\frac{\phi_i}{2} \cdot \log\frac{\left(\cos\frac{\phi_i}{4} - \sin\frac{\phi_i}{4}\right)}{\left(\cos\frac{\phi_i}{4} + \sin\frac{\phi_i}{4}\right)} - \frac{\sin\phi_i}{2} \right\} \tag{8}$$

where the index $i$ refers to parabolic segments ($i$ = 1, 2), $f_i$ is the focal distance of the parabola $i$ ($f_1$ = 0.27 m, $f_2$ = 0.67 m) and the angle $\phi_i$ is the angular interval in which the parabolas are defined ($\phi_1 = \phi_2 = \pi/3$). Made the calculus, results that $L_{parab,1}$ = 1.92 m and $L_{parab,2}$ = 3.43 m. The total length of CPC is $L_{CPC}$ = 5,35 m.

## 5. OPTICAL PROPERTIES OF CONCENTRATORS

The optical efficiency is defined as the rate of the radiation received by the absorbing surface to the radiation that passes by the aperture area. According to Tiba *et al.* (2005), the optical efficiency, $\eta$, of CPC (for $r > 0.75$) can be well approximated by $\eta = \alpha\tau\rho^{\langle n\rangle}$ where $\rho$ is the reflectivity of the reflector surface, $\alpha$ the absorber absorptivity, $\tau$ the cover transmissivity and $\langle n\rangle$ the mean number of reflections that an incident ray at the aperture undergoes before reaching the absorber. The mean number of reflections for a concentrator can be calculated by the expression (Carvalho *et al.*, 1985):

$$\langle n\rangle = E_{refl-abs}\left(\frac{A_{refl}}{A_{abs}}\right) \tag{9}$$

where $A_{refl}$ is the reflector area, $A_{abs}$ the absorber area, and $E_{refl\text{-}abs}$ is the fraction of the radiation emitted by the ideal reflector surface (reflectivity equal to 1) that would reach the absorber. Fraidenraich *et al.*, (2007), develops the expression of the mean number of reflections for the involute:

$$\langle n \rangle = \frac{r\phi}{2L_{abs}} \tag{10}$$

with $r$ is the radius of involute, $\phi$ is the angular interval of the involute and $L_{abs}$ is the perimeter of the absorber plate.

For the parabola the expression of the mean number of reflections is:

$$\langle n_i \rangle = \frac{L_i}{2L_{abs}} - \frac{f_i}{L_{abs}}\left[\frac{\cos(\theta_a + \phi_i)}{1-\cos(\theta_a + \phi_i)}\right] \tag{11}$$

where $L_i$ is the length of the parabola given by the Eq. (8), $f_i$ is the focus of the parabola in subject (subsection 3.1), and $\phi_i$ is the angular interval of the segment parabolic. The mean number of reflections for the CPC is given by the sum of $\langle n_i \rangle$.

With the dates of the section 3 was possible to calculate the mean number of reflections and the optical efficiency for the circular concentrator and of CPC, presented in the next section.

## 6. RESULTS AND DISCUSSION

Table 1 summarizes the main results of the geometrical and optical properties of the circular concentrator and CPC.

Table 1. Geometrical and optical properties of the circular concentrator and CPC.

| Geometrical and Optical Properties | Circular Concentrator | CPC |
|---|---|---|
| Segments | 1 | 3 |
| Absorbing Area (m) | 0.61 | 0.61 |
| Aperture Area (m) | 1.22 | 1.22 |
| Concentration ratio | 2 | 2 |
| Height (m) | 0.31 | 2.58 |
| Length (m) | 2.2 | 5.35 |
| Mean Number of Reflections | 0.9 | 1.8 |

In spite of the actual adsorber's geometry is multi-tubular, for dimensioning the CPC a flat and smaller absorbing surface than the circular concentrator was considered. The extreme points of that surface are located in the center of the most external tubes. This procedure was adopted due to a better distribution of the radiation on the respective tubes by the second segment of CPC that implicates in values of aperture and absorber area smaller than for the circular concentrator. As consequence, the absorption area for the CPC is the sum of both upper and lower areas, while in the circular concentrator the absorbing area viewed by the concentrator is given just by the under side of the adsorber-solar collector.

An aperture area larger implicates that the energy received by the CPC is about 75% larger than the energy received by the circular concentrator. As expected, the CPC has much larger dimensions than the circular concentrator; it is about 8.3 times larger in the height and 2.4 times larger in the perimeter. This implies in an increase of the number of reflections and, consequently, in a decrease of the optical efficiency of the collector.

To compare the optical parameters among the concentrators, calculations of the fraction of the solar radiation direct component deviated by the reflectors, we have considered an incidence angle of $0^o$. The circular concentrator deviates all solar radiation through the aperture area to the lower part of the absorbing surface, while the CPC deviates only 12.5% of the incident radiation, 39.1% is deviate to the upper part, and 23.5% is deviate to the lateral part of the collector. The remaining fraction of the radiation, about 24.9%, arrives directly from the upper side of the collector.

The radiation received by the lower part of the CPC absorbing surface is about 80% less than that received by one of the circular concentrator. However, in the CPC this reflection is more efficient, since 80% of the incident radiation arrives on the lower part, while in the circular concentrator only 67% arrives due to multiple reflections.

The values of the total solar radiation ($I_{total}$) and the direct and diffuse components ($I_{dir}$ and $I_{dif}$) presented below are measured during the desorption phase of a solar adsorption refrigeration cycle for an icemaker prototype (Andrade, 2004).

Tables 2 and 3 show the calculated results for the fraction of the direct radiation that arrives on the upper face of TIM covers ($I_{ps\ dir}$), for the fraction of the direct radiation that arrives on the lower face ($I_{TIM}$), and for the fraction of the direct radiation that the absorbing surface receives ($I_{pi\ dir}$), respectively, for the circular concentrator and for the CPC.

Table 2. Total solar radiation and respective fraction, for the circular concentrator.

| Local Hour | $I_{total}$ (J m$^{-2}$) | $I_{dir}$ (J m$^{-2}$) | $I_{dif}$ (J m$^{-2}$) | $I_{ps\ dir}$ (J m$^{-2}$) | $I_{TIM}$ (J m$^{-2}$) | $I_{pi\ dir}$ (J m$^{-2}$) |
|---|---|---|---|---|---|---|
| 6:00 | 372892 | 107581 | 265311 | 129894 | 256650 | 12220 |
| 7:00 | 1103827 | 591246 | 512581 | 446451 | 753178 | 38119 |
| 8:00 | 1946830 | 1220099 | 726731 | 925361 | 1324127 | 68496 |
| 9:00 | 2711488 | 1818322 | 893166 | 1437460 | 1841347 | 96247 |
| 10:00 | 3258634 | 2258090 | 1000545 | 1877998 | 2211159 | 116188 |
| 11:00 | 3500350 | 2458800 | 1041549 | 2146001 | 2374377 | 125044 |
| 12:00 | 3399962 | 2390006 | 1009956 | 1986920 | 2306240 | 121470 |
| 13:00 | 2972047 | 2060948 | 911099 | 1607319 | 2016659 | 105980 |

Table 3 Total solar radiation and respective fraction, for the CPC.

| Local Hour | $I_{total}$ (J m$^{-2}$) | $I_{dir}$ (J m$^{-2}$) | $I_{dif}$ (J m$^{-2}$) | $I_{ps\ dir}$ (J m$^{-2}$) | $I_{TIM}$ (J m$^{-2}$) | $I_{pi\ dir}$ (J m$^{-2}$) |
|---|---|---|---|---|---|---|
| 6:00 | 654089 | 188708 | 465381 | 171958 | 65932 | 2981 |
| 7:00 | 1936221 | 1037104 | 899118 | 677628 | 195171 | 9258 |
| 8:00 | 3414931 | 2140174 | 1274757 | 1402420 | 344225 | 16609 |
| 9:00 | 4756217 | 3189516 | 1566702 | 2148424 | 479427 | 23322 |
| 10:00 | 5715966 | 3960912 | 1755054 | 2760911 | 576169 | 28144 |
| 11:00 | 6139957 | 4312977 | 1826980 | 3107392 | 618908 | 30284 |
| 12:00 | 5963867 | 4192306 | 1771562 | 2921412 | 601158 | 29418 |
| 13:00 | 5213263 | 3615106 | 1598157 | 2413150 | 525497 | 25671 |

Obviously, the radiation received by the upper TIM cover is larger for CPC than for the circular concentrator, since the first one receives it directly and still deviates a fraction of the radiation from the upper part. Concerning the direct radiation, the augmentation is about 47% larger than that received by the circular concentrator. However, for the CPC, a decrease is noticed in the radiation deviated to the lower TIM covers, and, consequently, in the radiation arriving in the respective absorbing plate; the incident radiation is around 75% smaller.

In this model, the diffuse radiation was neglected, but it will be evaluated from field tests with a prototype that is nowadays in construction (Fig. 10).

Figure 10. The view of CPC structure and the adsorber at the Laboratory of Solar Energy.

## 7. CONCLUSION

We have proposed a cylindrical-parabolic geometry as an alternative for improving the efficiency of the solar collector, as part of an autonomous adsorptive refrigerator prototype. An analytical model has been developed and it was used for dimensioning the CPC concentrator. The original proposal of a solar collector bifacially irradiated was retained.

The new concentrator is larger than the original, and this implies an increase of construction costs of the solar collector. However, with the CPC it is possible to have solar concentration also on the upper face of the tubes, and not only in their lower face, as in the case when the circular geometry is used.

The number of reflections in the CPC geometry is twice larger than that for the circular concentrator, what implicates a smaller optical efficiency. The concentration on the lower side is smaller than that obtained with the circular concentrator because in the last one there is a decrease of the optical efficiency and the radiation.

An increase in the concentration on the upper TIM cover is verified, since the CPC also concentrates in this surface.

## 8 ACKNOWLEDGEMENTS

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## 9 REFERENCES

Andrade, R R D, 2004, "Avaliação Teórico-Experimental do Ciclo Termodinâmico em um Adsorvedor Multitubular de um Refrigerador Solar", pp 125, Dissertação (Mestrado em Eng Mecânica), Universidade Federal da Paraíba, João Pessoa, PB, 2004

Anyanwu, E E, 2003, "Review of Solid Adsorption Solar Refrigerator I: An overview of the Refrigeration Cycle", Energy Conversion & Management, Vol44, pp 301-312

Carvalho, MJ, Collares-Pereira, M, Gordon, JM and Rabl, A, 1985, "Truncation of CPC Solar Collectors and its Effect on Energy Collection" Solar Energy, v35, n 5, pp 393-399

Duffie, J A and Beckman, W A, 1991, "Solar Engineering of Thermal Processes", 2$^{nd}$ Ed John Wiley, New York, USA

Fraidenraich, N, Tiba, C, Brandão, BB and Vilela, OC, 2007, "Estudo Analítico de Concentradores CPC Estacionários com Absorvedor V Invertido", Proceedings of the I Congresso Brasileiro de Energia Solar, Vol1, Fortaleza, Ceará, Brazil

Goetzberger, A, Dengler, J, Rommel, M Götischf, J and Wittwer, V, 1992, "A New Transparently Insulated, Bifacially Irradiated Solar Flat-Plate Collector", Solar Energy, Vol49, No 5, pp 403-411

Leite, APF, 1998, "Thermodynamic Analysis and Modelling of an Adsorption-Cycle System for Refrigeration from Low-Grade Energy Sources", Journal of the Brazilian Society of Mech Sci, Vol20, pp 301-324

Leite, APF, Grilo MB, Andrade RRD and Belo FA, 2004, "Dimensioning, Thermal Analysis and Experimental Heat Loss Coefficients of an Adsorptive Solar Icemaker", Renewable Energy, Vol29, pp 1643-1663

Leite, APF, Grilo MB, Andrade RRD, Belo FA and Meunier, F, 2005a, "Experimental Evaluation of a Multi-Tubular Adsorber operating with Activated Carbon-Methanol", Adsorption - Journal of Int Adsorption Society, Vol 11, pp 543-548

Leite, APF, Grilo MB, Andrade RRD, Belo FA and Meunier, F, 2005b, "An Improved Multi-Tubular Solar Collector Applied to Adsorption Refrigeration", Proceedings of the ISES 2005 - Solar World Conference, 6-12 August, Orlando Florida, USA

Niemann, M, Kreuzburg, J, Schreitmüller, K R and Leppers, L, 1997, "Solar Process Heat Generation Using an ETC Collector Field with External Parabolic Circle Concentrator (PCC) to Operate on Adsorption Refrigeration System" Solar Energy, Vol59, No 1-3, pp 67-73

Tamainot-Telto, Z and Critoph, R E, 1999, "Solar Sorption Refrigerator Using a CPC Collector", Renewable Energy, Vol16, pp 735-738

Welford, WT and Winston, R, 1978, "The optics of nonimaging concentrators", Academic Press, New York

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