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HEAT PRODUCTION BY STATIONARY PARABOLIC, CYLINDRICAL SOLAR CONCENTRATOR

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Abstract. *Stationary parabolic, cylindrical solar concentrator for heat production consists of the absorber (with water pipes) and parabolic, cylindrical reflector (with metal surface) and has geometrical concentration ratio up to 4. For the concentrator of CP-90A type with infinite length, the paper presents investigation by using computer software CATIA how direct solar radiation approaches the concentrator aperture and the concentrator reflector. When a solar ray enters the concentrator aperture, it may hit absorber either directly or indirectly after hiting one or several times the concentrator reflector. In addition the paper would present results of efficiency of use of solar rays at concentrator as a function of angles of incident of solar rays and type of reflector surface.*

Keywords*: solar concentrator, CATIA, reflector*

1. INTRODUCTION

Temperature increase has been constantly recorded on the global level. The increase is due to green-house effect because of mainly CO2 emission from different sources in atmosphere. Usually this emission is blamed to combustion of fossil fuels mainly for heating and electricity production. A response to such a situation may be increased use of solar energy for heating, cooling, and electricity production. Solar energy is source of all life on the earth and it is in abundance but dispersed. Here, we propose use of stationary, asymmetric solar concentrator for conversion of solar energy to heat.

The subject of this research (in Centre for Heating, Air Conditioning and Solar Energy of Mechanical Engineering Faculty at Kragujevac in Kragujevac University in Serbia) is design optimization of stationary asymmetric solar concentrator of CP-90A type for heat and electricity production with geometric concentration of up to 4.

The stationary solar concentrators have advantages over tracking concentrators as they can be part of building façade and used in building and city architecture.

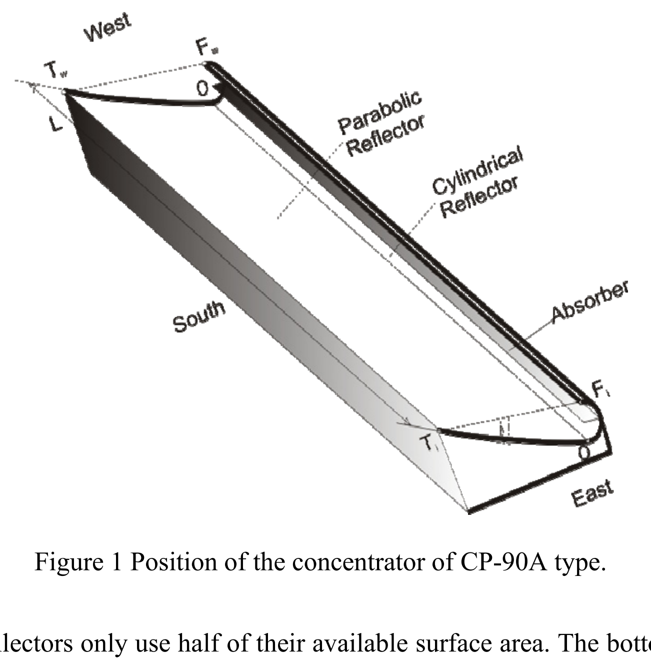

Figure 1 Position of the concentrator of CP-90A type.

The conventional solar collectors only use half of their available surface area. The bottom half of the collector faces downward and is in contact with opaque insulation. The heat-transfer fluid within a panel is easily able to accept more energy than is incident on the top surface of a conventional panel. Then, illumination of both sides of the collector with non-imaging reflectors is performed. This allows a single absorber to be used instead of the two standard single-sided absorbers. This represents a substantial cost and materials saving.

Such a design approach has a number of implications: (a) the panel must be substantially thicker because of the necessity for reflective optics to reside underneath. This can be an aesthetic issue. (b) The heat loss mechanism underneath the panel is different to that of the top surface. (c) Additional reflector material must be used. Its cost and pollution must be compared to that of the replaced panel.

Concentrators of similar and the same type were already subject of intensive research (Bojić et al., 2007, Mills & Morrison, 2003, Russian UNESCO Chairs Newsletter, 2004, Strebkov et al., 2007,Tripanagnostopoulos & Souliotis, 2004). By using computer software CATIA, this paper investigates how at different angles, direct solar radiation approaches the concentrator aperture and propagates inside the concentrator. In addition the paper would present results of the efficiency of use of solar rays at the concentrator as a function of angles of incident of solar rays for different types of reflector surface. The concentrator length is infinite meaning that side radiation losses are not studied.

2. **CONCENTRATOR DESIGN**

2.1. Design description

A stationary asymmetric solar concentrator of CP-90A type shown in Fig.1 consists of a reflector and absorber. In this figure, L stands for the concentrator length, and y= for the width of the concentrator aperture. The concentrator length L is assumed to be infinite or to be significantly larger than that of y. In the type name CP stands because of the fact that the reflector has partially parabolic and partially cylindrical shape. The reflector is covered with different materials that have good reflectivity. The absorber has plate shape. This is basically aluminum painted black. Inside the absorber, there are copper pipes where the heat transfer fluid flows. In the type name, 90A designates the location of absorber that is perpendicular to the focal plane of the concentrator reflector.

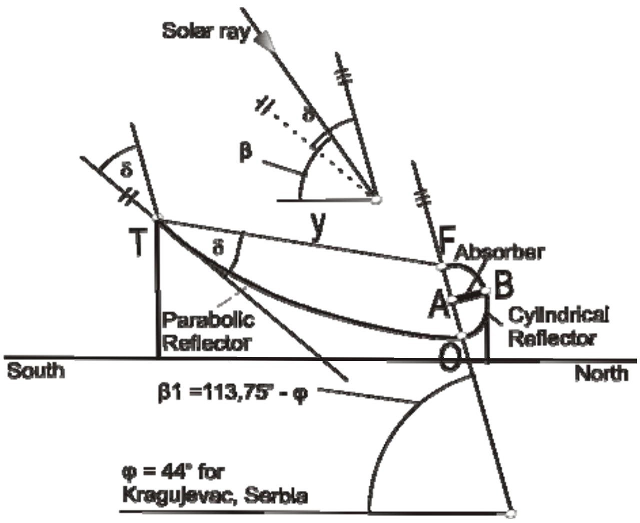

Figure 2 Vertcal cut throuh the concentrator in the plane perpendicular to the direction east- west.

The geometry of the concentrator is better explained by using Figure 2 that schematically shows the vertical cut of the concentrator in Fig.1. Figure 2 shows reflector (bold curve TOBF), absorber (bold line AB), and concentrator aperture width (thin line y=TF) . The reflector consists of parabolic reflector (curve TO) and cylindrical reflector (curve OBF). Curve TO represents a part of parabola with its focus at F and vertex at O. Point T represents rim of reflector parabola for this concentrator. The line FAO passing through points F, A, and O is called focus line of the reflector parabola. Cylindrical reflector curve (curve OBF) represents a half of circle with its centre at point A. The parabola focal distance OF is equal to the diameter of the reflector circle. The bold line AB represents the absorber width. The line is perpendicular to the focal line and represents a radius of reflector circle OBF.

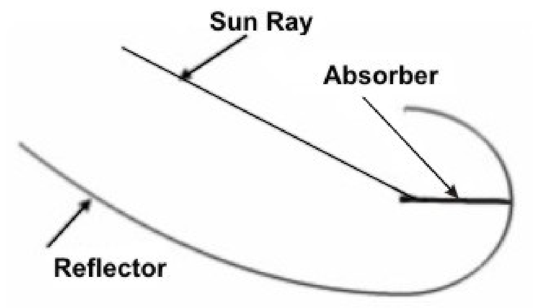

Figure 3 Solarray path toward the concentretor
that hits the absorber directly
(the cross cut of parabolic-cylindric concentrator).

The concentrator operates as the following. The direct solar radiation falls on the different parts of the reflector surface. The reflector surface reflects the solar radiation toward the absorber. All reflected solar radiation hits and concentrates to the absorber. In the absorber, the concentrated solar radiation is transformed into heat. The heat is collected by the heat transfer fluid and directed to the storage tank.

2.2. Concentretor position

The position of the concentrator is shown in Figs.1 and 2. Figure 2 shows the vertical cut of the concentrator in Fig.1. The concentrator is positioned to have the reflector trough in the direction east-west, while the reflector surface faces south (valid for the north hemisphere). In Fig.2, three angles are defined such as φ, β_1, and δ. Angle φ represents the latitude, angle β_1 represents the vertical location angle of the concentrator absorber, and angle β the vertical location angle of the solar ray, and angle δ stands for the aperture angle of the concentrator. The figure reveals that β_1 is the angle between absorber and horizontal direction due south. This angle is calculated as

$$\beta_1=113.75^0-\varphi. \tag{1}$$

Also, this figure reveals that β is the angle between the solar ray and horizontal direction due south.

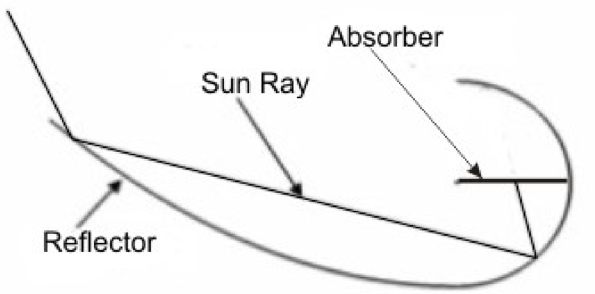

Figure 4 Solar ray path toward the concentretor
with two reflections from reflector
(the cross cut of parabolic-cylindric concentrator).

2.4 Solar ray paths

Figures 3-5 show the solar ray paths toward the absorber of the concentrator obtained by computer software CATIA. In these figures, we show the travel path of several solar rays. Basically, solar rays may hit the absorber from the front side (Fig.3), from the back side, and may miss the absorber. In Fig.4, the solar rays hit absorber after single hit to the reflector. In Fig. 5, the solar rays hit absorber after two hits to the reflector. In Fig. 6, the solar rays hit absorber after 5 hits to the reflector.

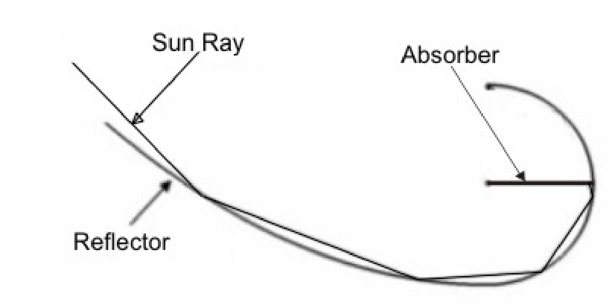

Figure 5 Solar ray path toward the concentretor
with 4 reflections
(the cross cut of parabolic-cylindric concentrator).

2.5 Efficiency

The efficiency of transfer of solar energy to concentrator absorber is given by the following expression

$$e=(A_0 + a\, A_1 + a^2\, A_2 + a^3\, A_3 + a^4\, A_4)/A \qquad (2)$$

Here $A=A_0+A_1+A_2+A_3+A_4$, A is total area of the concentrator aperture, A_0 is area of aperture surface where the direct solar radiation enters that hits absorber without any reflection from reflector, A_1 is area of entrance aperture surface for solar ray that hits absorber with one reflection from reflector, A_2 is area of entrance aperture surface for solar ray that hits absorber with two reflections from reflector, A_3 is area of entrance aperture surface for solar ray that hits absorber with three reflections from reflector, A_4 is area of entrance aperture surface for solar ray that hits absorber with four reflections from reflector, a is solar ray reflectivity from the surface of the reflector.

3.0 RESULTS AND DISCUSSION

3.1 Number of reflections

Figure 6 shows percentage values of the aperture area as a function of angles β of incident of solar rays. The aperture area was given in percents of the total aperture area of concentrator. These angles were varied from $\beta=21.75^0$ to 69.75^0. These curves are provided for different types of solar rays that are incident on the aperture surface. Types of solar rays depend on the way how they propagate inside the concentrator to reach the absorber surface. The investigated types were solar rays that hit absorber surface without reflection from the reflector, with one reflection from the reflector, with two reflections from the reflector, with three reflections from the reflector, and with more than three reflections from the reflector.

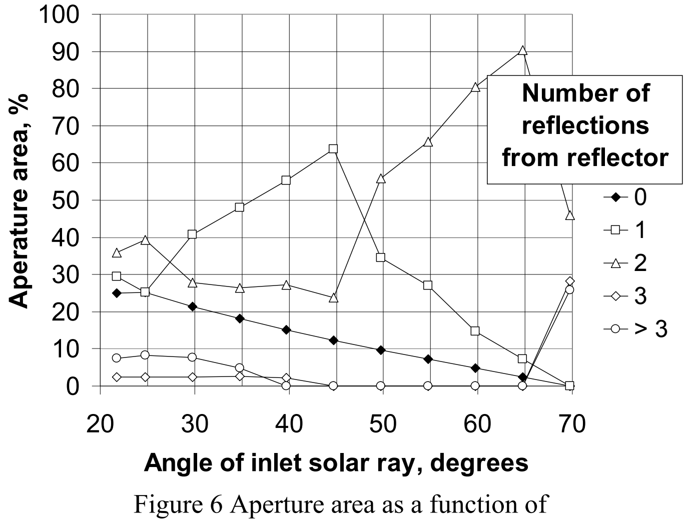

Figure 6 Aperture area as a function of
inlet angle of solar ray

Regarding the type of solar ray, the highest percentage of aperture area is that of the solar rays that hit absorber with one reflection from reflector. This would happen for the incident angles β from 48^0 to 69.75^0 with maximum value of around 90% for $\beta=65^0$. For angles from around 22^0 to 48^0, the highest percentage of aperture is that of the solar rays that hit absorber with two reflections from the reflector.

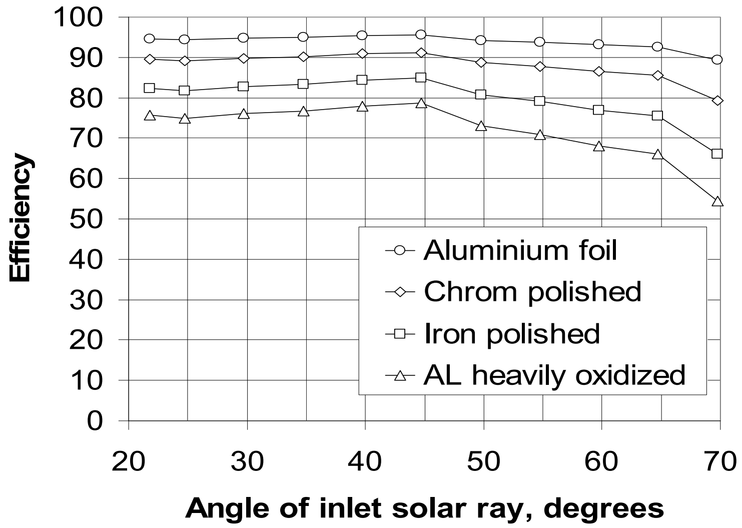

Fig. 7 Efficiency of use of solar rays at reflector

3.2 Efficiency of concentrator

Figure 7 shows efficiency of use of solar rays at concentrator as a function of angles of incident of solar rays. These angles were varied from $\beta=21.75^0$ to 69.75^0. These curves are provided for different types of reflector surfaces: Aluminum foil, polished chrom, polished iron, heavily oxidized aluminum.

Regarding the type of reflector surface, the highest efficiency is that of the solar rays that hit reflector having aluminum foil surface. Regarding the angle of solar ray incidence, the highest efficiency is that for angles from 21.75^0 to 45^0. This efficiency is up to 10% greater than that for angles of 45^0 to 69.75^0.

5. Conclusion

Temperature increase due to green-house CO2 emission from different fossil sources is recorded in atmosphere. World community tries to respond to such a situation by increased use of solar energy for heating, cooling, and electricity production.

In this paper, we present the investigations of the solar concentrator that uses solar energy to generate heat of CP-90A type. The concentrator is stationary trough, and has parabolic-cylindrical reflector surface. The concentrator length is assumed to be infinite meaning that side radiation losses are not studied. Its geometrical concentration depends on the concentrator aperture angle and type of energy production and is between 1.8 and 36. By using CATIA software, we investigate propagation of solar rays inside the concentrator to reach the absorber surface. We found that solar rays may hit absorber surface without reflection from the reflector, with one reflection from the reflector, with two reflections from the reflector, with three reflections from the reflector, and with more than three reflections from the reflector.

We found that the highest percentage of aperture is that of the solar rays that hit absorber with one reflection from reflector. By using previuos results, we calculate efficiency of use of solar rays at concentrator as a function of angles of incident of solar rays. Regarding the type of reflector surface, the highest efficiency is that of the solar rays that hit reflector with aluminum foil.

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