Some Characteristics of Electricity Production by Stationary Parabolic, Cylindrical Solar Concentrator

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Abstract–**Stationary parabolic, cylindrical solar concentrator for electricity production consists of the absorber (with photovoltaic panels and water pipes) and parabolic, cylindrical reflector (with metal surface) and has geometrical concentration ratio up to 4. Direct solar radiation approaches the concentrator aperture at different angles and pathways. For different aperture angles and different kinds and types of metal surfaces of the reflector, the investigation of long concentrator of this type would be that of how efficiently the direct solar radiation reaches absorber to be converted to electricity.**

I.. INTRODUCTION

Temperature increase has been constantly recorded on the global level. The increase is due to green-house effect because of 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 of world community 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 of 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 for heat and electricity production with geometric concentration of up to 4 (see Fig.1 and 2).

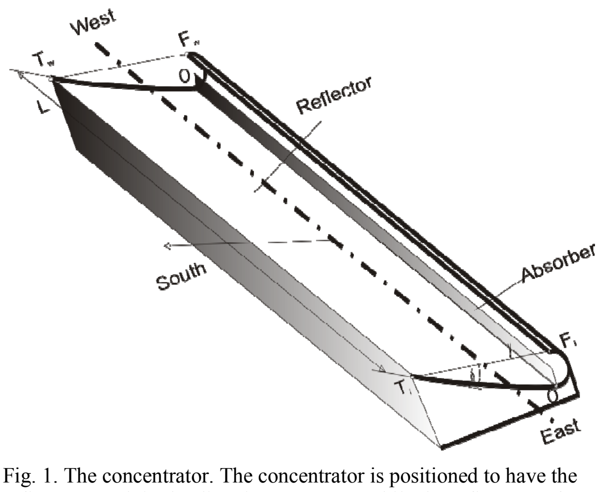

Fig. 1. The concentrator. The concentrator is positioned to have the reflector trough in the direction east-west, while the reflector surface faces south (valid for the north hemisphere)

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

The conventional solar panels only use half of their available surface area. The bottom half of the panel faces downward. The panel is easily may accept more Solar energy than is incident on the top surface of a conventional panel. Here, illumination of both sides of the panel is performed with non-imaging reflectors. This allows a single absorber to be used instead of the two standard single-sided absorbers. This may 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.

This type of concentrators was already subject of intensive research [1-3]. This paper investigates at different altitude angles, the pathways of the direct solar radiation through the concentrator aperture and inside the concentrator by using computer software CATIA. In addition the paper would present results of efficiency of use of light rays at concentrator and efficiency of their conversion to electricity as a function of angles of incident of solar rays for different types of reflector surface.

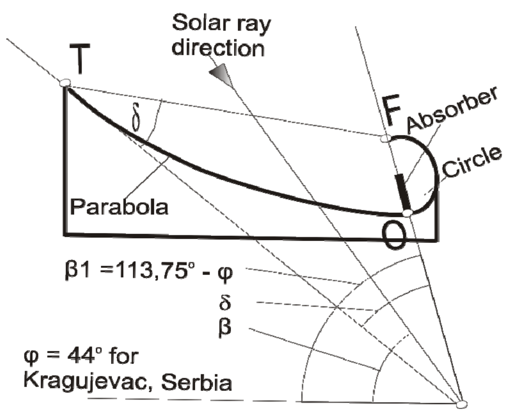

Fig. 2. Vertcal cut throuh the concentrator in the plane perpendicular to the direction east west.

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II. CONCENTRATOR DESIGN

A. Design Description

A stationary asymmetric solar concentrator shown in Fig.1 consists of a reflector and absorber. 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 covered with solar cells from the both sides. Inside the absorber, the heat transfer fluid flows through the copper pipes and takes excess heat out.

The concentrator operates as the following. The direct solar radiation falls on the different parts of the reflector surface (Figs.3-6). 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 electricity and heat. The heat is collected by the heat transfer fluid and transferred away from the absorber. Namely, high temperatures decrease efficiency of solar-to-electricity conversion.

B. Concentretor Position

The position of the concentrator is shown in Fig.1 and Fig.2. 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). Reflector trough is long enough to minimize loss of solar radiation for sun rays with solar azimuth different than zero.

Fig. 2 shows the vertical cut of the concentrator in Fig.1. The vertical location angle β_1 of the concentrator facing south and the aperture angle δ of the concentrator are shown in Fig. 2. The figure reveals that β_1 is the angle between absorber and horizontal direction due south. This angle is calculated as

$$B_1=113.75^0-\varphi. \quad (1)$$

Here, φ stands for the latitude.

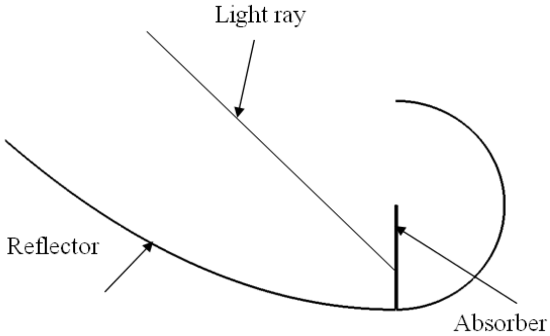

Fig. 3. Light ray path toward the absorber of the concentretor that hits the absorber directly (the cross cut of parabolic-cylindric concentrator with one parabolic and cylindric reflector).

C. Light Ray Paths

Fig. 3-6 shows the light ray paths toward the absorber of the concentrator obtained by computer software CATIA. In these figures, we show the travel path of several light rays. Basically, light rays may hit the absorber from the front side (Figs.3 and 4), from the back side (Figs.5 and 6), and may miss the absorber. In Fig.3,

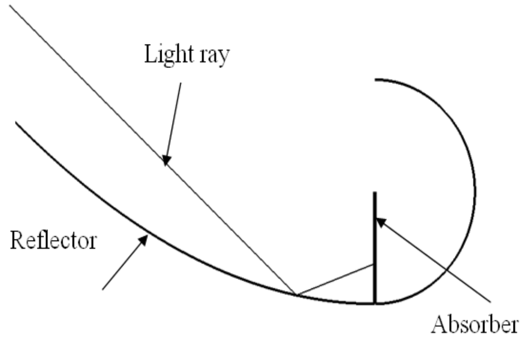

Fig. 4. Light ray path toward the absorber of the concentretor with one reflection from reflector (the cross cut of parabolic-cylindric concentrator with one parabolic and cylindric reflector).

the light rays hit absorber directly. In Fig.4, the light rays hit absorber after single hit to the reflector. In Fig. 5, the light rays hit absorber after two hits to the reflector. In Fig. 6, the light rays hit absorber after 5 hits to the reflector.

C. Efficiency

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

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

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 light enters that hits absorber without any reflection from reflector, A_1 is area of entrance aperture surface for light that hits absorber with one reflection from reflector, A_2 is area of entrance aperture surface for light that hits absorber with two reflections from reflector, A_3 is area of entrance aperture surface for light that hits absorber with three reflections from reflector, A_4 is area of entrance aperture surface for light that hits absorber with four reflections from reflector, a is light reflectivity from the surface of the reflector.

The efficiency of transfer of solar energy into electricity in the entire concentrator is given by the following expression

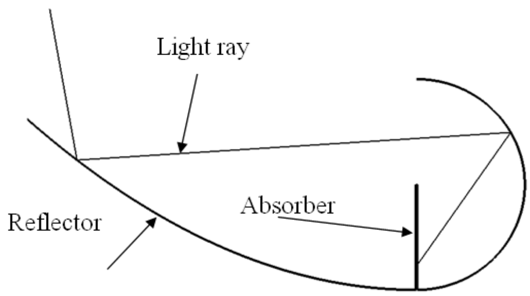

Fig. 5. Light ray path toward the absorber of the concentretor with two reflections from reflector (the cross cut of parabolic-cylindric concentrator with one parabolic and cylindric reflector).

$$ee = e\,\eta. \tag{3}$$

Here, η stands for the efficiency of transfer of solar energy into electricity in the concentrator absorber.

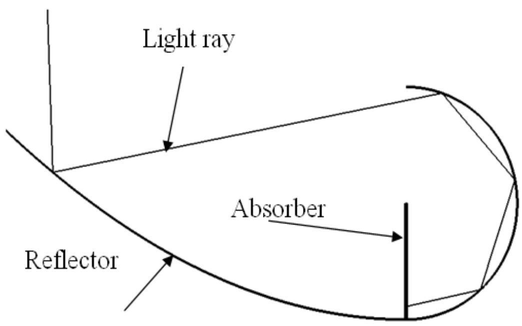

Fig. 6. Light ray path toward the absorber of the concentretor with 5 reflections (the cross cut of parabolic-cylindric concentrator with one parabolic and cylindric reflector).

III. Results and Discussion

A. Number of Reflections

Fig. 7 shows percentage values of the aperture area as a function of altitude angles of incident solar rays. The aperture area was given in percents of the total aperture area of concentrator. These angles were varied from 21.75^0 to 69.75^0. These curves are provided for different types of light rays that are incident on the aperture surface. Types of light rays depend on the way how they propagate inside the concentrator to reach the absorber surface. The investigated types were light 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.

Regarding the type of light ray, the highest percentage of aperture is that of the light rays that hit absorber with one reflection from reflector for the incident angles from 40^0 to 50^0. For angles from around 50^0 to 60^0, the highest percentage of aperture is that of the light rays that hit absorber with two reflections from the reflector. For angles from around 60^0 to 69.75^0, the highest percentage of aperture is that of the light rays that hit absorber with three reflections from the reflector.

B. Efficiency of Concentrator

Fig. 8 shows efficiency of reflectors to transfer light rays to the absorber at the concentrator as a function of altitude angles of incident of solar rays. These angles were varied from 21.75^0 to 69.75^0. These curves are provided for different types of reflector surfaces: Aluminum foil, polished chrome, polished iron, heavily oxidized aluminum.

Regarding the type of reflector surface, the highest efficiency is that of the light rays that hit reflector with aluminum foil. Regarding the angle of solar ray incidence, the highest efficiency is that for angles from 21.75^0 to 45^0. When angle of altitude of solar ray goes up from 45 to 69.75, this efficiency decreases between 10-45% depending on the material of the reflector surface.

Fig. 9 shows efficiency of concentrator to thansform solar energy into eletricity as a function of altitude angle of solar rays. These angles were varied from 21.75^0 to 69.75^0. These curves are provided for different types of reflector surfaces: Aluminum foil, polished chrome, polished iron, heavily oxidized aluminum.

Regarding the type of reflector surface, the highest efficiency is that of the light rays that hit reflector with aluminum foil. Regarding the angle of solar ray incidence, the highest efficiency is that for angles from 21.75^0 to 45^0. When angle of altitude of solar ray goes up from 45 to 69.75, this efficiency decreases between 10 and 45% depending on the reflector surface material.

IV. Conclusion

In this paper, we present the investigations of the “long” solar concentrator that uses solar energy to generate heat. The concentrator is stationary trough, and has parabolic-cylindrical reflector surface. Its geometrical concentration depends on the concentrator aperture angle

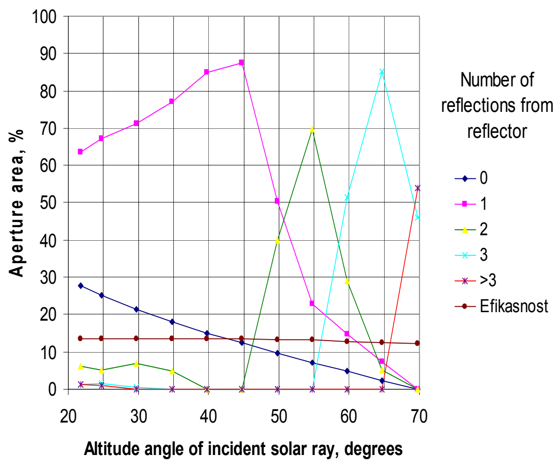

Fig. 7. Aperture area as a function of altitude angle of incident solar ray

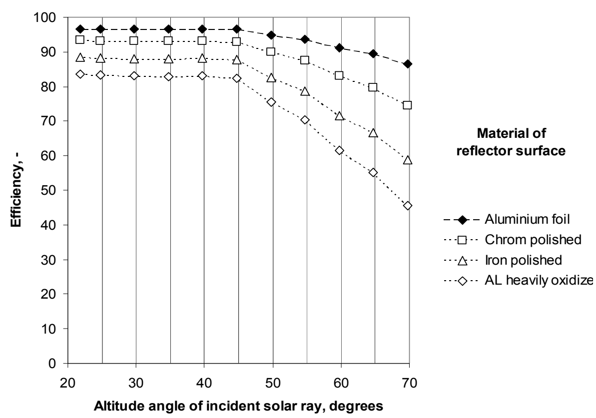

Fig. 8. Efficiency of reflectors as a function of the altitude angle of incident solar rays.

and type of energy production and is between 1.8 and 36.

Propagation of light rays inside the concentrator to reach the absorber surface was investigated by using CATIA software. We found that light 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 light rays that hit absorber with one reflection from reflector for the incident angles from 40^0 to 50^0.

For angles from around 50^0 to 60^0, the highest percentage of aperture is that of the light rays that hit absorber with two reflections from the reflector. For angles from around 60^0 to 69.75^0, the highest percentage of aperture is that of the light rays that hit absorber with three reflections from the reflector.

Efficiency of reflectors to transfer light rays to the absorber and efficiency of concentrator to thansform solar energy into eletricity were calculated as a function of altitude angle of solar rays by using previuos results. Regarding the type of reflector surface, the highest efficiency is that of the light rays that hit reflector with aluminum foil. Regarding the angle of solar ray incidence, the highest efficiency is that for angles from 21.75^0 to 45^0. When angle of altitude of solar ray goes up from 45 to 69.75, this efficiency decreases between 10-45% depending on the material of the reflector surface.

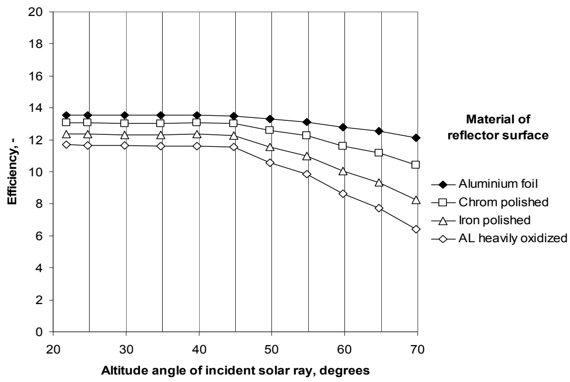

Fig. 9. Efficiency of concentrator to thansform solar energy into eletricity as a function of altitude angle of solar rays

ACKNOWLEDGMENT

This paper is a result of project 27003 of Ministry for Science of Republic of Serbia. We are grateful for their financial support.

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