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Modelling of Radiation Regime Receiver Cavities of Solar Power Plants

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Abstract

In this work, we develop a model for radiant heat transfer calculations inside spherical and cylindrical spaces. The analysis of the possibility of mirror cone subreflector applications for uniform flux density attainment is carried out.

A procedure optimizing equiilluminate space forming a search for an indicatrix's composition is developed.

1. Introduction

Some ten years ago, tower type power plants solar concentrator were constructed. Since then much experience has been accumulated with new sugestions for their perfection.

One of the directions for perfection is the system's optimization, including the investigation of radiation regime receivers of central power plants. The low efficiency of first generation solar power plants (SPP), to some extent, is connected with the utilization of some components of the traditional heat power plant, for example, the open configuration of receivers. This is the cause for long duration starts and stops and frequent breakdowns of some elements of SPP. The analysis carried out in [1] of convective losses in open type receivers mounted on the SPP-5 and "Solar One" and receivers of the cavity configuration had shown the preference for the last type. Factors such as the indicatrix of reflection of concentrating systems, geometrical form of the cavity and the optical parameters of the surface of the receiving panels influence the efficiency of cavity receivers.

2. Investigation and Discussion

Investigation of the central receivers after use show a strong dependence of the structure's reliability on the uniformity of the radiation flux density supply. In this article, cavity receivers of cylindrical and spherical forms are considered with the problem and possibility of applying mirror cones as the functional sub-reflectors to equalize the nonuniform distribution of radiation flux around of the cavity.

The equation for the density of the resulting radiation at a surface point inside, for example, a cilindrical receiver, can be presented as:

$$\begin{aligned} q(x_0) &= \alpha\left\{q_0(x_0) + \int_0^L \rho * q(x) * d\varphi_{dx_0-dx} + \int_0^{D/2} \rho * q(r) * d\varphi_{dx_0-dr}\right\} + \\ &+ \alpha\left\{\int_0^L \varepsilon * \sigma * T^4(x) d\varphi_{dx_0-dx} + \int_0^{D/2} \varepsilon * \sigma * T^4(r) * d\varphi_{dx_0-dr}\right\} \\ &- \varepsilon * \sigma * T^4(x_0). \end{aligned} \tag{1}$$

For the bottom part of cylinder:

$$\begin{aligned} q(r_0) &= \alpha_T * \left\{q(r_0) + \int_0^L \rho * q(x) * d\varphi_{dr-dx}\right\} + \alpha_T * \int_0^L \varepsilon * \sigma * T^4(x) * d\varphi_{dr_0-dx} - \\ &- \varepsilon * \sigma T^4(r_0), \end{aligned} \tag{2}$$

where

$$\begin{aligned} d\varphi_{dr_0-dx} &= 8(\frac{L}{D} - \bar{x}) * \frac{4(L/D - \bar{x})^2 + 1 - \bar{r}^2}{\left\{[4(L/D - \bar{x})^2 + 1 - \bar{r}^2]^{1/2} - 4\bar{r}^2\right\}^{3/2}} * dx \\ d\varphi_{dx_0-dx} &= \left\{1 - \bar{x}_0 - \bar{x}| * \frac{2(\bar{x}_0 - \bar{x})^2 + 3}{2[(\bar{x}_0 - \bar{x})^2 + 1]^{3/2}}\right\} * d\bar{x} \end{aligned} \tag{3}$$

and $\bar{x} = x/D$, $\bar{x}_0 = x_0/D$ and $\bar{r} = 2 * r/D$.

The flux density at any given point of the receiver is defined as:

$$q_0 = \int\int B(\omega) * (\omega, \bar{n}) * X(\omega, \bar{n}) * d\omega. \tag{4}$$

Model function of the indicatrix of the heliostat field's reflection is the following:

$$B = \frac{n+2}{2*\pi} * < K > * J_0 * \cos^n \Theta, \tag{5}$$

where K is the average geometrical concentration factor and J_0 is the flux density of solar reflection.

Equations (1) and (2) with registration repeated reflections are solved by the iterative method and initial density of flux radiation is determined by the method of tracking ray's reverse motion.

Calculating with a computer, we get the graphs of dependence of this radiation density (Figure 1) $J/(< K > \cdot J_0 \cdot C_1)$ on the inside wall surface of the cavity (L/R_1) relative the dimension of the inlet (R_2/R_1) and a model of the distribution of reflection indicatrix at $n = 0, 2$. For equal values of relative dimensions of the inlet, maximum flux density is reached for lesser values of L/R at n=0.

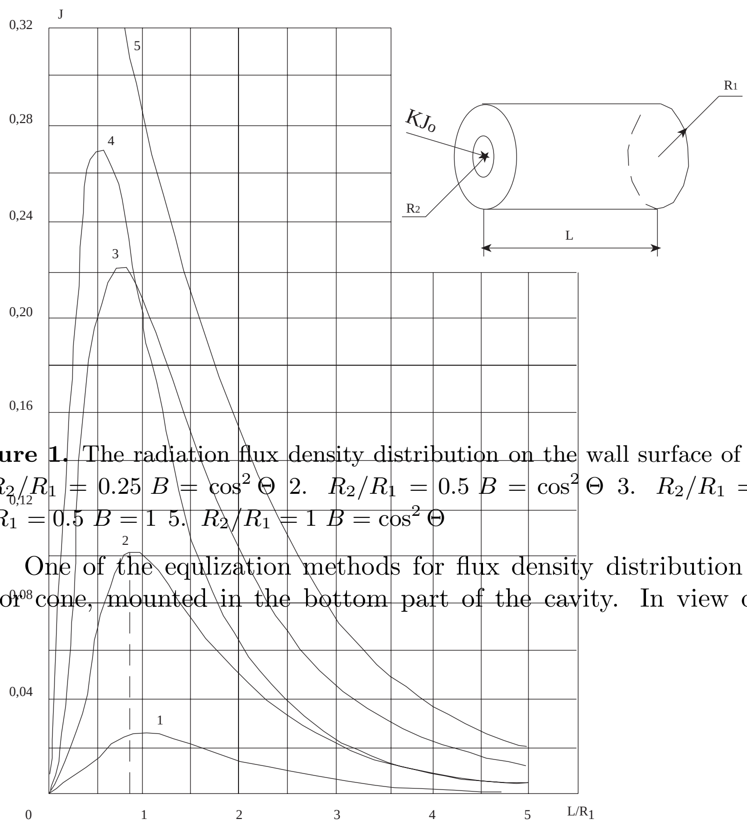

Figure 1. The radiation flux density distribution on the wall surface of cylindrical cavity, at: 1. $R_2/R_1 = 0.25$ $B = \cos^2\Theta$ 2. $R_2/R_1 = 0.5$ $B = \cos^2\Theta$ 3. $R_2/R_1 = 0.75$ $B = \cos^2\Theta$ 4. $R_2/R_1 = 0.5$ $B = 1$ 5. $R_2/R_1 = 1$ $B = \cos^2\Theta$

One of the equlization methods for flux density distribution is the usage of the mirror cone, mounted in the bottom part of the cavity. In view of the fact that the crossing of the collected flux $\int 2 * \pi * r * J(r) * dr$ and $\int 2 * \pi * R_1 * J(z) * dz$ takes place in the interval $1 \leq L/R_1 \leq 1,5$ for discrete distribution of the reflection's indicatrix, dimension of the cylindrical cavity is needed to choose in the interval $1.5 \leq L/R_1 \leq 2.5$.

Varying the parameter z defining in the chosen coordinate system for the vertex of the cone, it can be possible to obtain a broadenning of the radiation flux density uniformity.

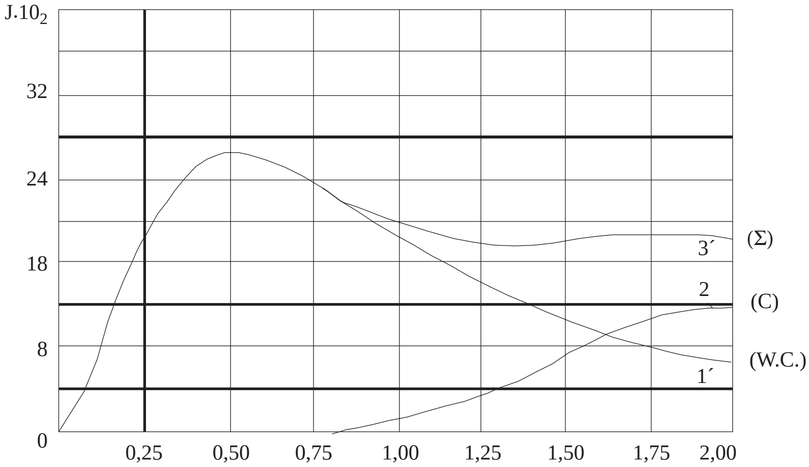

Figure 2. The radiation flux density distribution on the wall surface of clindrical cavity with cone subreflector. The system's parameters are $B(\Theta) = \cos^n \Theta$; $R_1 = 1$; $R_2 = 0,5$; $Z_A = 1$; $n = 0$

In Figure 2 is shown the distribution flux density $(L/R_1 = 2, z_A/R_1 = 1, B(\Theta) = C_1 * \cos^n\ \Theta, n = 0, R_1 = 1,\ R_2 = 0.5)$ in a cylindrical cavity.

Figure 3 illustrates the influence of the cone subreflector with respect to the resulting distribution of radiation flux density in a spherical cavity.

Comparing the results of numerical calculations for the flux density distribution inside cylindrical and spherical cavities, it can be noted that the existence of the cavity, in view of the geometrical figure, occupies the interval position so that the flux density in these cavities will be constant. We suggest an algorithm allowing to determine the geometry of an equally lighted cavity [2].

Figure 4 shows the inlet of the cavity with the radius R and chosen coordinate's system are given.

The flux density at the optional point M can be given in the view $J(M, \bar{n}) = J(r, z, \theta)$. Divide axis OZ into N equal parts for building the lines of equal concentrations. From the point A under the angle φ_0 we draw a stright line to a crossing with stright line AA_1. In the middle of AA_1 we recover the normal, with the components $n_y = \cos\varphi_0$, $n_z = \sin\varphi_0$.

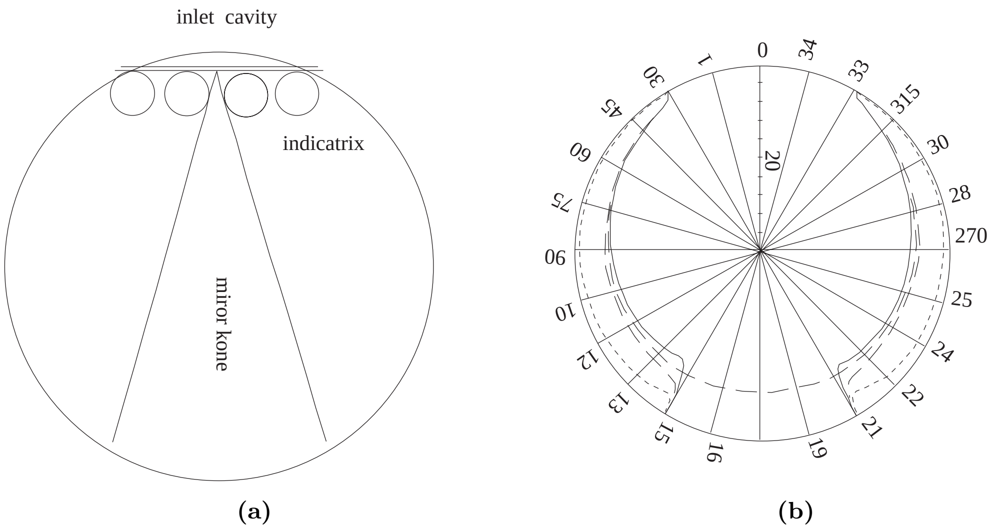

Figure 3. The radiation flux density distribution in spherical cavity. The systems parameters: $B = \cos^n \Theta;\ n = 1;\ R_1 = 1;\ R_2 = 0.5;\ Z_L = 1,7321;\ Z_A = 0$. (a. spherical cavity scheme; b. distribution)

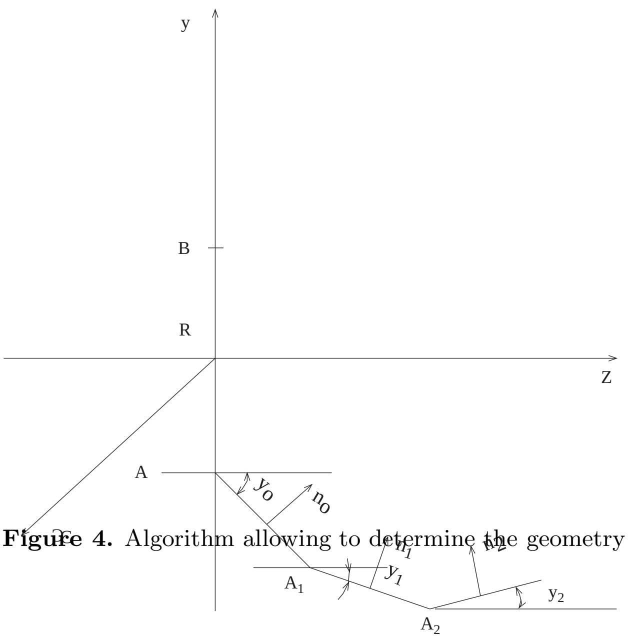

Figure 4. Algorithm allowing to determine the geometry of equal lighted cavity

Change φ_0 untill the flux density reaches the given value at the point with coordinate $y_{i+\frac{1}{2}}, z_{i+\frac{1}{2}}$. Further, define the coordinate points y_{i+1}, z_{i+1} correspondent to relations:

$$\begin{aligned} y_{i+1} &= y_i + d * \sin\varphi_0, \\ z_{i+1} &= Z_i + d * \cos\varphi_0, \; d = \Delta z \end{aligned} \tag{6}$$

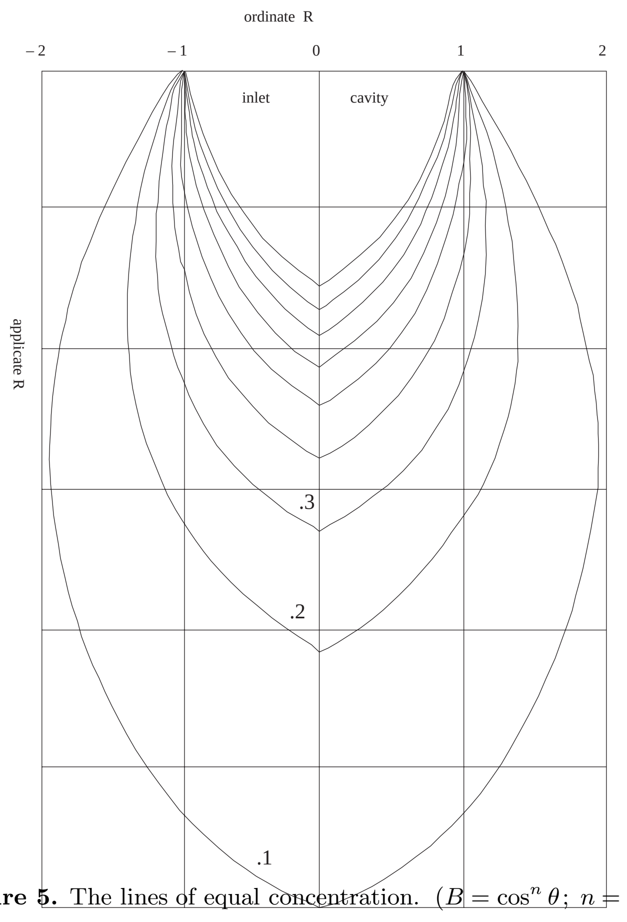

Figure 5. The lines of equal concentration. $(B = \cos^n\theta;\ n = 2;\ J_{\max} = 0.786)$

The process is repeated and the accuracy of the method and thus the amount of computer time depend on the choice Δz and frequency of division of φ [3]. Figure 5 by means of computer graph the lines of equal concentrations created by the geliostat fields with the reflection indicatix being presented with $B = c * \cos^2 \theta$.

3. Conclusions

1. The carried out investigation shows that only for cylindrical cavities with selection of cone subreflectors geometry thermostress relief can be reached on the receiving panels.
2. A Search algorithm of the cavity geometry, with constant radiation flux density on the inside surface, has been developed and the variant calculations, showing that the form of the surface "tracks" the radiation indicatrix given at the inlet to cavity, and having the more extended form with increasing of the value n.

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