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Design and Optimization of a New Solar Dish Cavity Receiver/Absorber

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Abstract This paper designed an innovative taper annulus structure for the solar dish cavity receiver based on the optical principle analysis of dish parabolic collector and the mathematic model. In the paper, the mathematic model of solar dish optic geometry is established to predict the radiation flux distribution of a cylinder cavity receiver. At the same time, the size of collector and receiver is calculated. The analytical result is confirmed using Tracepro software to simulate the ray tracing. The analytical and numerical results indicate that the radiation flux distribution of the designed receiver is more uniform comparing with the DIAPR type receiver built by Israel Weizmann Institute of Science. At the same time, the designed receiver has considerably uniform power profile on both of the cavity and the absorber wall. Comparing with other applied receiver, the new model also has low flow resistant and easy to be manufactured.

Keywords: solar dish, cavity receiver/absorber, flux distribution, uniform

1. Introduction

Solar thermal power generation system is the popular method to utilize the renewable solar energy [1]. Comparing with other solar collections, solar dish system has an excellence application foreground for its high concentrated ratio and high thermal collection ability [2]. As the crucial component of dish system solar-thermal conversion process, the cavity receiver plays a significant role in the overall system. However, the non-uniform flux distribution is harmful to the system, especially for the high temperature solar thermal utilization, that can cause local overheating in the cavity receiver which can lead partial melting and crack. Receivers are expected to hold a high and uniform temperature field, which is beneficial for its efficiency, reliability and life-span.

The existing published work on solar receiver cavity energy distribution is insufficiency. In 1985, James et al. [3] firstly analyzed the power profiles produced in cavities of varying geometry, and found that cavity geometry can greatly affect the cavity power profile without a large effect on system efficiency. Jorge et al.[4] used the ray-tracing method to study a linear Fresnel solar collector concentrator trapezoidal cavity receiver, but energy intensively around the edge of the cavity. Yong et al. [5] used Monte-Carlo ray-tracing method to calculate the radiation flux distribution in five different geometry cavity receivers, and put forward an upside-down pear cavity receiver based on the idea of equivalent radiation flux, but this receiver is difficult to be manufactured.

Most of previous work focus on the cavity but neglect the flux distribution of the absorber, which is the key component of the solar-to-thermal conversion progress.

In this paper, the mathematic model of solar dish optic geometry is established to predict the radiation flux distribution of a cylinder cavity receiver, and simulated verification is performed using Tracepro software. An innovative taper annuluses structure of the receiver/absorber is proposed according to the optical principle of dish parabolic collector and the analysis of the mathematic model based on the concept of uniform flux distribution in the cavity and easy to be accomplished.

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2. Mathematic Model

The incident sunlight concentrates on the focus of the parabolic dish collector through the mirror reflection, where the impact of the solar angle is ignored. As can be seen from Fig.1, the reflected light from the edge of the concentrator (position A for example) irradiates into the bottom of the cavity, and the incident light from the inner part of the concentrator irradiates into the upper part of the cavity (from P to P1). Figure.2. shows a top view of the dish concentrator. It indicates that the ring size of A is larger than that of P, in another word, the quantity of sunlight reaches on A is greater than that on P.

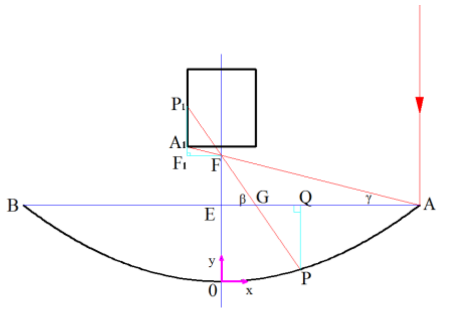

Fig. 1: Schematic flux distribution of a cylinder cavity receiver

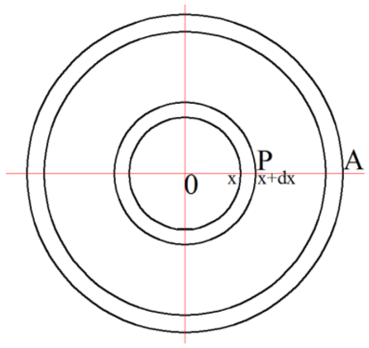

Fig. 2: Top view of the dish concentrator

An energy distribution mathematic model of a cylinder cavity is built according to the optical geometry analysis. Cartesian coordinate system is established as the fig.1 shows1.The located ordinate of the aperture is given by:

$$y_a = f\left(1+\frac{r}{R}\right)-\frac{rR}{4f} \tag{1}$$

where f is the parabolic focus length ,R and r is the radius of the concentrator and the cylinder cavity respectively.

Take a point P（x,y）on the dish concentrator, and its corresponding point P1(x1,y1) on the cavity wall can be obtained by the concentration principle. The differential relationship between the x and H can be obtained:

$$d_x = \frac{a-\sqrt{a^2+r^2}}{b\sqrt{a^2+r^2}} d_H \tag{2}$$

According to the solar radiation intensity I, corresponding to the concentrator differential area, the differential energy received by the cavity related wall can be got:

Calculate the equations presented above by processing a program, just given the certain value radiation intensity I, the energy distribution among the cavity height can be obtained.

$$d_Q = \frac{2\pi I}{b^2}\left(2a+\frac{r^2}{\sqrt{a^2+r^2}}-2\sqrt{a^2+r^2}\right)d_H \tag{3}$$

Figure 3 shows the mathematic model calculated results of energy distribution of a decided solar dish collection system, which related parameters are given in the table1.

Table 1: Parameters of the calculation case.

Content	Symbol	Unit	Value
Dish concentrator parabolic function		m	$x^2 = 28.8y$
Radius of the concentrator	R	m	6.3
Radius of the cavity	r	m	0.15
Height of the cavity	h	m	0.5
Solar radiation intensity	I	w/m2	800

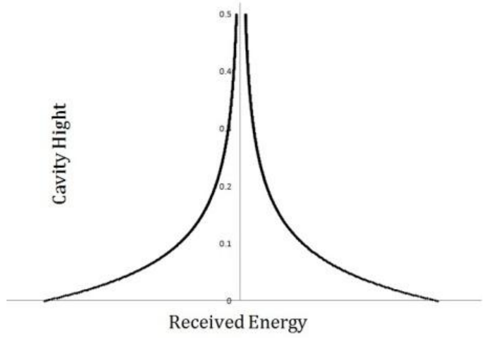

Fig. 3: Energy distribution of the mathematic model calculated results

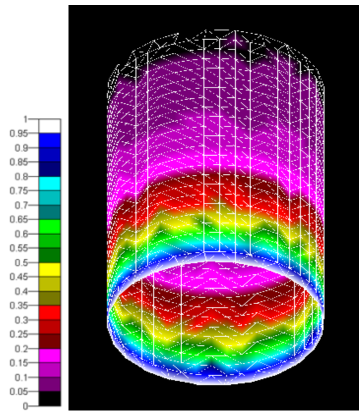

Fig. 4: Contours of the simulated cylinder cavity receiver energy profile

3. Ray-tracing Simulation

Ray-tracing simulation was taken to verify the mathematic model calculated results by using TracePro software, which is based on the Monte-Carlo method to predict sun light directional performance. Solar angle (32’) was taken into consideration in the ray-tracing simulation. For it is primarily investigate the performance of the receiver rather than the concentrator, setting the surface of the solar parabolic dish concentrator as a perfect mirror, reflectivity ρ =1. Fig.4 shows the energy profile contours of the simulated cylinder receiver, which inner wall was set as ideal absorber (α =1) to agree with the calculated mathematic model. It can be obviously seen that the determined curve in Fig.3 fits the contours well.

Built up the simplified geometry model of the DIAPR [6-8] and simulated in Tracepro program, as shown from the fig.5, the flux distribution in the DIAPR cavity of two kinds of absorptivity shows that the lower absoptivity makes the flux distribute in the overall cavity more uniformly, but this case is not optimistic about the vast majority of the porcupine absorber. One of the porcupine absorbers energy profile with absorptivity 0.2 was illustrated in fig.6 .As can be seen, most energy concentrated on the top of the porcupine and vanished in the root segment.

To pursue a better uniform flux distribution among the cavity receiver, it is necessary to research a new structure of receiver/absorber to achieve excellent performance for solar energy high temperature utilization.

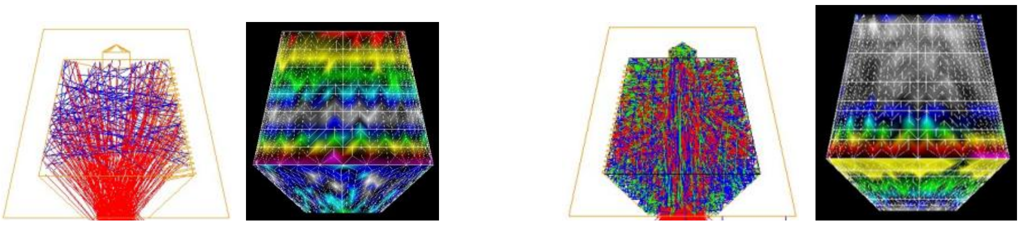

Fig. 5: Contours of the simulated DIAPR receiver energy profile（left）cavity inner wall absorptivity=0.9 （right）cavity inner wall absorptivity=0.2

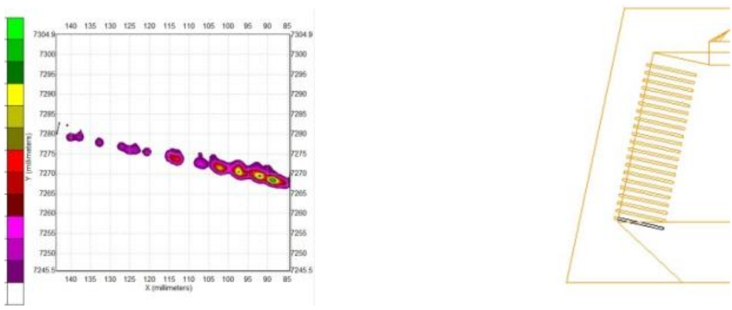

Fig. 6: (a) Contours of the porcupine absorber energy profile (b) Position of the porcupine absorber on the DIAPR

4. Innovative Receiver/Absorber Structure

As the accordance between the mathematic model calculation and the ray tracing simulation results, it still can ignore the solar angle to further study the dish collector concentrated law. Parabolic dish collector concentrates the sunlight into the focus, and make the parallel rays shape into circular cone beam. As the fig.2 showed above, separate the parabolic dish concentrator into numerous ring structures, each ring region can concentrated sunlight into cone-shape beam , and all the beam has one same vertex but different inclined angles. Setting two parallel planes under the focus plane, it will appear a frustum shape, and the fig.7 shows a 2D diagram of this configuration. Each cone-shape beam comes into one frustum shape and all the frustums consist of a configuration of taper annuluses, see fig.8.

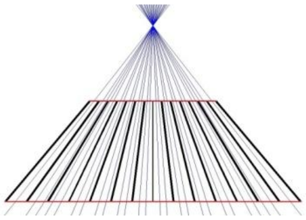

Fig. 7: Schematic diagram of the dish collector circular cone beam distribution

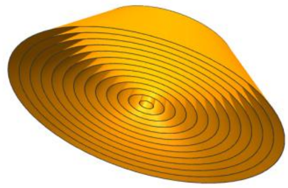

Fig. 8: The proposed taper annuluses structure

The design of this taper annuluses structure depends on the dish collector concentrated rays shape, which can realize uniform energy receiving. The space between annuluses and the number the annuluses can be rest with the solar system heat transfer demand. As to the ray tracing process of the taper annuluses cavity receiver/absorber simulation, set the receiver/absorber material as ceramic which α =0.2 , concentrator as perfect mirror ρ =1, and tracing ray 500 bunches with solar angle 32’.

Figure 9 shows the taper annuluses cavity receiver/absorber flux distribution contours of the simulation. It is obvious that this structure has a commendable uniform power profile on each taper annulus (absorber).

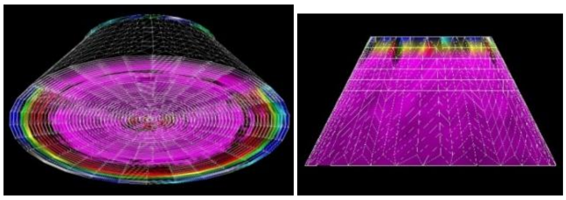

Fig. 9: Contours of the taper annuluses receiver/absorber energy profile

This innovated taper annuluses type receiver/absorber not only can get uniform energy distribution on almost all the absorber walls, this structure also possesses several other advantages. First of all, this type receiver/absorber has a high volume-to-surface ratio and relatively low flow resistance which can easily convert large amount of power to the working fluid. In addition, this structure is easy to manufacture compared with the special curve faces one, and by using ceramic material it can achieve excellent performance in high temperature solar energy thermal utilization. To sum up, the proposed taper annuluses type receiver/absorber may has a remarkable application prospect in solar dish high temperature thermal system. And more results on this innovative structure, such as efficient analysis, heat transfer performance and flow property on simulative and experimental verification will be published in the future.

5. Conclusion

An innovative taper annulus structure for the solar dish cavity receiver is designed and optimized based on the optical principle analysis of dish parabolic collector and the mathematic model. This innovated taper annuluses type receiver/absorber is consisted with several taper annuluses which have the same vertex and different taper angles. The taper angles are designed according to the dish collector concentrated sun-light direction, so that the uniformity of energy distribution on the absorber walls can be achieved. Not only that, this structure also possesses several other advantages. First of all, this type receiver/absorber has a high volume-to-surface ratio and relatively low flow resistance which can easily convert large power heat transfer to the working fluid. In addition, this structure is easy to be manufactured comparing with the special curve faces one. To sum up, the proposed taper annuluses type receiver/absorber may has a remarkable application prospect in solar dish high temperature thermal system.

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