EVALUATION OF DUAL COMBINED PARABOLIC SOLAR CONCENTRATOR IN EVACUATED TUBE

Abid Ustaoglu*, Junnosuke Okajima**
,Xin-Rong(Ron.) Zhang***, Shigenao Maruyama**
*Graduate School of Engineering, Tohoku University, Sendai, 980-8577, Japan
**Institute of Fluid Science, Tohoku University, Sendai, 980-8577, Japan
***Department of Energy and Resources Engineering, Peking University, Beijing 100871, China

An evacuated solar concentrator, which is a non-tracing, non-imaging solar concentrator, consists of a compound parabolic and an involute reflector was designed. The thermal efficiency of the concentrator was calculated as a function of the incidence ray angle and absorber temperature. The concentrator was compared with a dual form of the concentrator on its optical and thermal performance by using 2-D ray tracing model when full surface of the concentrator taken into account as the solar projected area.

INTRODUCTION

Many studies have been conducted for compound parabolic concentrator (CPC) that deals with a wide range of analysis and improving of design, since the invention of CPC. The CPC was defined as a collector for light from Cerenkow counters by Hinterberger and Winston [1, 2]. The CPC in 2D geometry was described by Winston [3]. Rabl [4] evaluated the optical and thermal properties of the CPC and compared it with those of a truncated CPC. Winston [5] proposed an alternative virtual absorber design that preserves ideal flux concentration on the absorber at the cost of slightly oversizing the reflector. Maruyama [6] proposed an involute reflector to generate uniform and homogeneous emission and carried out ray-tracing calculation to evaluate optical characteristics of that reflector. However, there are some problems in these kinds of systems. Efficiency in solar concentrators decreases with aging, because the reflector surface is affected by environmental factors, such as dust and climate variation. Furthermore, thermal efficiency abates due to convective and conductive heat losses. Maintenance of many solar systems can be difficult because of their geometry. Another issue is high production cost for sun tracking systems [7].

In order to eliminate these problems, an evacuated concentrator, which consists of involute and compound parabolic reflector, was proposed to obtain higher performance and low material cost [8]. When the projection area of full concentrator is considered as solar projection area, ray losses come into existence. In other words, only a small part of solar rays can pass aperture of CPC. In order to obtain higher solar ray acceptance, the rate of the aperture area of reflector to diameter of glass cover should be increased. Therefore, a dual concentrator is proposed in this study. The objective of this study is to improve the performance and to reduce the manufacturing cost of proposed solar concentrator with an emphasis on its optical and thermal performance.

CONCEPT

The concentrator is consisted of a conventional CPC and an involute reflector. The involute reflector is added to the focus points of the compound parabolic reflector. A tubular absorber is placed in the cusp point of the involute reflector and the concentrator is covered by an evacuated glass tube, which is shown in Fig. 1a [8]. The concentrator is designed by determining of maximum acceptance angle of CPC. Because the absorber surface area is equal to aperture area of involute reflector, the optimized reflector and absorber configuration can be derived using a fixed absorber radius of 0.01 m. The size of the glass cover is determined for as minimum radius as possible and the radius of glass cover is 0.075m for single one. The double concentrator comprises two pieces of solar concentrator and it has two absorber tubes as it is shown in Fig. 1b. The circumference of the glass tube is 0.96 m. In the case of double concentrator; the radius of glass is about 0.0975 m and the circumference is about 1.22 m. Although two combined reflectors were used in the double concentrator, a slightly oversizing of 28% occurred on the circumference of the glass cover. Therefore, using the double concentrator can provide low manufacturing cost.

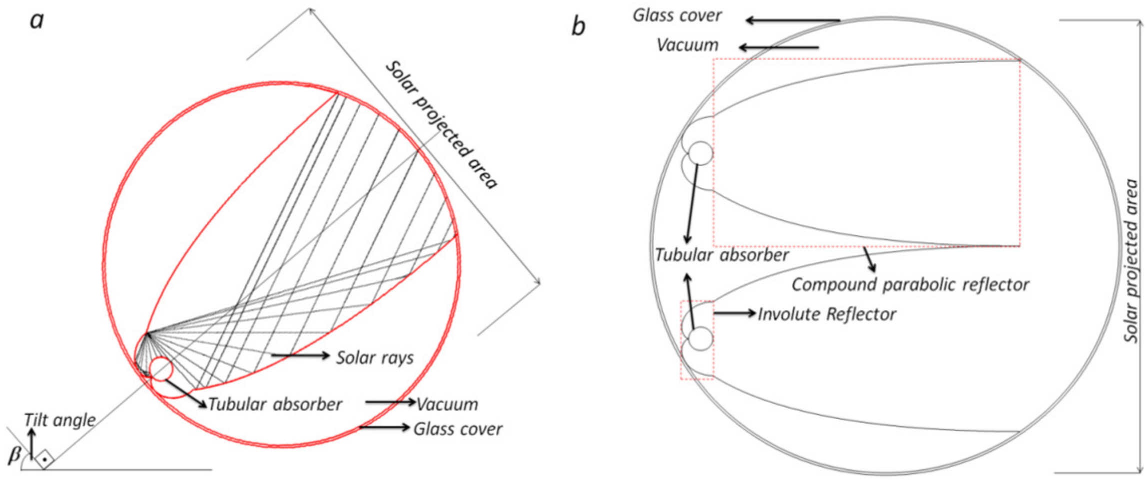

Figure 1. Geometry of (*a*) single and (*b*) dual concentrator

OPTICAL PERFORMANCE

The ray-tracing method has been used to evaluate the performance of the double concentrator in terms of the incidence angle of solar irradiance for the 2-D model [9]. Optical efficiency η_{opt} is a function of the absorptivity α_{ab} of absorber, transmissivity τ_c of glass cover and reflectivity ρ_r of the reflector as well [6]. The concentrator was designed for Sendai, Japan and its acceptance angle was estimated as 23.44°. Incidence rays within the glass cover area were taken into account as a solar projected area on the concentrator and it is shown in the Fig. 1 for clarity. Solar irradiation was divided into 1000 rays. The absorptivity of absorber, transmissivity of glass cover and reflectivity of reflector are 0.9, 0.95 and 0.9, respectively and independent from the ray angle.

As a result, the average optical efficiency of the dual concentrator is about 57%, as the single one is 37%. For the case of the normal incidence angle only 52% of rays can enter the aperture of the single concentrator, as 82% of rays can enter to the aperture of the double concentrator. Therefore, optical efficiency of the double concentrator is higher than the single concentrator.

THERMAL PERFORMANCE

The thermal efficiency can be calculated with considering the radiation heat loss by [10]. $\eta_{th} = \eta_{opt} - \varepsilon\sigma\left(T_{ab}^4 - T_{amb}^4\right)/(q_s C)$. T_{ab} and T_{amb} are the absorber and ambient temperature, respectively. q_s is the solar heat flux. C is the concentrator rate and can be calculated by $1/\sin\theta_{\max}$. In order to calculate the thermal efficiency some assumptions were adopted. Solar beam intensity I_b was assumed as 1000 W/m^2. The absorber was considered as a gray surface and emissivity ε of the absorber was assumed to be 0.9. The ambient temperature and the absorber temperature were assumed to be 293 K, 373 K, respectively. The absorber temperature of 373 K is the condition to generate hot water. The other assumptions were made such as the temperatures were uniform throughout each reflector surface, and the absorptivity, transmissivity and reflectivity are constant.

Figure 2 shows the thermal efficiency of dual and single cases as a function of incident ray angle. Efficiency of the double concentrator, when the side rays losses taken into account, is higher than the single concentrator. When the temperature of absorber assumed as 373 K, the single concentrator has the average thermal efficiency of 12.6%, as the average thermal efficiency of the double concentrators reach 33.63%.

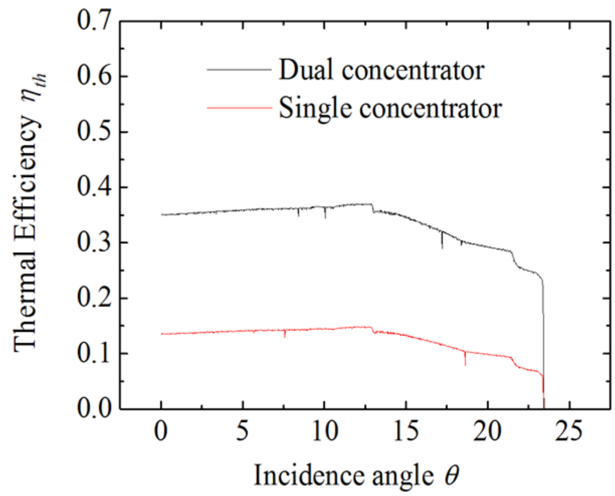

Figure 2. Thermal efficiency with incidence angle

CONCLUDING REMARKS

In this study, the proposed concentrator was analyzed to improve the performance and to reduce the manufacturing cost with an emphasis on its optical and thermal performance by using dual one. The dual concentrator can reduce the manufacturing costs because of the reducing glass cover area. Furthermore the thermal and optical efficiencies of the dual concentrator were higher than the single solar concentrator because of the higher ray acceptance in the case of the double concentrator. When temperature of absorber was assumed as 373 K, the average thermal efficiency of the single concentrator was 12.6%, as average thermal efficiency of the dual one reached to 33.63%.

RERERANCES

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