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# High temperature collecting performance of a new all-glass evacuated tubular solar air heater with U-shaped tube heat exchanger

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ABSTRACT

Experiment and simulation are conducted on a new-type all-glass evacuated tubular solar air heater with simplified compound parabolic concentrator (CPC). The system is made up of 10 linked collecting panels and each panel includes a simplified CPC and an all-glass evacuated tube with a U-shaped copper tube heat exchanger installed inside. Air is gradually heated when passing through each U-shaped copper tube. The heat transfer model of the solar air heater is established and the outlet air temperature, the heat power and heat efficiency are calculated. Calculated and experimental results show that the present experimental system can provide the heated air exceeding 200 °C. The whole system has an outstanding high-temperature collecting performance and the present heat transfer model can meet the general requirements of engineering calculations.



## 1. Introduction

With the forthcoming global energy crisis, solar energy as the most promising new energy has been used widely in a variety of fields. Solar collector is designed to absorb solar radiation and converts it into heat. It is mainly divided into three categories: flat plate collector, evacuated tube collector and concentrating collector.

In the past few years, flat-plate solar air heater used to hold a dominant position in the air heater field because of its unique characteristics differing from conventional heat exchangers. In this kind of air heaters, the solar radiation energy is converted into internal energy [1]. Then the energy is utilized to heat the passing air through a conduit system located between the bottom and the absorbing plate. The heated air is subsequently used for space heating and drying [2]. Ong [3] proposed a mathematical model and solution procedure for analyzing the performance of solar flat-plate air heater. Garg and Adhikari [4] carried out a performance evaluation of a single solar air heater with n-subcollectors. Oommen and Jayaraman [5] analyzed the development and performance of non-evacuated compound parabolic concentrator (CPC) cavities with flat absorbers. Tchinda [6] introduced a mathematical model for analyzing the air collector thermal performance for quantifying the heat transfer within CPC solar energy collectors with a flat one-side absorber. A lot of experimental studies concerning configuration design and thermal performance have been reported [7–16].

Flat-plate collector and evacuated tube collector are mainly used to collect heat for low temperature applications. However, the latter has better performance and lower cost than the former. Recently, the market of the evacuated tube solar water heater has been expanded by the development of low cost sputtering technology for producing the absorber surface on all-glass evacuated tubes [17]. In China, all-glass evacuated tube solar water heater is widely used due to its excellent thermal performance, low cost, easy installation and transportation [18,19]; however, most studies were carried out at low temperature for water heating instead of moderate or high temperature applications [20]. Compared as various flat-plate solar collectors, the evacuated tube solar collectors have low energy loss due to the vacuum envelop around the absorber surface, if these collectors can be applied in the forced-circulation solar air heating system with high operation temperature, they will have a better performance than flat plate collectors. However, there are few publications related to the performance of the all-glass evacuated tube high temperature collectors system. For the evacuated tube solar air collector, developing of the thermal conduction medium between the inner glass tube and metal heat exchanger are the key technology in order to obtain outstanding collecting performance.

Currently, the widely used all-glass evacuated tube solar collector can only heat water or air to about 100 °C, which fails to meet the diversified development demand of solar collector. If the solar collector can achieve higher temperature over 100 °C, it will get more extensive application, especially for a variety of industrial

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**Nomenclature**

| | |
|---|---|
| $A$ | area ($m^2$) |
| $A_{cpc}$ | lighting area of one CPC plate ($m^2$) |
| $c_p$ | specific heat of air (J/(kg °C)) |
| $E$ | radiation energy flux density ($W/m^2$) |
| $f_{ref}$ | multiple reflection coefficients between cover glass tube and inner glass tube |
| $g$ | gap distance (m) |
| $q_r$ | solar irradiance ($W/m^2$) |
| $Q_e$ | net gain energy absorbed by air in each collecting panel (W) |
| $Q_{loss}$ | radiation heat loss on absorbing coating in each collecting panel (W) |
| $Q_r$ | solar radiation incident on selective coating in each panel (W) |
| $Q_{cpc}$ | total solar radiation incident on each CPC plate (W) |
| $P_e$ | heater heat power (W) |
| $p$ | gap loss coefficient |
| $T$ | temperature (°C) |
| $m$ | mass flow rate of air (kg/s) |
| $V$ | volume flow rate ($m^3$/h) |
| *Greek symbols* | |
| $\lambda$ | thermal conductivity (W/(m K)) |
| $\varepsilon$ | emissivity |
| $\theta_A$ | acceptance half angle (°) |
| $\rho$ | reflectivity |
| $\eta_e$ | collector efficiency |
| $\tau_e$ | transmissivity |
| $\tau_d$ | dust stratification factor |
| $\alpha_i$ | absorptivity of absorbing coating |
| *Subscript* | |
| *cal* | calculated value |
| *exp* | experimental value |

application. CPC is an effective equipment to improve the collector temperature despite its complex processing and high cost.

CPC can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any entering radiation within the collector acceptance angle will find its way to the absorber surface located at the bottom of the collector. As a kind of highly efficient moderate temperature solar collector, CPC solar collector has been widely studied in the design and analysis [21,22]. Up to now, most of the reported solar air heaters are based on the flat-plate solar collector with CPC systems and the maximum air temperature at the system outlet is usually less than 120 °C, whereas much less attention has been paid to the application of all-glass evacuated tube collectors. Considering the low heat dissipation due to the vacuum encapsulation around the absorber surface, if these collectors can be applied in the forced-circulation solar air heating system with high operation temperature, they will have a better performance than flat plate collectors.

This study designed a solar collector system to obtain moderate air temperature of 150–200 °C. The solar collector system consists of 10 linked collector panels. Each panel includes a simplified CPC and an all-glass evacuated tube with a U-shaped copper tube heat exchanger installed inside. A kind of high thermal conductivity medium is filled between the copper tube and the inner all-glass tube. Air passes through the solar collector system and is progressively heated in each copper tube. The experimental results fulfill the expected goals and have profound guiding significance for designing evacuated tube solar moderate temperature collectors with simplified CPC applied in industrial processes. In this paper, simplified theoretical analysis and numerical simulation are also carried out for the evacuated tubular solar collector system in the above statement for engineering design. Calculation and experimental results show that the whole system has an outstanding high-temperature performance. The present simulation model can meet the general requirements of engineering design.

## 2. Experimental apparatus and structure of simplified CPC

### 2.1. Integral structure of experimental apparatus

The schematic of the experimental system and the photograph of the actual solar collector are separately shown in Figs. 1 and 2. The first part of the experimental apparatus is composed of an air compressor and a large pressure container, which provides a steady air flow through the test process. The second part is the solar collector system which consists of 10 linked collector panels. Each panel is made up of four sections: a simplified CPC, an all-glass evacuated tube, a U-shaped copper tube and the heat conduction medium between the copper tube and the inner glass tube. The all-glass evacuated tube includes two concentric glass tubes sealed at one end with a vacuum space and a selective absorbing coating on the outer surface (vacuum side) of the inner tube.

### 2.2. Geometry of simplified CPC type concentrator

CPC can absorb solar radiation without following the tracks of the sun. It also has the advantage of concentrating the diffuse radiation, which is impossible when using an imaging collector. In the present study, a CPC type concentrator with a tubular absorber is designed using the method proposed by Khonkar and Sayigh [23]. The tubular absorber is an all-glass evacuated solar tube, which consists of two concentric glass tubes sealed at one end with an annular vacuum space and a selective absorbing coating on the outer surface (vacuum side) of the inner tube. To overcome the weak point of standard CPC, a simplified CPC type concentrator (it is referred to as the simplified CPC) is designed in this experiment.

This simplified CPC is designed with a flat curve bottom instead of involute curve shape bottom for reducing processing difficulty and cost. In addition, the upper half part of CPC is also cut to decrease cost and increase actual acceptance angle. Fig. 3(a) and (b) separately shows the standard CPC and the simplified CPC profile

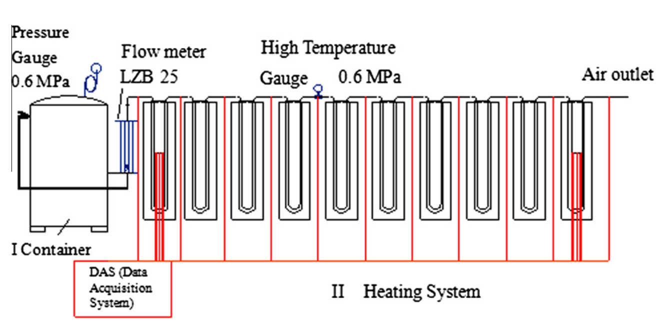


**Fig. 1.** Whole structure of solar air heater system.