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INDOOR HEAT LOSS AND OUTDOOR THERMAL EFFICIENCY TESTING AND ANALYSES ON THE PARABOLIC TROUGH SOLAR RECEIVERS WITH AN INNER RADIATION SHIELD

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ABSTRACT

Parabolic trough collectors (PTCs) harvest high-temperature heat and are widely applied in solar thermal utilization. The key parts of the parabolic trough collectors are the solar receivers, the thermal performance of the solar receivers has significant impacts on the PTCs. However, the high temperature incurs considerable radiative heat loss of the solar receivers. A structural optimized solar receiver with an inner radiation shield was proposed for reducing the heat loss and improving the thermal performance. The indoor heat loss and the outdoor thermal efficiency testing were conducted in Electricity Engineering of China Academy to validate comprehensive thermal performance of the novel solar receivers. The experimental results show that the heat loss of novel solar receiver can be reduced by 28% at absorber temperature of 550 °C, and the thermal efficiency can be enhance by 4.9 % at 350 °C inlet temperature.

Keywords: *Parabolic trough collector; PTC; Concentrated solar power; CSP; Radiation shield*

NONMENCLATURE

Abbreviations

PTC	Parabolic trough collector
HCE	Heat-collection element
HTF	Heat transfer fluid
DNI	Direct normal irradiance
SSC	Solar selective-absorbing coating
CSP	Concentrated solar power
RS	Radiation shield
CHCE	Conventional HCE
NHCE-RS	Novel HCE with a RS

Symbols

T	Temperature, K	in	Inlet
η	Efficiency	P	Percentage

1. INTRODUCTION

Up to now, Parabolic trough collectors (PTCs) are the most mature and commercial technology to achieve high-temperature heat source among the solar thermal utilization. The PTC system includes the trough mirrors, heat-collection elements (HCEs), tracking devices, heat transfer fluid (HTF) flowing in the solar receivers, and so on. HCEs are mainly composed of glass envelope, absorber tube, metal bellows. The solar selective-absorbing coating (SSC) is covered on the outer surface of the absorber tube for ensuring absorber tube high absorptance to the solar irradiance.

As the key part of the PTC system, HCEs usually operate with thermal oils of Therminol VP-1 for operation up to 400 °C. Moreover, HTF of molten salts is applied into the HCEs and PTC system, which can operate up to 550~600°C. Beside of corrosion under harsh environmental conditions, the deformation and stress rupture under such high temperature need to be overcame for the HCEs [1]. Some researchers brought insight into the nonuniform-temperature-induced deformation of receiver tubes focusing on the thermo-elastics [2], and superheating phenomenon with the highest thermal load [1][3][4]. Apart from firm structures and reliable resistant materials, the design core of the HCEs is to maximize the heat gain. The heat gain of the HCEs depends on the absorption of the solar irradiance and the heat loss, thus strengthening the absorption and reducing the heat loss are two main approaches focused by the researchers for enhancing the thermal performance of the HCEs. For effectively blocking heat conduction and convection from the absorber tube, the annular space between the absorber tube and glass envelope is evacuated. The glass envelope uses ultra-white glass due to its high transmittance to the solar irradiance compared with other glasses. In addition, the upper and lower surfaces of glass envelope are covered with anti-reflective coatings, which contribute to higher transmittance of the solar irradiance and enhance the glass envelope transmittance to 96%. The absorber tube is coated with SSC which has high absorptance of the solar irradiance and low emittance of the infrared radiation. The latest SSC used in the HCEs can reach absorptance of 96% and the emittance of 10% at the absorber temperature of 400 °C. And the performance enhancement of the SSC is research hotspot [5].

However, the improvement room of the SSC performance is limited, especially the emittance of the SSC. Different with the traditional optimization method of enhancing optical performance of the SSC, a novel structural optimization strategy was proposed based on the characteristics of the circumferentially uneven solar irradiance distribution in HCEs [6]. As shown in Fig. 1, the bottom half part of the HCE towards the mirrors receives high-energy density solar irradiance by the mirror concentrator (called Concentration part), but the top half part of the HCE back towards the mirrors only receives low-energy density solar irradiance without the projection of the concentrated solar rays (called Nonconcentration part). In the case of sufficiently high operating temperature in HCEs, it is noteworthy that the radiation heat from the absorber tube would exceed the absorbed solar irradiance by the absorber tube in the nonconcentrated part, this rarely discovered phenomenon demonstrates the negative net heat gain occurs in nonconcentration part, and reveals the structural imperfection appearing in the HCEs. For reducing the heat loss in nonconcentration part and thus improving the comprehensive performance in HCEs, we put forward a novel structure of radiation shield (RS), which was placed into the vacuum annular in the nonconcentration part [7]. The proposed RS could intercept much radiation heat from the absorber tube without incurring excessing solar irradiation blockage loss because of received low-energy density solar irradiance in this part. Comprehensively, the net heat gain of the absorber tube in the nonconcentration part could be positively improved after the structural optimization of adding RS.

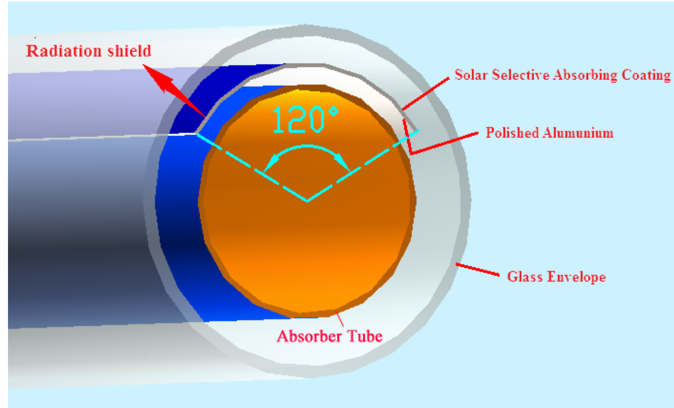

Fig 1 a novel HCE with an inner radiation shield

2. EXPERIMENTAL SETUP AND METHOD

2.1 Heat-collection elements

The specifications of conventional and novel heat-collection elements (CHCEs and NHCEs) are shown in Table 1, they were trail-manufactured by the TRX Solar technology Co. Ltd as exhibited in Fig 2.

Table 1 Specifications of the tested HCE

	Material	Dimension
Length	/	4060 mm
Glass envelope	Borosilicate glass	Outer diameter: 125 mm Thickness: 2.5 mm
Absorber tube	stainless steel (SS 321)	Outer diameter: 70 mm Thickness: 3 mm
Radiation shield (NHCE)	Aluminum sheet	Diameter: 80 mm Angle: 120°

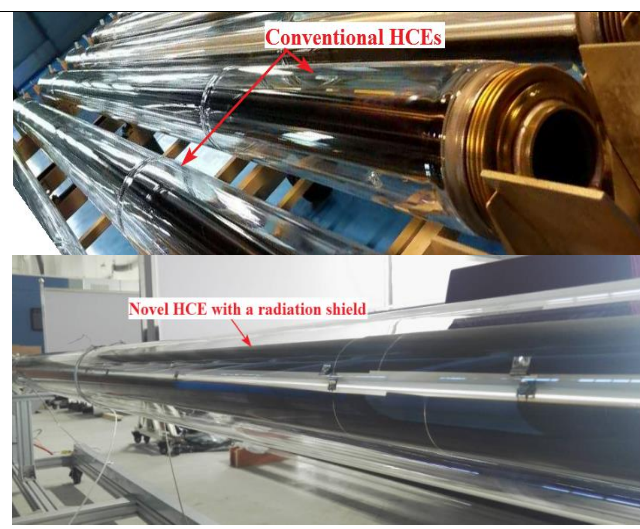

Fig 2 Trial-manufactured, (a) conventional HCE, and (b) novel HCE with a radiation shield

2.2 Indoor and outdoor experimental setups

As exhibited in Fig 3 and Fig 4, the NHCE with a radiation shield (NHCE-RS) was tested in indoor heat loss platform and outdoor thermal efficiency platform, respectively. Indoor heat loss testing employed the heat balance method by the utilization of the heaters for creating the expected absorber temperatures. Outdoor thermal efficiency testing platform possesses high tracking precision due to its two-axis tracking mode.

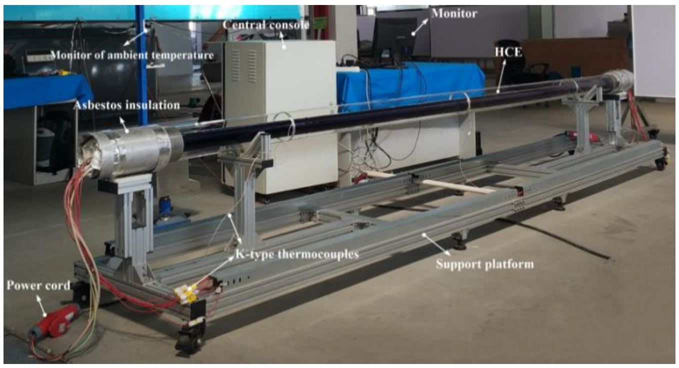

Fig 3 Indoor heat loss testing platform

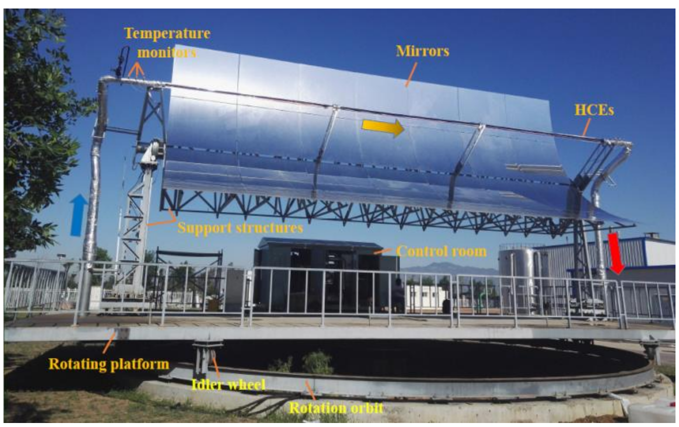

Fig 4 Outdoor thermal efficiency testing platform

In indoor testing process, the absorber temperatures were heated from 200 to 550 °C with the interval of about 50 °C, the heat loss of the HCE can be calculated by the monitored powers of the heaters. In outdoor testing process, the inlet temperature of the tested PTC system is preheated to a certain temperature approximately from 200 to 370 °C, and then fluid flow rate, inlet temperature and outdoor temperature were monitored, the thermal efficiency of the PTC system can be achieved. It is noticeable that the experimental data is considered to be valid in indoor and outdoor testing processes once the quasistatic process remains 15 mins.

3. RESULTS AND DISCUSSIONS

3.1 Indoor heat loss

In the case of the ambient temperature of 295 K, the heat losses of the CHCE and NHCE-RS were tested and exhibited in Fig 5. The heat loss of the NHCE-RS is lower than that of the CHCE, and the former is much obviously lower than the latter with the high absorber temperature. It demonstrates that the radiation shield plays key role in reducing the heat loss of HCE, and NHCE-RS achieves superior thermal performance compared with the CHCE.

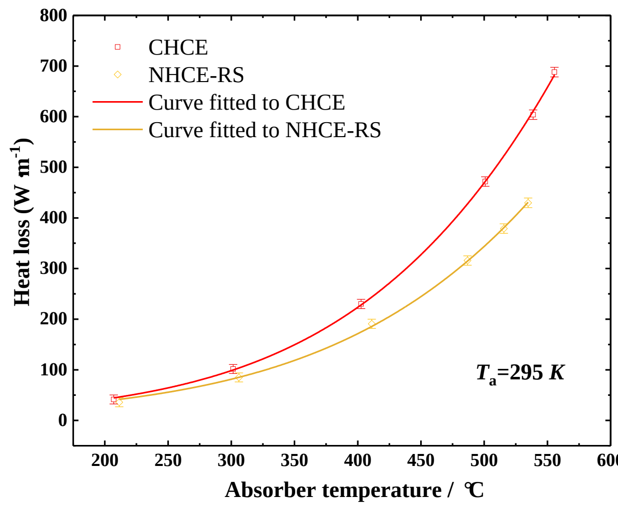

Fig 5 Heat loss of the NHCE-RS

With increasing absorber temperature, the percentage of the heat loss reduction in NHCE-RS compared with CHCE is enhanced. The reason for this is because the radiation heat from the absorber tube is much higher at higher absorber temperature, correspondingly, much radiation heat loss can be blocked by the radiation shield, thereby the NHCE-RS has lower heat loss. When the absorber temperature reaches 550 °C, the heat loss of the NHCE-RS can be effectively reduced by 28.0 %, as shown in Fig 6.

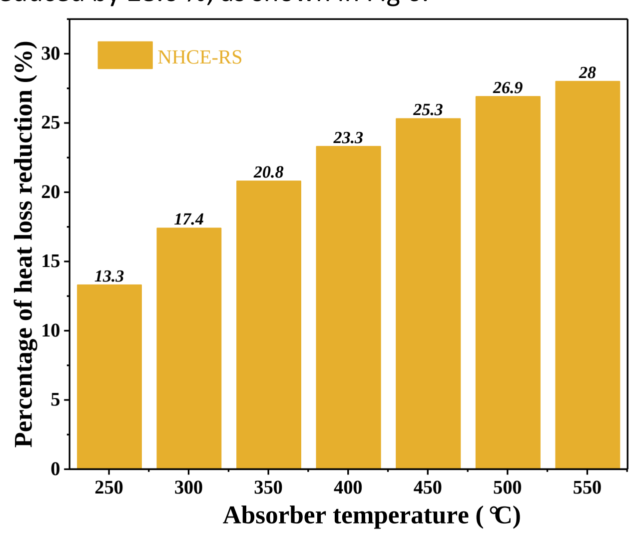

Fig 6 Percentage of the heat loss reduction in NHCE-RS compared with the CHCE

3.2 Outdoor thermal efficiency

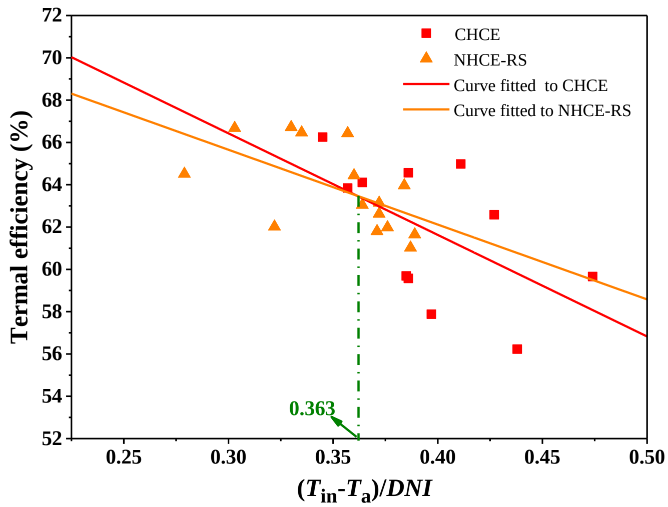

Fig 7 Thermal efficiencies of the NHCE-RS and CHCE based on normalized temperature difference

As shown in Fig 7, the thermal efficiencies of the NHCE-RS and CHCE were achieved based on the normalized temperature difference. The fitted linear equations for the NHCE-RS and CHCE are $\eta_{NHCE-RS} = 80.8 - 48.0\dfrac{T_{in} - T_a}{DNI}$, and $\eta_{CHCE} = 76.3 - 35.4\dfrac{T_{in} - T_a}{DNI}$. The results show that the NHCE-RS possesses higher intercept thermal efficiency but higher heat loss coefficient compared with the CHCE which results in lower thermal efficiency at higher X-axis value. That means lower *DNI* and higher inlet temperature, NHCE-RS would have greater enhancement of the thermal efficiency compared with CHCE. As exhibited in Table 2, the thermal efficiency of the NHCE-RS can improve by 4.9 % in the case of the absorber temperature of 350 °C and *DNI* of 600 W/m^2.

Table 2 Thermal efficiencies of CHCE and NHCE-RS at the inlet temperature of 350 °C with different *DNI*

Type	600 W/m^2		700 W/m^2		800 W/m^2	
	η (%)	P_η (%)	η (%)	P_η (%)	η (%)	P_η (%)
CHCE	49.4	\	54.2	\	57.8	\
NHCE-RS	51.8	4.9	55.7	2.8	58.7	1.6

4. CONCLUSIONS

In this study, for effectively reduce the heat loss and improve the thermal performance of the solar receivers, we proposed a novel heat-collection element with a radiation shield (NHCE-RS) and conducted indoor heat loss and outdoor thermal efficiency experiments in Electricity Engineering of China Academy. The experimental results are summarized as:

(1) The NHCE-RS has lower heat loss compared with the conventional HCE (CHCE), RS in NHCE plays a key role in reducing the heat loss. The heat loss of novel solar receiver can be reduced by 28% at absorber temperature of 550 °C.

(2) NHCE-RS possesses superior comprehensive thermal performance. The thermal efficiency of NHCE-RS can be enhanced by 4.9 % at 350 °C inlet temperature and 600 W/m^2 *DNI*.

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