Applied Thermal Engineering 95 (2016) 357–364

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Performance investigation of parabolic trough solar receiver

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HIGHLIGHTS

- There exists an optimal mass flow rate for exergy efficiency.
- The appropriate evaluation criterion has crucial effect on optimization.
- The optical heat loss far outweighs the heat loss of solar receiver.
- The exergy lost from receiver ends dominates in all exergy losses.

ARTICLE INFO

Article history:
Received 10 August 2015
Accepted 8 November 2015
Available online 1 December 2015

Keywords:
Heat loss
Exergy efficiency
Thermal efficiency
Solar receiver
Heat transfer
Exergy loss

ABSTRACT

The influences of some parameters on the performance of parabolic trough solar receiver are investigated in the present work. When the mass flow rate of working fluid, ambient temperature and solar incident angle increase, the heat losses of solar receiver decrease. The exergy losses of solar receiver increase as the inlet temperature of working fluid, wind velocity, and the inner diameter of glass cover increase. The convective heat loss of glass cover predominates in the heat losses of solar receiver based on thermal efficiency, but the exergy lost from absorber ends takes the largest proportion. The optical heat loss of solar collector is far more than the heat losses of solar receiver, especially in the larger solar incident angle. There exists an optimal mass flow rate of working fluid for exergy efficiency, and the thermal efficiency and exergy efficiency have opposite changing tendencies under some conditions. Therefore, the selection of evaluation criteria is crucial to the performance optimization of solar collector system. This study is of great significance to guide the design and optimization of parabolic trough receivers.

1. Introduction

With the decline of storage capacity and aggravation of environmental contamination for fossil fuels, solar energy, which is an inexhaustible, clean and safe energy, has received more and more attention as one of the most promising candidates to substitute fossil fuels [1–4]. As one of the most matured solar concentrators, the parabolic trough concentrator has been successfully used in many countries [5]. The solar receiver is the key component of parabolic trough solar plants [6], so the parabolic trough solar receiver has attracted a great deal of attention. Xiong et al. [7] investigated the thermal performance of parabolic trough receiver; they found that the selective coating and annular pressure have more influence on the heat loss of parabolic trough receiver than wind velocity. Tao and He [8] developed a two-dimensional numerical model for parabolic trough solar receiver, and presented the corresponding dimensionless governing equations. An optical model and a heat transfer model were developed for the parabolic trough solar collector in [9], and the numerical results had a good agreement with experimental results. Cheng et al. [10,11] conducted numerical studies on the parabolic trough solar receiver by combining MCRT method and FLUID software, and the numerical results agreed well with the experimental data. Wang et al. [12] numerically investigated the performance of parabolic trough collector using molten salt as working fluid; the influences of key operation parameters on the performance of the parabolic trough collector were reported. Padilla et al. [13] proposed a heat transfer model for the parabolic trough collector based on segmental analysis method, which had a good agreement with the experimental data from SNL. Hachicha et al. [14] numerically investigated the performance of the parabolic trough collector and its receiver based on large eddy simulation modeling, and they presented the velocity, pressure and temperature fields around an isolated parabolic solar collector and its receiver. Mohamad et al. [15] analyzed the heat losses of parabolic trough solar receiver; they found that the heat losses increase with the length of receiver and the temperature difference between the working fluid and the environment. The single glass cover is more economical than double glazing layer for a shorter receiver, while the double glazing layer has more advantages for a longer receiver. Bader et al. [16] adopted a corrugated absorber tube to decrease

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http://dx.doi.org/10.1016/j.applthermaleng.2015.11.035
1359-4311/

heat loss from the receiver, and they reported that the single-glazed receiver has better performance at low temperature of working fluid, while the double-glazed receiver has higher collector efficiency at high temperature of working fluid. Lei et al. [17] experimentally studied the thermal characterization of parabolic trough receiver; a series of heat loss tests were conducted based on the steady state equilibrium method, and the results showed that it is essential to shield the end of receiver to reduce the end heat loss. Xu et al. [18] conducted an optical analysis on the end loss effect of parabolic trough solar collector; they found that the end loss effect decreases with the increase of receiver length, and varies greatly when the length is shorter than 15 m. Odeh et al. [19] developed a model of thermal losses from the collector based on absorber wall temperature, which could be used to evaluate the performance of solar receiver with heat transfer oil or water. Padilla et al. [20] conducted an exergy analysis to study the effects of operational and environmental parameters on the performance of parabolic trough collectors; the results showed that the highest exergy destruction is caused by heat transfer, and the highest exergy losses is due to optical error. Lüpfert et al. [21] presented a method for measuring the heat loss of solar receiver based on energy balance between the working fluid in receiver and the ambient, and they found that the similar results can be achieved with different kind of methods. You et al. [22] analyzed the heat transfer and flow in a parabolic trough solar collector of direct steam generation; the results showed that the outlet temperature of once-trough DSG system was difficult to control, and extra heat was required to maintain the normal operation. The heat transfer analysis and modeling of a parabolic trough solar receiver, and the heat loss of solar receiver, were reported in detail by the National laboratory of the U.S. Department of Energy [23,24].

The performance of parabolic trough solar receiver has been studied extensively. However, most of the works focus on the analysis based on the first law of thermodynamics. The energy is conserved in solar receiver, but the useful energy (available work or exergy) is destructed, since the heat transfer is seriously irreversible in the solar collector system. In order to improve the capacity of solar receiver for doing work, the exergy analysis is required for the design of solar collector system. Bejan [25,26] stated that the second law analysis should play a central role in heat transfer analysis. Therefore, we attempt to conduct a thermal performance analysis of the parabolic trough solar receiver based on the first- and second-law of thermodynamics. The heat transfer model is established based on energy balance between the working fluid and the environment, and the exergy analysis is employed in the thermal performance evaluation of solar receiver, and the influences of some important operation parameters on the performance of solar receiver are presented.

2. Theoretical analysis of solar receiver

2.1. Solar receiver description

The schematic diagram of parabolic trough solar receiver is shown in Fig. 1. The solar receiver consists of a metal absorber inside a glass envelope with bellows at either end. There is a special coating (selective coating) on the outside surface of the absorber to enhance absorption for radiation heat and reduce radiation heat loss. The annular space between the absorber and glass envelope is under vacuum to reduce heat loss and protect the selective coating [27]. The difference in accuracy for diverse one-dimensional models for parabolic trough solar receiver were analyzed and presented in [28]; the results indicated that an appropriate one-dimensional model under a certain condition was precise enough compared with the three-dimensional model. Therefore, the energy balance model proposed by [24] is adopted in the present work. The solar energy is absorbed by selective coating on absorber $Q_{a,ab}$, and glass envelope $Q_{g,ab}$. The energy absorbed by selective coating is partly conducted to the inner wall of absorber $Q_{a,c}$, and further transferred to the working fluid by convection Q_{gain}. Some energy absorbed by absorber is transmitted to the glass envelope by convection $Q_{c,a\text{-}g}$ and radiation $Q_{r,a\text{-}g}$, and lost through ends of receiver $Q_{l,b}$. The energy absorbed by glass envelope and the energy conducted from inner wall to the outer wall of glass envelope are lost to the environment by convection $Q_{c,g\text{-}e}$ and radiation $Q_{r,g\text{-}e}$ [24]. The energy balance in the solar receiver can be written as follows [24]:

$$Q_{gain} = Q_{a,c} \tag{1}$$

$$Q_{a,ab} = Q_{c,a-g} + Q_{r,a-g} + Q_{a,c} + Q_{l,b} \tag{2}$$

$$Q_{g,c} = Q_{c,a-g} + Q_{r,a-g} \tag{3}$$

$$Q_{g,c} + Q_{g,ab} = Q_{c,g-e} + Q_{r,g-e} \tag{4}$$

2.2. Thermodynamic calculation

The DOWTHERM A is selected as the working fluid, and its thermophysical properties are expressed as functions of temperature.

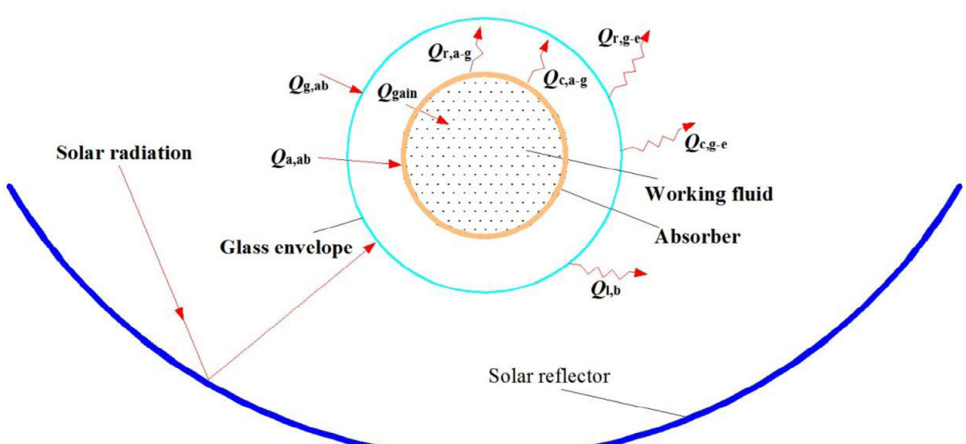

Fig. 1. The energy balance for solar receiver.