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An on-site test method for optical efficiency of large-size parabolic trough collectors

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Abstract

An on-site test method for optical efficiency of large-size parabolic trough collectors (PTCs) is proposed. This method is based on energy balance of incident solar radiation, heat gain, cosine loss, end loss, optical loss and heat loss. The heat loss is calculated based on the correlation between the cooling power and absorber-ambient temperature difference obtained by fourth-order polynomial data-fitting. The incident solar radiation and heat gain are calculated based on the experimental data. The cosine and end losses are calculated based on local time and astronomical conditions. Therefore, the optical loss is achievable based on the energy balance and so is the optical efficiency. This method was implemented on the 300kWt PTC experimental rig located in Langfang, Hebei, China. The optical efficiency is evaluated to be (76.15 ± 1.7) %, which agrees well with that of the LS-3 collector (77%). On the other hand, a thermohydraulic model for PTC using heat transfer fluid (HTF) developed before is incorporated with the optical efficiency obtained on the 300kWt PTC experimental rig. The good agreement between the simulation results and experiment data verifies the on-site test method and the thermohydraulic model.

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Keywords: Concentrating solar power; Parabolic trough collector; Optical efficiency; Heat loss

1. Introduction

The parabolic trough collector (PTC) is the earliest and the most mature concentrating solar power (CSP) technology. The annual solar-to-electric efficiency of a PTC-CSP plant is 15.4~16.1%, due to low collector efficiency. The energy losses mainly include cosine loss, optical loss and heat loss. The cosine loss is caused by the incident angle. The heat loss is due to the convective and radiative heat transfer to the ambient.

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The optical loss is caused by the optical performances of the mirror reflectance, overall intercept factor, absorptivity of absorber and transmittance of glass envelope. An on-site rather than in-door testing method is significant for the practical performance. Kutscher et al.[1] experimentally determined the optical efficiency. However, the optical performance changes with operating temperature due to deformation of HCE supports. Therefore, this method is not suitable for a loop longer than 100m. Lopez-Martin and Zarza [2] proposed a test method for optical efficiency of large-size PTCs. They calculated the heat loss according to the linear correlation and obtained the optical loss based on energy balance. However, in this method, the HTF temperature, rather than the outer surface temperature of absorber, is used to calculate the temperature difference regarding ambient, which may affect the accuracy.

In the present work, an on-site test method for optical efficiency of large-size PTCs is proposed. This method is based on energy balance and could measure the optical efficiency in operating temperature. The heat loss is calculated based on the correlation between the cooling power and absorber-ambient temperature difference obtained by fourth-order polynomial data-fitting. The optical loss is determined by subtracting the other contributors. This method was implemented on the 300kWt PTC experimental rig located in Langfang, Hebei, China. On the other hand, a model of PTC using HTF developed before is incorporated with the optical efficiency test result. Good agreement between the simulation and experimental result verifies the proposed method and thermohydraulic model.

2. Methodology

The energy balance of PTC can be written as:

$$Q_{\mathrm{inc}} = Q_{\mathrm{gain}} + Q_{\mathrm{loss,cos}} + Q_{\mathrm{loss,end}} + Q_{\mathrm{loss,heat}} + Q_{\mathrm{loss,opt}} \tag{1}$$

where Q_{inc} is the incident solar radiation to PTC; Q_{gain} is the heat gain by PTC; $Q_{\mathrm{loss,cos}}$, $Q_{\mathrm{loss,end}}$, $Q_{\mathrm{loss,heat}}$ and $Q_{\mathrm{loss,opt}}$ are the cosine loss, the end loss, the heat loss and the optical loss, respectively.

2.1. Evaluation of heat loss

For a particular PTC, heat loss ($Q_{\mathrm{loss,heat}}$) is determined by the temperature difference between the outer surface temperature of absorber and the ambient temperature (ΔT_{amb}). Heat loss of collector is hard to measure while the PTC is in heating (in-focus) mode. Since the correlation of $Q_{\mathrm{loss,heat}}$ with ΔT_{amb} holds once it is obtained. It is possible to carry out cooling (de-focus) mode tests for this correlation. Then the correlation can be used to evaluate the heat loss of PTC in heating tests. The $Q_{\mathrm{loss,heat}} - \Delta T_{\mathrm{amb}}$ correlation is obtained by the following steps:

(1) The PTCs before the tested PTCs in the same loop is partially de-focus while the tested PTCs are fully de-focus. The HTF is circulated through the loop. Therefore, the HTF is heated when it passes the partially de-focus PTCs while cools down when it passes the fully de-focus PTCs. When the thermal equilibrium state is reached, record the inlet and outlet HTF temperatures of the tested PTCs, the HTF mass flow rate and the ambient temperature.

(2) $Q_{\mathrm{loss,heat}}$ is calculated as:

$$Q_{\mathrm{loss,heat}} = \dot{m}^{\mathrm{df}} c_p \left(T_{\mathrm{in}}^{\mathrm{df}} - T_{\mathrm{out}}^{\mathrm{df}} \right) \tag{2}$$

where $\dot{m}^{\mathrm{df}}$ is the HTF mass flow rate, $T_{\mathrm{in}}^{\mathrm{df}}$ and $T_{\mathrm{out}}^{\mathrm{df}}$ are the inlet and outlet temperatures respectively; c_p is the isobaric thermal capacity of HTF, of which the characteristic temperature is the average of $T_{\mathrm{in}}^{\mathrm{df}}$ and $T_{\mathrm{out}}^{\mathrm{df}}$. ΔT_{amb} is calculated as:

$$\Delta T_{\mathrm{amb}} = T_{\mathrm{tube,out}} - T_{\mathrm{amb}} = \frac{T_{\mathrm{in}}^{\mathrm{df}} + T_{\mathrm{out}}^{\mathrm{df}}}{2} - \frac{Q_{\mathrm{loss,heat}}}{\pi Nu_{D_{\mathrm{tube,in}}} k_{\mathrm{HTF}} L} - \frac{Q_{\mathrm{loss,heat}} \ln\left(D_{\mathrm{tube,out}} / D_{\mathrm{tube,in}} \right)}{2\pi k_{\mathrm{tube}} L} - T_{\mathrm{amb}} \tag{3}$$