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Influences of installation and tracking errors on the optical performance of a solar parabolic trough collector

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ABSTRACT

The parabolic trough collector is an important component of parabolic trough solar thermal power generation systems. Coordinate transformations and the Monte Carlo Ray Trace (MCRT) method were combined to simulate the circumferential flux distribution on absorber tubes. The simulation model includes the optics cone with non-parallel rays, geometric concentration ratios (GCs), the glass tube transmissivity, the absorber tube absorptance and the collector surface reflectivity. The mode is used to analyze the effects of absorber tube installation errors and reflector tracking errors. The results are compared with reference data to verify the model accuracy. Influences of installation and tracking errors on the flux distribution are analyzed for different errors, incident angles and GCs. For a GC of 20 and 90° rim angle, X direction installation errors are −0.2%~0.2%, Y direction installation errors are −1.0%−0.5%, and the tracking error should be less than 4 mrad. As the incident angle increases, the errors become larger, but the errors become smaller as concentration ratios are increased. The results provide foundations for heat transfer analysis of the absorber tube, for parabolic trough plant to ensure the safe intensity, and for economic analysis of the installation process and control system.

1. Introduction

Since the 1970s, increasing energy demands, greenhouse effects and environmental pollution due to the burning of fossil fuels have revealed in more and more attention on the utilization of solar energy, as a clean and sustainable energy source that is widely distributed with many applications [1]. Concentrating solar power (CSP) system is a promising source of high temperature energy which has experienced revived market growth. David et al. [2] focused on innovation in CSP technologies over the last decade and introduced the parabolic trough technology. The global installed capacity was 1789 MW by the end of 2013 with about 90% of the commercial CSP plants using parabolic trough solar technology [3], including the SEGS plants in the California Mojave Desert and the 100 MW “Shams 1” plant in Abu Dhabi.

The parabolic trough collector (PTC) is a key component of parabolic trough solar power systems. Many researchers have developed energy models for PTCs. In 1977, Evans [4] used a “cone optics” model for the cylindrical parabolic solar concentrators with flat absorbers and considered the influence of the finite size of the sun in the model. Jeter [5,6] developed an integral model for the concentrated energy flux distribution using a semifinite formulation for various incident angles and “cone optics”. Thomas and Guven [7] considered the effects of optical errors and the geometry on the circumferential flux distribution around the absorber tube. Jiang et al. [8] used the spectral beam splitting method to develop optical model for two-stage PTCs, which considered the optics cone and the absorber tube diameter for an incident angle of 0°. He et al. [9] calculated the flux distribution using the MCRT method with consideration of the optics cone, collector reflectivity and glass transmissivity to analyze the effects of the GC and rim angle. Cheng

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et al. [10,11] calculated the flux distribution for vertical incidence and ideal conditions using the MCRT method coupled with the Finite Volume Method (FVM) to simulate the temperature distribution in the absorber. Yang et al. [12] used the MCRT method to analyze the tracking errors of an ideal parabolic trough collector with a point source model and a uniform sunshape model when an incident angle is 0°. Khanna et al. [13] developed analytical expressions for both the circumferential and axial flux distributions on an absorber tube and gave expressions for the reflected rays for different incident angles with a point source. Huang and Han [14] gave general equations to calculate the standard deviation of the reflected ray error considering the slope error and simulated five kinds of solar concentrated reflectors. Xu et al. [15] considered the refractive surface error transfer process with an optical performance model of a solar trough system to analyze the effect of the reflective surface error for glass mirror and film mirror reflectors. Risi et al. [16] proposed an innovative solar Transparent Parabolic Through Collector (TPTC), and analyzed the optical properties of nanofluids by means of light scattering theory. Wang et al. [17] analyzed the effects of a glass cover on the flux distribution by the Monte Carlo Ray Tracing (MCRT) method. Mwesigye et al. [18] used the Monte Carlo ray-tracing method and a computational fluid dynamics model to numerically investigate the flux distribution and minimum entropy generation for rim angles of 40°–120° and concentration ratios of 57–143.

Thus, while many researchers have developed energy models for installations, with only a few models taking into considerations the effect of errors, all real systems have absorber tube installation errors and parabolic trough reflector tracking errors. The high accurate installation methods and tracking systems are very expensive and difficult. In the "12th Chinese 863 plan" from 2012 to 2016, a 1 MW parabolic trough plant was built at Yanqing in Beijing with the support of the Chinese government to evaluate parabolic trough solar thermal power systems in China. A simulation model of the 1 MW plant is being developed. The PTC model is an important part that can analyze the flux distribution including the effect of errors to determine the range of accurate errors, to evaluate the costs and to protect the PTCs in the 1 MW parabolic trough plant. The coordinate transformation method was used to develop the energy model with an optics cone with non-parallel rays, various incident angles, GCs, rim angles, glass tube transmissivity and reflectivity, absorber tube absorptance and reflector reflectivity. The model is used to analyze the effects of absorber tube installation errors and reflector tracking errors. The model accuracy is verified against reference data. Then, the flux distribution on the absorber tube is given as a function of the installation errors at the X and Y directions and the tracking errors to determine the reasonable error ranges to ensure the optical performance and intensity of the PTCs for reasonable installation and tracking control system costs.

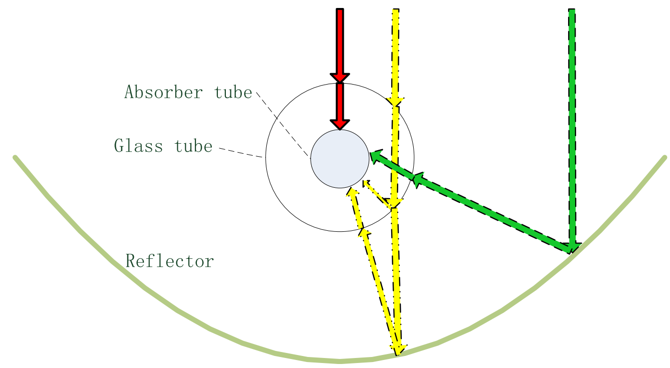

Fig. 2. Ray paths in the parabolic trough collector.

2. Simulation model

The traditional parabolic trough collector (PTC) system shown in Fig. 1 consists of the parabolic trough reflector and the receiver tube. There are three main ray paths in the PTC referred to as the absorber tube ray path, the evacuated space ray path and the reflector ray path, which are shown by the solid line, the dashed line and the dotted line in Fig. 2. The absorber tube ray path is the rays transmitted to the glass tube that directly hit the absorber tube

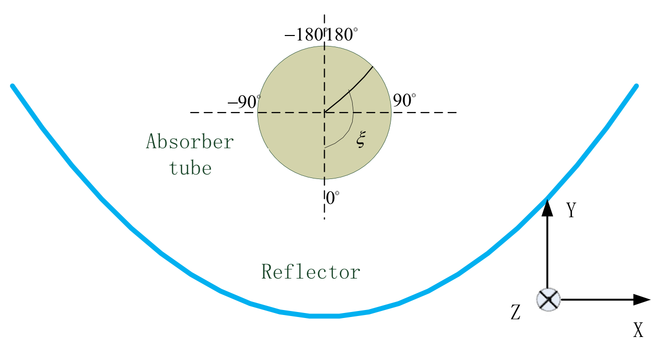

Fig. 3. Circular angle ξ on the absorber tube.

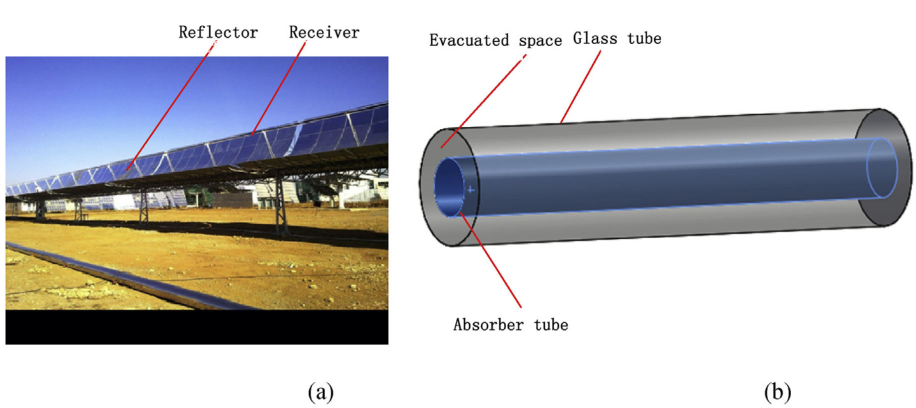

Fig. 1. (a) Experiment system at Yanqing in Beijing and (b) receiver tube.