ABSTRACT

Xu, Donghao. Ph.D., Purdue University, August 2015. Integrated Optical and Thermal Model of External Compound Parabolic Concentrator for Thermal Application in Medium Temperature Range. Major Professor: Ming Qu

Energy crisis and global warming has been driving people to use renewable energy as a substitute for fossil fuels. As one type of renewable energy systems, solar thermal system collects and transforms solar energy into thermal energy for various thermal applications. A crucial device in solar thermal systems is the solar collector. Currently, flat-plate collectors and tracking concentrators have been commercialized and widely used in low temperature and high temperature applications. But the medium temperature between 100 ℃ and 300 ℃ is barely covered by solar thermal systems despite numerous possible applications. And the two mature collectors are not suitable. Facing this problem, external compound parabolic concentrators (CPCs) stand out among existing solar collectors. CPC is a type of stationary non-imaging concentrators, which is cost-effective and can retain high efficiency at medium temperature range. However, it is not widely used in practice due to incompetent economic performance against conventional energy system.

In order to improve the performance of CPCs, this research aims to develop a comprehensive platform for optimal design based on an integrated optical and thermal model of CPC validated by experiment data. In order to reach this goal, the study includes four objectives as follows:

Objective 1: Conduct experiments to reveal the actual performance of CPCs at relatively high temperature in medium range and provide data for model validation. The test facility is located in Bowen Lab at Purdue University. To achieve comprehensive experimental data, CPCs were operated at various outdoor conditions and operation conditions that covered a wide range of incident angles, operating temperature, ambient temperature, beam radiation, diffuse radiation, and wind velocity, etc. The data points were collected at quasi-steady state for high accuracy.

Objective 2: Develop an integrated optical and thermal model of CPC. This integrated model consists of an optical model and a thermal model. The optical model is mainly based on a fast and accurate novel ray-tracing (NRT) engine together with profile generation program and sky model. The thermal model is a conjugate heat transfer (CHT) model that includes convection,

conduction and radiation heat transfers. Heat balance equations are built accordingly and solved for the temperature distribution. Integrating the optical and thermal models, solar flux calculated from the optical model is supplied to thermal model as heat source term. And both models are solved under the same weather conditions, operation conditions and CPC configurations.

Objective 3: Validate the integrated model by proven studies and experimental data. Since the integrated model involves many complex physical mechanisms, the model needs to be validated by verifying each step in the model. For the optical part, profile generation program, NRT engine and coating property calculation are validated individually. Once the optical model is verified, experimental data is used to validate the thermal model by comparing several measures of thermal performance.

Objective 4: Develop an optimization model and provide guidelines for the design of CPC. The optimization model is based on the validated integrated model. It searches for the optimal geometric configuration and installation of CPCs to maximize the energy output. Real location and weather information is incorporated in the optimization model. And the model investigates the optimal design of CPCs at various operating temperatures to provide design guidance in the full range of medium temperature.

This research would have significance for the development of CPC-based solar energy systems. The optimal design platform can be conveniently used to find out the best design of CPC to a specific temperature requirement at a specific location, which can serve as a powerful tool for designers. The underlying model can also be used to verify the optimal results and help designer to adjust the optimal design to their additional needs. In addition, the novel ray tracing algorithm and bin method to simplify the optimization can be extended to other fields that face the similar mathematical problems.