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Thermal performance of parabolic trough solar collectors

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ABSTRACT

The thermodynamics of a Parabolic Trough Solar Collector (PTC) play an important role in solar energy and the efficiency of the collectors. This report presents an up-to-date review on the thermal performance of PTC collectors. Various types of mathematical models, simulation and numerical methods, and experimental set-ups of the Parabolic Trough Solar Collectors are reviewed. These have been studied in terms of heat loss, environmental conditions, temperature and heat flux. Furthermore, the report cost analysis and economic strategy used for PTC collectors. The primary goal is to demonstrate the principal thermal aspects that need to be considered in future developments. The principal challenges that engineers face are (a) combining the thermal models that have been reported in the literature, (b) introducing numerical methods and simulations with less computational requirements, (c) proposing new methodologies that efficiently measure the thermal performance of a Parabolic Trough Solar Collector and (d) reducing the costs of these collectors.

Contents

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1. Introduction

Growing energy demands have led engineers and technicians to develop new prototypes for the use of renewable energy without degrading the environment. Over the past decade, solar power technology was seen as a future viable alternative. Currently, both photovoltaic (PV) and concentrating solar power (CSP) technologies are feasible commercial options to generate electrical energy and heat.

The innovative aspect of capturing and concentrating the energy of the sun in CSP technology is that it supplies the heat needed to produce electricity or a heat fluid; instead of using fossil fuels or nuclear reactions. Several significant contributions have been made in PTCs, to optimise the design and thermal performance of CSP technology. They are primarily focused on the physical aspects of the PTC collectors, which can be given as follows: (1) Optimisation of geometrical parameters in the collecting surface, receiver tube [1,2], thermal storage systems and tracking system [3]. Thus, the specifications, design and manufacturing of a PTC collector were described by [4–6]; and (2) Using new materials, such as ReflecTech in the collecting surface, reinforced fiberglass and Pyrex in the receiver [7], and nanofluids in the Heat Transfer Fluid (HTF) [8,9].

Other studies, such as [10–12], studied the thermal performance of the solar collector for power plants and industrial processes. These studies considered the mathematical models [13–15], simulations [16–18] and experimental set-ups of Parabolic Trough Collector systems [19,20]. Furthermore, researchers enhanced heat transfer by increasing the thermal conductivity of the HTF [21,22], varying the geometrical parameters (focal length [23,24], aperture of the solar collector [25–27], etc.) and proposing new control schemes and innovative strategies of instrumentation and experimentation [28–30].

Despite the efforts made in theoretical and experimental analysis, researchers are still attempting to determine the optimal design of the collector/receiver that increases the efficiency and reduces the costs of the system [31,32]. Therefore, this report offers an up-to-date review on the thermal performance of Parabolic Trough Solar Collectors (PTC). To present the aspects that need to be considered in future developments.

In this review, we focused on thermal mathematical models, simulation and numerical methods, and experimental set-ups of the collector/receiver of a Parabolic Trough Solar Collector; in terms of heat loss, ambient conditions, temperature and heat flux.

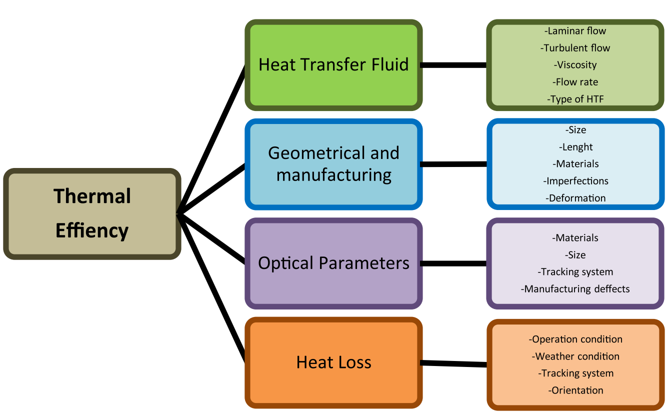

Fig. 1. Parameters that affect the thermal performance of a PTC.

The report is organised in the following manner. In Section 2, we describe and classify thermal mathematical models. An analysis of the effectiveness of the thermal models is included. In Section 3, we depict the simulation and numerical methods commonly used in the literature. In Section 4, we describe a few examples of the experimental set-up of PTC collectors. In Section 5, we show the key parameters considered in the cost analysis. Certain strategies used by the authors in this analysis are included. Lastly, Section 6 summarises the primary conclusions.

2. Thermal models for a PTC collector

This section provides information on various thermal models using in the analysis of a PTC collector. The goal is to explain the characteristics of each model and demonstrate their main mathematical expressions; because it helps in identifying physical parameters and processes that have an opportunity for improvement. Several research studies on thermal models focus on the solar collector/receiver and can be listed as follows: (1) Three heat transfer modes: conduction, convection and radiation; (2) Non-uniform thermal model; (3) Three-dimensional thermal model; (4) Statistical model; (5) Energy and exergy model; and (6) Dynamic model. These models are described in detail below.

These models depend on the geometric and optical parameters, mass flow of the heat transfer fluid (HTF), ambient conditions, etc. Fig. 1 depicts the different parameters that affect the thermal performance of a parabolic trough solar collector.

2.1. Heat transfer model

Heat transfer always occurs from a higher temperature object to lower temperature object. There are three heat transfer modes in a PTC collector: conduction, convection and radiation, which are based on the energy flow in and out of the collector/receiver, as indicated in Fig. 2. To simplify the complexity of the heat transfer model, several assumption are made: (1) The temperature and heat flux are uniform; (2) This model does not consider optical inaccuracies, such as shading, cleanliness of the mirrors; and

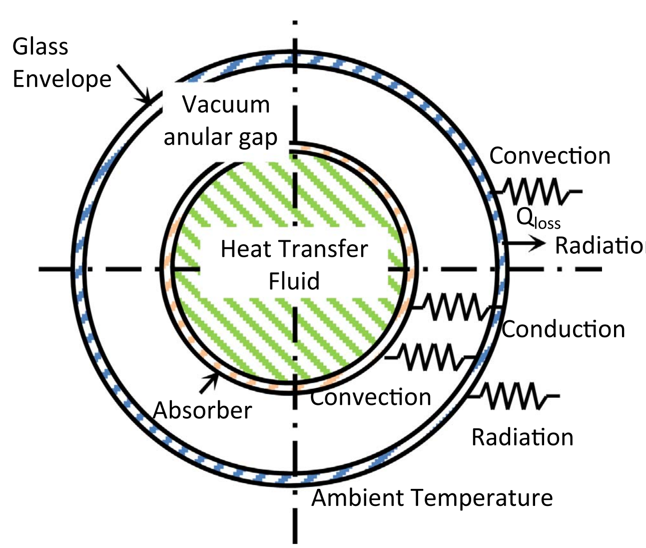

Fig. 2. Cross-sectional scheme of a PTC receiver for the Heat Transfer Model [49].