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Thermal Performance of a Heat Pipe Embedded Evacuated Tube Collector in a Compound Parabolic Concentrator

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Abstract

This paper presents the design, development and performance evaluation of a compound parabolic concentrator for medium temperature application. In the present study Compound Parabolic Concentrator (CPC) has been used as a non-imaging solar concentrator. A single piece of evacuated tube heat pipe solar collector has been used to collect the solar radiation which is concentrated by the CPC. The condenser of the heat pipe has been directly inserted into the storage tank. The performance of the system has been evaluated for different tilt angles. Different performance parameters such as system thermal efficiency and standard power have also been evaluated in this paper.

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Keywords: Evacuated tube heat pipe solar collector; Compound Parabolic Concentrator; System thermal efficiency; Standard Power

1. Introduction

Solar thermal energy systems are considered as the most economical choice among all renewable energy systems. Different types of solar collector are used depending upon the level of temperature application. Flat Plate Collectors are used for low temperature applications. To attend medium temperature applications, i.e. applications in the temperature range between 100˚C -250˚C, it has become imperative to concentrate the solar radiation. Various methods are available for concentrating the solar radiation like compound parabolic concentrator, parabolic trough concentrator, fixed reflector-moving receiver, fixed receiver-moving reflector, Fresnel lens and central receiver etc [1].

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In our present study we have restricted our study to concentrating the solar radiation utilizing compound parabolic concentrators. These non-imaging concentrators have the capability of reflecting to the receiver the entire radiation incident on the aperture over ranges of incident angles within the acceptance angle of the concentrators. Compound Parabolic Concentrators are special types of solar collector fabricated in the shape of two meeting parabolas. It is considered among the collectors having the highest possible concentrating ratio. It belongs to the non-imaging family. As it has large aperture area, only intermittent tracking is required [2].

In addition, the evacuated tube-heat pipe mechanism is adopted for transferring the useful heat at a higher efficiency. In such evacuated tube systems, losses are significantly reduced due to vacuum enclose. Both diffuse as well as beam component of solar radiation are converted to useful heat [3].

The heat pipe integrated into the evacuated tube collector systems result in a very quick response provide higher level of attainable temperature. Compound Parabolic Concentrators (CPC) are used in such kinds of applications where medium temperatures at around 1000C are required. Thus, a system combining a compound parabolic collector with an evacuated tube heat pipe is proposed for concentrating and collecting solar radiation. This in turn will attend higher degrees of temperature. The collected heat energy at medium temperature can be utilized for various applications. In the present study, the collected heat has been utilized for boiling a given quantity of water to evaluate the performance of the solar water heating systems for medium temperature application.

Nomenclature

C_c	Specific heat of the material of sterilizing container (J/ kg-K)
C_w	Specific heat of water (J/ kg-K)
M_C	Mass of container, kg
M_w	Mass of water kept during the test, kg
t	Duration of the interval, s
A_a	Aperture area of the CPC
I	Average solar radiation during the interval, W/m^2
T_f	Water final temperature, °C
T_i	Water initial temperature, °C
T_w	Water temperature, °C
T_a	Average ambient temperature during the interval, °C
ΔT	Temperature difference, °C
A_c	Total surface area of the container, m^2
τ_o	Time constant, minute
F_{UL}	Heat loss factor, W/(m^{2}K)
η	Efficiency

2. Methodology

2.1. Experimental set up

Ideal CPC was designed in AutoCAD as shown in Fig. 1. Three structures were created using mild steel bars which were used as two end supports and middle support. These three supports were integrated into a single structure by four steel bars. A thin fiber sheet was screwed on the inner surface of the CPC structure. Before screwing, an aluminum tape was pasted on the top of the fiber sheet. Stand 2 had three cross arms to hold the CPC at three different angles. It also had three hole-pairs at three different heights to hold the container holder. The storage tank was made of galvanized iron sheet. A small hole was created at the side surface of the container such that the heat pipe condenser could easily be inserted into the container. The heat pipe was connected to storage tank using high temperature silicon sealant. Extruded polystyrene sheet (XPS) and asbestos tape were used as thermal insulation. In the present work two pyranometers were used to measure the global radiation. One pyranometer was