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Research Paper

Study of heat transfer through a cavity receiver for a solar powered advanced Stirling engine generator

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ABSTRACT

Stirling engine operated by concentrated solar energy can be a great mean to generate power. Highly concentrated solar radiations with minimum heat loss from cavity receiver are required to operate the Stirling engine. Therefore, heat transfer study of the cavity receiver is required for the maximum utilization of solar energy with minimum heat losses for the efficient Stirling engine generator. In this study, experiments were performed to find the most suitable cavity receiver configuration for maximum solar radiation utilizations by an Advanced Stirling Engine Generator (ADSEG). Dimensionless parameter: aperture ration ($AR = d/D$) and aperture position ($AP = H/D$) were used to characterize the different configurations of cylindrical cavity receiver. Experimental heat loss analysis (Convection, radiation and total heat loss) as well as air film temperature profiles along the wall height (H) of the receiver for different configurations of the cavity receiver was performed in this experiment for its selection. Based on experimental results, among the four different configurations of cylindrical cavity receiver, Type IV ($AR = 0.5$ $AP = 0.53$) was found to be the most suitable receiver for the ADSEG system.

1. Introduction

Energy and environment is an important issue now in the current world. The main reason behind the global warming is the CO_2 emission. New environment friendly and affordable power systems have become very important and thus, they are needed to be installed urgently [1]. Solar Power Generation is a useful approach to achieve this task. Since the sun is the most abundant source of power, thus the regions with high insolation (more than 500 W/m^2) have an advantageous option in implementing environment compatible solar power plants [2]. Particularly in Mediterranean countries including South Europe, Middle East and North Africa (MENA Region) are highly suitable for large scale industrial exploitation of solar power [3].

In the concentrated solar powered generator system, solar radiations are focused on the heater head of the engine at very high temperature, convective, radiative and conductive heat losses are usually occurred from the heated surface. So, minimization of heat losses is very important to effectively utilize the solar energy in order to generate a highly efficient solar powered Stirling generator system. To minimize the heat loss from the concentrated light, cavity receivers are preferred for concentrated solar power system i.e. dish/Fresnel lens-Stirling engine system. The main idea of the cavity receiver is to uniformly distribution of the high flux over the large surface of the cavity in order to minimize the peak flux absorbed at any one point [4].

The literature shows that numerous work has been conducted to develop the semi empirical model for heat loss analysis [5]. Different types of cavities are used for heat loss analysis and a number of correlations are developed. However all those correlations are based on a specific geometry and shape and hence lacking the universal applicability for heat loss analysis of the cavities. The convection heat loss occurs at the open cavity. The density of the air is a function of temperature and pressure. Air enters from the aperture opening to the cavity and gets heated from the hot absorber surface and due to density gradient light air flows out from the cavity receiver resulting convective heat losses [6,7].

Aperture size and its direction tend to exhibit a completely different streaming function of the air entering into the cavity. The prediction of heat loss is possible by analyzing the complete stream line function of the air at different tilt of the cavity ($-90°$ to $90°$). $-90°$ is defined as the angle between normal direction of the aperture plane and the horizontal line. For receiver facing upward is $-90°$ and $90°$ tilt for the receiver surface facing downward. The minimum heat loss occurs when the receiver is facing

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upward vertical or downward vertical and maximum heat loss occurs when the receiver is at horizontal position (0°). This is because when the receiver tilt is ±90°, the cavity is almost dominated by a stagnant region which causes a very low convection heat loss out of the cavity receiver. At this stage, hot air will rise up because of density variations making almost same temperature of the air inside the cavity and the walls of the cavity thus resulting very low temperature gradient. But as the tilt decrease from ±90° to 0°, the convective zone started to dominate and extent of stagnant zone gets weaker and weaker, resulting high heat losses. Radiation losses are significant and occur when the receiver operates at high temperature. Conduction losses occur from the wall of heating chamber and can be minimized by effective insulation implementation. This is a really complex task to find the convective heat loss from the chamber.

The present system of solar power generation by Stirling engine operates with a Fresnel lens which focuses the light to the receiver in the heating chamber. The opening of the chamber is called aperture. The aperture dimension and its positions are very important. The convective heat loss can be minimized by reducing the aperture opening to a minimum. Since measuring the heat loss from the aperture is complex phenomena, many experiment and numerical work have been performed to reduce and to find the exact phenomenon of convective heat loss and many correlations have been developed for different kinds of cavities.

There are basically two kinds of receiver which are used for concentrated power systems. Horizontal to vertical downward is used for the Dish/Stirling System and Vertical upward to horizontal Fresnel Lens/Stirling Engine system and solar trough system. Numerous researches are conducted for the heat loss analysis of first type of cavity receivers but for the upward facing cavity receivers a detailed knowledge for heat loss analysis is still required. In this experiment we have done detailed experimental heat loss analysis to find a suitable cavity receiver for our ADSEG system (see Fig. 1).

2. Experimental apparatus

The conventional heater head (Fig. 2) of the Stirling engine has a major drawback of non-uniform heating of the working gas, while sodium Heat pipe (HP) have some appealing characteristics. So, in our experiment conventional heater head was covered by a sodium HP as shown in Fig. 3. Fig. 4 shows the schematic of the Solar heating techniques of the heater head: conventional direct heating and HP using the cavity receiver. The geometry of the cavity receiver

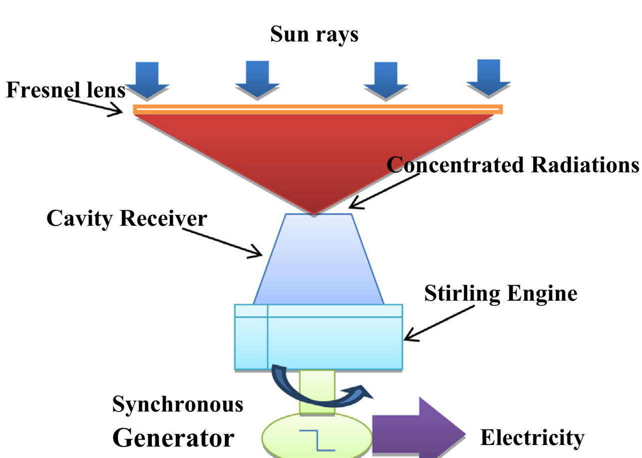

Fig. 1. Schematic of the working principle of 1 kW solar thermal power plant with its components.

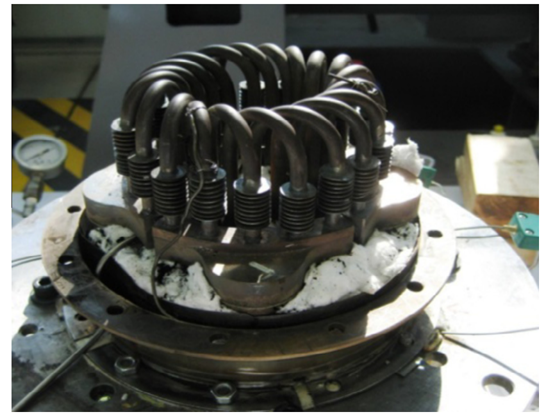

Fig. 2. Conventional direct heating receivers.

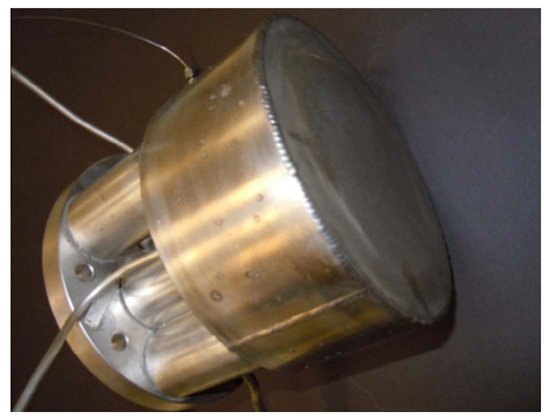

Fig. 3. Heater head covered with heat pipe.

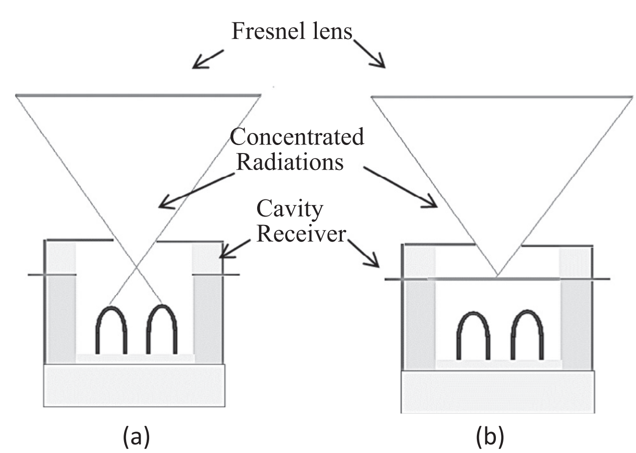

Fig. 4. Solar heating techniques of the heater head. (a) Direct. (b) Using the HP.

always has an opening called aperture (Fig. 5). The aperture allows the concentrated radiation to focus on the absorber surface. The spot focus increases the temperature of the absorber surface to very high Since the aperture has opening and air can flow into or out from the chamber. This free movement of the wind can have considerable effect on the conventional heat loss for the cavity receiver operating with Fresnel Lens/Stirling Engine. The total heat loss is therefore a combined effect of wind speed, its direction, aperture size, aperture position, and tilt angle. The present work considers only the vertical direction (−90°) cavity receiver. In this study for the heat loss analysis two dimensionless parameters