Thermal Performance of a Billboard External Receiver

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The receiver serves as a critical component in tower-type concentrated solar power plants. The current entry experimentally evaluated the thermal efficiency of bill-board shaped receiver to be employed in concentrated solar power plants.

Keywords: solar power ; external receiver ; heat losses ; thermal efficiency

1. Introduction

The solar receivers serve as the fundamental component in tower-type Concentrated Solar Power (CSP) plants. Their function is to absorb solar heat flux reflecting from a heliostat field and transfer the absorbed heat to the Heat Transfer Fluid (HTF). The solar receiver plays a crucial role in CSP plants that affects the power plants' efficiency. Based on their geometric shapes, the solar receivers are categorized into two types, i.e., (1) cavity receivers, (2) external receivers. Both shapes have been utilized in the actual power plants, although the research on the cavity receivers is more extensive than on the external receivers.

At first, a large-sized cubical-shaped cavity receiver was analytically modelled by Sandia laboratories [1], using heat transfer coefficients (HTC) for heat transmission within the receiver by employing the standardized semi-empirical formulations as well as the heat transferred through air flowing out of the aperture. The results were later verified against experiments [2]. Similarly, Koenig & Marvin [3] investigated a heat loss model at very high temperatures up to 550–900 °C for the cavity receiver surface and put forward an empirical correlation. Le Quere et al. [4] performed numerical formulations and carried out experiments to evaluate natural convection losses on a cubical-shaped cavity receiver having isothermal side panels. Their results depict that the convective losses are highly influenced by the inclination. James & Terry [5] examined five geometries of the cavity receivers including cylinder, sphere, elliptical, conical & hetero-conical to gauge the thermal performance of the receivers. They attained significant trends on the power profile of the receiver as well as the rim angle disparity of the concentrator, without any substantial effect on the receiver's performance.

During a series of experiments, Kraabel [6] found natural convection losses by electrically heating the cavity receiver to achieve the desired temperature. In subsequent studies [7], radiant losses were also evaluated directly, and correlations were presented as a function of average Nusselt number dependent on Grashoff number and other geometric parameters of the cavity receivers including receiver's length and height. McMordie et al. [8] also performed an experiment on the cavity receiver and evaluated heat losses via radiation, conduction, and (natural and forced) convection losses. The ensuing results were then validated against correlations proposed by Siebers and Kraabel [6].

The experiments were later extended by Stine & Mc Donald [9] and results were validated by employing the correlations earlier proposed by Clausing [1] for an upward-facing cavity receiver. Based on combined convective and radiation heat losses, Balaji and Venkateshan [10] examined the natural convection losses along with the radiation losses for an open square-shaped cavity receiver. They found out that radiation losses are responsible for higher losses. Behnia et al. [11] investigated the rectangular-shaped cavity receiver to study combined radiation and natural convection entrapped with non-participating fluid.

A different receiver shape by adding a cone-shaped opening onto the aperture was investigated by Hahm et al. [12]. A single cavity receiver without the cone-concentrator was also analyzed to draw a comparison. They observed an optimal cone concentrator could increase the number of rays transmitted by 97%. The results were also theoretically verified. Ramesh and Venkateshan [13] experimented with an air-filled cubical cavity using a differential interferometer to examine the free convection heat transfer as well as the surface. They verified that losses through free convection diminished due to surface radiation.

A series of investigations were carried out using numerical simulations using the Computational Fluid Dynamics (CFD) Paitoonsurikarn et al. [14] examined the combined free-forced convection losses for three different shapes of open cavity receivers. They proposed a correlation based on the Nusselt number for natural convective losses. Later [15], they numerically examined the combined free-forced convection losses at various tilt angles for a cavity receiver. In a subsequent study, Paitoonsurikarn and Lovegrove [16] investigated wind-induced losses on a dish structure open receiver. They reported a complex airflow over the dish surface. However, the results cannot be generalized. Later, researchers [17] put forward a correlation for the free-stream wind for the wind flowing parallel to the aperture of the cavity at different wind directions. The use of secondary receivers on multiple aperture cavity receivers also resulted in increased thermal efficiency of the cavity receiver [18]. They increased the number of apertures up to six with an individual heliostat field for every aperture. This also resulted in lowering the capital investment needed for power plant setup. In another study [19], they extended the research into 3D and compared the result for natural convection losses. A Nusselt number correlation was also developed to evaluate the losses.

It can be observed that researchers mostly focused on cavity receivers. However, with rapid growth in CSP technology [20] and due to their easy integration with thermal energy systems all the large-scale plants have employed external receivers [21] but only a few researchers have focused on external receivers. Whereas, the experimental work on external receivers is even scarce. Rodriguez et al. [22] put forward the thermal design guidelines for the external receiver. In subsequent research, Rodriguez et al. [23], analyzed the potential for energy recovery for two different solar power systems with external cylindrical receivers. Later they analyzed different flow patterns, [24] and evaluated the global efficiency. Qaisrani et al. [25][26] performed CFD simulations and numerically evaluated the thermal efficiency of various external receiver designs. Similarly, Du et al. [27] evaluated the thermal efficiency of a flat plate receiver through experiments.

2. Thermal Efficiency of the Receiver

The absorbed energy was measured indirectly as there is some difference between the heat flux obtained onto the testing system and the external receiver. The receiver pipes were made up of steel, and there exists a significant portion of light rays' deflection because of reflectivity. The steam being generated was measured through the mass flow rate and the difference in the temperature at the inlet and the outlet of cold water of the condenser. Specific heat at ambient conditions of the cold water in the condenser was kept constant to measure the energy of the cold water. The quantity of generated steam in the receiver depicts the energy gained. This energy was divided by the heat energy absorbed at the surface of the receiver to evaluate the thermal efficiency of the external receiver.

3. Conclusions

The cold start-up and the performance of the external receiver at a steady-state were investigated under a pressure of 0.5 MPa. The fans attached at the back of the xenon lamps were responsible for the forced convective losses. The heat absorbed by the receiver and transferred to the water converts it to steam. The steam was then weighed to evaluate the thermal efficiency of the receiver. To extend the research by exploring the effect of wind in various directions is recommended. Similarly, the research should be extended to other receiver shapes with different arrangements of the heliostats/lamps to have a more realistic condition of the heat flux as in the real scenario.

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