Experimental study on heat losses from external type receiver of a solar parabolic dish collector

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Abstract. Solar parabolic dish systems find applications in steam generation for cooking, laundry process industries etc. Receiver is an important component of a solar parabolic dish collector system. Since the concentration ratios are very high for these kind of systems, high temperatures are present in the receiver, which increases the possibility of large amount of thermal losses. Heat losses from receiver can greatly reduce the efficiency of the collector system. Efficient design is required to minimise losses and improve conversion efficiency. This paper aims to present an experimental investigation of heat losses from circular receiver, external type of a 16m² solar parabolic dish concentrator system. Receiver geometry is of a short cylinder type. Convection and radiation losses from the receiver are studied experimentally. Results show that the receiver surface with high temperature of 150 °C is exposed to ambient leading to average thermal loss of 260 Watts. Results of this experimental investigation emphasize the need for efficient receiver design to reduce heat losses.

Keywords: Solar parabolic dish system, Heat loss, receiver

1. Introduction

Concentrated Solar Power (CSP) systems are high temperature collector systems which operate on the principle of concentrating the incident solar irradiation into small enclosures via reflectors. Conventional CSP systems consist of four different configurations such as parabolic trough, central receiver, linear Fresnel lens and parabolic dish. Solar parabolic dish systems are considered to be most efficient over other solar thermal technologies such as parabolic trough, central receiver and linear Fresnel lens. As such, they can achieve very high light concentration ratios, reaching up to 1000 sun. At temperatures exceeding 1500°C, they can produce steam/ power efficiently by utilizing high energy conversion cycles. Since operating temperatures of the receivers/absorbers are high, minimization of thermal losses are of great concern to the researchers.
Solar parabolic dish system consists of a parabolic dish with an array of mirrors and a receiver/absorber located at the focal point of the dish. The solar radiation incident on the dish is reflected towards the focal point of the dish. Maximum concentration ratio of 45000 can be achieved by parabolic dish concentrating systems [2]. Temperature of receiver can be achieved in the range of 550-750°C.

Thermal receiver is a vital component of solar parabolic dish concentrating system. Thermal losses from the receiver greatly affect the thermal performance of the system. Thus it becomes significant to analyse the thermal losses from the receiver to improve the performance of the system. Thermal losses occurs in all the three modes. Radiative heat loss is the result of collector surface reflection and emission. Convective heat loss is due to the wind as well as natural convection. Conduction losses are very less compared to convection and radiation losses as all the surfaces are well insulated except the one which is exposed to the incoming radiation. Literature survey shows that most of the research works have been focussed on studying the convection and radiation losses from cavity type receivers of different geometries.

Kaushika and Reddy (2000) experimentally studied cavity, semi-cavity and modified cavity receivers of spherical geometry. Siyoul Ryu and Taebeam Seo (2000) experimentally analysed heat losses from conical receiver and dome receiver. Taumoefolau and Lovegrove (2002) experimentally investigated natural convection heat losses from cylindrical receiver. Paitoonsurikarn and Lovegrove (2002) numerically investigated natural convection heat losses from three different cavity receivers.

Paitoonsurikarn and Lovegrove (2003) numerically studied natural and combined convection heat loss from cavity receivers. Taebeam Seo et al., (2003) numerically studied the heat losses from conical and dome shaped receivers of solar parabolic dish system. Taumoefolau et al., (2004) carried out parametric study of several relevant parameters in natural convection heat loss. Paitoonsurikarn and Lovegrove (2006) numerically studied and presented an improved version of natural convection correlation. Numerical investigations on modified cavity receiver of spherical geometry was carried out by Sendhil Kumar and Reddy (2008), Reddy and Sendhil Kumar (2009).

Prakash et al., (2009) made experimental and numerical study of convection heat losses from cylindrical cavity receiver. Xie et al., (2011) carried out numerical and experimental analysis of a point focus solar collector using Fresnel lens. Xie et al., (2012) theoretically and experimentally studied collector efficiency factor and heat removal factor of solar collectors using Fresnel lens with cavity receivers of eight different geometries. Thirunavukkarasu et al., (2017) developed and tested a conical cavity receiver for scheffler type parabolic dish concentrator and reported that the system works better at higher flow rates. The overall heat loss factor is low for higher flow rates.

Though extensive research work has been carried out on the analysis of thermal losses from cavity receivers, research on external type receivers which are simple and cheaper than cavity receivers have not been reported. Analysis of thermal losses from a circular receiver of external type is presented in this paper. Heat losses through the receiver walls by conduction mode are neglected because the receiver is thermally insulated on all sides except the aperture.

2. Experimental set-up
The Scheffler type reflector system with multi-faceted mirrors has a total reflective area of 16 m² and reflectivity of 90%. Concentrator has a two-axis tracking mechanism. Circular absorber has an aperture of 406 mm diameter, which is of short cylinder type with circular cross section.

The thickness of the absorber is 150 mm, of hollow internal section through which the heat transfer fluid (HTF) flows. Glass wool insulation is provided on all sides of the absorber, except the front surface to prevent thermal losses. The aperture area of the absorber is 0.1294 m². The receiver which is made up of high grade mild steel has absorptivity and emissivity of 0.7 and 0.2 respectively.

HTF used in the study is water. Water is stored in a storage tank of a capacity of 100 litres, which is well insulated. Water is circulated from the tank to the solar absorber with the help of a centrifugal pump. Flow of water is controlled by flow control valve and measured using rotameter. Pressure of water has been measured using pressure gauge. Flow control valve, rotameter and pressure gauge are fixed in the piping system. Experimental study has been carried out for a mass flow rate of 0.025 kg/sec. The temperature of absorber has been measured using infrared thermometer. Global solar radiation was measured using pyranometer, diffuse radiation was measured using pyranometer with shading ring. Wind speed was measured using cup type anemometer.

3. Estimation of thermal losses

3.1 Estimation of convection losses

Convection losses occurs from the absorber surface directly exposed to the moving stream of air in contact with it. Nusselt number for convection for a flat plate is determined by [2]

\[ Nu = 0.664 \cdot [Re_D]^{0.5} [Pr]^{0.333} \]  
\[ Re_D = \frac{V \cdot D}{v} \]

where \( Nu \) is the Nusselt number, \( Re \) is the Reynolds number and \( Pr \) is the Prandtl number.
V is the velocity of air over the receiver surface, D is the diameter of receiver and $\nu$ is the kinematic viscosity of the air at mean film temperature.

Convective heat loss coefficient is determined by [4]

$$h_{\text{conv}} = \frac{Nu \cdot K_{\text{air}}}{D}$$  \hspace{1cm} (3)

where $K_{\text{air}}$ is the thermal conductivity of air at mean film temperature.

Total convective heat loss from receiver is calculated by [2]

$$Q_{\text{conv}} = A_r \cdot h_{\text{conv}} \cdot (T_{\text{wall}} - T_{\text{amb}})$$ \hspace{1cm} (4)

where $A_r$ is the receiver surface area exposed to ambient, $T_{\text{wall}}$ is the absorber surface temperature and $T_{\text{amb}}$ is the ambient temperature.

3.2 Estimation of radiation losses

Thermal losses due to radiation is determined by

$$Q_{\text{rad}} = \varepsilon \cdot \sigma \cdot A_r \cdot (T_{\text{wall}}^4 - T_{\text{amb}}^4)$$ \hspace{1cm} (5)

where, $T_{\text{wall}}$ and $T_{\text{amb}}$ are considered in K and $\sigma$ is Stefan Boltzmann constant and $\varepsilon$ is emissivity of the absorber material.

4. Results and discussion

Convection losses, radiative losses from the circular absorber were determined by conducting experimental tests for the whole day in the month of February. The variation of global radiation, diffuse radiation and beam radiation for the full day is given in the figure (2). For the concentrated solar collector, only beam radiation is considered for calculation, as diffuse radiation cannot be
concentrated.

![Graph](image)

**Figure 2.** Variation of intensity of radiation with time

The beam radiation rises gradually from morning to noon and then decreases. Figure (3) gives the variation of absorber surface temperature and ambient temperature with time. It shows that a maximum temperature of 197 °C was observed in the surface of the circular absorber. Ambient temperature ranged from 32 °C to 39 °C. Solar beam radiation was observed to be a maximum of 717 W/m². The rise in absorber temperature showed a similar trend to that of beam radiation which shows its direct influence. The variation of wind speed with time is plotted in figure (4). Wind speeds leads to forced convection heat losses. Wind speed was observed in the range of 0.1 – 3.5 m/sec.

![Graph](image)

**Figure 3.** Variation of absorber surface temperature and ambient temperature with time
From Fig. 5, it can be inferred that the convection losses from the circular absorber was found to be in the range of 140 W to 200 W. Radiation losses from the circular receiver was observed in the range of 85 W to 110 W. Convection losses are higher when compared to radiation loss. Radiation loss depends on the absorber surface temperature and radiative characteristics like emissivity and absorptivity of the receiver material. Hence modifying the radiative characteristics of the receiver surface is a promising option to reduce radiation loss. Convection losses depends on the absorber surface temperature, area of the absorber and wind speed. To reduce the effect of wind speed, a wind skirt can be provided to the absorber. To reduce the absorber temperature, cavity receiver is a better option.

5. Conclusions

An experimental study of thermal losses from the circular absorber of a solar parabolic dish concentrator system has been conducted under Chennai climatic conditions. The findings of the experimental study are listed as under.
1. Surface temperature of the absorber which is exposed to ambient plays a crucial role in determining the convection and radiation losses from the absorber. In this study, under an average beam solar radiation of 400 W/m², the surface temperature of the absorber went up to 197 °C, resulting in an overall thermal loss of 6.71 MJ for the whole day.

2. External type circular absorbers are simple and cheap to manufacture, thus conventionally used by solar parabolic dish cooking system manufacturers. But the experimental study shows that the geometry of the absorber invites for high thermal losses resulting in decrease in overall thermal efficiency of the system.

3. Cavity type receiver with helical tubes can seem to be a better option to reduce the heat losses, which has to be experimentally studied further.

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