EXPERIMENTAL STUDY ON A CASCADED PCM STORAGE RECEIVER FOR PARABOLIC DISH COLLECTOR

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ABSTRACT

A flat surfaced solar receiver with integrated phase change material (PCM) in a cascaded manner is investigated to act as the short-term heat storage. The objective of this work is to store the heat energy effectively at the focal point using different melting point PCM. Three PCM dish receivers are attached in a series. The Scheffler reflector of 16 m² aperture area is used to concentrate the incident solar rays on the cascaded PCM receiver. The selected PCM are Xylitol, Erythritol and Galactitol having melting points of 94°C, 118°C and 166°C respectively. The solar receiver is heated to a temperature of 250°C. The heat stored is determined based on the temperature measurements. The total heat stored in the solar receiver with PCM depends on the temperature of individual PCM and the thermal properties. The receiver material stores 30% of the heat and the PCM stores the remaining 70% of the incident energy on the receiver. Such cascaded PCM solar receiver is useful to store the heat at the focus of the dish reflector for the remote applications.

Keywords: Parabolic dish, Solar receiver, Phase change material, Thermal energy storage, Flat surface receiver.

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1. INTRODUCTION

Solar energy is one of the renewable energy options to be used for the power and thermal applications in every potential country to reduce the effects of fossil fuel usage like climate change and global warming. Solar thermal collectors are conveniently used for the low to high temperature applications. Concentrated solar collectors are operating at the elevated temperatures and are prone to convective and radiation heat losses. The phase change material (PCM) are successfully utilized in the thermal energy storage systems of concentrated solar energy collectors for the past few decades [1-3]. Several researchers have been investigated the new methods and materials for thermal energy storage in a small to large scale systems. The potential applications of solar energy are ranges from domestic to industrial process.
heating and power generation also. Yilbas and Kaleem [4] investigated the effect of selective surfaces for the high temperature solar receivers. The void in the PCM storage is resulted in the increased melting time of PCM in a volumetric solar absorption system [5].

The effect of recirculated fluid flow through solar receiver and effect of incorporation of PCM in the receiver were reported with thermal enhancement of the solar receiver by Senthil and Cheralathan [6-8]. An improvement of energy and exergy performance of the solar receiver are reported as 9% and 10% respectively. The heat transfer enhancement methods in PCM and the effect of nanofluid on direct heat absorption using the parabolic dish collector (PDC) are discussed by Senthil and Cheralathan [9, 10]. Anwar et al. [11] investigated the volumetric solar receiver to act as a solar thermal battery numerically with PCM. Thermal performance study of solar collectors using energy and exergy aspect is studied by Mawire and Taole [12]. The concentrated solar receivers have non-uniform temperature distribution in the receiver and the use of PCM in the receiver produces the receiver to the uniform temperature [13]. Vinod et al. [14] determined the convection heat losses from the spherical cavity receiver. The influence of fluid inlet temperature and flow rate has been studied by Senthil et al. [15]. Different high temperature solar dish collectors - receivers and the effect of PCM on thermal management of solar receivers and buildings are discussed [16-21].

The effective use of PCM in solar thermal applications are discussed in the literature. In this work, flat surface solar receivers are preferred for the simplicity of construction, surface coating feasibility and an ease of maintenance. The charging of PCM integrated solar receiver is investigated at the focus of the PDC at outdoor experiments. Three melting point PCM are arranged in a cascaded manner to reduce the entropy losses to the surroundings instead of the single PCM. The energy stored based on the operating temperature of the receiver material and PCM are reported.

2. EXPERIMENTAL WORK

A parabolic dish collector (PDC) is used as the reflector (Made by Thermax Ltd, India). Dish reflector of $16 \, \text{m}^2$ surface area is used to concentrate the incident beam solar radiation on the black coated receiver surface. The solar receiver has the 406-mm diameter incident surface. The solar receiver is made up of mild steel with a wall thickness of 5 mm. The attached mild steel fins (2 mm thick) on each section are used to transfer the to the PCM. There are three short cylindrical enclosures with PCM are used in a series attachment. The receiver sections are having the same aperture area. However, the depth of the sections are 30 mm, 25 mm and 20 mm respectively from the front surface to the rear surface of the receiver section. The fin heights in each section from the incident surface are 30 mm, 25 mm and 18 mm respectively. Figure 1 shows the construction of the solar receiver. One section of the receiver is shown and other two are identical. The constructed solar receiver is kept at a focal distance of 2.7 m from the PDC.
The depth of the receiver is varying to melt the PCM effectively due to the axially decreasing temperature gradient. The selected PCM are Xylitol, Erythritol and Galactitol. The melting point are 94°C, 118°C and 166°C respectively. The enthalpy values of melting are 263 kJ/kg, 340 kJ/kg and 530 kJ/kg respectively. The high melting point PCM (Galactitol) is placed in the first section, the medium temperature PCM (Erythritol) is kept at the middle and the lower melting point PCM (Xylitol) is kept in the third section. This series arrangement of PCM cylinder is aimed to avoid the storage of heat at a single PCM with a higher temperature. The depth of the solar receiver is 95 mm including the wall thickness and three receiver sections. A glass wool insulation of 60 mm thickness is covered over the receiver. Aluminum sheet enclosure is used on the outer surface of the insulation. Figure 2 shows the schematic layout of the parabolic dish collector.

![Figure 2](a) Schematic layout of the Parabolic dish reflector and solar receiver.

The PCM selected are three sugar alcohols for their higher enthalpy values. The total mass of PCM is 10.5 kg (Galactitol 4.5 kg, erythritol 3.5 kg and Xylitol 2.5 kg). The solar radiation, wind speed and ambient temperature are observed using pyranometer, anemometer and K-type thermocouples respectively at the site.

Heat stored in the receiver material is given by

\[ Q_u = m C_p (T_f - T_i) \]  

Where \( Q_u \) - heat gain, \( m \) – mass of the receiver material, \( T_f \) – final temperature, \( T_i \) – initial temperature and \( C_p \) - Specific heat of the receiver material.

The heat stored in the PCM is expressed as:

\[ Q_u = m_{pcm} \int_{T_i}^{T_f} C_p dT + H + \int_{T_a}^{T_f} C_{pl} dT \]  

Where, \( C_p \) - the specific heat, \( dT \) - temperature range and \( H \) - latent heat.
The error analysis is carried out using the square mean values of individual measurement uncertainty and the thermal performance is observed with the error of less than five percent. This is within the acceptable limit.

3. RESULTS AND DISCUSSION

The outdoor experiments are carried out on sunny days in Chennai, India to study the thermal performance of cascaded PCM solar receiver. The heating of PCM to a different temperature is used to determine the energy stored by the PCM in the receiver. The solar radiation, PCM temperature, wind speed, ambient temperature and sky temperature are measured at the site. The temperature of PCM depends upon the beam solar radiation. The beam radiation component obeys the optical law and reflected by the parabolic dish reflector. The variation of wind speed and ambient temperature during the trials are found to be similar. K-type thermocouples are used to measure the temperature inside the PCM. The average temperature is considered.

Figures 2 - 4 show the operating conditions of the charging process of PCM integrated solar receivers for three experimental trials. The PCM temperatures tested in this work is up to 250°C. The experiment is started at 10:00 AM that PCM temperature increased with solar radiation in 90 minutes to 250°C. All the charging experiments are conducted with similar radiation conditions and clock hours. The PCM solar receiver is tested consecutively for five days to ensure the operating and thermal performance of the flat surface receiver. The temperature trend of the experiments is used to conform the reliability of the results. Hence, the charging time mainly depends upon the solar radiation. When radiation level is maximum the time required by the receiver for charging is minimum.
Figure 3 Solar radiation and the PCM temperature rise over the test period (Trial-2).

Figure 4 Solar radiation and the PCM temperature rise over the test period (Trial-3).

Figure 5 indicates the sensible and latent heat stored in the receiver in terms of receiver materials and PCM. Dominant heat losses from the solar receiver. Around 30% of the heat stored in the receiver; whereas, the remaining 70% of the heat energy is stored in the PCM alone through sensible and latent heat. The increase in heat losses is mainly due to the increased average surface temperature of the receiver.
Figure 5 Sensible and latent heat stored in the receiver and PCM at the average receiver temperature of 220°C.

Figure 6 Heat stored in the receiver at various operating temperatures.

Figure 6 shows the quantity of heat stored based on the average receiver temperatures. The increase in temperature increases the energy stored by the receiver. Around 7 to 10 MJ of energy is stored in the receiver for an average receiver temperature range of 140°C to 220°C. At maximum temperature, the amount of energy stored by the receiver is maximum due to the sensible heat of receiver and latent heat of PCM. The total heat stored in the solar receiver is the sum of the heat stored in the PCM and the receiver material. The sugar alcohols are having better thermal stability when operating below 300°C.
4. CONCLUSIONS
A flat surface receiver with sugar alcohols as selective PCM in the cascaded manner is investigated at outdoor operating conditions. Thin rectangular fins are used to increase the heat transfer from the receiver inner surface to the PCM. The heat energy stored in the receiver alone reduces the heat transport losses in piping. The temperature of the energy storage material defines the maximum energy content of the receiver for the certain thermal applications. The energy stored in the cascaded PCM solar receiver consists of 30% stored energy is in the receiver construction material and 70% of the heat is stored in terms of sensible and latent heat of PCM. The cascaded PCM solar receiver are useful to store the thermal energy effectively rather than a single PCM used in the solar receiver. The time of charging PCM is almost same under the same operating conditions. The energy stored by the receiver can be utilized in the different heating application such as drying, space heating, cooking application and water heating application with suitable heat retrieval methods.

REFERENCES


