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Effect of Dead Space in the Rear End of Conical Cavity Receiver on Thermal Performance

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Abstract—*Solar receiver is one of the key components of concentrating solar collectors because its performance directly affects the efficiency of the whole system. Due to high operating temperatures of concentrated solar systems, radiation and convection losses strongly penalize the efficiency of the receiver. Cavity receiver is one of the optimal solutions for the improved collector efficiency due to uniform distribution of the high heat flux incident on its aperture over the large internal surface of the cavity.*

A conical cavity receiver is developed for 16 m^2 Scheffler parabolic dish concentrator. The heat transfer surfaces of the receiver are composed of coiled metal tube. Heat transfer fluid flows in the internal spaces of coiled metal tube, and the external surfaces of coiled metal tube would absorb the highly concentrated solar energy. The bottom surface of conventional cavity receiver cannot be fully covered by coiled metal tube during fabrication because of low coiling radius, which would induce a dead space of solar energy absorption. The dead space of solar energy absorption can severely decrease the efficiency of cavity receiver.

In present work, an experimental study has been made on the performance of solar parabolic dish concentrator with two types of conical cavity receivers. First one is the conventional type with dead space and second one without dead space. A comparative analysis has been carried out to showcase the advancement of the thermal performance of the receiver in solar concentrator system.

1. INTRODUCTION

Our world energy needs continue to increase at a rapid pace due to industrial growth, modernization and changing life style. Switching over to usage of renewable energy sources like solar, wind, biomass energy could not only be an option to meet the growing energy demand but also can provide clean form of energy without creating adverse effect to the environment. Solar energy is considered to be most promising renewable energy source due to its greater global potential. Solar thermal energy technology utilizes thermal energy from the incident solar radiation for various applications such as power production, domestic cooking and hot water needs, desalination, industrial process heating applications etc.

During the past three decades various studies have been carried out both experimentally and numerically on cavity absorbers for central receiver systems and solar parabolic dish systems. Extensive study has been carried out by researchers on the study of heat losses from cavity absorbers. R.D. Jilte et al (2013) [1] carried out numerical three dimensional studies of the combined natural convection and radiation heat loss from downward facing open cavity receiver of different shapes These studies are carried out for five isothermal wall temperatures (523 to 923 K in steps of 100K). Taumoefolau et al., (2004) [2] carried out a parametric study of several relevant parameters in natural convection heat loss from open cavity receiver in solar dish application with varying aperture diameter to cavity diameter ratio. Siyoul Ryu and Taebeam Seo (2000) [3] analyzed and compared heat losses from conical receiver of surface area 0.35 m^2. It was concluded that conical receiver has 1.5% higher efficiency than dome receiver for a working temperature of 200 ºC. A number of studies on convection and radiation from cavities have been reported in the literature. However, each correlation has a limited range of applicability, which is inherently based on a particular cavity geometry and operating conditions used in the experiment in each of those works.

In present work, an attempt to study the thermal performance of a cavity type conical absorber using experimental approach with 16 m^2 Scheffler parabolic dish concentrator system has been made. The conical absorber has been fabricated using coiled metal tube. During the process of fabrication, because of the low coiling radius of the tube at the rear ends of the absorber a dead space was generated. Dead space refers to the open space at the rear end of the absorber which allows the concentrated solar radiation to pass through the absorber. It was observed that because of such an open area at the rear end, a considerable amount of concentrated solar radiation would pass through it. These fabrication difficulties for the conical absorber were observed to limits its thermal performance which affects the overall efficiency of the system. To overcome such a practical difficulty, the dead space (rear open space) has been closed by a hollow circular metal plate welded to the coiled tube. This avoids the solar radiation to pass by the absorber and also adds to the area of the absorber taking part in the process of heat transfer to HTF.

2. EXPERIMENTAL SETUP

The conical cavity absorber is bent and wound from mild steel tube of outer diameter 21.3 mm and a thickness of 3.5 mm. The mild steel tube is bent to form a conical frustum cavity of major diameter 403 mm, minor diameter 300 mm and a length of 300 mm. The conical frustum has an included angle of 21.24º. High temperature resistant flexible hoses were used for connecting the inlet and outlet of the absorber with the piping system. Glass wool insulation is provided on the absorber outer surface to prevent conduction losses. There are two different featured conical absorbers used for experimental study. Fig. 1, shows the basic absorber with the open rear end (with dead space). Fig. 2. shows modified version absorber (without dead space) with closed rear end with hollow circular mild steel plate of diameter 150 mm.

Fig. 1: Absorber with dead space

Fig. 2: Absorber without dead space (with metal plate)

Heat transfer fluid (HTF) used in the study is water. Water was circulated from the storage tank to the absorber through the pipes by using a centrifugal pump run by a 1/4 hp electric motor. The storage capacity of the insulated tank is 100 litres. Flow was controlled by flow control valve and measured using rota meter of range 0 LPH to 150 LPH with a least count of 5 LPH. Rota meter can sense water up to a pressure of 1.5 MPa with an accuracy of ±4%. Pressure of water was measured using pressure gauge. Flow control valve, rota meter and pressure gauge were fixed in the piping system. Schematic layout of HTF circulation in the litres for continous circulation of the HTF experimental set-up with location of measuring instruments and line diagram of water circulation layout are presented in Fig. 3.

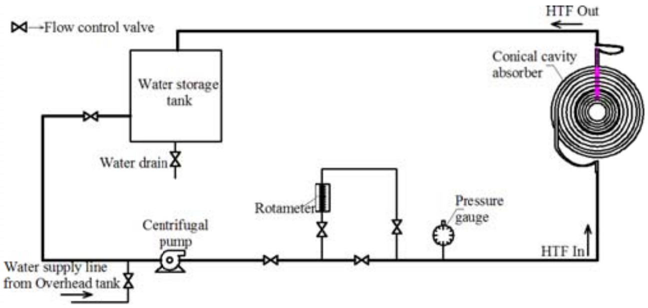

Fig. 3: Schematic layout of experimental set up

3. MEASUREMENT INSTRUMENTS/PROCEDURES

Temperature of water at inlet and outlet of the absorber were measured using thermocouple of 0 °C to 250 °C range with an accuracy of ±0.5 °C. Thermocouples were inserted at two locations in the storage tank to measure water temperature. The thermocouple of 0 °C to 250 °C range with an accuracy of ±0.5 °C were used. Global solar radiation was measured using Pyranometer, diffuse radiation was measured using Pyranometer with shading ring. Beam radiation is obtained by subtracting diffuse radiation from global radiation. Wind speed was measured using an anemometer. Surface temperature of the absorber was measured by digital infra-red laser thermometer DT-8811 - MEXTECH make, of range -50 °C to 550 °C with an accuracy of ±2 °C, distance to spot ratio is 12:1 and repeatability is ±1%.

4. RESULTS AND DISCUSSION

The experiments were conducted during the day time on clear sunny days during the month of February 2015 with average beam radiation raging from 450 W/m^2 to 650 W/m^2. The data were taken at the intervals of 10 minutes. Fluid mass flow rate of 2 liters per minute has been used for both the absorbers to showcase the development in the outcome.

5. EFFECT ON RISE IN TEMPERATURE OF HTF

The heat transfer fluid has been continuously circulated from storage tank to the absorber as a closed loop system for complete duration of the experiment. The HTF whilst flowing inside the tubes of absorber absorbs heat. The temperature inside the tank constantly increases forming a stratified temperature layer. The inlet and outlet temperature of HTF for the absorber with dead space has been shown in Fig. 4.

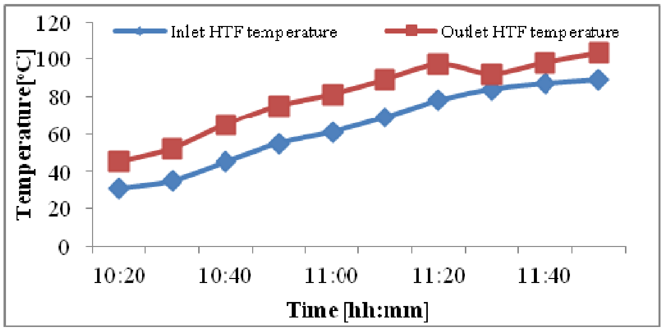

Fig. 4: Inlet and Outlet HTF temperature for absorber with dead space

The average temperature between the outlet and the inlet of the absorber is 16.30°C with highest difference of 20°C. The inlet and outlet temperature of HTF for the absorber with dead space has been shown in Fig. 5.

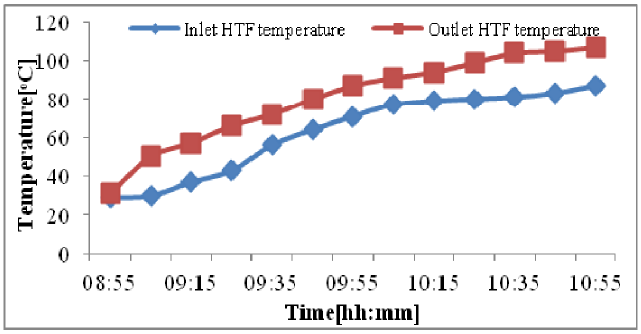

Fig. 5: Inlet and Outlet HTF temperature for absorber with dead space

The average temperature difference for the absorber without dead space is 17.38°C with peak difference of 23°C. It was observed that HTF temperature increases at an higher rate for absorber without dead space as compared to the absorber with dead space.The time duration required for HTF to reach the temperature of 99°C for absorber with dead space was 5400 sec for average radiation of 610.97 W/m^2 whereas for absorber without dead space was found out to be 3600 sec for average radiaiton of 468.32 W/m^2.

6. EFFECT ON THERMAL EFFICIENCY

Dead space at the rear end decreases the amount of radiation absorbed by a considerable amount which affects the optical efficiency as well as thermal effciency of the absorber. This is because the intenisty of solar radiation falling on the absorber is observed to be maximum at the centre of the rear end. After the closure of the rear open space (dead space), the experimental data recorded showed an increase in the thermal performance of the system. A significant increase in the efficiency was observed for the absorber without dead space. Fig. 6. and Fig. 7. shows the thermal efficiency of the absorber with and without dead space respectively.

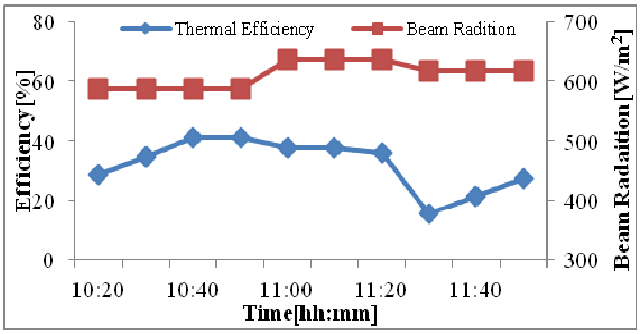

Fig. 6: Thermal Efficiency for absorber with dead space

The average thermal efficiency for the first absorber was observed to be 32.22 % with peak thermal efficiency of 41.08 % whereas for later the average thermal efficiency was observed to be 40.72 % with peak thermal efficiency of 67.25 %. With the increase in the inner area in the absorber without dead space , the HTF flows for higher amount of time inside the coiled tube. Thus, absorbing higher amount of energy from the incident solar radiation. Thereby, the average useful energy absorbed by the fluid increases significantly. Overall efficiency of the system has been observed to increase substantially for the absorber without dead space (73.69 %) as compared to the absorber with dead space (69.1 %).

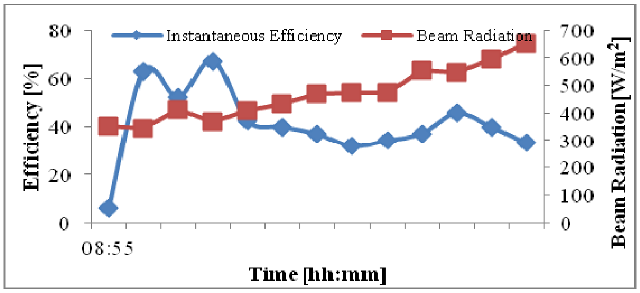

Fig. 7: Thermal Efficiency for absorber without dead space

7. CONCLUSION

An experiment analysis for absorber with and without dead space has been carried out. Dead space has a significant effect on various thermal parameters such as fluid outlet temperature, thermal energy efficiency and overall efficiency of the collector system. The rise in outlet temperature of the HTF at the absorber and the thermal efficiency were found to be higher in case of the absorber without dead space. The overall efficiency of the system were found to increase by 15.32 %.

8. ACKNOWLEDGEMENT

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