THERMAL PERFORMANCE ENHANCEMENT OF SOLAR PARABOLIC TROUGH COLLECTOR USING SECONDARY REFLECTOR

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***Abstract*— The slight misalignment in the focal of a parabolic trough collector (PTC) resulted in more heat losses and lower thermal efficiency due to seasonal movement of the Sun. With a negligible change in the intercept factor, the secondary reflectors are attached over the receiver to reflect the concentrated solar rays again on the receiver. Thermal performance of PTC is carried out numerical and experimentally. Use of secondary reflector improves the thermal efficiency by 10% and the heat loss from the PTC has been reduced by 0.5 kJ/s.**

Keyword - Solar PTC, Secondary reflectors, Receivers, Experimental work

I. INTRODUCTION

In solar thermal energy conversion system, which the collector absorber and concentrator are acting major to affect the performance. PTC had a simple geometry and used for medium temperature solar thermal applications. Solar collector performance investigated based on the inputs of optical properties, heat transfer fluid (HTF) properties, inlet temperature and flow rate of HTF, solar insolation, wind speed, and atmospheric temperature and outputs of collector efficiency, HTF outlet temperature, heat gain, and heat and optical losses. Abhijeet Audi et al. [1] performed the thermal tests on concentrator at various time periods and mass flow rate to investigate the variation of optical efficiency and heat loss factor. Umayal Sundari et al. [2] designed and investigated the performance solar collector with various operating parameters. Kumaresan et al. [3] investigated the storage system integrated with PTC (parabolic trough collector) for its performance during charging process. The absorber tube transfers solar radiation to the HTF (heat transfer fluid) which circulates through the tube which is connected to the storage tank. The performance of collector system improved by increasing the intensity of beam radiation. Senthil and cheralathen [4] experimentally investigated the effect of temperature distribution on the receiver. Based on obtaining results concluded that the collector efficiency improved by the configuration of solar radiation absorber. Cheng [5] investigated a PTC system that uses mirrored surfaces of a linear parabolic reflector to focus direct solar radiation on the absorber tube. The effects of various reflector parameters and receiver parameters are discussed. The analysis proves that the PTC system of different active receiver lengths or different glass cover diameters has little effects on the optical performance and little sensitivity to optical errors. Rizwan Masood et al. [6] performed the parabolic trough collector design and its feasibility for industrial applications. The simulation results show that the significant amount of high-temperature heat energy were attained which can be used for industrial applications. Ricardo et al. [7] studied the effects of working and environmental parameters on the performance of PTC using exergy analysis. Selvakumar et al. [8] presented the evacuated tube collector by using therminol D-12 working fluid integrated with PTC. The results concluded that the therminol D-12 as an HTF gives better performance compare then the water. From the literature studies, PTC collector design and its configuration of absorber and heat transfer fluid pointed as important. The present work performs the experimental performance of PTC with a secondary reflector.

II. MATERIALS AND METHODS

The system used is a parabolic trough collector whose function is to reflect the solar rays falling on it onto the absorber tube placed on the focus. The absorber tube is made of copper and oil flows through and is heated continuously over a specific period between which readings are taken. A secondary reflector of three different configurations is to be attached to the absorber tube to reflect the rays escaping from the absorber tube back to the absorber tube. The objective of the project is to improve the efficiency of the trough using a secondary reflector of different configurations. The Methodology is used, is that after readings are taken on the trough without any secondary reflector and the efficiency and losses are calculated for the readings. A sheet of a chosen metal is used to cut and shape into different configurations and is attached to the absorber tube on the trough. After attaching the different configurations, readings are taken, and the efficiencies and the losses are calculated for the configurations and are then compared with the efficiency and losses of the trough and graphs are drawn. The PTC had the aperture of 1.22 m, focal length 0.61 m, depth of parabola 0.21 m, arc length 1.83 m and made up of stainless steel with mirror film. The absorber tube is made up of copper having diameter 0.0254 m and length 1.22 m respectively. The trough is tracked in a single axis. The oil circulation pump is 0.5 kW capacities. The supply and storage tanks are 10 and 28 liters respectively. The experimental test setup is constructed by Ecosense Sustainable Solutions Pvt.Ltd., New Delhi, India. The secondary reflectors considered are triangular and curved configurations. The configurations are prepared with a sheet of polished aluminum and are attached to the absorber tube one after the other as shown in fig. 1.

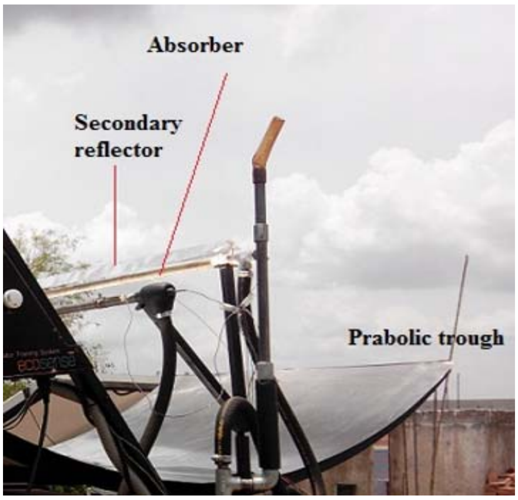

Fig. 1. PTC test facility with secondary reflector

III. THERMAL ENERGY ANALYSIS

A. Thermal analysis of the system

Thermal performance investigated by measuring the temperature difference of working fluid through the receiver, together with fluid properties, mass flow rate and solar direct radiation incident. In order to evaluate the thermal performance of the PTC collector based on heat gained by working fluid is expressed as the absorbed energy by the solar receiver is given by the following equation,

$$Q_s = \gamma \rho A_c \tau \alpha I_b \tag{1}$$

The useful heat gain by the HTF can be determined from the experimental data is given by

$$Q_u = mC_p \left(T_o - T_i\right) \tag{2}$$

The Reynolds number can be calculated by the relation of $\mathrm{Re} = V_{HTF} D_i / v_{HTF}$ The convective heat transfer from the inner surface of the receiver to HTF can be calculated from the Nusselt correlations given by the Dittus-Boelter equation,

$$Nu_{HTF} = 0.036\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33}\left(D_i/L\right)^{0.055} \qquad \text{for } 10 < L/D_i < 400 \tag{3}$$

The convective heat transfer coefficient (h_{HTF}) between receiver inner surface and HTF can be calculated as equation [4] and Heat transfer to the HTF by convection can be given by equation (5)

$$h_{HTF} = \frac{Nu_{HTF} k_{HTF}}{D_i} \tag{4}$$

$$Q_{conv} = h_{HTF} A_i \left(T_m - T_i\right) \tag{5}$$

Where the inner surface area is defined as:

$$A_i = \pi D_i L \tag{6}$$

B. Heat losses from the receiver

The Reynolds number can be calculated by the relation,

$$\mathrm{Re} = \frac{V_{air} D_o}{v_{air}} \tag{7}$$

Nusselt number for air flow over the receiver tube is given by the following equations

$$Nu = 0.4 + 0.54\,\mathrm{Re}^{0.53} \quad \text{for } 0.1 < \mathrm{Re} < 1000 \tag{8}$$

$$Nu = 0.3\,\mathrm{Re}^{0.6} \quad \text{for } 1000 < \mathrm{Re} < 50000 \tag{9}$$

The convective heat transfer coefficient h_w between receiver and ambient air due to wind can be calculated as [10],

$$h_w = \frac{Nu.k_{air}}{D_o} \tag{10}$$

The radiation heat transfer coefficient h_r between receiver surface to ambient temperature can be calculated from the equation,

$$h_r = \sigma\varepsilon\left(T_r + T_a\right)\left(T_t^2 + T_a^{\,2}\right) \tag{11}$$

The overall heat loss coefficient may be determined using the following relation,

$$U_{loss} = h_w + h_r \tag{12}$$

The following correlations have been used for determining the temperature obtainable and heat loss for the given PTC configurations. The maximum obtainable and optimum temperature of the HTF with reference to solar beam radiation (I_b) is given by

$$T_{\max} = -0.793\,\mathrm{I}_b + 283.6 \tag{13}$$

$$T_{opt} = 0.523\,\mathrm{I}_b + 187.1 \tag{14}$$

Maximum obtainable and optimum temperature of the HTF with reference to concentration ratio (CR) is given by,

$$T_{\max} = -0.009CR^2 + 6.318CR + 240.4 \tag{15}$$

$$T_{opt} = -0.006CR^2 + 4.17CR + 158.7 \tag{16}$$

Convective heat loss coefficient with respect to wind speed is given by the equation:

$$h_w = -0.489\,\mathrm{V}^2 + 11.6V + 1.635 \tag{17}$$

Convective heat loss from the receiver with respect to surface temperature is given by the equation:

$$Q_{\mathrm{conv}} = 1.552T_r - 49.41 \tag{18}$$

Radiation heat loss from the receiver with respect to surface temperature is given by the equation:

$$Q_{rad} = 0.307T_r - 17.98 \tag{19}$$

Total heat loss from the receiver is given by,

$$Q_{loss} = 1.859T_r - 67.39 \tag{20}$$

IV. RESULTS AND DISCUSSION

The geometric concentration ratio is an important parameter in the solar concentrating collectors and it influences the receiver surface temperature. The effective ratio is the product of geometric concentration ratio and optical efficiency. The increase in concentration ratio increases the maximum and optimum temperatures of the receiver. The concentration ratio of the given PTC is 68. In the observation of fig. 2 show that the maximum obtainable and optimum temperature are 560 °C and 300 °C respectively.

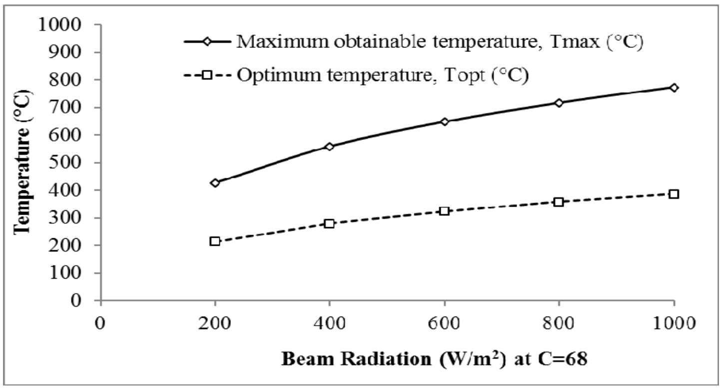

Fig. 2. Effect of beam radiation on the maximum and optimum temperature of PTC

The effective ratio is the product of geometric concentration ratio and optical efficiency. The increase in solar beam radiation increases the maximum and optimum temperatures of the receiver. The average beam radiation during the test months (March and April) in Chennai is about 700 W/m^2. As observed from the fig. 3 show that the maximum obtainable and optimum temperature are 540 °C and 250 °C respectively.

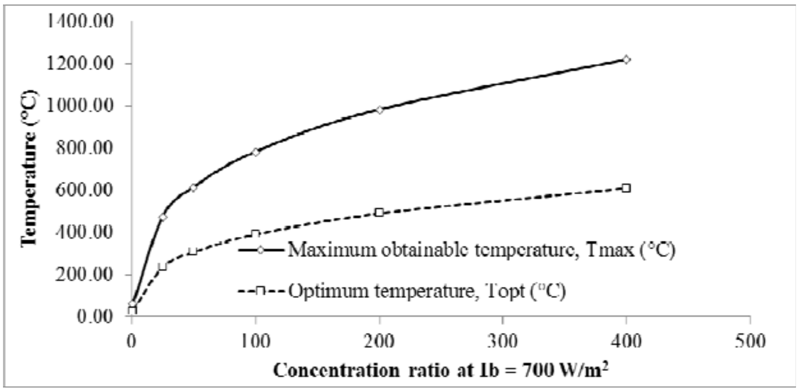

Fig. 3 Effect of maximum obtainable and optimum temperature at 700 W/m^2

The wind speed in the test site is around 1 m/s, and it is responsible for the heat loss from the receiver surface. It is an important parameter in the solar concentrating collectors, and it severely affects the thermal performance of the receiver. The increase in wind speed increases the convective heat losses and the heat loss coefficient increases linearly with wind speed and the convective heat loss coefficient is around 25 W/m^{2}K. As observations from the fig. 4 show that the convective heat loss increased ten times as that of wind speed beyond the speed of 1 m/s.

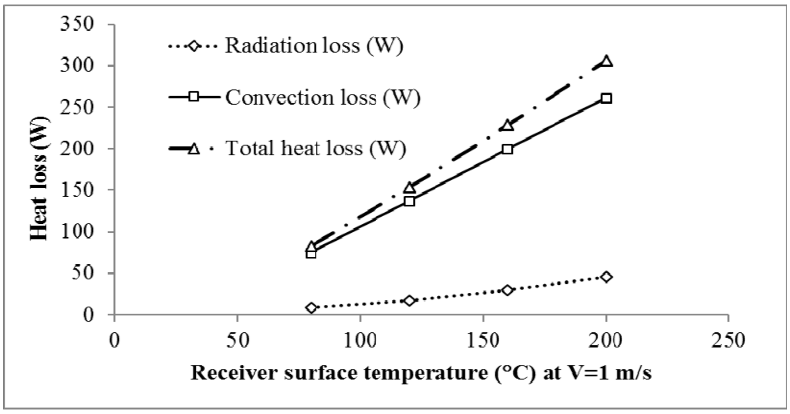

Fig. 4 Heat loss from the receiver at the normal wind speed of 1 m/s.

The overall heat loss coefficient mainly depends on wind speed and receiver surface temperatures. It is an important parameter in the solar concentrating collectors to determine the convection and radiation heat losses from the receiver. It severely affects the thermal performance of the receiver. The increase in wind speed and receiver temperature increases the convective heat losses, and the heat loss coefficient increases linearly with wind speed.

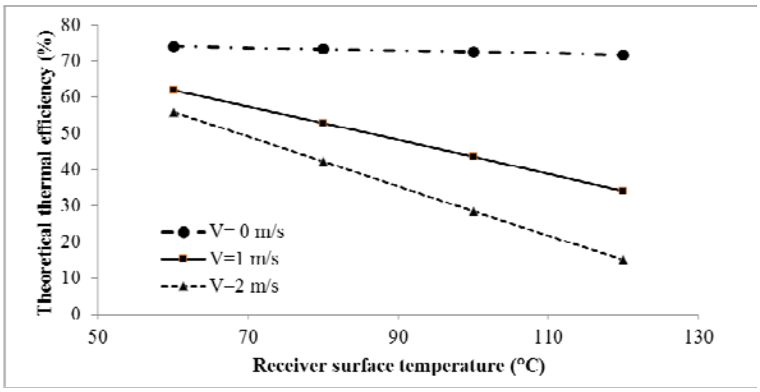

Fig. 5 Heat loss from the receiver at the normal wind speed of 1 m/s.

The overall heat loss coefficient is less than 5 W/m^2K for the wind speed of less than 1 m/s. The convection, radiation and total heat loss for the given PTC are mainly depends on receiver surface temperatures and wind speed. It is an important parameter in the solar concentrating collectors to determine the convection and radiation heat losses from the receiver. It radiation loss is less than 50 W/m^2K whereas the convection loss is dominant and in the range of 75 to 275 W/m^2 K.

In fig. 5 depicts the theoretical thermal efficiency of PTC at an optical efficiency of 75% and the increase in wind speed decreases the efficiency steeply. The lower wind speed results in almost in a narrow range and gives about 75%. The practical wind speed at the site is around 1 m/s and the theoretical maximum efficiency is around 69%.

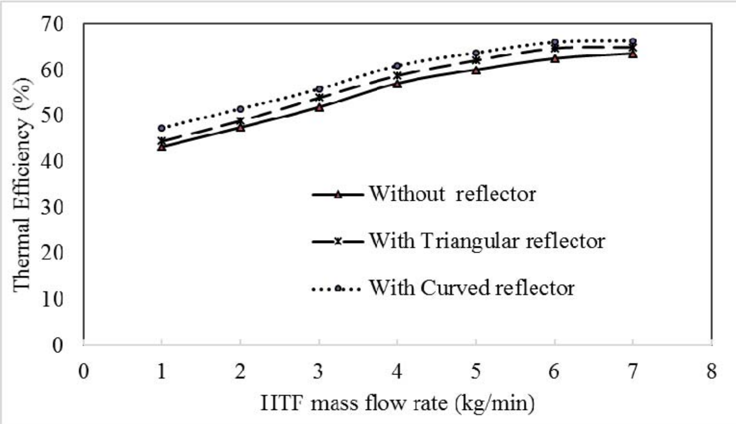

Fig. 6 Effect of mass flow rate on the thermal efficiency

In fig. 6 resulted in the heat losses and thermal efficiency of the PTC with and without a secondary reflector. The efficiency of the trough is 41% without the secondary reflector. After the secondary reflector, has been attached, the efficiency of the trough with the flat secondary reflector increased to 43%. The efficiency of the trough with the angular secondary reflector was increased to 48%. The efficiency of the trough with the curved secondary reflector was increased to 51%. The heat losses of the trough with and without the secondary reflectors were calculated.

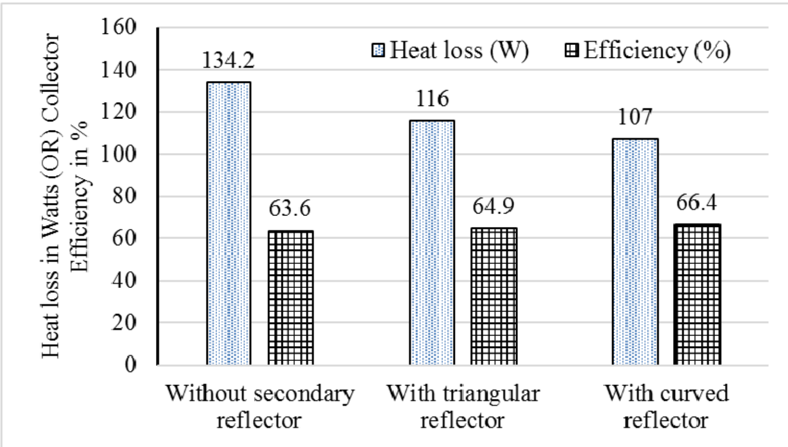

Fig. 7 Heat loss and thermal efficiency of the PTC with and without secondary reflector

The heat loss that occurred in the piping of the trough without the secondary reflector is 0.395 KJ/s. The heat loss that occurred in the trough with the flat secondary reflector is 0.375 KJ/s. The heat loss that occurred in the trough with angular secondary reflector is 0.212 KJ/s. The heat loss that occurred in the trough with curved secondary reflector is 0.161 KJ/s. The beam radiation is one of the most important factors that affect the heating of Oil in the solar trough. The increase of radiation could result in an increase in the heating up of the tube which in turn will increase the temperature of the oil flowing through it. Any increase in the ambient temp could directly result in an increase in the temperature of the tube and turn the temperature of the fluid- Oil. Wind velocity, however, could have an inverse effect on the heating and result in the decrease in the temperature of the tube and turn the temp of the oil.

V. CONCLUSION

The secondary reflector is attached to the equipment, and the readings are taken for all configurations of the secondary reflector. The efficiencies and heat losses are calculated for the equipment with the secondary reflector. A numerical analysis also performed for the same parabolic trough collector and few correlations are formed. The experimental efficiencies are compared. The following conclusions are made from the experimental results:

- The thermal efficiency of PTC increases 10% with the help of secondary reflectors.
- The heat loss from the PTC has been reduced by 0.5 kW with the help of secondary reflector

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