Numerical Analysis of Linear Parabolic Collector with Parabolic Absorber Tube

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Abstract: In the present study, the shape of the absorber tube of parabolic trough collector is modified and a fin is employed inside the absorber tube to improve the heat transfer. The regular circular absorber tube is replaced with a parabolic absorber tube. The distribution of solar flux over the absorber tube is calculated by using the Monte Carlo ray tracing method. Finite volume approach is used to carry out the thermal analysis and both the method are validated by comparing their results with analytical and experimental results. A comparative study is presented between circular absorber tube and parabolic absorber tube, for the range of Reynolds numbers 0.14×10^5 to 2.93×10^5. The maximum gain in the collector efficiency of the parabolic trough collector is found to be 6.2%.

Keywords: Solar thermal energy, CSP, MCRT, FVM, PTC

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I. INTRODUCTION

Global warming issues and limited availability of conventional fuels leads the world to look for alternative energy sources [1]. The energy from the SUN is unlimited and clean. The Parabolic trough solar collector technology is one of the technique to harness the sun energy [2]. It is well-established commercial level power generation technology. Parabolic trough solar collector has two vital components a linear parabolic mirror and a heat collection element (HCE) [3]. The parabolic mirror focuses the incident rays to an HCE located at its focal line as shown in the Figure. 1. The HCE absorbs the energy of the concentrated rays and transmits it to a heat transfer fluid (HTF) in the form of heat. The absorbed heat is then dissipated in the heat exchanger to generate the steam that is used to run the turbine to generate the electricity [4].

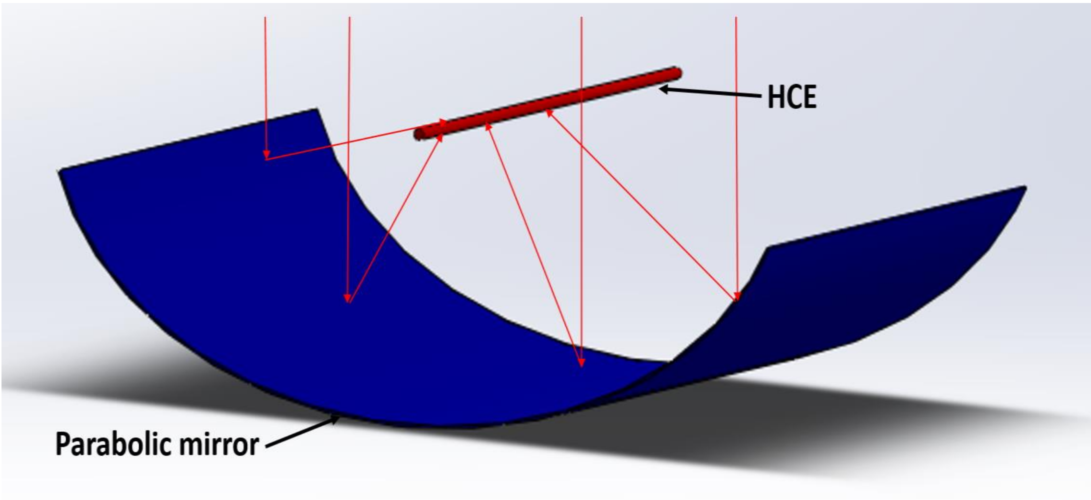

Figure. 1 Parabolic trough collector with the ray path

Improving the energy absorption by the HTF in the HCE is one of the challenges in the PTC technology. A part of the energy incident on the HCE is transferred to the HTF and the remaining energy is lost to the atmosphere. Reducing the heat loss to the atmosphere is one of the ways to increase the heat absorbed by the HTF. In order to achieve this, in HCE, a metal absorber tube is enclosed in a concentric evacuated glass tube [5, 6]. The rays reflected from the parabolic mirror passes through the glass tube and incident on the metal absorber tube. The absorber tube absorbs the incident energy and transfers it to the HTF that is flowing inside the absorber tube. The glass tube isolates the absorber tube from the atmosphere to minimize the convective heat losses from the absorber tube. In order to increase the absorption of radiation and reduce the radiative heat losses, the surface of the absorber is coated with the high absorptivity and low emissivity material but these coating materials have some limitations [7].

Another way of increasing the heat absorption by the HTF is to enhance the heat transfer in the absorber tube. The heat transfer can be enhanced by using longitudinal fins or tabulators inside the abso rber tube. The fins increase the effective heat transfer area and the tabulators increase the heat transfer by increasing the turbulence in the HTF flow. Various heat transfer models are available in the literature to study the heat transfer characteristics in the HCE of the parabolic trough collector. Few models considerers the uniform heat flux over the absorber tube and some considerers the non-uniform heat flux over the absorber tube [8]. Out of these two, the non-uniform heat flux model is more accurate as the heat flux over the absorber tube is non-uniform in real conditions [9-11]. The non-uniform heat flux over the absorber tube can be obtained from the numerical ray tracing simulations. Later the non-uniform heat flux can be used in the heat transfer simulation of HCE. Monte Carlo ray tracing method is the most widely used method to calculate the non-uniform heat flux distributions [12-14].

In the present study, a parabolic absorber tube is used with a fin to enhance the heat transfer. As the concentration of solar flux is higher on the lower portion of the absorber tube, the fin is provided on the lower portion of the absorber tube. The heat transfer analysis is performed by using the finite volume method and the optical analysis are conducted by using Monte Carlo ray tracing method.

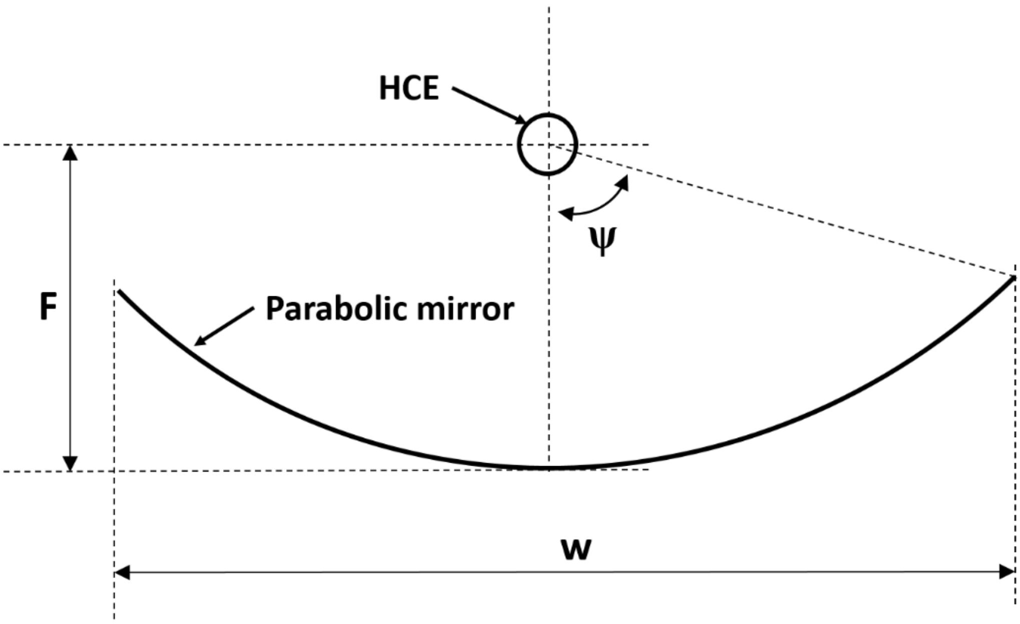

Figure 2. Parabolic trough collector geometry

Parabolic trough solar collectors are line focused collectors. A cross-sectional view of a typical solar collector is shown in Figure. 2. where f is the focal length the distance between vertex and focus, w is aperture width the distance between two rim points and ψ is the rim angle the angle between the line joins the focus to vertex and the line joins the focus to rim point.

II. NUMERICAL ANALYSIS

The heat transfer simulations of HCE are performed by using finite volume method. The Reynolds averaged Navier stokes are used to simulate the fluid flow and heat transfer in a discretized domain of HCE. These are turbulent flow equations for mass, momentum and energy conservation. The discrete ordinates radiation model is used to model the radiation heat transfer.

The boundary considered in this study are as follows; (i) Adiabatic wall boundary condition is used for the end walls of the glass tube and absorber tube. (ii) Radiation and convection boundary condition is used for the outer surface of the glass tube. (iii) No slip boundary condition is used on the inner surface of the absorber tube. (iv) The heat flux distributions obtained from the SolTrace is specified as a boundary condition on the outer surface of the absorber tube. (v) The inlet mass flow rate for absorber tube inlet and pressure outlet is specified for the absorber tube outlet. The assumptions considered in the finite volume analysis are: (i) steady flow, (ii) only radiation (no conduction and convection) in the vacuum space, (iii) radiative surfaces are diffusive and gray and (iv) the HTF is syltherm800.

A structured mesh of HCE is created with circular absorber tube and parabolic absorber tube as shown in the Figure. 3. Mesh independent test was carried out and the mesh with 1,231,546 and 1,534,574 elements is found to be accurate for the circular absorber tube and parabolic absorber tube respectively.

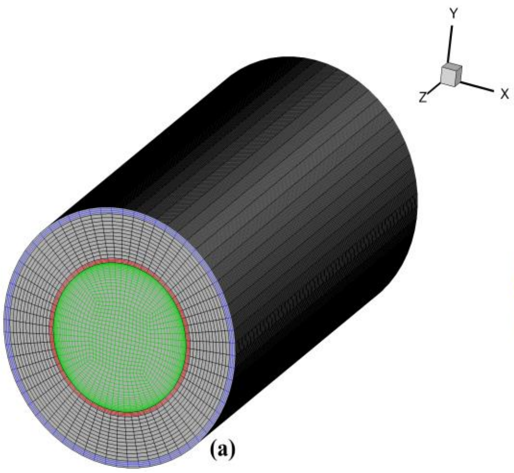

Figure.3 Mesh of HCE (a) circular absorber (b) parabolic absorber

III. RESULTS AND DISCUSSION

The heat flux and temperature distributions over the absorber tube and collector efficiency at different operating conditions for both the absorber tube are presented in this section. Figure. 4 (a) shows the heat flux distribution over the circular absorber tube and Figure. 4 (b) shows the heat flux distribution on the flat surface of the parabolic absorber tube. In the case of the circular absorber tube, the value of heat flux is high on the lower portion of the absorber tube due to concentrated solar flux and low on the upper portion due to direct sunlight. Similar way, in the case of the parabolic absorber tube, the heat flux distribution on the flat surface is high due to concentrated solar flux.

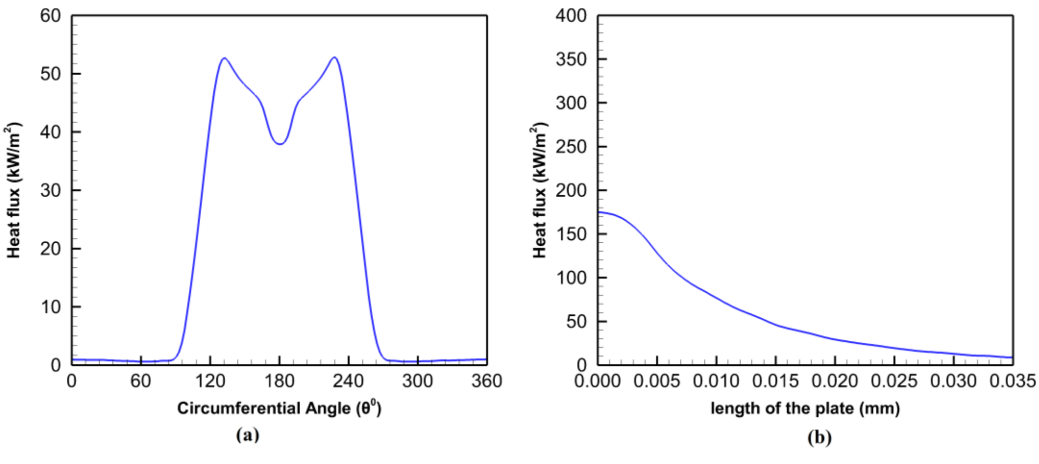

Figure.4 Local heat flux distributions over (a) circular absorber (b) flat surface of the parabolic absorber

The temperature distributions in the circular absorber tube parabolic absorber tube are shown in Figure. 4 for the volumetric flow rate of HTF 29 m3/hr and inlet temperature 350 K. As shown, the temperature distributions follow the trend of heat flux distributions. The temperature gradients in both the absorber tubes are almost the same. The temperature at the lower portion of the absorber tube high due to concentrated rays and it is low on the top portion of the absorber tube due to direct sun rays.

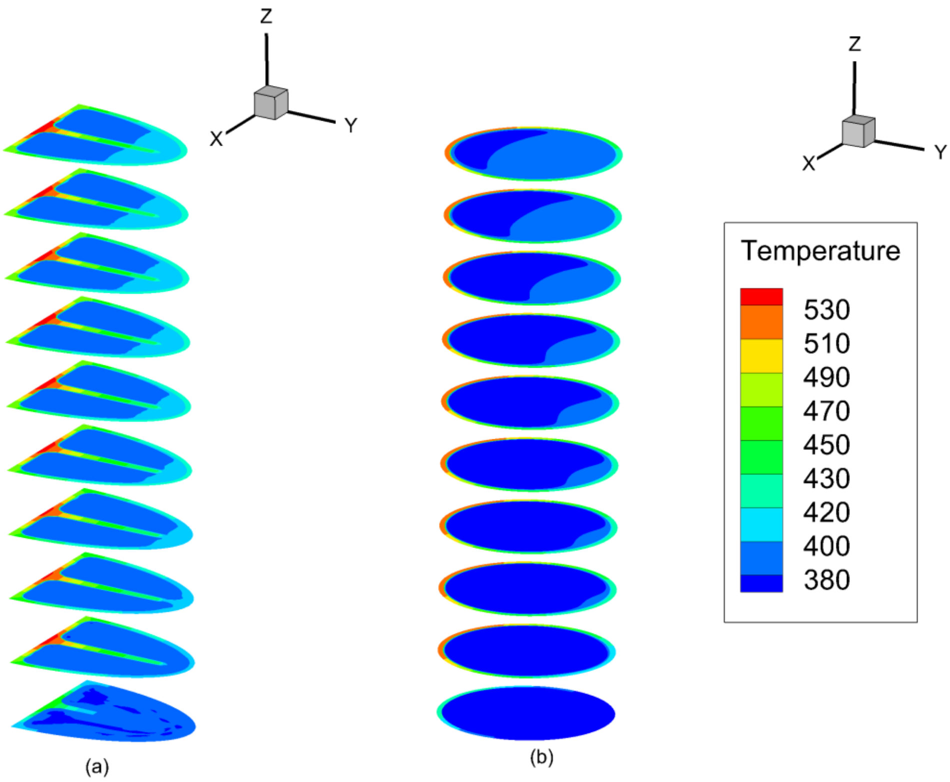

Figure. 5 Temperature distributions in absorber tube (a) parabolic absorber (b) circular absorber

Figure. 6 shows the variation of collector efficiency with Reynolds number for an inlet temperature of 500 K. It can be observed that the collector efficiency is high in the parabolic absorber tube in comparison to the circular absorber tube for the range of Reynolds numbers considered in this study. The fin inside the parabolic absorber tube increases the heat transfer in the absorber tube that results in a higher collector efficiency in the parabolic absorber tube. The improvement in the collector efficiency with parabolic absorber tube is very low at low Reynolds numbers and increases with the increase of Reynolds number. The increase in Reynolds number increases the turbulence in the flow that results in a higher convective heat transfer. The maximum improvement in the collector efficiency is 6.2% and it is observed at the Reynolds number 2.93 $x10^5$.

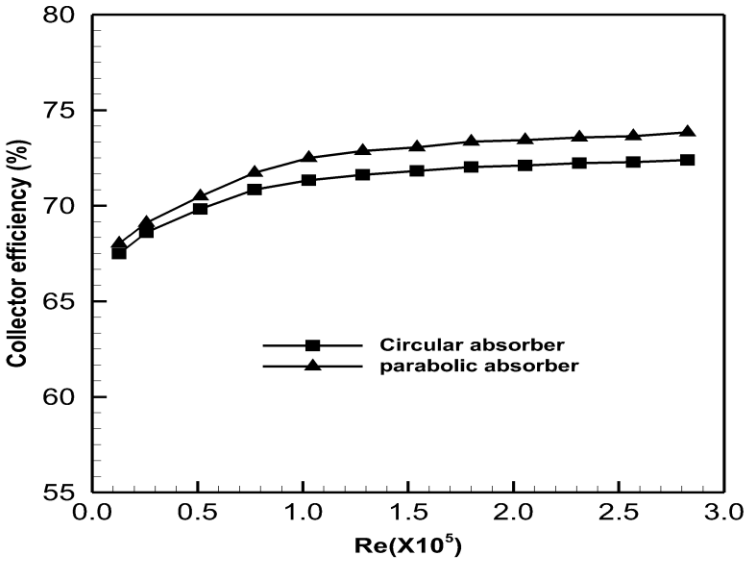

Figure. 6 Collector efficiency of the PTC

IV. CONCLUSION

In this paper, the performance of parabolic trough solar collector has been studied with conventional absorber tube and parabolic absorber tube. The simulations have been performed by coupling MCRT and FVM for different Reynolds number ($0.14x10^5$ to $2.93\ x10^5$). An improvement in the collector efficiency is obtained with parabolic absorber tube at low Reynolds numbers on account of slightly higher pressure drop. Parabolic absorber tube can be used in the parabolic trough collector.

Abbreviations

CR : concentration ratio
CSP : concentrated solar power
PTC : parabolic trough collector

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