Analysis of Parabolic Trough Collector using Ansys Fluent Software

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Abstract: Concentrated Solar Power has a great potential to utilize the solar energy more efficiently than other solar systems. Parabolic Trough collector found to have better efficiency with higher concentration ratios and effective conversion of solar energy. In this paper, an effort is made to model a Parabolic Trough Collector using Ansys 15.0 Workbench software. The PTC is designed for a Concentration Ratio of 25.The PTC was modeled at different mass flow rates of 0.25 kg/hr, 0.5 kg/hr, 0.75 kg/hr and 1kg/hr respectively and the results are discussed. The heat transfer characteristics such as heat transfer co-efficient, Nusselt number and heat flux are also studied for different mass flow rates. The maximum water temperature is found to be 367^0K for the mass flow rate of 0.25 kg/hr with collector efficiency of 51.2%.

***IndexTerms*–Solar, Parabolic Through Collector**

I. INTRODUCTION

Solar energy has great potential to cater the ever increasing energy demands and to solve the global problems such as climate change, fossil fuel depletion, increased pollutions and so on[1]. The concentrated solar power technologies such as parabolic dish, compound parabolic concentrator and parabolic trough, have a potential to operate at high temperature. These concentrators are widely used to many solar power plants which are installed worldwide. The Parabolic Trough Collectors (PTC) is found to be the most mature solar technology with 4.2 Gigawatt (Gw) capacity worldwide [2] and is found to be an effective solution to meet the energy requirement. The Parabolic trough collectors are the parabolic surface which concentrates the falling solar radiations at the focus of the parabola which concentrated the dilute solar energy and high temperature is obtain at the focus. By placing a receiver which is a tube of thermal conductivity this concentrated energy is utilized for the known applications. Murtuza et al[3] stimulated the strength of 5 m length PTC model Torque tube with water as working fluid and Stainless steel receiver. It is concluded that an advance metal matrix. The torque tube design was found to be more robust and more effective in order to take the load of the mild steel ribs assembly in order to accommodate the aluminum sheets for reflection. Zhiyong Tian [4] simulated the performance of hybrid solar water heating system using flat plate collector for pre-heating the water along with PTC for further heating for district water network in Nordic region. The results showed that the use of PTC hybrid system leads to increase in the thermal efficiency by 25.2 % leading to the new design to meet the requirement. Ghasemi et al[5] simulated numerically the thermo-hydraulic characteristic of PTC with porous ring using Syntherm 800 as heat transfer fluid. The result showed that the the heat transfer characteristics got enhanced by inserting the porous ring in tubular solar absorber by decreasing the distance between the porous ring.

Jian Jin et al[6] proposed a new method of analyzing the performance of PTC using the principal of similarity principles and dimensional analysis. The method provides the new perspective for solar thermal research by demonstrating the possibility of performing experiments on PTC using a reduced scale. The simulation results showed the increased in collector efficiency with augmentation of direct normal irradiance. Houcine et al[7] simulated optically the model of sun tracking PTC using computational Ray Tracing 3 Dimensional 4 Ray (TR3D-4R) method. The variation of Geometric Concentration Ratio and rim angle on the hourly concentrated solar flux is studied. For the Geometric Concentration Ratio of 50 and an hourly angle of 90^0, the solar flux was found to be maximum. Filho et al [8] analysed numerically and experimentally the thermal losses through parabolic trough collector. The One Dimensional heat transfer model was developed to predict the losses in PTC under steady state conditions. Wang et al [9] simulated and experimentally verified the on-site test method and thermo-hydraulic model. This method is based on energy balance of incident solar radiation, heat gain, cosine loss, end loss, optical loss and heat loss. The optical efficiency of the 300 kWt PTC rig was found to be 76.15 % which agrees with that ofLS-3 collector(77%). Bellos et al[10] simulated the small parabolic trough collector model to determine the optical and thermal efficiency using Solidworks software and compared with 1-D numerical model. The collector efficiency and optical efficiency were found to be 80 % and 75% which are verified using numerical model.

Bellos et al[11] investigated the use of various internal longitudinal fin configuration in the absorber tube of the LS-2 PTC by varying their lengths and thickness and simulated in Solid works Simulation software to evaluate theie heat transfer characteristics. The effect of pressure drop and heat transfer enhancement both are studied with changing the number of fins and also its geometrical configurations. The maximum thermal efficiency was found to be 68.80% with Nusselt number 1.682 times higher than the smooth case while pressure drop and friction factor were found to be twice as compared to smooth case. W.Fu et al[12] simulated the effect of wind load on the deformation of the reflecting mirrors for the PTC with torque box using ANSYS CFX software and optimized the design to reduce the weight of torque box. The simulation result showed that the performance of thecollector has improved, the weight of the collector was reduced by 5.8% and the maximum deformation of the collector was reduced by 4.6% with the proposed new design.

Abad et al [13] investigated the performance of PTC with absorber tube filled with metal foam in order to improve the thermal efficiency andinhance the heat transfer rate.the experiment was performed for different volume flow rates from 0.5 Lit/min to 1.5 Lit/min and the ASHRAE 93 standards were used to test the performance. Also, the Friction factor and Nusselt number had been evaluated for both the cases. With increasing the mass flow rate, the efficiency was found to increase and the same occurred while using the absorber filled with metal foam. The use of metal foam decreases the overall loss co-efficient by 45% and thus enhancing the heat transfer rate. Bellos et al[14] investigated the use of nano fluids in PTC using $Al_2O_3$and CuO nanofluidsalong with thermal oil Syltherm 800. A detailed thermal model is developed in EES (Engineering Equator Solver) and its results are validated with experimental results for various inlet temperatures from 25^0C to 325^0C for the cases mentioned. The result showed that both the nanofluids gives best performance with CuO nanofluid with Syltherm 800 being the best. The heat Transfer enhancement of about 50% took place with the use of nanofluids than thermal oil and is found to be increased with increase in temperature. The use of CuO increase the efficiency by 1.26 % while the use of Al_2O_3by1.13% when the concentration ratio is maximize and flow rate is relative low.

II. MODEL AND SIMULATION METHOD

The simulation of the Solar Parabolic Though Collector is the aim of this study. For this, a PTC model is designed and modeled in ANSYS Workbench 15.0 software.The schematic model of Parabolic Solar Collector as shown in fig.1 is made of a long reflective surface and long tube placed at the focus. It is modeled in Ansys workbench software with reflector 1.34m wide, 1.5m long and it is made up of aluminum. The receiver is a copper tube of diameter 1cm, 1mm thick and 1.5m long. The receiver tube is placed at the focus of the parabolic through collector with focal length 30cm with the Concentration Ratio of 30.

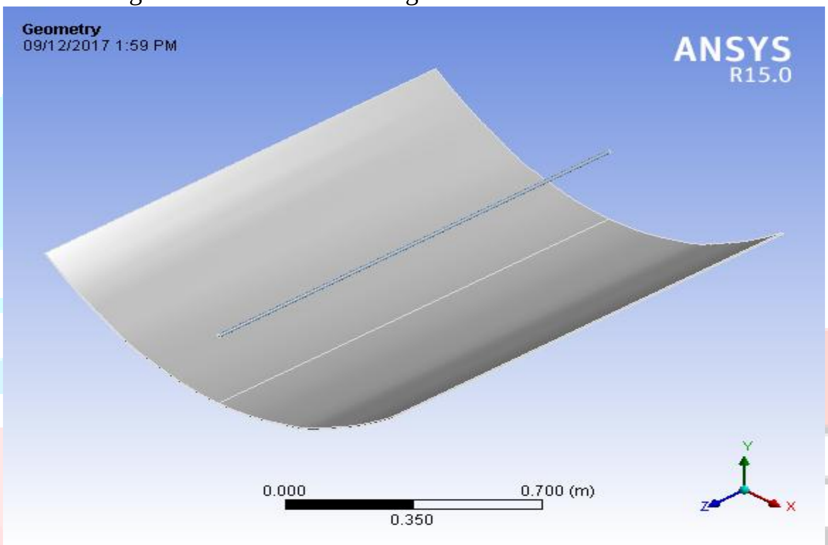

Fig. 1 Model of the Parabolic Trough Collector

The meshing is an important operation in CFD modeling as the quality of the meshing determines the accuracy of the solution. The meshing of the PTC model is as shown in Fig. 2 below

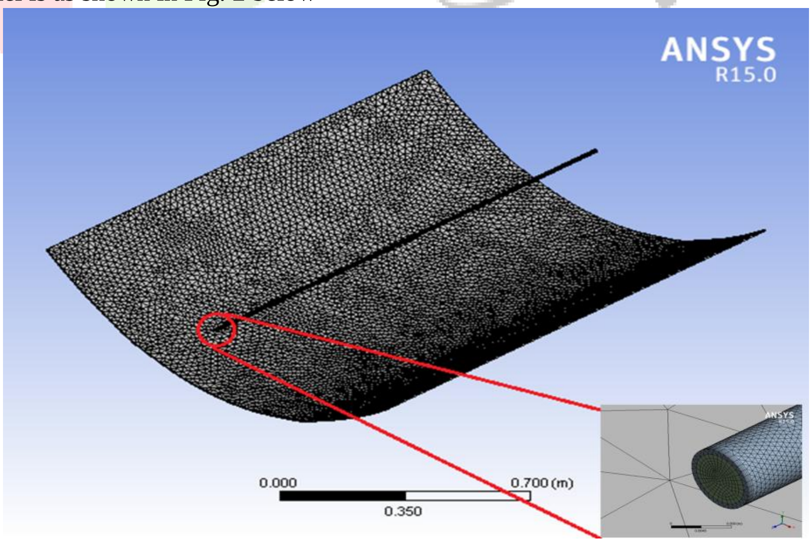

Fig. 2 Meshing of the model

The model designed is simulated in the Ansys Workbench Software with K-e Realizable fluid model and Solar Roseland Radiation model with Solar Calculator. The simulation is performed for different mass flow rates of 0.25kg/hr, 0.5 kg/hr, 0.75 kg/hr and 1kg/hr respectively. The solar calculator is set at the 73^0E Longitude, 20^0N Latitude which corresponds to Nashik at 05:30GMT

(IST). The inner pipe surface and the water surface in contact with the pipe are wall coupled for better heat transfer results. The various properties of the simulation model is simulated in the table below.

Table 1. Simulation Parameters

Simulation Parameters	Values
Incident Solar Insolation	884(W/m^2)
Reflectivity of collector	0.9
Atmospheric Temperature	250C
Collector Emissivity	0.88
Receiver Absorptivity	0.96

III. RESULTS AND DISCUSSION

The simulation of the Parabolic through collector is done during the study and the results obtained are discussed in the following section. The figure 3 shows the temperature variation across the receiver and the collector surface. The maximum receiver surface is found to be 384^{0}K near the water outlet region of the absorber while the collector surface found to remains at constanttemperature.

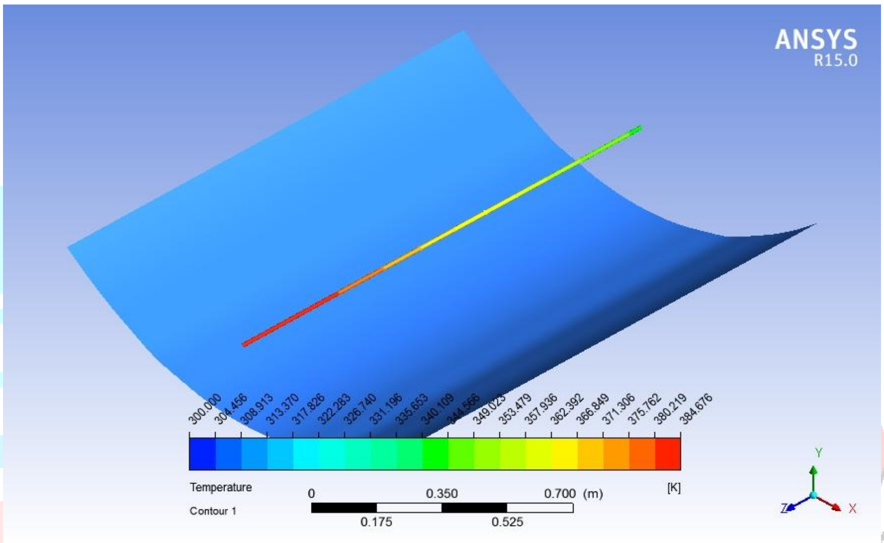

Fig. 3 Temperature profile of the collector

The figure 4 shows the temperature variation of the receiver surface along the length from inlet to outlet. The maximum temperature of the pipe is found to be 384^{0}K for a long length towards the water outlet for a mass flow rate of 0.25 kg/hr. It can be seen that the temperature of the pipe surface is found to increase along the length of the pipe.

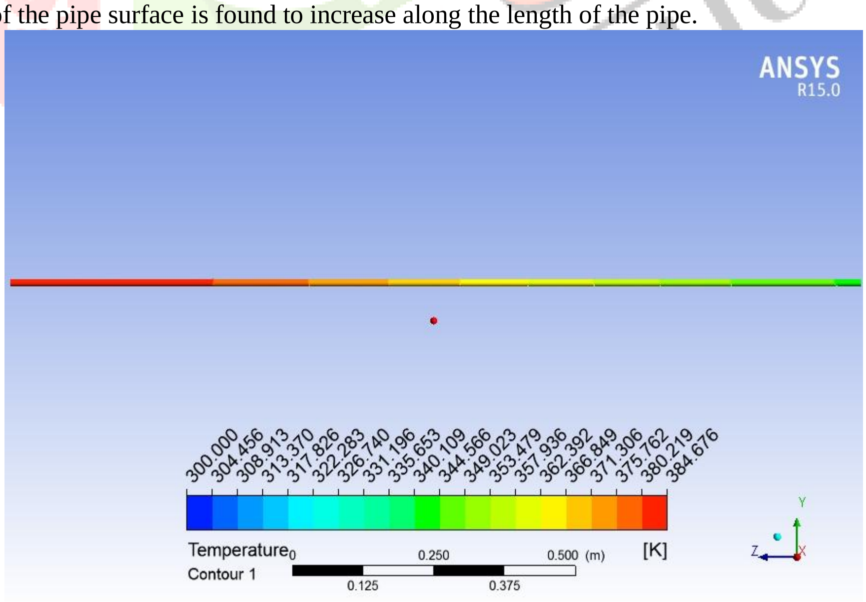

Fig.4 Pipe Surface Temperature variation along the pipe length

The figure 5 shows the temperature variation of the water in contact with the pipe surface from inlet to outlet along the length. The maximum water temperature is found to be 366.7^{0}K for mass flow rate of 0.25 kg/hr of water. The water surface is found to increase as the flow advances along the pipe length.

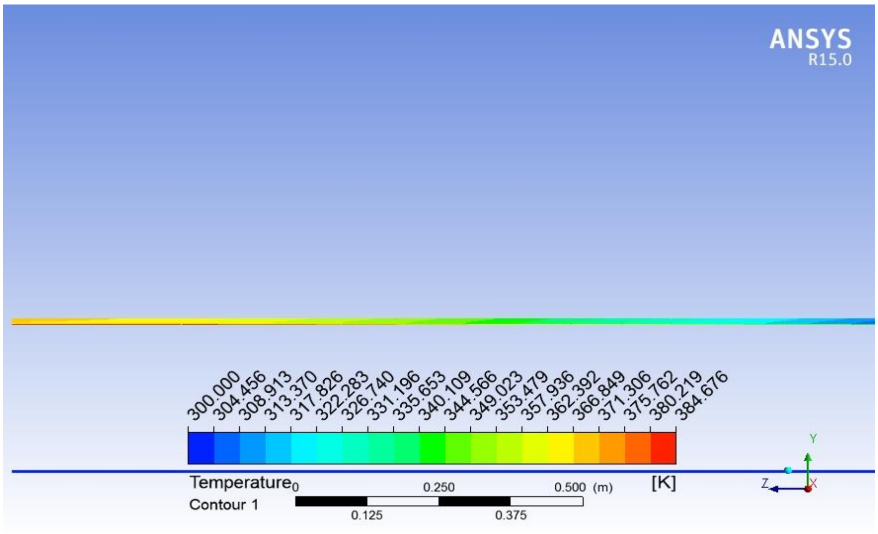

Fig. 5 Water Temperature variation along the pipe length

The figure 6 shows the velocity variation of the water along the pipe cross section which shows the flow to be laminar flow inside the pipe as the velocity increases linearly. The water is almost stationary near the pipe surface due to higher shear stress and it considerably decreases thus the water velocity increase as me move towards the pipe center.

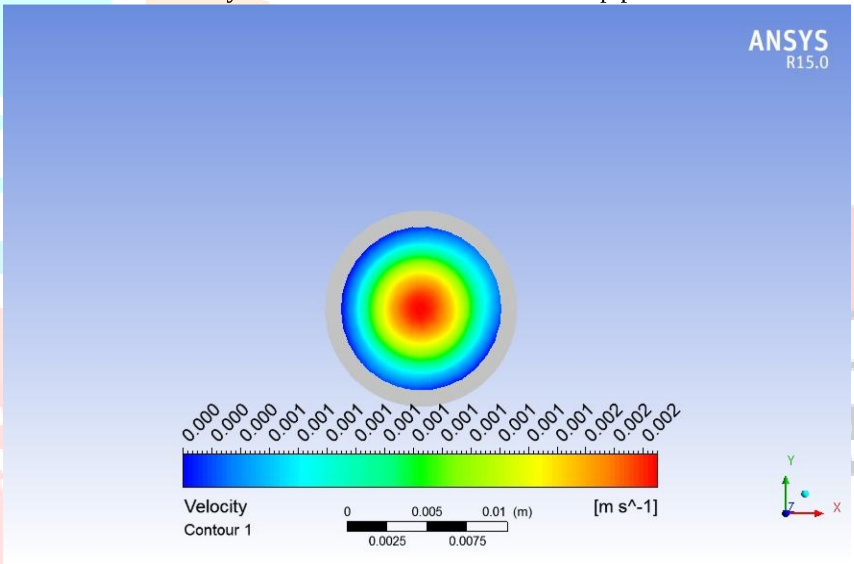

Fig. 6 Velocity variations across the pipe cross section.

The figure 7 shows the variation of temperature of outlet water with respect to mass flow rate of the water though the receiver. The mass flow rate is found to decrease from 366^0K to 318^0K with increase in mass flow rate from 0.25 kg/hr to 1 kg/hr respectively.

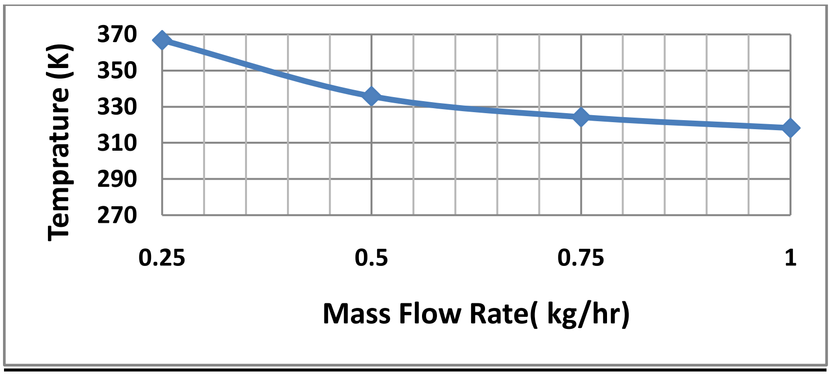

Fig.7 Outlet Water Temperature with mass flow rate

The figure 8 shows the variation of heat transfer coefficient with different mass flow rate for the flow of water though the copper tube. The heat transfer rate is found to increase from 6.02 W/m^{2}K to 9 W/m^{2}K with increase in mass flow rate from 0.25 kg/hr to 1 kg/hr respectively.

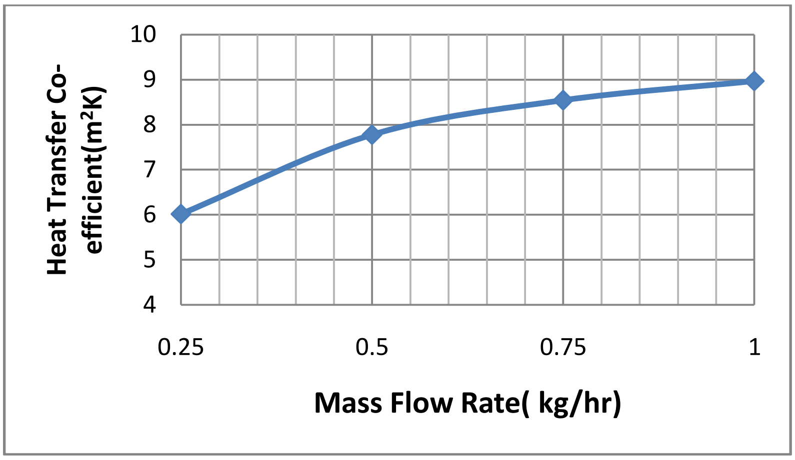

Fig.8 Variation of heat transfer coefficient with mass flow rate

The figure 9 shows the variation of Nusselt number with different mass flow rate for the flow of water though the copper tube. The Nusselt number is found to increase from 10.04 to 14.45 with increase in mass flow rate from 0.25 kg/hr to 1 kg/hr respectively.

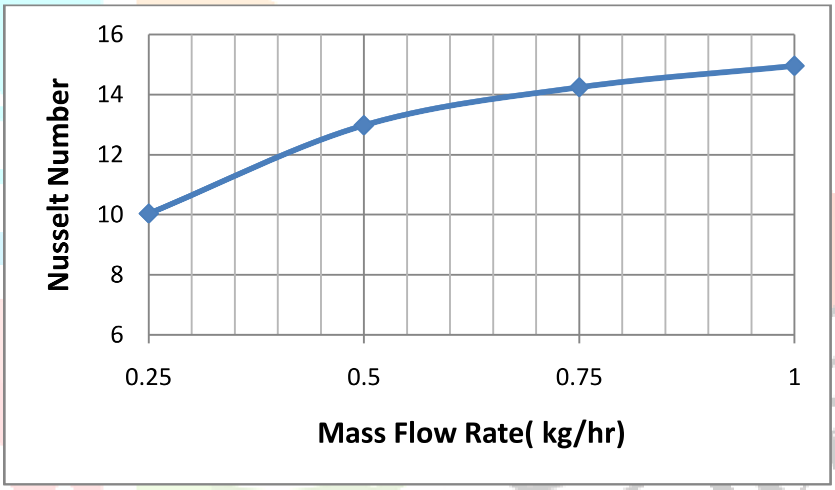

Fig. 9 Variation of Nusselt number with mass flow rate

The heat absorbed by the water is also calculated from the simulated results and is found to be 453 W which remains constant for the different mass flow rate conditions. Also, the model is simulated with Roseland radiation solar model for which the heat insolation remains constant as 854 W/m^2 for the various cases of the mass flow rate. Thus, the collector efficiency is found to be constant as 51% irrespective of the mass flow rate of the water through the collector.

IV. Conclusion

A Parabolic Trough modeled is designed and simulated in the Ansys Workbench software for different mass flow rate of the water in the receiver. The Roseland radiation model is used along with the solar calculator to simulate the parabolic trough collector for the solar loading. The mass flow rate of water through the receiver pipe is varied and all the results obtained were noted. The maximum water outlet temperature is found to be 366^{0}K and it is found to decrease up to 318^{0}K with increase in mass flow rate from mass flow rate of 0.25 kg/hr to kg/hr respectively. Although the temperature decreases, but the heat transfer rate enhances with the increase in mass flow rate shown by increased heat transfer coefficient and Nusselt number. The heat transfer co-efficient increases as well as the Nusselt number with increase in the mass flow rate of water inside the receiver of the PTC model. The collector efficiency is found to be constant as 51 % irrespective of the mass flow rate with heat absorbed as 453 W remains constant for all the cases.

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