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Thermal analysis of Copper tube receiver of solar parabolic dish collector using computational fluid dynamics

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ABSTRACT- Parabolic dish collector is one of Concentrating Solar Power technologies that convert sunlight into heat energy. Parabolic dish has shown the highest efficiency by converting nearly 31.25% of solar radiation into heat energy and Parabolic dish has emerged as one of reliable and efficient Renewable Energy technology. However, the evaluation for the parabolic dish collector performance by using experimental approach is costly and time consuming. Therefore, a model has become necessary to predict the system performance under several of operating conditions. A numerical study on the performance of a solar parabolic dish collector has been done by focusing on helical coiled receiver made up of different material which is placed at focal point, which is designed and modeled using 3D modeling software NX™ 8.5 The experimental device consists of a dish has 1.4 m opening diameter. The interior surface of the parabolic dish collector is covered with a anodized aluminum reflecting material and equipped with a helical coil receiver in its focal position. The present model has 15 turns' coils for solar receiver and Water at room temperature is use as a working fluid to receive the heat from the solar radiation incident on the reflector. Heat transfer analysis is done on the parabolic dish collector by applying different temperatures effecting in a particular day, also performance of solar parabolic dish collector is validated by using three materials such as Copper, Steel and Steel with experimental results. Computational fluid dynamics analysis has been carried out to determine the outlet fluid temperature and mass flow rate of the fluid. Heat transfer analysis and computational fluid dynamics analysis is done by using ANSYS™ 14.5 software.

Key wards: Parabolic Dish Collector, Helical coil receiver, Thermal Analysis, ANSYS™ 14.5, NX™ 9.0

I. INTRODUCTION

Thermal radiation, conduction and convection continue to emerge as an important heat transfer mechanism in a wide variety of practical systems such as solar concentrators and high-temperature heat exchangers. So many high temperature solar concentration systems are available in the market such as parabolic reflectors. Four concentrating solar power technologies are developed such as parabolic trough collectors (PTC), linear Fresnel reflector systems (LF), power towers or central receiver systems (CRS) and parabolic Dish collectors (PDC). Among the CSP technologies, the parabolic dish collector is recognized as the most efficient system for energy conversion. The successful implementation of any new technology depends on the cost efficient conversion of energy. The cost of a solar collector field were determined basically by its size, while the cost of the energy generation depends on both the collector field cost and the amount of the energy collected by the collector. The way to increase solar energy conversion is by decreasing the effect of shadow falling on the collector. The economic viability of the solar concentrator system depends on design and configuration of the system. The configuration of the solar collector has to be based on minimum shading of one dish on another so that land utilization is maximum. Ouederni and et.al [1] has been studied experimentally on a parabolic solar concentrator consists of a dish of 2.2 m opening diameter. The interior surface of the concentrator was covered with a reflector and disc receiver in its focal position. Two semi-automatic jacks ensured the orientation of the parabola of the concentrator. Readings of the solar flux and temperature distribution on the receiver carried out experimentally. In this work, solar concentrator system has been constructed and tested by using two discs receivers. The first experiment consists of a thick disc at the focal position in order to carry out the temperature distribution on the lighted face of the thick disc. The second experiment consists of a thin disc at the focal region in order to determinate the concentrated solar flux and efficiency of the system. Temperature at the center of the disc is about 400 K. and found that the parabolic dish collector has good efficiency. Atul and et.al [2] worked on the nickel chrome coated receiver and found the effect of variation of mass flow rate on the performance of the parabolic dish collector. They design of solar parabolic dish collector with truncated cone shaped helical coiled receiver made up of copper. They compare the parabolic solar dish collector water heater, flat plate and evacuated tube collectors, and found that the parabolic solar dish collector water heater is a good alternative. Also found that when receiver is covered with glass cover and flow rate is reduced, system performances get enhanced. Deepak Sonawane and Vinod Tungikar [3] worked on theoretical and experimental study for evaporation of water in the effluent by using serpentine tube flat plate collector. The performance of the flat plate collector depends on various factors including the collector construction and the arrangement of the system. The working model is fabricated to prove the feasibility and viability of the evaporation system. Results obtained show that the evaporation rate of water in the effluent increases, with the increase in solar radiation, wind velocity and decrease in mass flow rate of effluent, relative humidity and concentration of the effluent. The evaporation rate of effluent in the single cover serpentine tube flat plate collector is found to increase by 41 % compared to the solar pan and 16% to the single cover FRP flat plate collector. Ketan and et,al [4] worked on the parabolic trough collector by using the finite volume based CFD code of ANSYS FLUENT 14.5. They used nano-fluids as a working fluid in parabolic dish collector to enhance its efficiency. They improve thermo-physical properties like thermal conductivity, heat capacity, density and viscosity by using nano-fluids. In this paper, both experimental and computational fluid dynamics study has been presented with used of 0.01% CuO- H_2O nano-fluid. The performance of the system is conduct with mass flow rate of 20 Liters/hr In ANSYS FLUENT 14.5 based computational fluid dynamics tool. The absorber tube in this model is used as metallic copper tube with working fluid flowing in it. Solar load model has been used for modeling solar fluxes. S2S radiation model has been used for modeling heat transfer comprising of conduction, convection and radiation. They reported that from both experimental and CFD analysis, the system performance is enhanced by using Nano-fluid as working fluid as compared to conventional fluids. From both the experimental and CFD analysis it is found that the thermal efficiency improved by and 7.4% when 0.01% CuO-H2O Nano-fluid is used. Deepak Sonawane and Vinod Tungikar [5] In this paper theoretical and experimental study of serpentine tube flat plate collector for evaporation of water in the effluent is presented. The performance of the flat plate collector depends on various factors including the collector construction and the arrangement of the system. The prototype-working model has been fabricated to prove the feasibility and viability of the evaporation system. Results obtained show that the evaporation rate of water in the effluent increases, with the increase in solar radiation, wind velocity and decrease in mass flow rate of effluent, relative humidity and concentration of the effluent. The evaporation rate of effluent in the single cover serpentine tube flat plate collector is found to increase as compared to the solar pan and single cover FRP flat plate collector. Mohand and et.al [6] design a solar parabolic dish collector with truncated cone shaped helical coiled receiver made up of copper and coated with nickel chrome. The present model has 15-coiled and 20-coiled receiver to investigate the performance of the collector. Heat transfer analysis is made on the parabolic dish collector by applying different temperatures effecting in a particular day. CFD analysis is done to determine the outlet fluid temperature, mass flow rates etc. The temperature of water increased from 308 K to 411 K for helical coil of 15 turns and the temperature of water increased from 308 K to 468 K for helical coil of 20 turns. He found that as surface area increases the temperature also increases. The temperature/heat of fluid can be used by micro-turbine to generate electric power in domestic steam power plant

II. METHODOLOGY

In this study, 1.4 m of the opening diameter of the concentrator and receiver is placed at the focal point, which is at 0.75 m from center of concentrator. Modeling is done on the 3D modeling software NX™ 8.5. Modeling starts with the describing of the boundary and initial conditions for the dominion and leads to modeling of the entire system. Finally, it is follow by the analysis of the results, conclusions and discussions. In this

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CFD model of Receiver is formulate and investigated by using the receiver of Copper and Steel on the ANSYS™ 14.5 software.

2.1 Concentrator

Concentrator is used for collecting the solar ray coming from sun and concentrates it on the receiver, which is placed at focal point. When solar radiation is concentrated in the small area, this will increase the solar radiation density to increase the temperature.

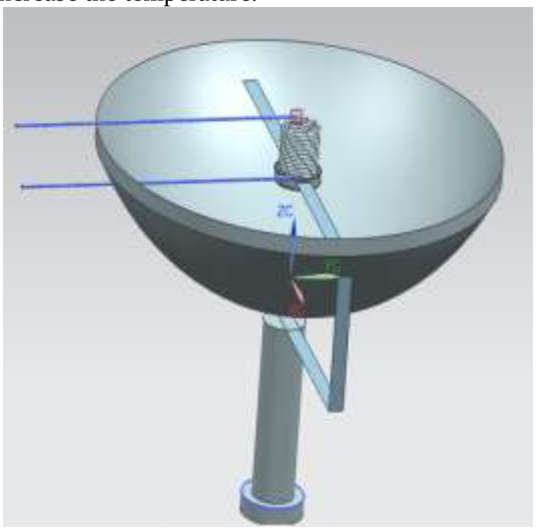

Fig-1: 3D Concentrator model

Fig-2: Experimental setup of concentrator

2.2 Receiver

Receiver absorbs the heat energy from solar radiation, which is incident on concentrator and heating the working fluid at receiver. Here we use 15 turns of coil of copper and steel material for the analysis.

Fig-3: 3D Receiver Model

Fig-4: Experimental setup of receiver

III. DESIGN PARAMETER

a) Receiver parameter

Table1.Receiver parameter

Receiver (Coil) Parameter CFD Meshing:	Value
Outer diameter of coil	125mm
Inner diameter of tube	10mm
Outer diameter of tube	8 mm
Thickness of tube	1 mm
number of turns of coil	15

b) Water properties

Table 2.Water property

Water Parameter	Value
Density	1000 kg/m^3
Viscosity	0.008 kg / m-s
Specific Heat	4.187 kJ/kg-K
Thermal Conductivity	0.6 W/m-K

c) Material properties (Copper)

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Table 3. Copper property

Copper Parameter	Value
Density	8978 kg/M^3
Specific Heat	381 J/kg-K
Thermal Conductivity	387.6 W/m-K

d) Material properties (Steel)

Table 4. Steel property

Steel Parameter	Value
Density	8030 kg/M^3
Specific Heat	502 J/kg-K
Thermal Conductivity	45 W/m-K

IV. INTRODUCTION TO CFD

The science of predicting fluid flow, heat transfer, mass transfer, phase change, chemical reaction, mechanical movement, stress or deformation of related solid structures (such as mast bending in the wind), and the related phenomena by solving mathematical equations that govern these processes using a numerical algorithm on a computer. The governing equations of fluid flow and heat transfer are considered as mathematical formulations of the conservation laws of fluid flow and are refer to as the Navier-Stokes equations. By using these conservation laws over discrete spatial volumes in a fluid domain, it is possible to achieve a systematic account of the changes in mass, momentum and energy as the flow crosses the volume boundaries. The resulting equations can be written as

Continuity equation

$$\frac{\partial \rho Ui}{\partial t} + \frac{\partial}{\partial xi}(\rho Ui) = 0 \quad (1)$$

Momentum equation

$$\left(\frac{\partial \rho Ui}{\partial t} + \frac{\partial}{\partial t}(\rho UiUj)\right) = -\frac{\partial}{\partial xj}(\rho \delta ij + \mu[\frac{\partial Ui}{\partial xj} + \frac{\partial Uj}{\partial xi}] + \rho gi$$

(2)

Energy Equation

$$\frac{\partial(\rho CpT)}{\partial t} + \frac{\partial}{\partial xi}(\rho UiCpT) - \frac{\partial}{\partial xj}(\lambda\frac{\partial T}{\partial xi}) = \mathrm{ST}$$

(3)

4.1 Geometry

Main component of parabolic disc collector is the receiver. The receiver has been developed as constructed drawing using a three-dimensional drawing tool NX.9. The whole model is developed by using real scale as outer surface as a wall. The resulting solid model has been exported as a file in .STEP format for next Analysis in ANSYS WORKBENCH

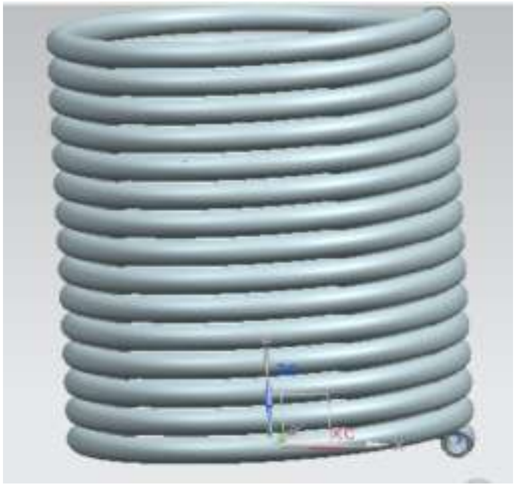

Fig-5: Receiver Geometry

4.2 CFD Meshing

The three-dimensional computational domain is modeled using mesh as shown in Figure 4. Then after making model by using ANSYS Work beach 14.5 Export in to the fluent computational fluid dynamics after that, import to in fluent make boundary as inlet water input coil to output water outlet coil.

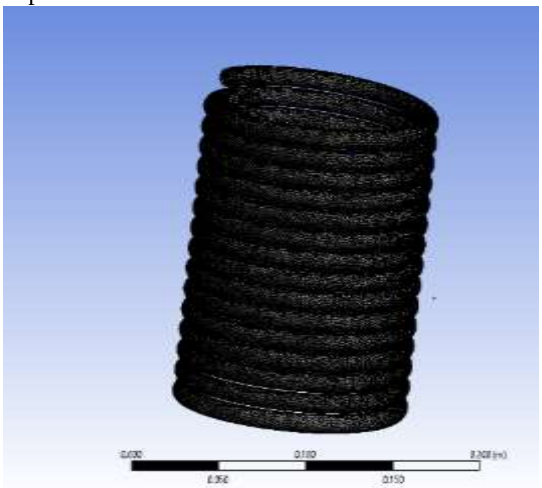

Fig-6: Meshed model

Table 5 shows the meshing details of a receiver

Table 5 meshing details of a receiver

Relevance center	coarse
smoothing	medium
nodes	227655
element	711541

4.3 Boundary Conditions

The inlet and outlet conditions are defined as velocity inlet and pressure outlet.

The inlet condition water mass flow rate 0.11 Kg/s.

Initial Temperature of water is 300K.

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Material Description = Water (saturated liquid) at 100
Density = 958.4 kg/m^3,
Molar Mass = 18.02 kg/kmol,
Specific Heat Capacity = 4215.7J/kg K,
Specific Heat Type = Constant Pressure.
Reference Pressure = 1.014 bar,
Reference Specific Enthalpy =1.5552049E+7 J/kg,
Reference Specific Entropy = 4.8215097E+03 [J/kg/K],
Reference Temperature = 100K,
Dynamic Viscosity = 2.817E-4 kg/m s,
Thermal Conductivity = 0.6791 W/m K,
Absorption Coefficient = 1.01/m,
Scattering Coefficient = 0.0 1/m,
Thermal Expansively = 7.4E-04 1/K.
Use default property of Steel and Copper.

V. RESULT AND DISCUSSION

The result contains the analysis performed on the receiver as a helical coil of 15 number of turns and the by using cooper and steel as a two coil material and find out the temperature analysis and pressure distribution on receiver by using CFD fluent. The longitude (deg) is 77.66, latitude (deg) is 19.09, and Time zone (+ GMT) is 5.3 at Nanded.

The convergence was monitored keeping the residual target for all equations as 10^{-4} except for the energy equation, for which a target of 10^{-6} was used, as shown in Figure 7 and this was achieved in most of the cases that were considered for the present analysis.

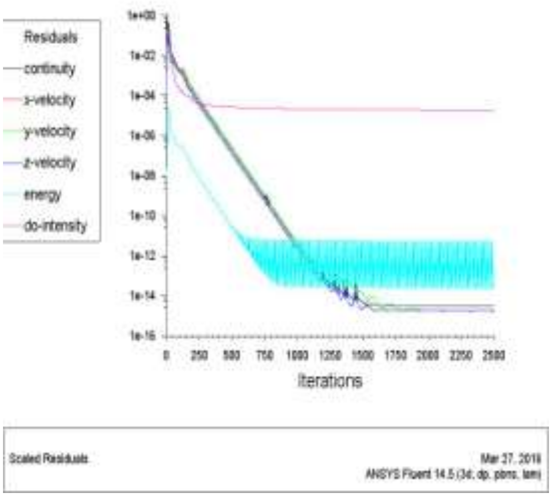

Fig-7: Convergence Graph

Radiation incident on receiver is up to the $5.01e^{03}$ (w/m^2) is shown in figure 8.

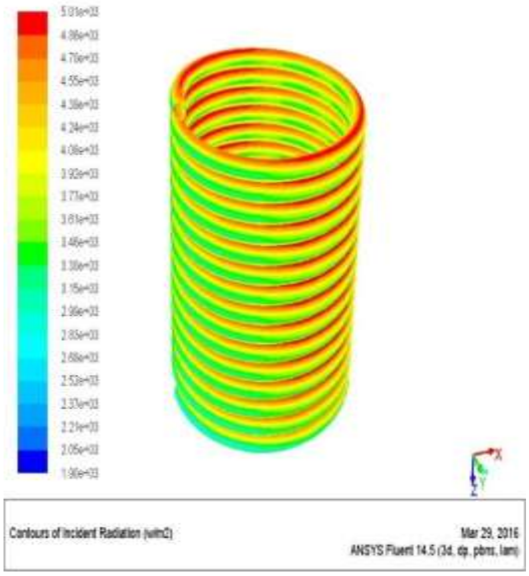

Fig-8: Radiation profile

Temperature analysis on steel coil receiver is shown in figure 9.

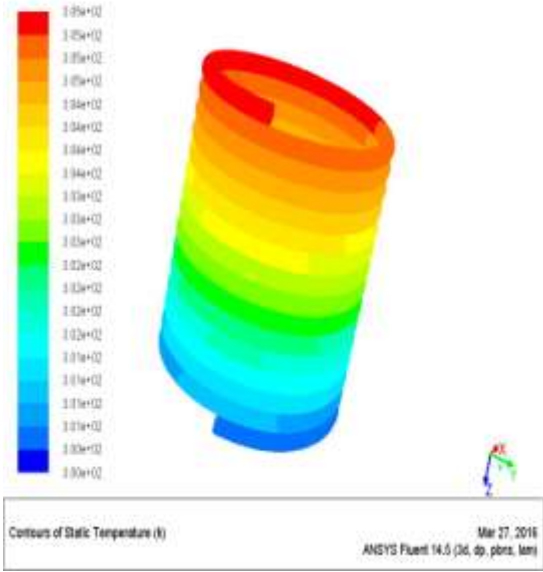

Fig-9: Temperature on Steel coil

Temperature analysis on Copper coil receiver is shown in figure 10.

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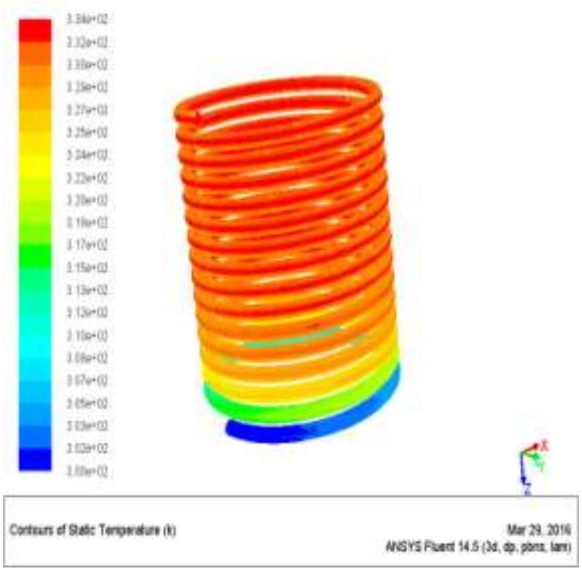

Fig-10: Temperature on copper coil

The temperature of the steel coil increase from 300 K to 305 K and for copper coil 300K to 334K.

VI. CONCLUSION

Parabolic dish concentrator and modeling of the helical coil receiver are created by using 3D modeling software NX^{TM} 8.5, where the helical coil receiver is the most important part in the parabolic shaped solar dish collector system. This study analyses the 3D CFD model of the receiver by comparison between copper and steel material of coil. The temperature of the steel coil increase from 300 K to 305 K and for copper coil 300K to 334K.its shows that rise in temperature is depends on the thermal conductivity of the material, the material having high thermal conductivity has better performance also if surface area is increases then we obtained the good efficiency. When receiver is covered with glass cover and flow rate is reduced, system performance get enhanced. The performance of the system get enhanced by covering the receiver

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