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Research Article

PERFORMANCE ANALYSIS OF Al_2O_3 / SiC COATING ON ABSORBER TUBE OF SOLAR PARABOLIC TROUGH COLLECTOR

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A R T I C L E I N F O

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A B S T R A C T

A parabolic trough is a type of concentrating collector in which the energy from the sunlight is reflected and focused on the absorber tube. In this paper a parabolic trough collector has been considered. Porous materials have higher thermal conductivity compared than the base material. This work focused on the performance of parabolic trough collector which have Al_2O_3 and SiC coating on the absorber tube. Absorber tube of collector was designed and modeled using SOLIDWORKS. The absorber tube's performance was calculated theoretically without coating on it. A 3D CFD model was developed and analyzed using ANSYS FLUENT. Absorber tube made up of stainless steel was simulated with flow of water and analyzed using computational fluid dynamics software. At the end of simulation, temperature distribution over the absorber tube was studied. A comparative simulation has been made between with and without Al_2O_3 and SiC coating on absorber tube. Absorber tube with SiC coating was found to better when compared than Al_2O_3 coating and without coating and its result has shown an increase on absorber tube performance. Simulation results were showed a better agreement with already available research articles.

INTRODUCTION

A solar thermal collector collects heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared to the ultraviolet wavelengths. The quantity of solar energy striking the Earth's surface averages about 1,000 watts per square meter under clear skies, depending upon weather conditions, location and orientation. The term "solar collector" commonly refers to solar hot water panels, but may refer to installations such as solar parabolic troughs and solar towers; or basic installations such as solar air heaters. Solar power plants usually use the more complex collectors to generate electricity by heating a fluid to drive a turbine connected to an electrical generator. Simple collectors are typically used in residential and commercial buildings for space heating. Solar collectors are broadly classified into two categories such as flat plate or non- concentrating type solar collector and focusing or concentrating solar collector.

In the non-concentrating type, the collector area is the same as the absorber area. In these types the whole solar panel absorbs light. Concentrating collectors have a bigger interceptor than absorber.

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Flat-plate and evacuated-tube solar collectors are used to collect heat for space heating, domestic hot water or cooling with absorption chillers.

Concentrating collectors are also known as focusing collectors. They employ curved and multiple point target reflectors or lenses to increase radiation on a small area. The area where the solar radiation is absorbed can be a point focus or a line focus. A concentrating collector consists of three basic components such as reflector, absorber and housing unit. A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal mirror. The energy of sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line where objects are positioned that is intended to be heated [12].

LITERATURE REVIEW

Literature papers are reviewed for the works done by other researchers related with advancement and development attained in solar parabolic trough collector has been used as a reference sources, support and back ground for this project. Many papers have been reviewed, but most of them are briefly mentioned and papers with more significant contribution to the field are discussed the advantages and disadvantages of the solar collectors, CFD, Al_2O_3 and SiC coating, which will be helpful in executing the project.

Solar energy is one among the freely available clean forms of renewable energy. Many technologies have been developed in India for extracting energy from assorted renewable energies, but the maximum extraction of thermal energy from solar energy is the most promising challenge. This paper focuses on the performance and efficiency of solar parabolic trough collector. It also reviews the pertinent applications of solar energy such as air heating system, desalination, refrigeration, industrial heating purposes and power plants [1]. A review on the applications of porous materials in solar energy systems, an idea of research was the insert of porous material inside a solar system is a simple modification without energy consumption for improving the efficiency of the system. Silicon carbide porous material is a prospective absorber material for heat transfer improvement in solar energy systems due to large specific surface areas and excellent temperature tolerance [2]. Concentrated solar power has great potential for large scale renewable energy sources, and is currently an eye catching one for its utilization with wide area of improvement. Especially, parabolic trough solar collectors are gaining popularity due to their increased efficiency as compared to photovoltaics. In this work, an effort has been made to evaluate the performance of a designed 5-m length PTSC model. Heat collecting element was made of stainless steel with water as working fluid. Simulation studies were carried out using ANSYS software on receiver tube to ensure the robustness and design effectiveness under static loading conditions [3]. Solar Parabolic Trough Collectors are currently used for the production of electricity and applications with relatively higher temperatures. A heat transfer fluid circulates through a metal receiver tube with an external selective surface that absorbs solar radiation reflected from the mirror surfaces of the PTC. In this paper a detailed one dimensional numerical heat transfer analysis of a PTC is performed [4].

METHODOLOGY

In this present work, computational fluid dynamics is used to analyse the performance of solar parabolic trough collector.

Computational fluid dynamics (CFD)

Computational fluid dynamics is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyse problems that involve fluid flows. Computational fluid dynamics is the science of predicting fluid flow, heat transfer, mass transfer, chemical reactions, and related phenomena by solving the mathematical equations which govern these processes using a numerical process. The fundamental basis of almost all CFD problem are the Navier –Stokes equations, which define any single-phase fluid flow.

Design consideration

The computational model is based on a steady-state heat transfer condition. The model was created by SOLID WORKS modeling software based on the following calculations. ***Fig.1*** shows a 3D model of parabolic trough collector.

Aperture is the opening through which the solar radiation enters.

Here, Aperture of collector = 2Ys= 1m

Height (h) = 0.2m

The **focal length** is calculated by,

$$f = Ys^2 / 4h \qquad \textbf{(1)}$$

$$= (0.5)^2 / (4\times0.2)$$

$$= 0.3125 \text{ m.}$$

Rim angle φ_R is related to aperture and focal length **f** by,

$$\tan\varphi_R = 8(f/Ys) / (16(f/Ys)^2 - 1) \qquad \textbf{(2)}$$

$$= 8(0.3125/0.5) / (16(0.3125/0.5)^2 - 1)$$

$$= 0.9523$$

$$\varphi_R = 43.6°$$

Absorber tube specifications

The absorber tube is typically stainless steel tube with selective absorber coating which provides the required properties.

- Inner diameter : 0.022m
- Outer diameter : 0.025m
- Length : 0.5 m
- Material : Stainless steel

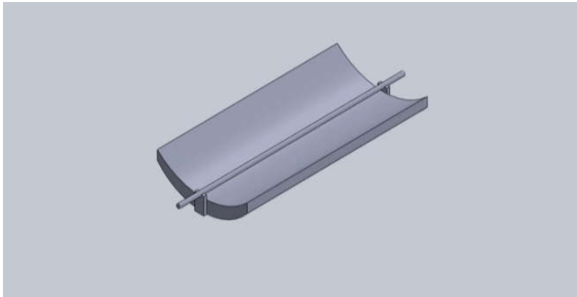

Fig 1 3D model of parabolic trough collector

Coating materials

- Aluminium oxide : 1mm
- Silicon carbide : 1mm

Table 1 clearly shows the properties of stainless steel, Aluminium oxide, silicon carbide, which are used for absorber tube and it's coating of parabolic trough collector.

Table 1 Material properties [13]

Properties	Materials		
	Stainless steel	**Aluminium oxide**	**Silicon carbide**
Density	8000 Kg/m^3	3950 Kg/m^3	3210 Kg/m^3
Thermal conductivity	16.2 W/m.K	25 W/m.K	120 W/m.K
Specific heat	500 J/Kg.K	880 J/Kg.K	750 J/Kg.K
Coefficient of thermal expansion	16.5×10^{-6}/°C	8.1×10^{-6}/°C	4×10^{-6}/°C
Melting point	1,400°C (1,673 K)	2,072°C (2,345 K)	2,730 °C (3,003 K)

Geometric model

The geometric model of absorber tube without and with coatings is shown schematically in ***Figures 2, 3*** and ***4***. Direct solar radiation is reflected by the parabolic trough reflector, most of energy is absorbed by absorber tube. This absorber tube transmits useful heat to fluid.

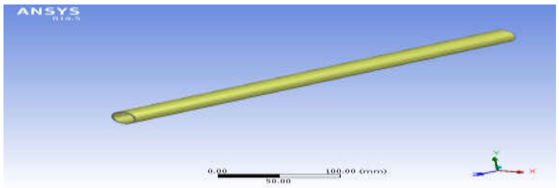

Fig 2 Stainless steel tube without coating

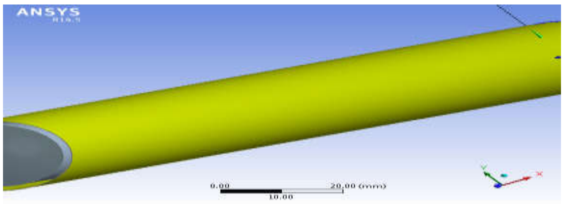

Fig 3 Aluminium oxide coated absorber tube

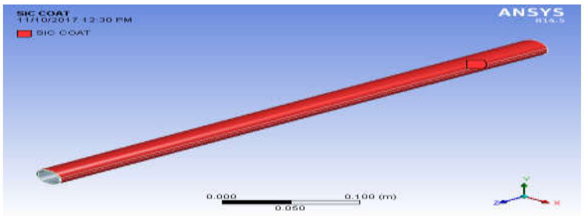

Fig 4 Silicon carbide coated absorber tube

Theoretical evaluation

Parameters of PTC without Coating:

- Reflectivity of concentrator = 0.85
- Glass cover transmissivity = 0.85
- Absorber tube [Emissivity
- /absorptivity (£/α)] = 0.95
- Intercept factor = 0.95

Operational and Geographical parameters

- Location : Coimbatore, Tamilnadu.
- Longitude : 76°59' E.
- Date : July 31.
- Time : 11.00 am.
- Solar radiation : 840 W/m^2.
- Ambient temperature : 27°C.
- Mass flow rate :0.04142 kg/s.
- Inlet temperature : 30 °C.
- Latitude : 11° 02' N.

Angle of declination of sun

$$\delta = 23.45 \sin [(360/365)(284+d_n)] \quad (3)$$

$$= 23.45 \sin [(360/365)(284+212)]$$

$$= 18.17^\circ.$$

Assume, $\omega = -7.5^\circ$

$\varphi = 19.12^\circ$

Angle of incidence

$$\cos\theta = (1-\cos^2(\delta)\sin 2(\omega))^{0.5} \quad (4)$$

$$= (1-\cos^2(18.17)\sin^2(-7.5))^{0.5}$$

$$\theta = 7.2668^\circ.$$

Beam radiation

$$r_b = \cos\theta/(\sin(\varphi)\sin(\delta)+\cos(\varphi)\cos(\delta)\cos(\omega)) \quad (5)$$

$$= 0.99196/(\sin(19.12^\circ)\sin(18.17^\circ)+\cos(19.12^\circ)\cos(18.17^\circ)\cos(-7.5^\circ)) = 1.$$

Where,

δ = Dispersion angle

ω = Hour angle

Solar flux absorbed

$$S = I_b r_b \rho\gamma(\delta\alpha)b + I_b r_b(\delta\alpha)b(D_o/(W-D_o)) \quad (6)$$

$$=840\times1(0.85\times0.95\times0.85\times0.95+((0.85\times0.95\times0.025)/(1.2-0.025))$$

$$= 562.15 \text{ W/m}^2.$$

Average velocity of fluid

$$(V) = m/(\pi/4)(D_i^2\rho) \quad (7)$$

$$= 0.04142/(\pi/4)\times(.022^2\times998.2)$$

$$= 0.109 \text{ m/s}.$$

Where,

m = Mass flow rate of water

ρ = Density of water

CFD Analysis

From the above theoretical evaluation boundary condition has given to the numerical model to get the result. Setting material properties – Stainless steel, Aluminium Oxide, Silicon carbide and Fluid properties- water Liquid properties at 300K.

- Tube wall : Heat Flux
- Fluid inlet : velocity of water
- Fluid outlet : pressure outlet
- Interface : convection

Solution

Setting material properties-Fluid properties- water Liquid properties at 300K,

- Density : 998.2Kg/m^3
- Specific Heat : 4182 J/KgK
- Thermal conductivity : 0.6 W/mK
- Viscosity : 0 .001003Kg/m.s

The ***Figures 5, 6*** and ***7*** shows the converged solution of absorber tube without coating, with Al_2O_3 coating and SiC coating

- Tube wall : Heat Flux
- Fluid inlet : velocity of water
- Fluid outlet : pressure outlet
- Interface : convection

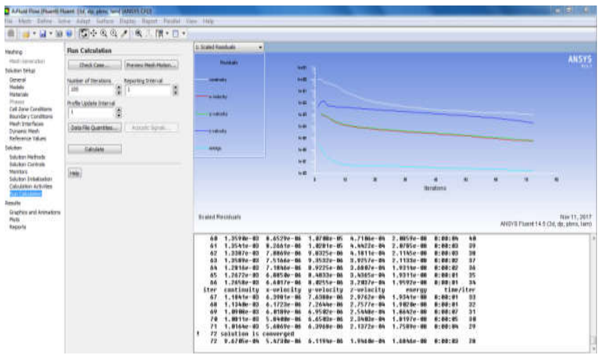

Fig 5 Converged solution of absorber tube without coating

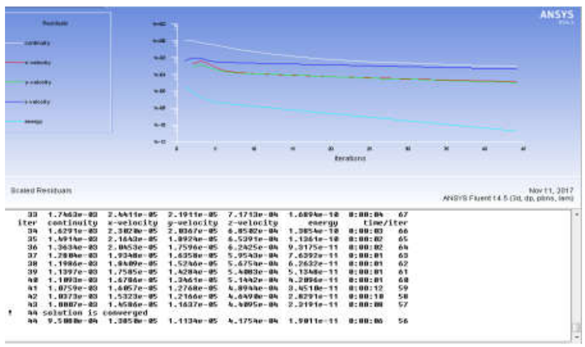

Fig 6 Converged solution of the absorber tube with Al_2O_3 coating

The simulation defined with 100 iteration and precision of the solution up to 10^{-4} However, the solution is converged at 44^{th} iteration.

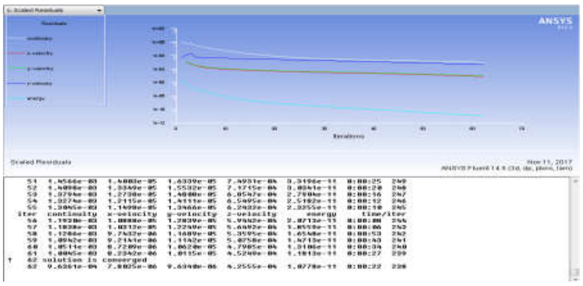

Fig 7 Converged solution of absorber tube with SiC coating

The simulation defined with 100 iteration and precision of the solution up to 10^{-4} However, the solution is converged at 62^{th} iteration.

Post processing

In the post processing the output can be displayed in contours.Temperature distribution and outlet temperature of stainless steel absorber tube without coating, with Al_2O_3 coating and SiC coating are presented in *Figures 8, 9* and *10*.

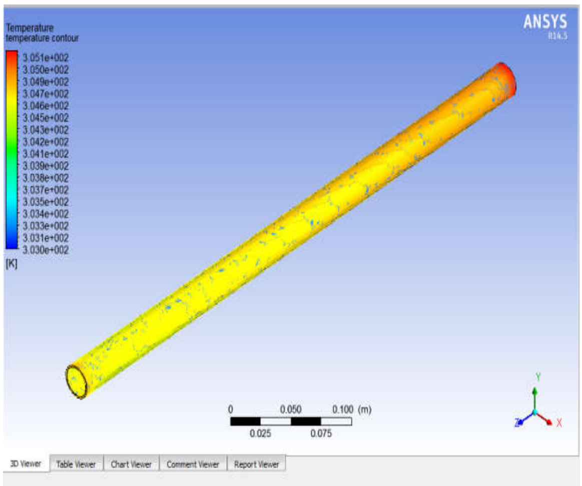

Fig 8 Temperature distribution and outlet temperature of fluid in stainless steel absorber tube

Inlet temperature = 303 k
Outlet temperature = 305 k
Net =304 k

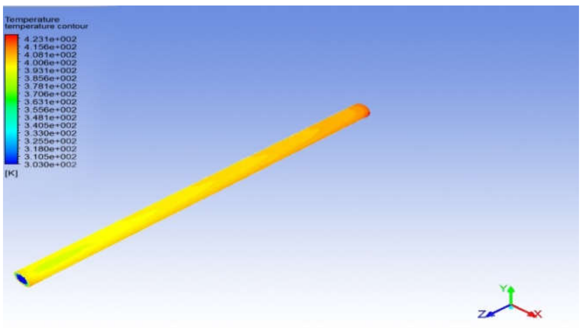

Fig.9 Temperature distribution and outlet temperature of fluid in Al_2O_3 coated absorber tube

Inlet temperature = 303k
Outlet temperature = 423k
Net = 363k

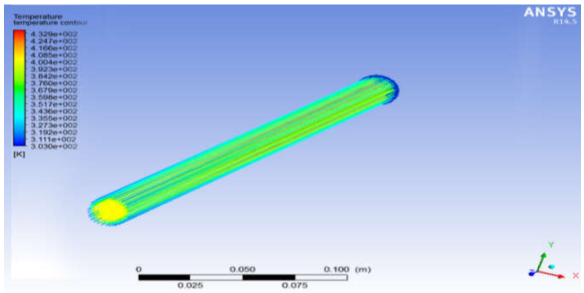

Fig 10 Temperature distribution and outlet temperature of fluid in SiC coated absorber tube

Inlet temperature = 303k
Outlet temperature = 433k
Net = 368k

RESULTS AND DISCUSSION

In this section, an analysis to determine the performance of the parabolic trough collector was carried out only under steady-state conditions.

Temperature profiles

Temperature profile of the absorber tube with SiC coating is shown in ***Fig.13***, which shows the uniform distribution and improved performance when compared with absorber tube without coating and with Al_2O_3 coating, are shown in ***Figures 11, 12*** respectively.

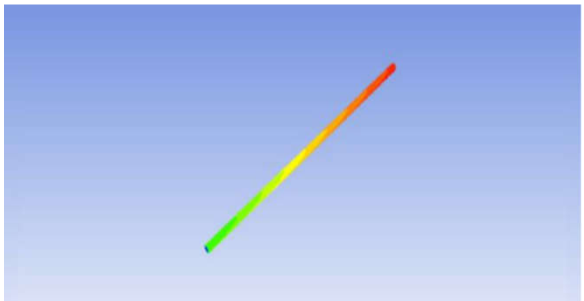

Fig.11 Temperature profile of the tube without coating

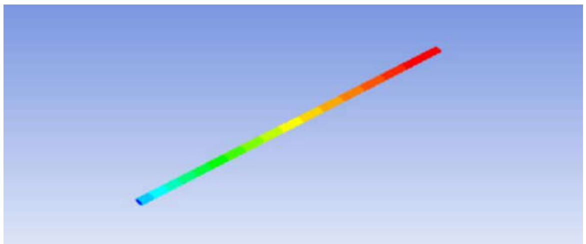

Fig.12 Temperature profile of the tube with Al_2O_3 coating

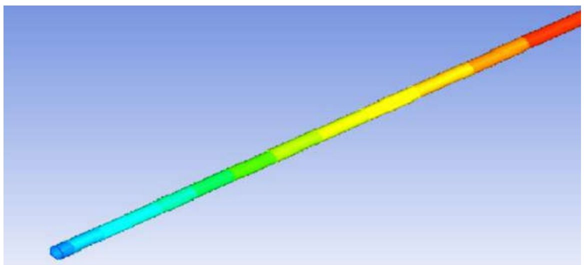

Fig.13 Temperature distribution of the tube with SiC coating

Velocity profile

Fig. 14 shows the velocity profile of SiC coated absorber tube in a steady-state condition, the fluid inlet velocity and temperature are 0.109m/s and 303K.

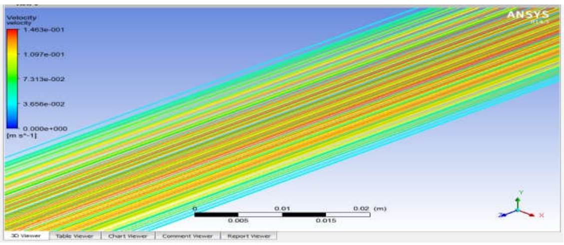

Fig 14 Velocity profile at the inner side of SiC coated absorber tube

Outlet temperature of the fluid increased when it coated with Al_2O_3 and SiC coating. ***Table 2*** shows the results of compared performance of materials. A comparison is made between with and without Al_2O_3 and SiC coating on absorber tube.

Table 2 Comparison of material performance

SS. No	Heat flux(W/m^2)	Material	Inlet temperature (k)	Outlet temperature (k)
1		Stainless steel	303	305
2	562.15	Aluminium Oxide coating	303	423
3		Silicon carbide coating	303	433

Comparison between without coating and with Al_2O_3 coating of absorber tube

Increased performance (%

$$= [(max-min)/max]\times 100$$
$$= [(423-305)/423] \times 100$$
$$= 27.8 \%.$$

Comparison between without coating and with SiC coating of absorber tube

Increased performance (%)

$$= [(max-min)/max]\times 100$$
$$= [(433-305)/433] \times 100$$
$$= 29.6 \%.$$

Fig.15 shows absorber tube performance variations with respect to inlet temperature and materials.

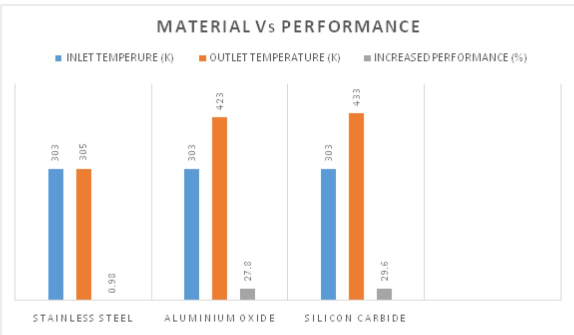

Fig15 Material Vs Performance

CONCLUSION

Power production from solar is gaining momentum in recent years. Among the various collectors, concentrated type parabolic trough collector is widely used in power plant applications. This work focused on to increase the performance of parabolic trough collector with coating on absorber tube.

The effective design of absorber tube is useful to convert solar energy to heat energy with minimum heat losses. In this work absorber tube of parabolic trough is designed and its performance evaluated theoretically without coating on the absorber tube. A comparative CFD analysis was performed on the absorber tube without and with Al_2O_3, SiC coating. Absorber tube with Al_2O_3 coating has shown a increased performance of 27.8% and SiC coating has shown a increased performance of 29.6%.

Absorber tube with SiC coating was found to better when compared than with Al_2O_3, without coating and its result has shown a increase on absorber tube performance. The results obtained showed good agreement with already available research article, such reported a 17.5% increase in the performance by including the silicon carbide inserts in absorber tube [2].

Future scope of this project

Based on the theoretical and CFD analysis the performance of the collector increased when it has Al_2O_3 and SiC coating on the absorber tube. From these results an experimental study is going to be done.

Acknowledgement

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