

HEAT TRANSFER ANALYSIS OF RECEIVER/ABSORBER TUBE OF PARABOLIC TROUGH COLLECTOR

¹D.R. Waghole., ²Dr. R.M Warhedkar, ³Dr. V.S.Kulkarni, ⁴Dr. N. K. Sane, ⁵Dr. G.V.Parishwad

¹PhD Research Scholar, Dept of Mechanical Engg, Govt. College of Engineering, Aurangabad, Maharashtra

²Dept Of Mechanical Engg, Government College Of Engineering, Aurangabad, Maharashtra

raviwar@indiatimes.com³Professor, Dept of Mechanical Engg, Government College Of Engineering, Aurangabad, Maharashtra

⁴Professor, Dept of Mechanical Engineering, Vishwakarma Institute of Technology, University Of Pune, Pune, Maharashtra

⁵Professor, Government college of Engineering Pune, Pune, Maharashtra gyparishwad@rediffmail.com

ABSTRACT

The solar energy option has been identified as one of the promising alternative clean source for future. Investigation of heat loss from receiver and Heat transfer from the receiver to the working fluid are very important in determining the performance of solar parabolic trough collector. In the present study the concepts of engineering, physics, energy, economy etc. are going to be used. In this study numerical Model is being formulated for the receiver for internal heat gain characteristics and heat loss due to Natural convection as studied by Ravikumar and Reddy. [2, 5] but in the present study smooth receiver geometry is designed for analysis. The internal flow and heat transfer analysis is being carried out on a RNG, $k-\epsilon$ turbulent model whereas external heat losses are treated as Laminar conventional model. The Numerical model is being solved using commercial engineering package Fluent 6.2. The experimental investigations of receiver is being carried out for various geometrical parameters such as angle, orientation, aspect ratio, height of receiver, heat flux conditions with working fluids (Heat transfer fluids, nanofluids). Also the experimental analysis of various receiver geometries (smooth and porous) is being considered for the evaluation of solar parabolic trough concentrator. The working fluids are heat transfer fluid, nanofluids. These fluids are engineered colloidal suspensions of nanoparticles in base fluid. The nanoparticles used in nanofluids are typically made up of metals, oxides, carbides, or carbon nanotubes. The commonly used nanoparticles include copper, CuO, Al₂O₃, TiO₂, gold and silver. Common base fluids include water, ethylene glycol and oil. A base liquid (nanoparticle fluid suspensions), is the term first coined by Choi in 1995 at the Argonne National Laboratory to describe the new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their base fluids or conventional particle fluid suspensions. The applications of additives in working fluid are one of the methods to enhance heat transfer of heat transfer devices to change fluid transport properties and flow features. Hence in this work an attempt is made to reduce heat losses and to enhance heat transfer from receiver/absorber.

Keywords-Heat transfer, receiver, Numerical Model, fluent, receiver geometries, CFD.

INTRODUCTION

Solar energy is an exhaustible source of energy potentially capable of meeting a significant portion of all nations Future energy needs with a Minimum of adverse environmental consequences. The current industrial growth and Environmental impacts shows that solar energy for solar thermal plant is the most promising of Unconventional energy source. The solar energy option has been identified as one of the promising Alternative source for future. Solar thermal utilization is of great importance for environmental Protection and conventional energy saving. . Higher thermodynamic efficiency can be achieved by using concentrator studied by S.P.Sukhatme [1].

Many designs have been considered for Concentrating collectors. Among the family of solar concentrating collectors, parabolic trough Collector (PTC) is currently receiving considerable attention for a wide range of applications from domestic hot water production to steam generation for power and industrial process heat generation.

The case of cylindrical parabolic concentrator /Compound parabolic concentrator fluid temperature up to 400°C can be achieved. The most common commercially available solar plants use parabolic trough concentrator. A parabolic collector includes the receiver tube, concentrator and power transmission collector structure. The Receiver is the element of system where solar radiation is absorbed and converted to thermal energy. It include the absorber tube, it's associated glass cover and insulation at its end .The Thermal Losses from the receiver of a concentrating solar collector significant influence the performance of collector system under high temperature operation.

Investigation of heat loss from receiver and Heat transfer from the receiver to the working fluid is very important in determining the performance of solar parabolic trough collector. The working fluids are heat transfer fluid, Nanofluids etc. Nanofluid is a fluid containing nanometer (10^{-9} m) sized particles, called Nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in base fluid. The nanoparticles used in nanofluids are typically made up of metals, oxides, carbides, or carbon nanotubes. The commonly used nanoparticles include copper, CuO, Al₂O₃, TiO₂, gold and silver. Common base fluids include water, ethylene glycol and oil.

The concept of "nanofluids" has been proposed as a route to surpassing the performance of heat transfer fluids currently available. A very small amount of nanoparticles, when dispersed uniformly and suspended stably in base fluids, can provide impressive improvements in the thermal properties of base fluids. Nanofluids, which are a colloidal mixture of nanoparticles (1–100 nm) and a base liquid (nanoparticle fluid suspensions), is the term first coined by Choi in 1995 at the Argonne National Laboratory to describe the new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their base fluids or conventional particle fluid suspensions.

The applications of additives in working fluid are one of the methods to enhance heat transfer of heat transfer devices to change fluid transport properties and flow features. Hence in this work an attempt is made to reduce heat losses and to enhance heat transfer from receiver/absorber

INTERNATIONAL AND NATIONAL STATUS (LITERATURE SURVEY)

There are many researchers have presented heat transfer characteristics of heat transfer fluids. In general heat transfer capabilities of heat transfer devices are limited by heat transfer working fluids transport properties. The applications of additives in working fluid are one of the methods to enhance heat transfer of heat transfer devices to change fluid transport properties and flow features. The Principle of Thermal collection and storage, have been studied by S.P.SuKhatme[1], K Ravikumar and K.S.Reddy[2] have studied the thermal analysis of solar parabolic trough with porous disc receiver. Eric W Grald and Thomos H Knehu [3] have studied the Performance analysis of a parabolic trough solar collector with porous absorber receiver. A Muftnoglul, and E Bilgen,[4] have analysed Heat Transfer In inclined rectangular receiver for concentrated solar radiation.

K.S.Reddy and, K Ravikumar,[5] have numerically Investigated energy efficient receiver for solar parabolic trough concentrator Eckhart Lufpert and Klaus J. [6] have Experimentally analysed overall thermal Properties of parabolic trough receiver. Liu Bin and Wuvuting [7] have Experimentally studied turbulent convective heat transfer with molten salt in circular pipe.. F.Sulaiman. and Balbir sing[8] have studied Simulation of vective heat transfer coefficient in reciver of parabolic trough concentrator,. Luca massidda, and Alberto varone[9] studied numerically analysis of high temperature solar collecting tube using helium as heat transfer fluid,. M.Ait saada. S Chikh, and A Campo[10] have studied natural convection around horizontal cylinder wrapped with layers of fibrous or porous material. As mentioned above the paper presented on heat transfer and flow characteristics of Receiver/absorber with heat transfer fluid have rarely been reported.. The objective of this work is to study heat transfer enhancement and performance of receiver with heat transfer fluids. Effect of % charge amount of working fluid, heat transfer coefficient, Nussult number and Reynold number on heat transfer enhancement and performance are Considered. The obtained results of heat transfer fluid are being compared with base fluid.

THERMAL PERFORMANCE OF THE SOLAR COLLECTORS

The thermal performance of the solar collector is determined partly by obtaining values of instantaneous efficiency for different combinations of incident radiation, ambient temperature, and inlet fluid temperature. This requires experimental measurement of the rate of incident solar radiation falling onto the solar collector as well as the rate of energy addition to the transfer fluid as it passes through the collector, all under steady state or quasi-steady-state conditions.

COLLECTOR THERMAL EFFICIENCY

The instantaneous thermal efficiency η_i of flat plate collector is given by

$$\eta_i = F_R \{ (\tau\alpha) - U_L (T_f - T_a) / I_T \} \text{-----(1)}$$

And for concentrating collectors the efficiency can be written as

$$\eta_i = F_R \{ (\tau\alpha\gamma) - U_L (T_{fi} - T_a) / C_b \} \quad -- (2)$$

Where η_i —instantaneousthermalefficiency , F_R —heat removal factor, U_L —heat transfer coefficient—concentration ratio—temperature, I_b —solar radiations , γ —intercept factor If it is assumed that F_R , τ , α , ρ , γ , U_L are constants for a given collector and flow rate, then the efficiency is a linear function of the three parameters defining the operating condition; solar irradiance, fluid inlet temperature and ambient air temperature.

Therefore, Eqs. (1) and (2) plot as a straight line on a graph of efficiency versus the heat loss parameter $(T_{fi} - T_a) / I_T$ for the case of FPCs and $(T_{fi} - T_a) / I_b$ for the case of concentrating collectors. The intercept (intersection of the line with the vertical efficiency axis) equals to $F_R (\tau\alpha)$ for the FPCs and $F_R (\tau\alpha\gamma)$ for the concentrating ones. The slope of the line, i.e. the efficiency difference divided by the corresponding horizontal scale difference, equals to $- F_R U_L$ and $- F_R U_L / C$; respectively. If experimental data on collector heat delivery at various temperatures and solar conditions are plotted, with efficiency as the vertical axis and $\Delta T / I$ (I_T or I_b is used according to the type of collector) as the horizontal axis, the best straight linethrough

the data points correlates collector performance with solar and temperature conditions. The intersection of the line with the vertical axis is where the temperature of the fluid entering the collector equals the ambient temperature, and collector efficiency is at its maximum. At the intersection of the line with the horizontal axis, collector efficiency is zero..

A direct comparison of the yearly performance of different collector types is given in fig.1. As seen in Fig.1 [1] the higher the irradiation level the better the efficiency and the higher performance collectors like the CPC, PTC retain high efficiency even at higher collector inlettemperatures.

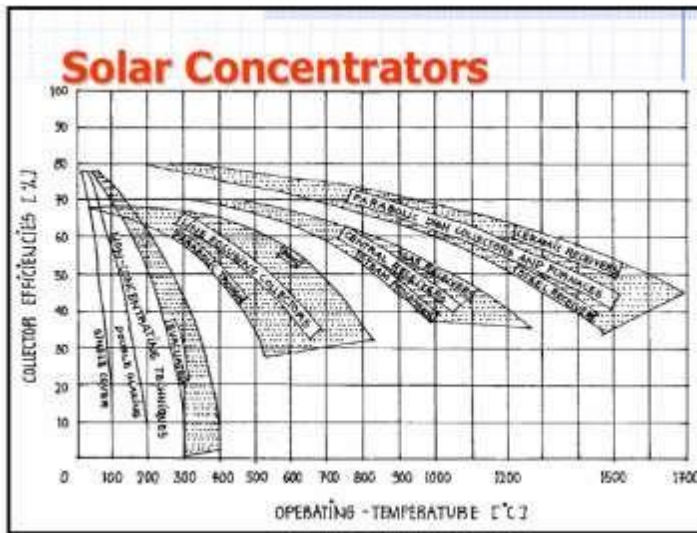


Fig. 1. Comparative performance of different collector types as a function of the difference between collector inlet temperature and ambient

It can be seen from Fig. 1 that there is decrease in thermal efficiency for FPC as the inlet fluid temperature increases and also for higher irradiance as by sukhatme [1] This is because as the operating temperature goes up the heat loss increases and efficiency decreases. This leads to the higher slope of the collector performance curve. The advantage of concentrating collectors is that the heat losses are inversely proportional to the concentration ratio C. This leads to the small slope of the collector performance curve. Thus the efficiency of concentrating collectors remains high at high inlet-water temperatures. The cross over point between flat plate collector and concentrating collector is approximately 25⁰C above ambient temperature whether the climate is sunny or cloudy. In the proposed work the solar parabolic trough collector receiver tube with heat transfer fluid for various geometries using CFD, will be analyzed and compared With experimental results.

EXPERIMENTAL SET UP

The installation consisted of the testing tube,htf tank ,pump,heater,temperature control system, data acquisition system valves, pipes etc.The heat transfer fluid(HTF) pumped into receiver/absorber and continued to be heated to the required experimental temperature. The flow is measured by flowmeter.The receiver is heated by electrical heater. The heat flux on testing tube can be changed to the required value by changing the output of electrical heater. All the pipes, valves should be insulated by asbestos sheet and then covered by the polished aluminum sheet.

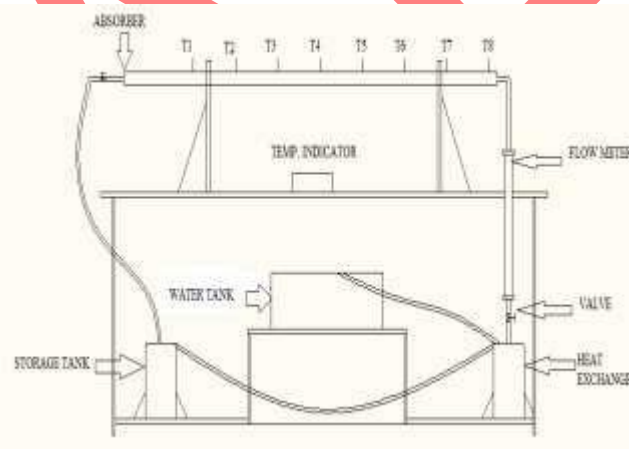


Fig 2. Experimental setup

MODELING & METHODOLOGY

In this study numerical Model is to be formulated for the receiver for internal heat gain characteristics and heat loss due to Natural convection. The governing equations used are as follows:

The continuity equation used is $\nabla u = 0$ ----- (3)

Momentum Equation for forced convection is $\rho f / \varphi \nabla [u.u / \varphi] = - \nabla p + \mu / \varphi \rho f \nabla^2 u - \mu / k p u - f / k p^{1/2} \rho f u^2$ ----- (4)

And energy equation is

$$(\rho c_p) \mathbf{u} \cdot \nabla T_f = \nabla \cdot (\lambda_f \nabla T_f) \text{ -----(5)}$$

Where u -velocity of fluid, ρ - density of fluid, c_p - specific heat at constant pressure, ∇ -differential operator, T_f - temperature of fluid, K thermal conductivity. The internal flow and heat transfer analysis is to be carried out on a RNG. k - ϵ turbulent model whereas external heat losses would be treated as Laminar conventional model. The Numerical model is to be solved using commercial engineering package Fluent 6.2. The thermal analysis of receiver is to be carried out for various geometrical parameters such as angle, orientation, aspect ratio, height of receiver, heat flux conditions with working fluids. Also the thermal analysis of various receiver geometries is being considered for the evaluation of solar parabolic trough concentrator. Experimental analysis is being carried out for the said parameters of receiver for validation

RESULTS AND CONCLUSION

1) Flow visualization

We are under investigation of flow visualization pictures (characteristics) due to natural convection

2) Turbulent statistics

We are under investigation of the influence of heat transfer fluid properties, receiver geometries, and solar radiation on overall heat collection. We are also examining the influence of various geometrical parameters such as angle, orientation, aspect ratio, height of receiver, heat flux condition with working fluids and analyzing with experimental results

RESULTS

Fluid	Flow rate m^3/s	Reynold Nubmer	Friction Factor	Convective heat transfer coefficient W/m^2C
water	7.245 $\times 10^{-6}$	1721.09	0.03718	420.23
Nanofluid	7.136 $\times 10^{-6}$	1507.7	0.03747	346.649

Table: 1 observation during experiment

CONCLUSION

Convective Heat transfer coefficient in both fluids are approximately similar because of concentration of nanoparticle is less and experimental errors due to limitations in least count of equipments used. The friction factor for nanofluid is slightly higher than water because of presence of solid nanoparticles. Effect of % charge of nanoparticle on convective heat transfer coefficient to be analyzed in future. Numerical and Experimental investigation on receiver tube of parabolic trough concentrator are in progress, the numerical results are being validated by experimental results.

NOMENCLATURE

α	constant(absorbivity)
c	concentration ratio
C_p	specific heat (KJ/KgK)
η_i	Instantaneous thermal efficiency
F_p	Factor forefficiency
F_R	Heat removal factor
I_b	Solar radiations
γ	Intercept factor
Φ	Constant
μ	Viscosity of fluid (Ns/sq mt)
ρ	density(Kg/cubmt)
t	temperature(C)
U_i	Overall HT Coefficient (W/sq mt K)
U	velocity of fluid(m/s)
∇	diffoperator

REFERENCES

1. S.P.Sukhatme, Solar energy –Principle of Thermal collection and Storage, second edition, (2004),198-257
2. K Ravikumar, K.S.Reddy, ,Thermal analysis of solar parabolic trough with porous disc receiver,heat Transfer an thermal power lab Dept of mech engg, IIT Madras-60036 India,(2008)
3. Eric W Grald, Thomos H Knehu, , Performance analysis of a parabolic trough solar collector with porous absorber receiver, Solar energy, Vol 42, (1984)281-292

4. A Muftnoglul,E Bilgen, ,Heat Transfer In inclined rectangular receiver for concentrated solar radiation,International communication in Heat and mass transfer ,vol 35, (Feb 2008)551-556
5. K.S.Reddy,K Ravikumar, ,Numerical Investigation of energy efficient receiver for solar parabolictrough concentrator Heat transfer engg,vol 29, (Nov 2008) 961-972
- 6.Eckhart Lupfert,Klaus J, ,Experimental analysis of overall thermal properties of parabolictrough receiver,Journal of solar enginnering,Vol 130 (May2008)
- 7.LiuBIn,Wuvuting, ,Experimental study on turbulent convective heat transfer with molten salt incircular pipe,International communication in Heat and Mass transfer ,vol 36, (June 2009) pp 912-916
- 8.F.Sulaiman.Balbir singh, ,Simulation of convective heat transfer coefficient in reciver of parabolic trough concentrator,Journal of solar energy (1992)
- 9.Luca massidda,alberto varone,A numerical analysis of high temperature solar collecting tube using helium as heat transfer fliud,renewable energy program CRS4,italy
- 10.M.Ait saada.S Chikh,A Campo, ,Natural convection around horizontal cylinder wrapped with layers of fibrous or porous material,International journal of heat and fliud flow,vol 28, (2007) 483-495