International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 07 | July-2018 www.irjet.net p-ISSN: 2395-0072

PERFORMANCE ANALYSIS OF SOLAR PARABOLIC TROUGH COLLECTOR SYSTEM FOR DIFFERENT CONCENTRATION OF Al_2O_3 WITH WATER AS BASE FLUID

[1]Miss. S. T. Kolekar [2]Mr. P. S. Patil

[1]Student, Department of Mechanical Engineering (ME Heat Power) JSPM's NTC Pune, Maharashtra, India.
[2]Professor Department of Mechanical Engineering, JSPM's Rajarshi Shahu College of Engineering Tathawade, Pune, Maharashtra, India.

---***---

Abstract- *In this paper we have analyzed thermal performance of solar parabolic trough collector system working with different volume concentration of Al2O3 nanoparticles with base fluid water. The maximum enhancement in thermal performance of PTC has been recorded, which reaches 63.52% to 73.12% of thermal efficiency. That means 10% of thermal performance increases when 0.5% of Al2O3 dissolved in water.*

Keywords- Heat transfer coefficient, Nano-fluid, Thermal Efficiency, Parabolic trough collector.

1. INTRODUCTION

Many researchers in all over world are investigating method to improve heat transfer rate in thermal device. We are interesting to improving performance of parabolic trough collector because they are used very much. Many country choose these technology in solar power station and produce heat energy at lower prices. One of the method to improve thermal performance of parabolic trough collector system is used to nano-fluid as working fluid. In fact Sharma et al. [`1] studied that enhancement of thermal conductivity of ethylene glycol based silver nano-fluid. 1-100nm silver nanoparticles suspended in ethylene glycol & stability as well as thermal conductivity of these nano-fluid was determined by transient hot wire apparatus. Result shows that thermal conductivity of nano-fluid increases. D.R.Waghole et al. [2] investigate on heat transfer rate and friction factor of silver nano-fluid in absorber of parabolic trough collector with twisted tape insert. The experimental result shows that the nusselt number for absorber is increased from 1.25 to 2.10. They also investigate tere is no significant increase in pressure drop. S.L.Lin et al. [3] conduct the experiment evalution of nanoparticles with base fluid paraffin wax for solar thermal energy storage. The analysis shows that 20nm hexagon shaped Cu nanoparticles added in paraffin wax, thermal conductivity of paraffin wax increases. Different volume concentration of Cu added to paraffin wax, at 2% they shown best result. R.G.Villareja et al.[4] studied that the solar thermal system. In this study base fluid used was eutectic mixture of di-phenyl oxide and biphenyl with Ag nanoparticles and analyzed theoretical and experimental performance. Ag nanoparticles added to base fluid density and viscosity of nano-fluid increases. By considering thermal properties thermal conductivity of nano-fluid increases, turns increases in heat transfer coefficient by 6%.

1.1 Problem Statement

Need of increasing thermal efficiency for solar parabolic trough collector.

1.2 Objectives:

- To design and develop copper tube as a receiver for solar parabolic trough collector.
- To design and develop twisted tape and insert in receiver tube.
- Use nano-fluid as working fluid.
- To analyze the results obtained from the experiments performed.

1.3 Scope of the Project:

- The project does not include the design of the parabolic reflector.
- The receiver tubes will be provided only a black paint coating.
- The parabolic trough collector used for this project is available at "Solar Thermal Laboratory" of Technology
- Department, Shivaji University Kolhapur.

2. DESIGNING OF EXPERIMENTAION

2.1 Reflector & Receiver Tube:

The reflector available at the Solar Thermal Laboratory, Energy Technology and Department of Technology is chosen for the purpose of experimentation. The details about the reflector and the receiver are given in the following table. The different properties of the materials for reflector and receiver are taken from previous experimentation done by Sagade et al. on the reflector. [8]

Table-1. Details about Reflector and Receiver.

Aperture of the concentrator (W)	1.10 m
Inner Diameter of Absorber tube (Dri)	0.019m
Inner Diameter of Absorber tube (Dro)	0.020m
Inner diameter of glass tube	0.050 m
Outer diameter of glass tube	0.052 m
Length of parabolic trough	1.21 m
Concentration ratio	17
Collector aperture area	1.33 m^2
Specular reflectivity of concentrator (ρ)	0.85
Glass cover transitivity for solar radiation(τ)	0.85
Absorber Tube Emissivity α	0.82
Intercept factor (γ)	0.95
Emissivity of absorber tube surface (εa)	0.078
Emissivity of glass (εg)	0.82

2.2 Incident Solar Radiation

The incident solar flux on the receiver is calculated using the formula as below,[6]

$$S = I_b r_{b\rho\gamma(\tau\alpha)b+I_d r_{d(\tau\alpha)d(\frac{D_o}{W-D_o})}} \quad (1)$$

incident beam solar radiation = 900 W/m^2

rb = geometric factor for beam radiation = 1

ρ = reflectivity of the parabolic reflector = 0.85

γ = intercept factor = 0.95

τ = transmissivity of the glass = 0.85

α = absorptivity of the receiver=0.95

Id = incident diffused solar radiation = 100W/m^2

rd = geometric or tilt factor for diffused radiation = 1

w = aperture of the reflector = 1.2m

Do = outer diameter of the receiver = 0.052 m

Substituting the values of all the above parameters in the equation we get,

$$S = 900 \times 1 \times 0.85 \times 0.95 \times (0.85 \times 0.95) + 100 \times 1 \times (0.85 \times 0.95)\frac{0.052}{1.1 - 0.052}$$

S = 590 W/m^2.

2.3 Design of Receiver Tubes:-

2.3.1 Outer and Inner Diameter of Receiver Tube

The outer diameter of the receiver tube is determined using concentration ratio of solar parabolic trough collector. As calculated above, the outer diameter of the receiver is 20mm. The optimum ratio of outer diameter to inner diameter for parabolic trough is approximately 1.1. [7] Therefore, the inner diameter of the tube is calculated as,

$$\text{Diameter Ratio} = \frac{OuterDiameter D_{r,o}}{InnerDiameter D_{r,i}} \quad (2)$$

$$1.1 = \frac{20}{D_{r,i}}$$

$$D_{r,i} = \frac{20}{1.1} = 19mm$$

2.4 Overall Heat Loss Coefficient

The different modes of heat transfer taking place in a receiver tube with glass envelope are shown in the fig. 3.3.1[9]

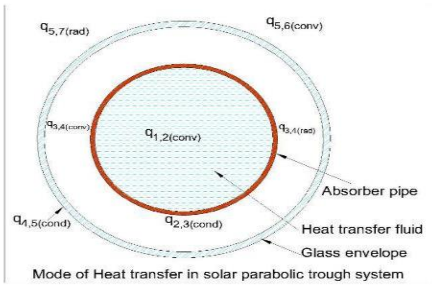

Fig-1: Mode of heat transfer.

2.4.1 Convective Heat Transfer between the Heat Transfer Fluid (HTF) and the Receiver:

From Newton's law of cooling, the convective heat transfer from the inside surface to the heat transfer fluid is given by the equation as,

$$q'_{1,2} = h_{fluid}\, D_{r,i}\, \pi\, (T_{r,i} - T_{fluid}) \quad (4)$$

2.4.2 Conduction Heat Transfer through the Receiver Wall:

The heat transfer through the receiver tube is governed by the Fourier's law of conduction which is given by,

$$q'_{2,3}=2\pi LK_{receiver}\left(\frac{Tr,i-Tr,o}{\ln(\frac{Dr,o}{Dr,i})}\right) \quad (5)$$

The thermal resistance for the above is as follows,

$$R_{2,3cond}=\frac{\ln(\frac{Dr,o}{Dr,i})}{2\pi LKreceiver} = 1.68\times10^{-5}\ m^2\,K/W \quad (6)$$

2.4.3 Convective Heat transfer from Receiver to the glass envelope:

The heat transfer between the receiver and the glass envelope is governed by convection. At low pressures (< ~1 Torr), the heat transfer takes place by molecular conduction and at high pressures (> ~1 Torr), the heat transfer takes place by free convection. Vacuum in Annular region between receiver and glass envelope When the annular region between receiver and glass envelope is under vacuum, then convective heat transfer occurs because of free molecular convection given as,

$$q'3,4=\pi Dr,ohgas(Tr,o-Tg,i) \quad (7)$$

where,

Pressure in Annular region between receiver and glass envelope:

When the annular region pressure is greater than 1 Torr, the convective heat transfer takes place because of free convection given by,

$$q'3,4 = \pi Dr,ohgas(Tr,o-Tg,i) \quad (8)$$

$$h_{gas}=\frac{Kgas\times Nu\times D_{r,o}}{D_{r,o}} \quad (9)$$

and

For $5 \times 10^3 \leq Ra \leq 1 \times 10^5$ (10)

$NuD\ r,o = 0.257\ (Ra)^{0.323}$ (11)

For $6 \times 10^8 \leq Ra \leq 3 \times 10^{11}$

$$Ra = \frac{g\beta(Tr,o-Tg,i)dr,o^3}{\alpha v} \quad (12)$$

The thermal resistance for vacuum inside the glass tube for air is calculated as bellow,

$$R_{3,4\ conv}=\frac{1}{hgasA} = 115329.66\ m^2\,K/W \quad (13)$$

Where,

hgas = heat transfer coefficient between the receiver and annular gas in vacuum = 0.000115 (W/m^2-K)

2.4.4 Radiation Heat transfer between receiver and glass envelope:

The radiation heat transfer between the receiver and the glass envelope is given by,

$$q'_{3,4rad}=\frac{\rho\pi Dr,o(Tr,o^4-Tr,i^4)}{\frac{1}{\epsilon r,o}+\frac{(1-\epsilon g,i)Dg,i}{\epsilon g,iDg,i}} \quad (14)$$

The thermal resistance for the above is calculated as,

$$R_{3,4rad}=\frac{\frac{1}{\epsilon r,o}+\frac{(1-\epsilon g,i)Dg,i}{\epsilon g,iDg,i}}{\rho\pi Dr,o(Tr,o^2-Tr,i^2)(Tr,o+Tr,i)} =1.046\ m^2\,K/W \quad (15)$$

2.4.5 Conduction between Outer surface and inner surface of Glass envelope:

The equation for conduction through the glass envelope is same as that of conduction through receiver. Therefore, the thermal resistance for conduction between glass surfaces is calculated as below,

$$R_{4,5cond}=\frac{\ln(\frac{Dg,o}{Dg,i})}{2\pi KglassL} = \frac{\ln(\frac{52}{50})}{2\pi\times0.8\times1.2} \quad (16)$$

$R_{4,5\ cond}$=0.0065 m^2K/W

where,

kglass = 0.8 W/m-K

2.4.6 Convection Heat Transfer from Glass envelope to the atmosphere:

The heat transfer from the glass envelope to the atmosphere takes place because of convection (losses in the receiver) which follows Newton's law of cooling give as,

q̇ 5,6 conv = hwindπDg,o(Tg,o –Ta) (17)

$$h_{wind}=\frac{K_{air}}{Dg,o}Nu_{wind} \quad (18)$$

The Nusselt number depends on whether the heat transfer is by natural convection (no wind) or forced convection (wind).

1. Natural Convection (no wind):

If there is no wind flowing around the parabolic trough, then the heat transfer takes place because of natural convection. The average outside Nusselt number for natural convection is given by,

$$NuD_{g,o} = [0.6 + \frac{0.387D_{g,o}Ra^{1/6}}{[1+(^{0.559}/_{Pr})^{9}/_{16}]8/27}] \quad (19)$$

$$R_aD_{g,o} = \frac{g\beta(T_5-T_6)D3^5}{\alpha_{5,6}v_{5,6}} \quad (20)$$

$$\beta = \frac{1}{T_{5,6}} \quad (21)$$

$$Pr_{5,6} = \frac{v_{5,6}}{\alpha_{5,6}} \quad (22)$$

2. Forced Convection (wind):

If wind is flowing through the parabolic trough, heat transfer takes place because of forced convection. The outer Nusselt number for the forced convection is given by,

$$Nu_{wind} = CRe^mPr^n\left(\frac{Pr_{air}}{Pr_{gas}}\right)^{1/4} \quad (23)$$

Rewind	C	M
1-40	0.75	0.4
40-1000	0.51	0.5
1000-200000	0.26	0.6
200000-1000000	0.076	0.7

and

n = 0.37, for Pr < 10

n = 0.36, for Pr > 10

This correlation is applicable for 0.7 < Pr6 < 500 and 1 < ReDo< 106.

The thermal resistance for forced convection is calculated as,

$$h_{wind} = \frac{K_{air}}{Dg,o}Nu_{wind} = 57.56\ (0.0257/0.052)$$

=28.452 m^2 K/W

$$R5,6,conv = \frac{1}{h_{wind}} = 0.1778\ m2K/W \quad (24)$$

Where, R5,6,conv = thermal resistance between glass envelope

and wind (m2-k/W)

2.4.7 Radiation heat transfer between Glass envelope and the Atmosphere:

The radiation heat transfer taking place between the glass envelope and the atmosphere is because of the temperature difference between them. The radiation heat transfer between the receiver and the atmosphere is given as,

$$q'_{5,7rad} = \sigma\pi D_{g,o}\varepsilon_{g,o}\ (Tg,o^4 - Tg,i^4) \quad (25)$$

For determining the thermal resistance due to radiation, the outer glass surface must be assumed. Therefore, the thermal resistance for the above is calculated as,

$$R_{5,7rad}=\frac{1}{Ahrad} = \frac{1}{\epsilon\sigma A(Tg,o^2+Tg,i^2)(T_{g,o}+T_{g,i})} \quad (26)$$

Tg,o = 303 K (Assumption)

Tsky = 298 K (Assumption)

$R_{5,7rad} = 0.997\ m^2\ K/W$

2.5 Overall Thermal Resistance

The thermal resistance between the heat collector element (HCE) and the support bracket is neglected.

$$R = R_{2,3} + \frac{R_{3,4rad} \times R_{3,4conv}}{R_{3,4rad} + R_{3,4conv}} + R_{4,5} + \frac{R_{5,7rad} \times R_{5,6conv}}{R_{5,7rad} + R_{5,6conv}} \quad (27)$$

R= 1.20 m^2 K/W

Therefore, overall heat transfer co-efficient (UL) = 1/R =0.8333 W/m2-K

2.6 Heat Removal Factor (FR)

The heat removal factor is determined by the

following formula,

$$F_R = \frac{mc_p}{A_c U_l}\left[1 - e^{\frac{-A_c U_l F'}{mc_p}}\right] \quad (28)$$

$\dot{m}$= 0.1 kg/s, Cp = 4.18kJ/kg-K

Ac = 1.331 m2, UL = 0.8333 W/m2-K

F' = thermal efficiency factor

$$F' = \frac{1}{U_l} + \left[\frac{1}{U_l} + \frac{Do}{D_i h_{fi}}\right] = 1.4402 \quad (29)$$

hi,f = heat transfer coefficient between the receiver and the

fluid, (12280 W/m2-K)

$$F_R = \frac{mc_p}{A_c U_l}\left[1 - e^{\frac{-A_c U_l F'}{mc_p}}\right] = 1.1994$$

2.7 Useful Heat Gain, (QU)

The theoretical useful heat gain in the heat transfer fluid is given by the following formula,[10]

$$Qu_{theo} = F_R(W - D_r)L\left[S - \frac{U_l}{CR}(T_a - T_i)\right] \quad (30)$$

$$Qu_{theo} = 924.60\ W$$

Ti = 300 K., Ta = 298 K

2.8 Instantaneous Thermal Efficiency (ηtheo):

The instantaneous thermal efficiency for the parabolic trough collector is given by the following formula, [10]

$$\eta_{theo} = \frac{Qu_{theo}}{(I_b \times r_b + I_d \times r_d)(w \times L)} \quad (31)$$

$$\eta_{theo} = \mathbf{69.46}\ \%$$

2.9 Design Results

The calculated parameters for the above design is as follows,

Table-2. Design Parameter.

Sr. No.	Parameter	Value
1.	Overall Thermal Resistance	1.20 m^2 K/W
2.	Overall Heat Loss Coefficient	0.8333W/m^2K
3.	Heat Removal Factor	1.4402
4.	Incident Solar Flux	590W/m^2
5.	Useful Heat Gain	924.60W
6.	Instantaneous thermal Efficiency	69.46%

3. TEST SETUP

The main aim of the experimentation is to find out thethermal efficiency of the copper tube receiver which flowing through nano-fluid. The experimentation consists of three stages viz. first copper tube containing ordinary water, copper tube containing different volume concentration of nano-fluid and last copper tube containing nano-fluid with insert twisted tape.

3.1 Preparation Al2O3 / Water Nano-fluid for this Experiment:

Al2O3 metal oxide nanoparticles is taken as nano materials and distilled water is taken as base fluid. Two-step method is taken for preparing Al2O3 /water nano-fluid. This is because the two-step method is better for oxide particles and this method gives higher stability and less agglomeration as proposed Das et al (2003). The Al2O3 nano-powder was purchased from Mythos Engineering Laboratory Pune.[11] The specification of Al2O3 purchased nano-particles are given in below Table.

Table-3. Properties of nano-fluid.

Aluminum Oxide Nano-particles.	
Molecular Formula	Al2O3
Molecular weight	101.96
CAS Number	1344-28-1
Lot Number	C02U033
Properties of Nano-fluid	
Form	Solid
Particle Size	100nm
Purity	99.5%
Supplier	Mythos Engineering laboratory Pune.

The testing standard considered for the experimentation is ASHRAE 93. This standard mainly focusses on finding the thermal efficiency of the parabolic trough collector. According to the standard, different parameters were measured. The mass flow rate of the fluid passing through the receiver was calculated using manual method. The actual view of the setup is shown in figure.

Fig.-3. Actual Test setup.

3.2 Testing

The thermal performance of the solar collector is determined in part by obtaining values of instantaneous efficiency for a combination of values of incident radiation, ambient temperature and inlet fluid temperature. This requires experimentally measuring the rate of incident solar radiation onto the solar collector as well as the rate of energy addition to the transfer fluid as it passes through the collector. The testing procedure carried out during the experimentation is, all sensors of the temperature data logger is fixed at a particular point to record the temperature of that point continuously. For every 5 minutes interval, all parameter as mentioned above are measured

Table-4. Observation table.

Type of fluid flow	Time	Fluid inlet Temp. (T_i)°C	Fluid outlet Temp. (T_o)°C	Ambient Temp. (T_a) °C	Incident Solar Radiation S (W)	Wind Velocity (m/s)	Receiver Temp. in °C
Ordinary water	10:30 Am	31.4	33.5	38.2	650	0.810	67.5
0.1% Al_2O_3	11:00 Am	31.2	32.9	38.2	660	0.231	68.2
0.2% Al_2O_3	11:30 Am	30.7	32.2	37.5	664	0.412	68.4
0.3% Al_2O_3	12:00 Pm	30.5	31.9	37.7	670	0.231	71.4
0.4% Al_2O_3	12:30 Pm	30.1	30.9	38.2	700	0.128	74.2
0.5% Al_2O_3	01:00 Pm	31.1	32.9	38.2	730	0.138	76.2
0.5% Al_2O_3 with tape insert	01:30 Pm	32.3	33.2	37.5	745	0.442	77.1

Table-5. Result Table.

Time	Types of Fluid	Useful Heat Gain (Qu) in W	Instantaneous Thermal Efficiency (η%)
10:30Am	Ordinary Water	845.50	63.52
11:00Am	0.1%Al2O3/Water	868.76	65.27
11:30Am	0.2%Al2O3/Water	871.18	65.45
12:00Pm	0.3%Al2O3/Water	876.74	65.87
12:30Pm	0.4%Al2O3/Water	913.41	68.63
01:00Pm	0.5%Al2O3/Water	953.45	71.63
01:30Pm	0.5%Al2O3/Water/twisted tape	973.23	73.12

3.3 Result and Discussion

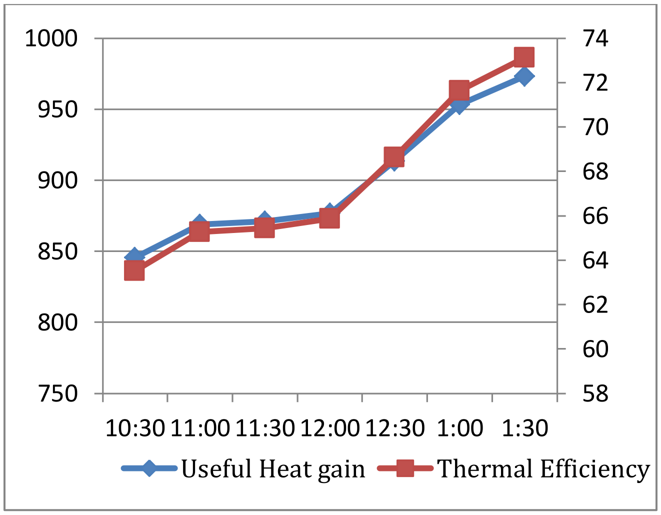

Chart-1. Useful Heat Gain Qu Vs Time on Day in hours.

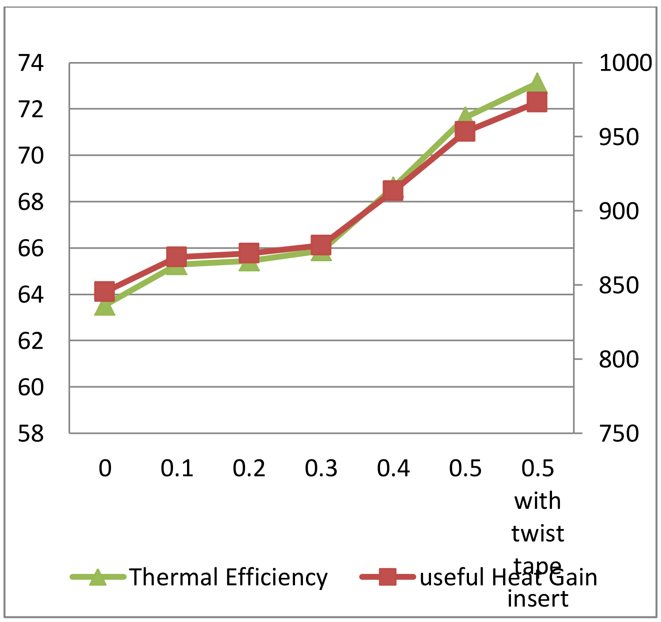

Chart-2. Useful heat gain & Thermal Efficiency Vs % Vol. Concentration.

4. CONCLUSION

In this analysis, thermal performance of solar parabolic trough collector (PTC) system using different volume concentration of Al_2O_3 nano-fluid with base fluid water are consider. Based on that following result are obtained.

1. When nanoparticle dissolved in base fluid i.e. nano-fluid the density and thermal conductivity increases while specific heat capacity decreases.

2. Nano-fluid increases the thermal performance of solar parabolic trough collector system.

3. When ordinary water flowing through system the thermal efficiency was obtained 63.52% and 73.12% efficiency obtained when 0.5% of Al_2O_3/ water when twisted tape inserted to the receiver tube, that means efficiency enhancement is 10%.

REFERENCES.

[1] Pankaj Sharma, Il-Hyun Baek, Taehyun Cho, Sangdo Park , Ki Bong Lee, “Enhancement Of Thermal Conductivity Of Ethylene Glycol Based SilverNano-Fluids”, Powder Technology 208 (2011) 7–19.

[2] Dnyaneshwar R.Waghole1, R.M.Warkhedkar, V.S. kulkarni, R.K. Shrivastva, “Experimental Investigations on Heat Transfer and Friction Factor of Silver Nano-fliud in Absorber/Receiver of Parabolic Trough Collector with Twisted Tape Inserts”, 68th Conference of the Italian Thermal Machines Engineering Association, ATI2013, Energy Procedia.

[3] Saw C. Lin, Hussain H. Al-Kayiem, “Evaluation of copper nanoparticles– Paraffin wax compositions for solar thermal energy storage”, Solar Energy 132 (2016)267–278.

[4] Roberto Gómez-Villarejo, Elisa I. Martín, Javier Navas, Antonio Sánchez-Coronilla, Teresa Aguilar, Juan Jesús Gallardo, Rodrigo Alcántara, Desiré De los Santos, Iván Carrillo-Berdugo, Concha Fernández-Lorenzo, “Ag-based nanofluidic system to enhance heat transfer fluids for concentrating solar power: Nano-levelinsights”.

[5] Andrey Yasinskiy, Javier Navas, Teresa Aguilar, Rodrigo Alcantara, Juan Jesús Gallardo, Antonio Sanchez-Coronilla , Elisa I. Martín, Desiree De Los Santos, Concha Fernandez-Lorenzo, “Dramatically enhanced thermal properties for TiO2-based nano-fluids for being used as heat transfer fluids in concentrating solar power plants.

[6] F. R .Bilal, U. C. Arunachala, H. M. Sandeep, “Experimental validation of energy parameters in parabolic trough collector with plain absorber and analysis of heat transfer enhancement techniques”,The 2nd International Joint Conference on Science and Technology2017.

[7] Liang Zhang, Meng Hua, Hai Lu, Liwu Fan, Renwei Mei, "Effect of receiver diameter ratio on thermal performance of natural circulation steam generation system as applied to parabolic trough collector using water as working fluid", International Journal of Heat and Mass Transfer 92 (2016) 1191–1200.

[8]Atul A Sagade1*, Satish Aher2 and Nilkanth N Shinde, "Performance evaluation of low-cost FRP parabolic trough reflector with mild steel receiver", International Journal of Energy and Environmental Engineering2013.

[9] R. Forristall, "Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver", October2003,NREL/TP-550-34169.