GRD Journals | Global Research and Development Journal for Engineering | International Conference on Innovations in Engineering and Technology (ICIET) - 2016 | July 2016
e-ISSN: 2455-5703

Performance Evaluation of Mo/Al_2O_3 Coating on Absorber Tube

[1]T.Rex [2]Dr. M. Sekar
[1]PG Scholar [2]Associate Professor
[1,2]Department of Mechanical Engineering
[1,2]Government College of Technology, Coimbatore, Tamil Nadu, India

Abstract

Concentrating collectors are also known as focusing collectors. A parabolic trough is a type of concentrating collector in which the energy from the sunlight is reflected and focused on the absorber tube. This paper focused on the performance of parabolic trough collector which has a ceramic-Metal coating on the absorber tube. A comparison of performance has made between with and without coating on the receiver. Here the ceramic metal coating is a multilayer coating and the layers are molybdenum – alumina. The Parabolic Trough Collector is designed and modeled using Pro/E and SOLIDWORKS. The absorber tube's performance was calculated theoretically without coating on it. A three-dimensional CFD-model was developed and analyzed using the ANSYS FLUENT15.0. Absorber tube made up of stainless steel is simulated with flow of water and analyzed using computational fluid dynamics software. At the end of the simulation, temperature distribution over the absorber tube was studied. A comparative simulation is made between with and without coating on absorber tube of the parabolic trough collector. Absorber tube with ceramic-metal coating has shown in its performance about 5.03% when the heat flux increasing gradually.
Keyword- Concentrating collectors, parabolic trough collector, Ceramic-Metal coating CFD analysis

I. INTRODUCTION

Solar energy is the energy that comes from the sun to the earth and every day the sun radiates an enormous amount of energy. Some matter is lost during nuclear fusion and the lost matter is emitted into space as radiant energy. The solar energy reached to the earth at a speed about 186,000 miles per second and the speed of light and a small portion of the energy radiated by the sun into space strikes the earth about one part in two billion. Still this amount of energy is enormous and some amount of the solar energy that strikes the earth is get back into space. A solar thermal collector is meant to collect heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is the energy which is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. A parabolic trough collector is a type of solar thermal collector that is straight in one dimension and curved like a parabola in the other two, lined with a polished metal mirror. Energy from the sunlight which enters the mirror parallel to its plane of symmetry is focused to the focal line where objects are positioned that is intended to be heated. The Parabolic trough collector applications can be divided into two main groups, the first and most important is Concentrated Solar Power (CSP) plants where temperature requirements of 300 to 400°C and second being for the Industrial Process Heat (IPH) where temperature requirements of 100 to 250°C. Heat collector element (HCE) is a key component in parabolic trough solar thermal generation system, mainly used to convert solar radiation to thermal energy. The collector tube consists of inner metal absorber tube and surrounded by a outer glass cover tube. The solar radiation is reflected to the outer surface of absorber tube by parabolic trough and absorbed by tube wall, a result, a majority of the energy will be conducted to the inner surface of inner tube and the energy is transferred by the working fluid in inner tube with mixed convective heat transfer.

Design and fabrication of a parabolic trough was done and its performance was studied experimentally [1] and also it was studied that the parabolic trough was the perfect solution for water heating application during winter season[2]. A study was made between theoretical and actual efficiencies of the parabolic trough and also a comparative analysis made between winter and summer season [3].

Development for mass production of SS-AlN cermet solar collector tubes in Himin Company is also presented which shows a solar absorptance of 0.94 - 0.96 and hemispherical emittance of 0.05 - 0.07 at 80oC were achieved [7]. A CFD analysis was done on the parabolic dish collector and concluded that increase in heat transfer when the surface area increased [4] and also a CFD analysis was made on parabolic trough, which shows that the pressure drop and temperature distribution throughout the absorber tube [5]. The present study focuses on analyzing the heat transfer of the absorber tube by modeling the HCE using finite volume based CFD code of ANSYS FLUENT 15.0..

II. METHODOLOGY

A. Design Considerations

In design consideration the geometrical characteristics of the mini parabolic solar collectors is made.

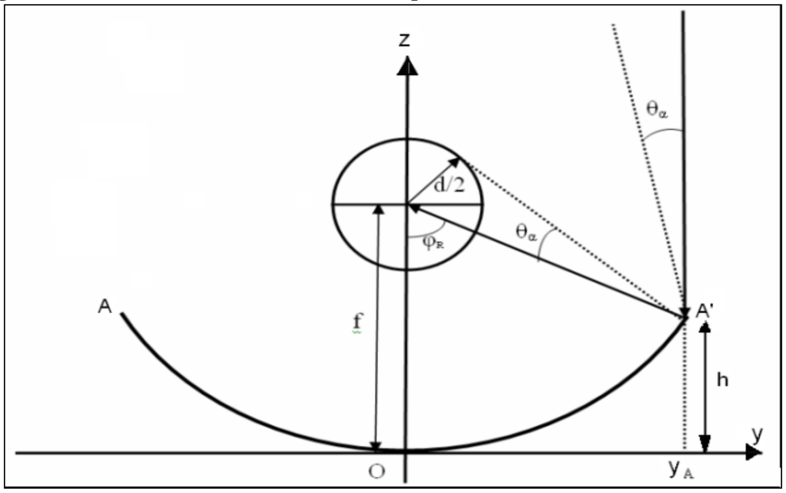


Fig. 1: Characteristics of the parabola

In Parabolic trough aperture is the opening through which the radiation from the sun enters. AA'=2ys
Concentrator or optical system is the part of the collector that directs the radiation onto the receiver of the parabolic trough.
Concentration ratio C is the ratio of the area of aperture of the parabolic trough collector. To the area of the receiver

The flux concentration ratio is defined as the ratio between the average energy fluxes absorbed on the receiver to that on the aperture.

Acceptance angle is the angular range over which rays from the sunlight are accepted without moving all or part of the collector. The value of half acceptance angle for the parabolic trough collector is given at the position y by the formula:

$$\sin\theta_y = \frac{d}{2f\left[1+\left(\frac{y}{2f}\right)^2\right]}$$

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

$$\tan\left(\frac{\varphi_R}{2}\right) = \frac{2y_s}{4f} = \frac{y_s}{2f}$$

$$\tan\varphi_R = \left[\frac{8(f/y_s)}{16(f/y_s)^2 - 1}\right]$$

Let a reflecting parabola with an aperture $2y_s$, height h, which implies a focal distance

$$f = y_s^2 / 4h$$

Parameter	*Dimension*
Aperture of the concentrator (W)	*1.2m*
Inner diameter of absorber tube (D_i)	*0.023m*
Outer diameter of absorber tube (D_o)	*0.025m*
Length of the parabolic trough	*1.5m*
Focal distance	*0.527m*
Concentration ratio	*15*

Table 1: Parabolic Trough Specifications

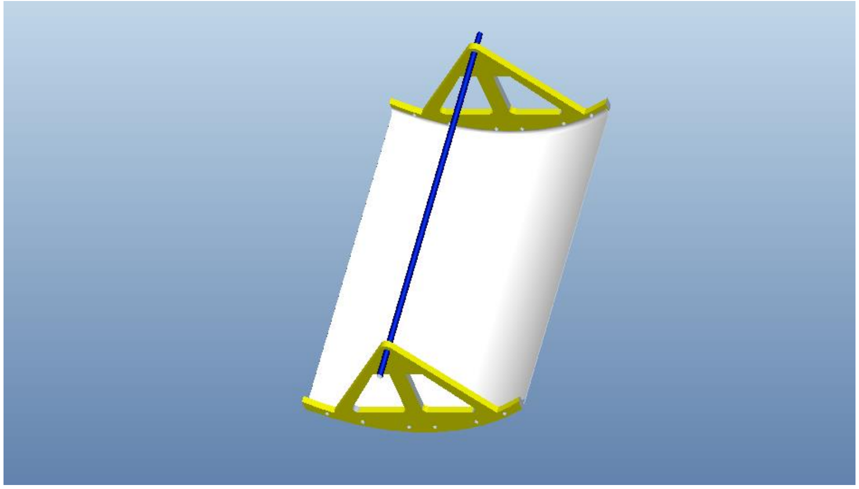


Fig. 2: 3D view of parabolic trough

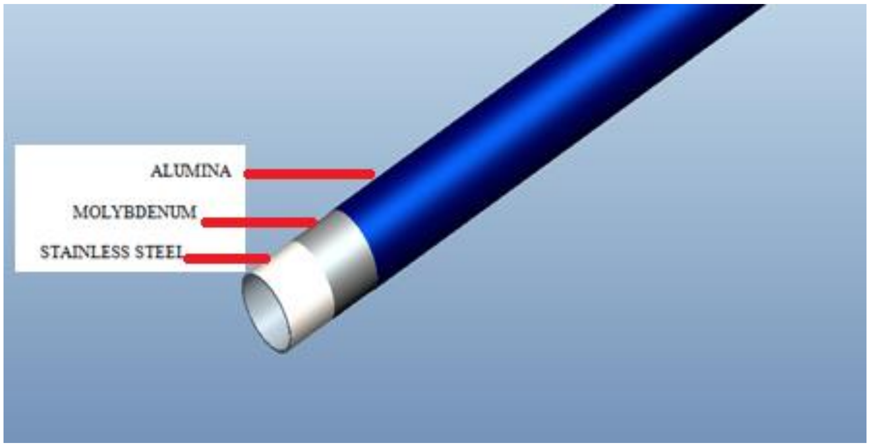


Fig. 3: Mo/Al_2O_3 coating on absorber tube

B. Reflector

Vapor deposited on pre-anodized Aluminium 1090 alloy 0.4 mm thickness
Purity 99.9% UV resistant, 30% loss noted for 30 Years
Total solar reflectance - 90%.
Diffuse reflectance - 1.6%
Specular reflectance - 88.3 %

C. Absorber Tube

Alloy 304L a T-300 series stainless steel austenitic, which has a minimum of 18% chromium and 8% nickel and has a carbon maximum is 0.030.

Alloys 304L is the most versatile and widely used alloy in the stainless steel family and ideal for a wide variety of home and commercial applications, Alloys 304L has excellent corrosion resistance and high ease of fabrication, outstanding formability.

D. Molybdenum

Molybdenum, element number 42 of the periodic table, lies in the second transition series, in Group 6A between chromium and tungsten. It has one of the high melting point temperatures of all the elements, but unlike most other high melting point metals, its density is only 25% greater than iron's and the coefficient of thermal expansion value of molybdenum is the lowest of the engineering materials. It has the ability to withstand high temperatures and also maintain strength under these conditions is responsible for the fact that molybdenum used applications where the requirement of high temperature.

E. Aluminium Oxide

Alumina is one of the most cost effective and widely used materials of the engineering ceramics. With an excellent combination of properties and an attractive price, alumina has a very wide range of applications. It has the key properties of wear resistant, good dielectric properties, good thermal conductivity and resists strong acid and alkali attack at elevated temperatures.

III. THEORETICAL EVALUATION

Theoretical evaluation starts with collection of operational and metro logical parameters and the specification of the parabolic trough was used to evaluate the performance of the collector by using the formulas,.
The useful energy delivered from the concentrator can be given by Equations 1 and 2

$$q_u = mc_p(T_o - T_{in}) \quad (1)$$

$$q_u = mc_p[(CS/U_l) + T_a - T_{in}][1 - \exp\{((F'D_O U_l L)/mc_p)\}] \quad (2)$$

Location & Latitude	*Coimbatore 11° 00' N*
Date	*April 15*
Time	*1230h(LAT)*
Beam radiation	*705 W/m^2*
Ambient temperature	*25 °C*
Mass flow rate of water	*0.04142 kg/s*
Inlet temperature	*30 °C*

Table 2: Operational and metrological parameters

Where, q_u is the useful energy delivered from the concentrator (W); m, mass flow rate(kg/s); T_o, outlet fluid temperature (°C); T_{in}, inlet fluid temperature (°C); C_p, specific heat of water (kJ/kg°C); C, concentration ratio; S, incident solar flux absorbed in the absorber plate (W/m^2); U_l, overall heat loss coefficient (W/m^2°C); T_a, ambient temperature (°C); F', collector efficiency factor; D_o, outer diameter of the tube (m); and L is the length of the concentrator (m).

$$F' = 1/U_l[(1/U_l)+(D_o/D_i h_f)] \quad (3)$$

$$q_u = F_R(W - D_o)L[S - (U_l/C)(T_{in}-T_a)] \quad (4)$$

Where D_i is the inner diameter of the tube (m); h_f, heat transfer coefficient on the inside surface of the tube (W/m^2°C); and FR is the collector heat removal factor. Heat removal factor is given by equation 5,

$$F_R = (mc_p/\pi D_o L U_l)[1 - \exp\{-(F'\pi D_O L U_l)/(mc_p)\}] \quad (5)$$

Instantaneous and Optical efficiency of the collector calculated using equations 6 and 7

$$\eta_i = q_u/I_b r_b WL \quad (6)$$

$$\eta_o = S(W - D_o)/I_b R_b W \quad (7)$$

Based on the parabolic trough specification, operational and metro logical parameters the calculations were made and the results were obtained.

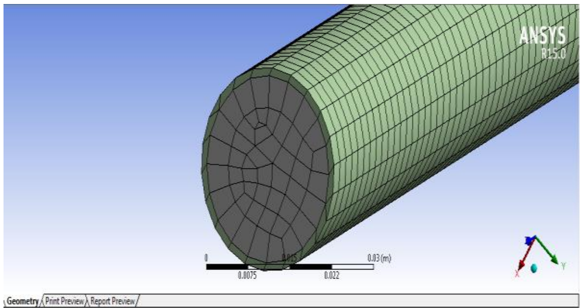
Solar flux absorbed	*(S)*	*478 W/m^2*
Heat transfer coefficient	*(h_f)*	*202.24 W/m^{2}k*
Collector efficiency factor	*(F')*	*0.9333*
Collector heat removal factor	*(F_R)*	*0.9293*
Useful heat gain	*(q_u)*	*776.56W*
Inlet temperature	*(T_{in})*	*303K*
Outlet temperature	*(T_o)*	*307K*

Table 3: Analytical results

IV. CFD ANALYSIS

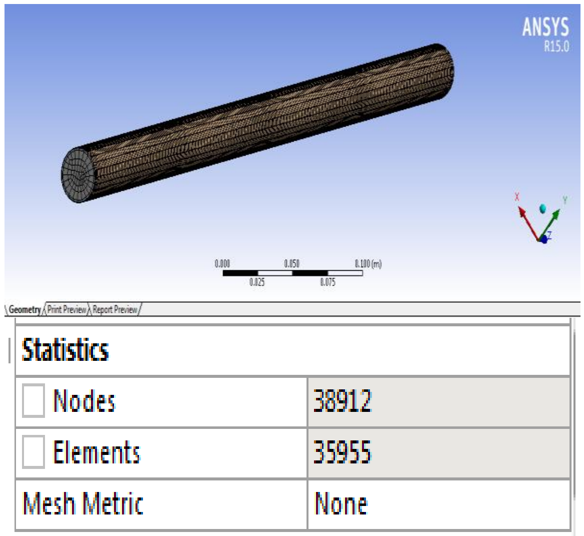
The three dimensional computational domain is modeled using (Tetra/Hydro) mesh as shown in Figures shown below. Then after making model by using ANSYS Work beach 15.0 Export to Influent CFD with extension

(ANSYS ICEM CFD tetrahedrons) after that, import to Influent makes boundary mane inlet tube (inlet water) outlet tube to (out water).



Nodes	25220
Elements	22274
Mesh Metric	None

Fig. 4: Meshing of absorber tube without coating



Statistics	
Nodes	38912
Elements	35955
Mesh Metric	None

Fig 5: Meshing of absorber tube with coating

Boundary conditions are used according to the practical situation. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. After completing the mesh by CFD fluent 15.0 imported the mesh to CFD Work bench 15.0 to inter the boundary condition inter the inlet condition water properties at 300K
Density - 990.9Kg/m^3, Specific Heat-4180J/JgK
Thermal conductivity - 0.6W/m-K, - 0 .001003Kg/m-s

Thermal expansion coefficient - 0.00021 1/K included from the library. After this the properties of stainless steel, Density – 8 g/cc, Specific heat – 0.5 j/g-°C, Thermal conductivity- 17 w/m.k and properties of Mo, Density-10.22g/cm^3, Thermal conductivity- 138W/m.k,
Specific heat capacity – 0.25 kJ/kgK and properties of alumina, Density - 3.95 g/cm³, Thermal conductivity - 30 $W.m^{-1}\cdot K^{-1}$, Specific heat capacity – 880 J/kg.k are included.

A. Results and Discussion

A detailed description of the analysis and results which were obtained for the concentrating solar energy was contained in this paper. Starts with an overview of the solar calculations needed for the solar concentrator to get the heat flux solar energy. An analysis to get the results for the receiver of solar concentrator in CFD fluent to get the temperature of steam from outlet of receiver. Its performance and increase the heat transfer rate between absorber tube with and without coating on it.

CFD simulation has performed on the receiver solar collector with and without coating on the absorber tube and the heat transfer rate is increased when it has a ceramic metal coating and also performance of the receiver is increased. A graphical representation of the temperature compared in K for both of the absorber tube with and without coating along the length of the heating tube is shown in figure,

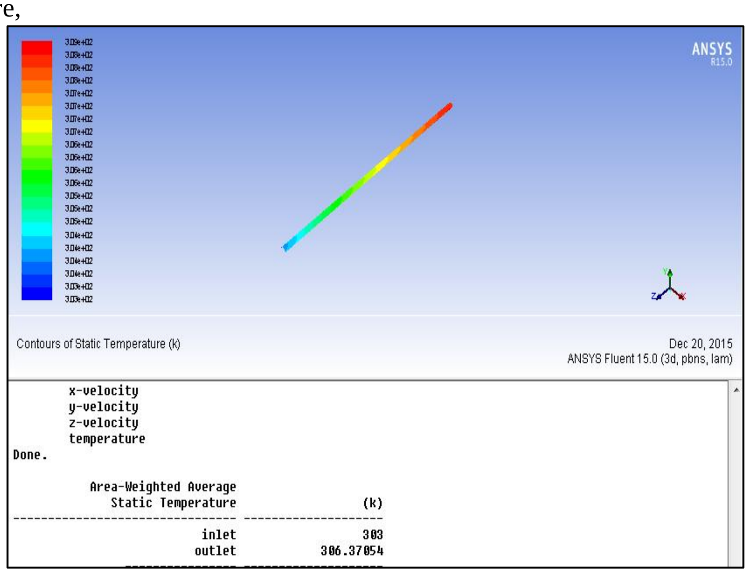


Fig. 6: Temperature distribution without coating

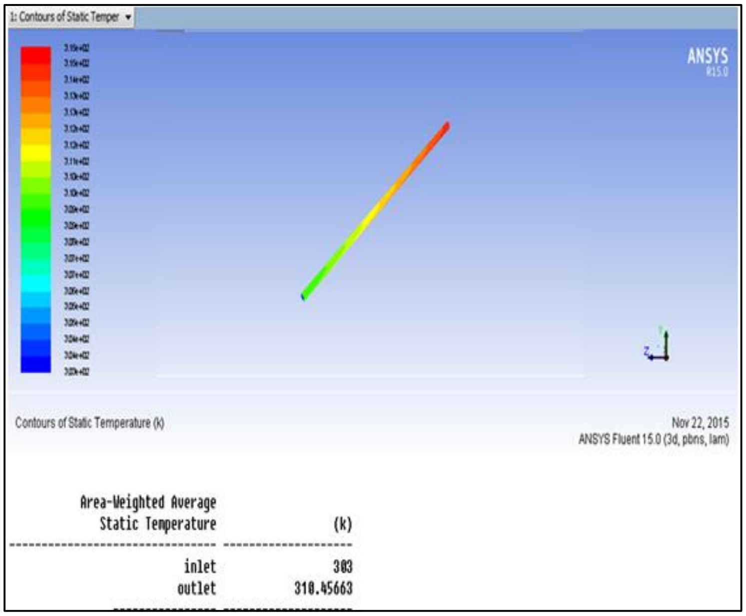


Fig. 7: Temperature distribution with coating

The velocity at the axis of the absorber tube is higher than the wall side of the tube when it has a ceramic metal coating on it and the outlet temperature is also increased which is shown in the figure,

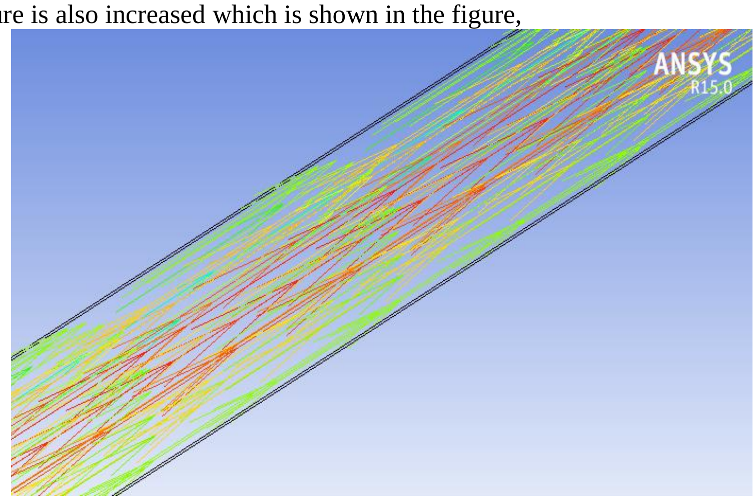


Fig. 8: Velocity profile inside the absorber tube

Outlet temperature of the absorber tube increased when it coated with ceramic- metal coating and a gradual increase in its temperature with increase in heat flux value. A comparison is made between with and without coating on absorber tube.

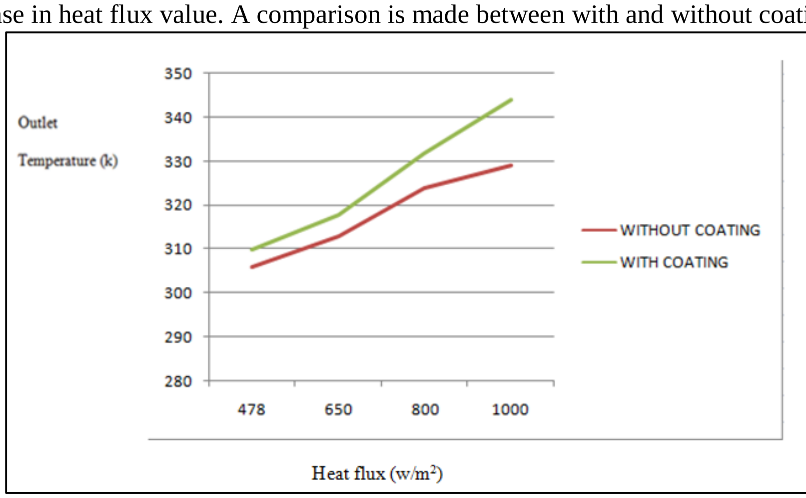


Fig. 9: Outlet temperature vs Heat flux

V. CONCLUSION

Parabolic trough concentrator and modeling of the receiver are created by using 3D modeling software Pro/Engineer, where the receiver is the most important part in the parabolic trough collector system. The receiver pipe made up of stainless steel. . In this work a parabolic trough is designed and its performance evaluated theoretically without coating on the absorber tube. After that a simulation is carried out by completing the mesh of model by using CFD work bench 15.0 and opened the result in the CFD fluid flow (fluent). The outlet temperature of working fluid for the temperature distribution in XYZ plane is presented. The temperature of water increased from 303K to 306K for without coating and the temperature of water increased from 303K to 310K for ceramic-metal coating on the absorber tube at 478w/m^2. Absorber tube with coating has shown a increased performance of 5.03% at the maximum heat flux value of 1000w/m^2 than the absorber tube without coating when increasing heat flux value gradually.

REFERENCES

[1] Saeed Iqbal, Umair Iqbal, Mubeen Umer Khan, Muhammad Saeed, Adeel waqas Design, fabrication and analysis of solar parabolic trough collector for steam engine (2014).
[2] Mayur G Tayade, R E Thombre, Subroto Dutt Performance evaluation of parabolic trough. (2015)
[3] Tadahmun Ahmed Yassen Experimental and Theoretical Study of a Parabolic Trough Solar Collector. (2012)
[4] Mohand Mosa Mohammad Design and heat transfer analysis of parabolic shaped solar dish collector. (2015)
[5] S. Mathew, G. Visavale, V. Mali. CFD Analysis of a Heat Collector Element in a Solar Parabolic Trough Collector. (2010)
[6] Harish C.Barshili Growth, characterization and performance evaluation of Ti/AlTiN/AlTiON/AlTiO high temperature spectrally selective coating for solar thermal power applications (2014).
[7] Qi-Chu Zhang Development of SS-AlN Cermet Solar Collector tubes (2007).
[8] Sukhatme SP Solar energy, McGraw–Hill, NY, 83-139, (1993)
[9] G.d rai Non renewable energy sources 80-123.
[10] Fernandez -Garcıa, E. Zarza a, L.Valenzuela a, M. Perez Parabolic-trough solar collectors and their applications.(2010)
[11] Chengmu Xu , Ming Li Xu, Ji Fei Chen Study on the Collection Efficiency of parabolic trough soar collector. (2013)