Numerical Study of Heat Flux on Parabolic Trough Reflector

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Abstract: *The purpose of this study is to construct three-dimensional numerical model for heat flux on the reflector of parabolic trough solar collector by SOLTRACE. Reflector material is made by steel AISI1020. Model with collector width of 0.9144m, focal point length was 0.2771m, length of 0.6096 m, rim angle is 44.83ºand tilt angle is 11.4 º and the concentration ratio is 15 was also done.*

Key Words: *heat flux, parabolic trough reflector, SolTrace.*

1. INTRODUCTION:

Solar energy is one of the alternative energy sources [1] .Most of the renewable technologies such as solar thermal and power systems, wind turbines and hydraulic turbines have come to a mature stage in developed countries [2]. National Renewable Energy Laboratory (NREL) to model concentrating solar power optical systems and analysed their performance. A ray tracing code (SolTrace) is an optical simulation tool designed to model optical systems used in concentrating. It is the useful application for solar system [4]. It is construct the three dimensional model of reflector for flux intensity values of line focus collectors in the absorber tube. In our Myanmar, parabolic trough collector has not been reported because it is not available in local market, expensive to construct and sufficient knowledge has not been distributed. Therefore, the purpose of this study is to construct the three dimensional model of parabolic trough reflector.

2. PARABOLIC TROUGH REFLECTOR (PTSC):

The reflecting surface of concentrator in line focusing is curved. Reflector is made by bending a sheet of reflective material into a parabola shape and it is reflected sun rays on the absorber tube [3]. The important of reflector shape parameters are length, width, focal point and radius of curvature [5]. They are depending upon to get maximum heat flux on the absorber tube. The reflectivity value of reflector material is important to get maximum flux on the absorber.

3. BASIC EQUATION FOR BEAM RADIATION

In this system, the main equations have seven parts. They are following described.

(i) Affective Irradiance on Aperture

$$I = I_b \cos\theta \quad (1)$$

where, I – effective irradiance on aperture
I_b – beam radiation
θ – angle of incidence of the sun on the aperture

(ii) Beam Irradiance

$$I_b = I_{0,\,eff}\left[a_0 + a_1 \exp\left(-\frac{k}{\cos\theta_z} \right) \right] \quad (2)$$

where,
I_b - beam irradiance,
$I_{0,\,eff}$ - effective solar constant,
θ_z - solar zenith angle
a_0, a_1 and k are coefficients of tropical climate type.

(iii) Effective Beam Irradiance

$$I_{0,\,eff} = I_0\left[1+0.033\cos\left(\frac{360n}{365.25}\right)\right] \quad (3)$$

where, n - the day of year after 1 January,
I_0 - the solar constant = 1367 W/m^2

(iv) Parabolic equation

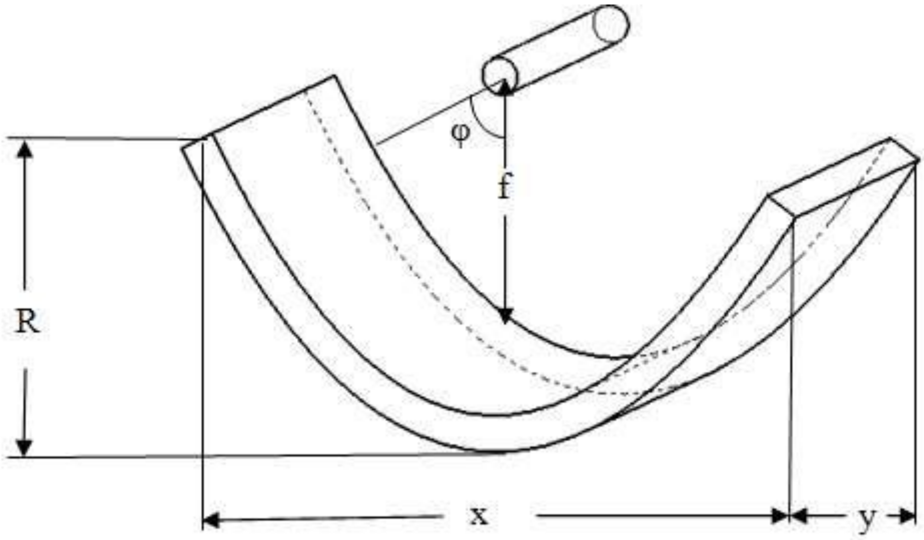

Fig 1. Cylindrical parabolic trough reflector

$$y = \frac{x^2}{4f} \quad (4)$$

where, y – length of reflector
x – width of reflector
f – focal length

(v) Curvature equation

$$x^2 = 2Ry \quad (5)$$

$$R = \frac{x^2}{16f} \quad (6)$$

where, R – radius of curvature

(vi) Rim angle , ϕ

$$\frac{\phi}{2} = \tan^{-1}\left(\frac{x}{4f}\right) \quad (7)$$

Concentration ratio of the collector, $C = \frac{\text{effective aperture area}}{\text{absorber tube area}} = \frac{W - D_0}{\pi D_0}$ (8)

where, W - width of collector
D_0 - outer diameter of the absorber tube

(vii) Radiation Flux, S

$$S = I_b R_b \rho\gamma(\tau\alpha)_b + I_b R_b (\tau\alpha)_b \left(\frac{D_0}{W - D_0}\right) \quad (9)$$

4. DESIGN DATA OF AVAILABLE ISOLATION:

Mandalay, North latitude, λ=21.98°
East longitude, L= 96.1ºE
Elevation above sea level, H=74.676x10^{-3} km
Climate type, Tropical
Local standard time of meridian, L_{st}=97.5ºE

5. SOLTRACE SIMULATION:

SolTrace is a software tool developed at the National Renewable Energy Laboratory (NREL) to model concentrating solar power optical systems and analyze performance. This is originally intended for solar applications. It can also be used to model and characterize many general optical systems. SolTrace can model parabolic trough reflector. The code utilizes a ray tracking methodology. The user selects a given number of rays to be traced. Each ray is traced through the system while encountering various optical interactions. In this simulation have five steps. They are:

a. Defining the sun shape and position. It is show in figure 1.

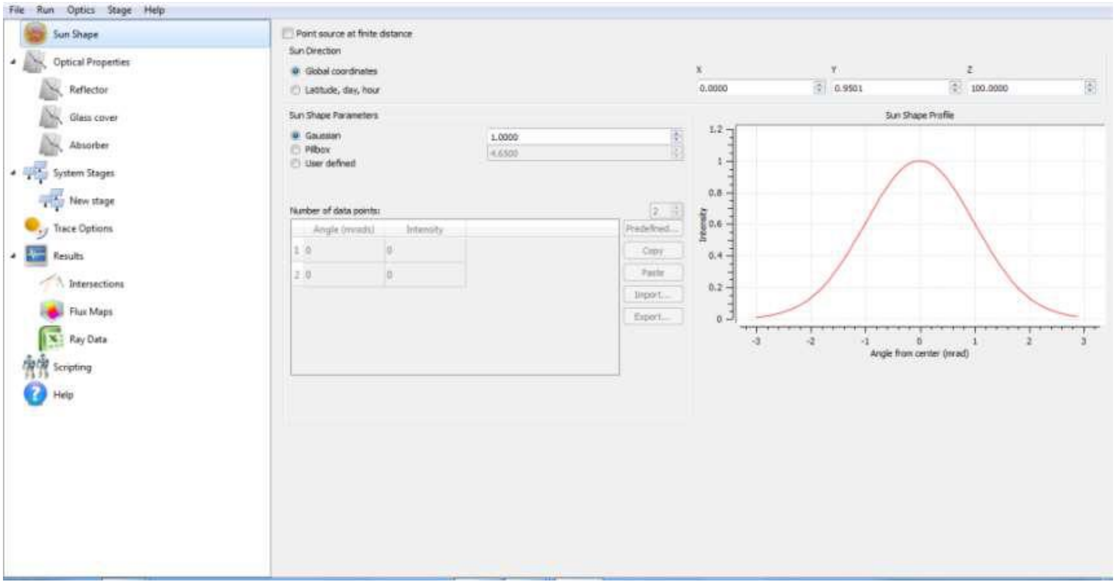

Fig 2. Sun Shape Position and User Defined Sun

The sun direction is determined assuming the z-axis of the global coordinate system points. The y-axis point towards zenith and x-axis points is west.

b. Defining optical properties.

This step can be defined requirement of material for this system. It is show in figure 3.

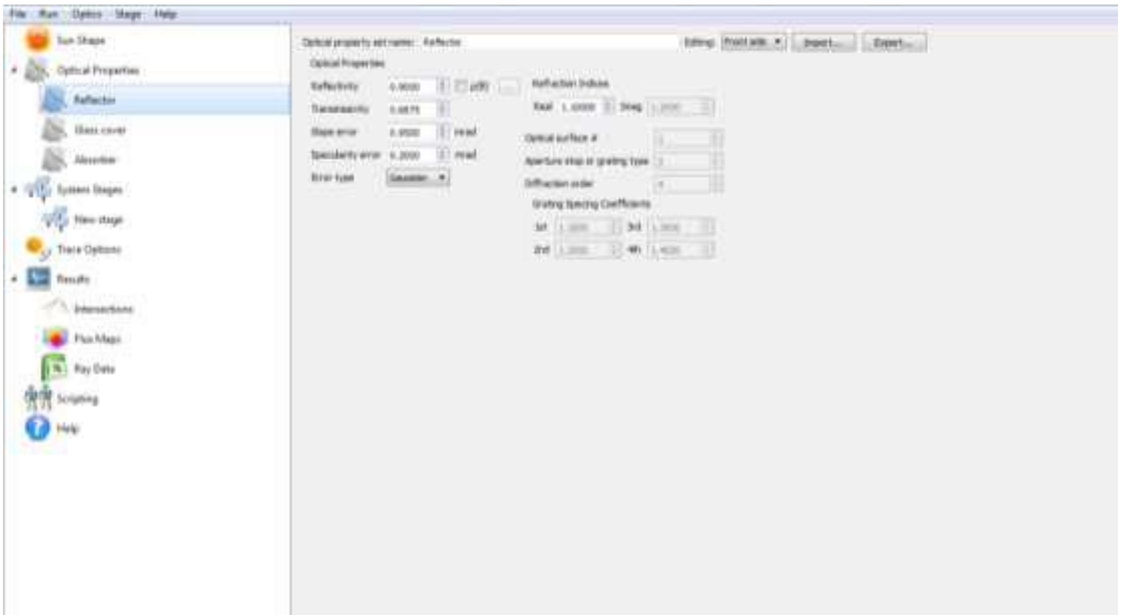

Fig 3. Optical Property

c. Defining system geometry.

This stage defined aperture width and absorber tube diameter. In figure 4, optical geometry is determined.

Fig 4. Optical Geometry

In this system geometry, it has to define the X-coordinate, Y-coordinate and Z-coordinate and aim points. Moreover, it is defined the parameter of the collector. For example, collector width, length, radius of curvature, and focal point. Figure 5 shows the model of parabolic trough collector.

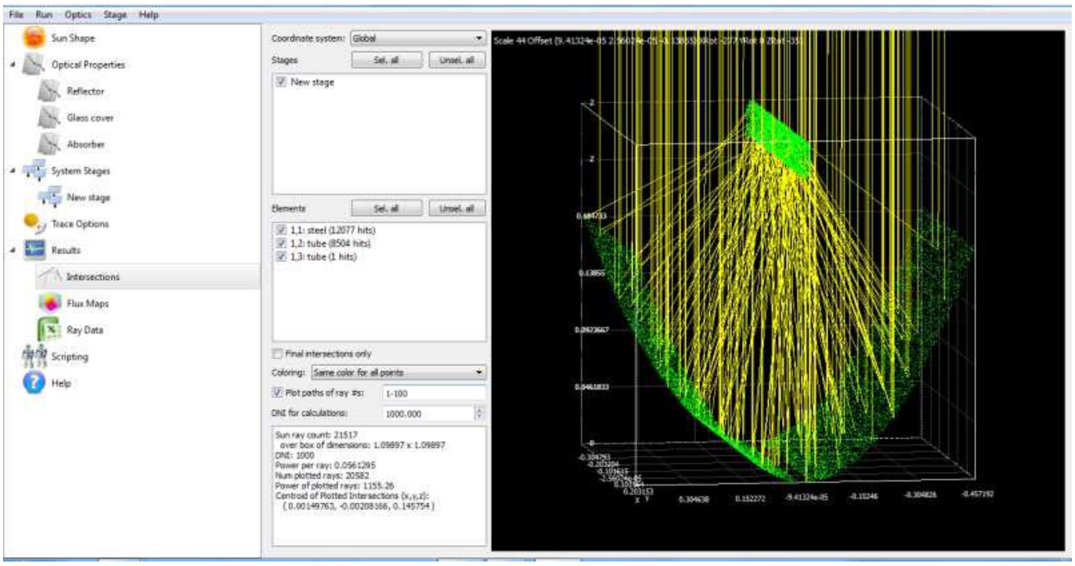

Fig 5. Modeling of Parabolic Trough Collector

d. Calculation procedure for multiple stages.

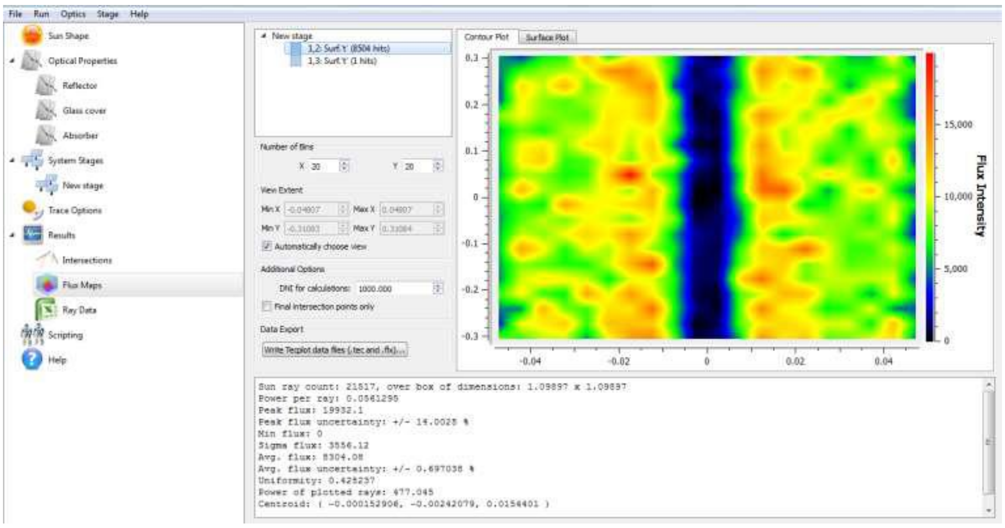

Fig 6. Value of Heat Flux on the Absorber Tube

This stage can be solved the value of heat flux on the absorber tube and this results can be show fig 6. It is display the intersections and flux maps.

6. CONSTRUCTED PARABOLIC TROUGH REFLECTOR BY USING SOLTRACE:

In fig 7 shows the 3D model of parabolic trough collector. It was described the sun rays hit the reflector and they were converged on the line focus absorber tube. The ratio of parabolic width and radius of curvature was 1.6491 and it values was the optimum design of this study.

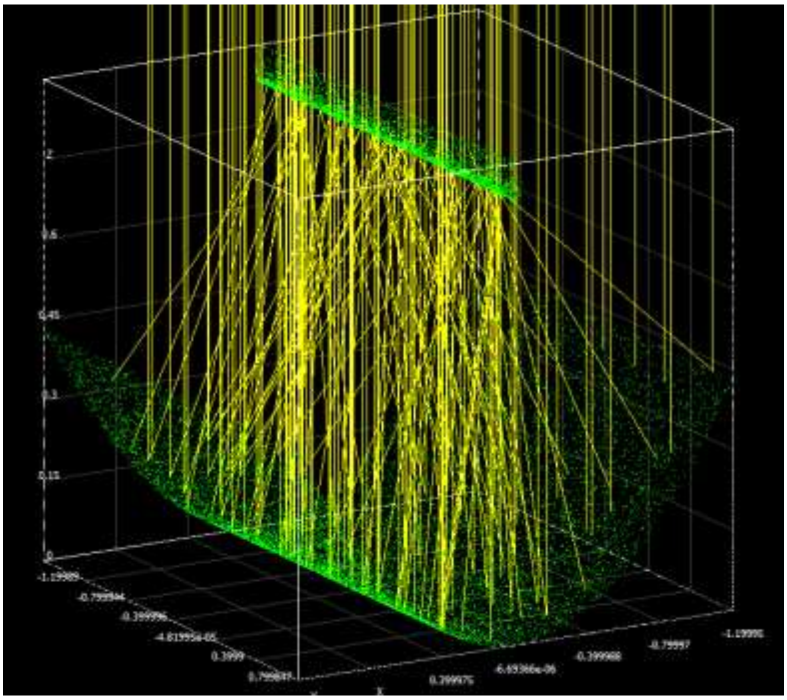

Fig 7. Constructed model of parabolic trough reflector

Fig 8 shows the value of heat flux on September 12, 2013. Horizontal axis described the circumference of the absorber tube; the left side vertical axis represented the length of absorber tube and the right side vertical axis showed the value of heat flux on the absorber tube.

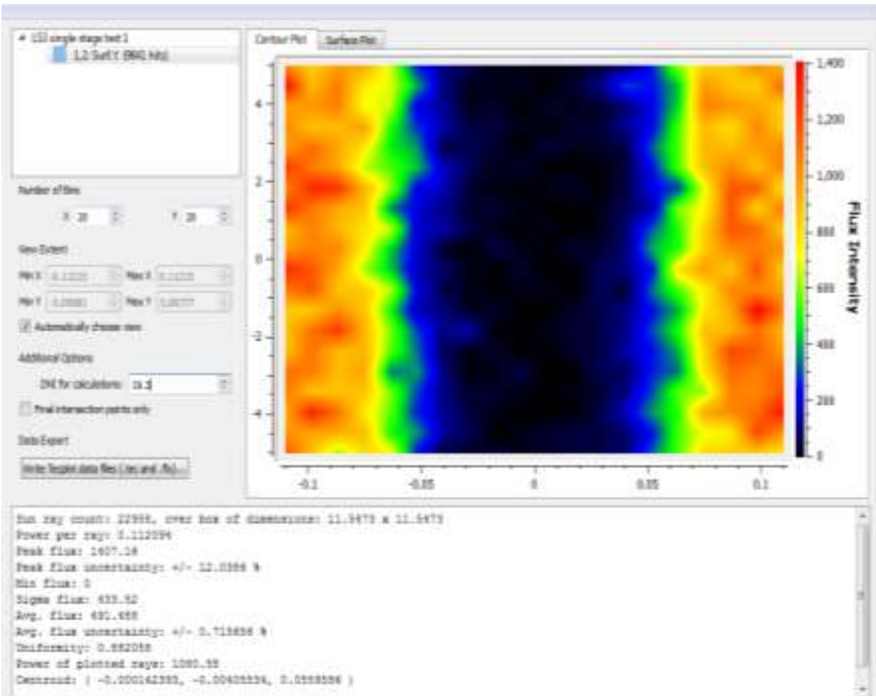

Fig 8. Value of heat flux on September 12, 2013

7. RESULT AND DISCUSSIONS:

Fig 9 shows the value of heat flux on the absorber tube. X- axis represent showed the working time (hour) and the Y- axis represent showed the value of heat flux. The highest value of heat flux is around at 619 W/m^2 at 12 noon and the lowest value of heat flux is around 470 W/m^2 at 4 pm.

In this simulation, the value of heat flux depended on the value of direct normal irradiance (DNI). It was varied with the daily solar radiation. This value was depended on the circumsolar radiation (CSR). In this stage, the CSR level is defined 0 because it was assuming the sun was a very clear day. The absorber tube with glass cover and its transmissivity was 0.6875. It was prevented the heat losses.

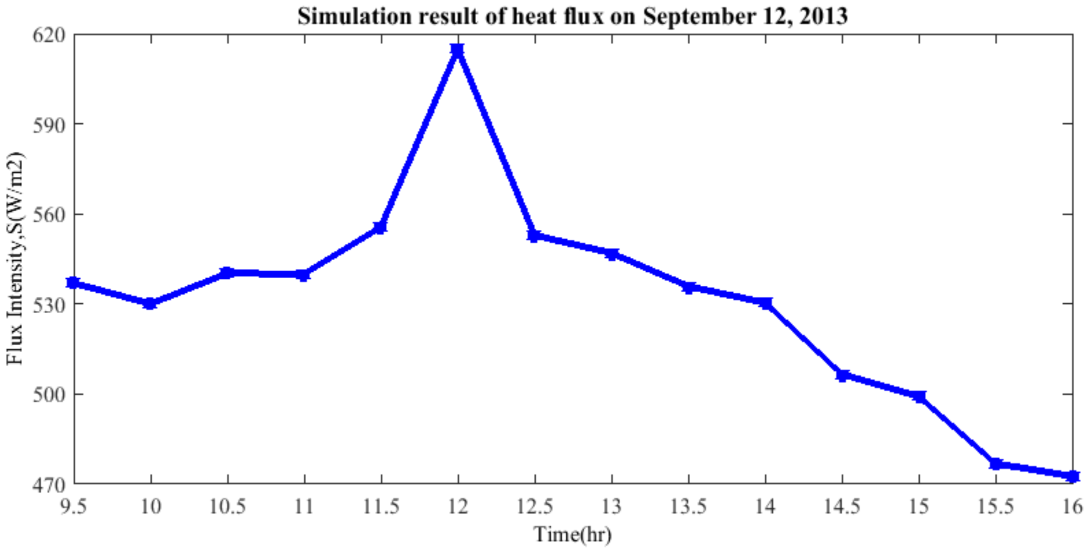

Fig 9. Value of heat flux on September 12, 2013

8. CONCLUSION:

Based on the results, the optimum value of rim angle is 44.83°, tilt angle was 11.4º, concentration ratio was 15, and focal point was 0.227 m. In simulation, the value of heat flux was fluctuated because it was definitely defined number of rays intersection on the surface of the absorber tube and direct normal irradiance.

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