EXPERIMENTAL STUDY AND SIMULATION ANALYSIS ON THERMAL LOSSES OF A SOLAR PARABOLIC TROUGH COLLECTOR

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ABSTRACT:

Energy plays a significant role in any country economic development and wealth generation. Due to the depletion of fossil fuels day by day there is a need to shift toward the renewable energy sources. Solar energy is the most widely available renewable energy resource all over the world. To use this solar energy we need solar collectors. Generally concentrating collectors are used for high temperature application. Solar parabolic trough collector is the most proven technology for indirect steam generation. This technology is using widely in solar thermal power plants. The purpose of this paper is to do experimentation, simulation and to determine the heat losses (radiation and convection) associated with heat collection element (HCE) of solar Parabolic Trough Collector (SPTC), the effect of different wind speeds and mass flow rate of the heat transfer fluid (HTF) on thermal losses are investigated. The receiver of the parabolic trough is modeled in CATIA V5 R20 software and it is imported to the STAR CCM+ 9.02 software for the analysis and the geometry is taken according to the experimental setup which is fabricated. Some assumptions have been made to ease and simplify the simulation. Solar radiation flux around the absorber tube assumed uniform and the radiation flux is treated as hat flux wall boundary condition for the absorber tube. Heat loss model is simulated by giving surface to surface radiation (S2S) radiation model. The convection and radiation heat loss to the surrounding is calculated by the resulting temperature of the absorber tube envelope from the experimental and simulation model.

***Keywords**: Solar parabolic trough collector, heat collection element, heat collection fluid, convection and radiation losses, CATIA V5R20, STAR CCM+ 9.02*

1. INTRODUCTION

Increasing in fuel prices and carbon emissions from the conventional energy resources like thermal energy and fossil fuels usage leads to global warming and air pollution. So there is a need to develop the unconventional energy resources. Solar energy is most widely available at all areas in abundant form. Generally they are mainly two types of collectors are used for the utilizing this power. One is flat collectors in this the maximum heat generation is less than 100^0 c which is not applicable to industrial usage. The other is concentrated collectors in this the maximum heat generation is 500^0c. This will be useful for the industrial usage. They are mainly two types in this line focusing collectors and point focusing collectors. The parabolic trough collector and Linear Fresnel collector comes under line focusing collectors. The solar tower and dish sterling collector comes under point focusing collectors. The solar parabolic trough collector technology is the most proven technology used widely for indirect steam generation in solar thermal power plants. Due to easy making and less maintenance this technology is widely using. The solar parabolic trough collector technology is having three major elements (1)Reflector (2) Heat collection element (3) Heat transfer fluid The reflector material reflect all the sun rays and all these sun rays are concentrated on to a line. On this line the heat collection element (i.e. absorber tube). Inside the absorber tube the heat transfer fluid is sent. This heat transfer fluid will gain the heat from the absorber tube walls as long as the HTF flows inside the HCE the temperature of the fluid will be increased. This is the working principle of the solar parabolic trough collector.

2. NOMENCLATURE

C Concentration Ratio

I_b Instantaneous hourly beam radiation (W/m^2)

I_g Instantaneous hourly global radiation (W/m^2)

I_{sc} Solar constant

L Length of concentrator (M)

LAT Local apparent time (Hr)

M Mass flow rate (kg/sec)

N Day of the year

Q_u Rate of useful heat gain (W)

R_b Tilt factor / Instantaneous hourly beam radiation

R_d Tilt factor / Instantaneous hourly diffuse radiation

T Time (s)

W Aperture width (m)

α Absorbivity of absorber surface for solar radiation

β Slope or tilt

Υ Surface azimuth angle

Θ Angle of incidence

Θ_a Half acceptance angle

Θ_z Zenith angle

Φ Latitude

Φ_r Rim angle

W Hour angle

T_i Inlet temperature

T_o Outlet temperature

T_p Surface temperature of HCE (^{o} c)

D_P Outer diameter of HCE (^{o} c)

V_w Wind Velocity (m/sec)

HCE Heat collection element

HTF Heat transfer fluid

σ Steffen Boltzmann constant

$€_p$ Emissivity of HCE

3. DESIGN OF PARABOLIC TROUGH COLLECTOR

The parabolic trough collector design starts with by selecting the dimensions of the parabola. For this parabola calculator 2.0 software is used with this parabola aperture and width the focal point is decided. On this focal line the absorber tube will be placed. The parabola shape is such that it will focus the sun rays on to the focal line.

3.1. Fabrication of parabolic trough collector

The 8 ms flat plates are bent in the form of a parabola according to the selected dimensions. These 6 flat plates which are in the shape of parabola are welded together to form a shape of parabolic trough. By this a Skelton parabolic trough is done. A suitable stand for holding this parabolic trough is done by welding the square pipes. The end of the parabolic trough are attached o the bearings so that the tracking of the rough according to the sun orientation can be done. A chain arrangement is done for the purpose of manual tracking. A steel foil is wrapped on the Skelton of the parabolic trough and it is fitted on the parabolic flat bars by using 8 mm bolts and nuts. At the focal line the heat collection element (copper tube) is arranged by using clamps and bolts.

4. EXPERIMENTAL SETUP

For the experimentation the parabolic trough was placed on north south direction and it is tracked along east to west direction along with the sun rays. Water connection is given to the heat collection element. The mass flow rate of the heat transfer fluid is controlled by using the valve. The inlet and outlet temperatures of the HTF (water) are measured by using a thermometer. The surface temperature of the absorber tube is measured by using a infrared thermometer. The mass flow rate of water is calculated by collecting the water in a jar and time taken for the collection.

Fig 4.1: Experimental setup

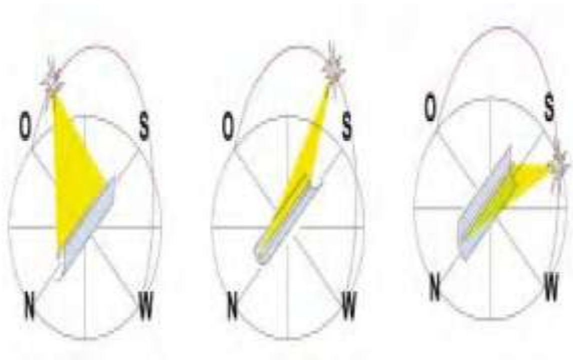

Fig 4.2: SPTC orientation and tracking

5. ESTIMATION OF SOLAR RADIATION

Hourly global and diffuse radiation on horizontal surface on clear days: ASHRAE (AMERICAN Society of Heating, Refrigeration and Air-conditioning Engineers) has given a method for estimating the hourly variation of global and diffuse solar radiation following on a horizontal surface on a clear day.

R_r=Tilt factor for beam radiation

R_b=Tilt factor for diffuse radiation

R_r=Tilt factor for reflected radiation

I_T=total solar flux falling on square meter

$I_T=I_bR_b+I_dR_d+(I_b+I_d)R_r$

$Rr=\rho\ (1-\cos\beta)/2$

$Rd=(1+\cos\beta)/2$

$Rb=\cos\theta/ \cos\theta_z$

$P_L/P_O=e^{[-0.0001184*Halt]}$

Slope $\beta = \tan^{-1}[\frac{-\cos\delta\ \sin\omega}{\sin\phi\ \sin\delta+\cos\phi\ \cos\delta\ \cos\omega}]$

$\cos\theta_z = [\sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \cos\omega]\ (P_L/P_O)$

$\cos\delta=23.45*\sin[\frac{360\,(N.D-80)}{370}]$

Beam radiation in direction of rays, $I_{dn}= A.e^{[-Pl}/po*\frac{B}{\sin\alpha}]$

Where A, B and C are constant A is called the apparent solar radiation at zero air mass and B is called the extinction coefficient. The values of the constants A, B&C vary throughout the year because of seasonal changes in the dust and water vapor content of the atmosphere and also because of the changing earth-sun distance

$A_1= 1158 *[1 + 0.066\cos\frac{360*111}{370}]$

$B= 0.175 *[1-\cos(0.93*ND)]-[0.0045*(1-\cos(1.86*ND))]$

$C_1=0.0965[1-0.42\cos(\frac{360*ND}{370})] - 0.0075[1-\cos(1.95*ND)]$

$\sin\alpha = (\cos\phi\cos\delta\cos\omega + \sin\delta\sin\phi)$

$I_{DN} = A_1 \exp[\frac{PL}{P0} *\frac{B}{\sin\alpha}]$

Beam radiation $I_b= I_{dn}* \cos\theta_z$

$I_d=I_{dn}[c1*\frac{(1+\cos\beta)}{2} + s1*(c1+\sin\alpha)(\frac{1-\cos\beta}{2})]$

$I_T=I_bR_b+I_dR_d+(I_b+I_d)R_r$

This available heat flux is calculated for March 20th at Pulivendula location and it is varying from 350 to 1100 w/m^2.

5.1. Governing equations

Heat is dissipated to the air by the convection and radiation losses. The convection heat transfer depends on the wind velocity at the experimental set up.

$$Q_{CONVENTIONAL} =h_a\,\pi\,D_p\,(T_p-T_a) \quad (1)$$

Here the convection heat transfer coefficient of the air is calculated by using Mullik&Nanda correlation [1] which is given by

$$Ha= 4D_p^{-0.42}V_w^{0.5} \quad (2)$$

Heat transfer by radiation from the copper tube surface to the atmospheric air is calculated by [1]

$$Q_{RADIATION} = \sigma\,\epsilon_p\,\pi\,D_p\,(T_p^4-T_a^4) \quad (3)$$

5.2. Geometry of Solar Parabolic Trough Collector

Geometry of SPTC	Value (m)
Collector width	1.2
Focal height	0.3
Collector aperture length	2.7
Outer diameter of the HCE	0.025
Inner diameter of the HCE	0.022

6. SPTC MODELING

The SPTC heat collection element (absorber tube) of length 2.7m,inner diameter 0.022m and external diameter of 0.025m is modeled in Catia V5 R20 software and it is saved in IGES (Initial graphic exchange specification) and this model is imported to the Star CCM+ 9.02 software for the analysis purpose.

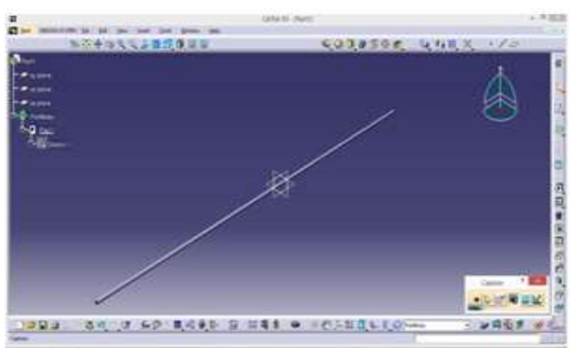

Fig 6.1: Modeling of HCE in CATIA

Fig 6.2: Imported CATIA Model

Fig 6.3: Side view of HCE

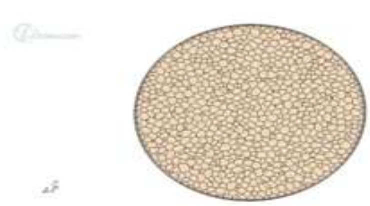

Fig 6.4: Meshed HCE

7. SOLAR PARABOLIC TROUGH COLLECTOR SIMULATION

The HCE is imported into the STAR CCM+ software in IGS format. The solid surface inner and outer regions are defined. The fluid inlet and outlet are defined. Interface is created between the solid inner surface and to the fluid outer surface so that they will share the information among them.

Polyhydral mesh element is taken for meshing for the solid surface the element size is 0.5mma and for the fluid the mesh size is 2 mm. The following assumptions are assumed for this analysis. Steady state heat transfer is considred throughout the absorbertube. The contact thermal resistance between the wall and fluid not considered and thermal conductivity of HCE is uniform and constant.

Uniform heat flux is given to the HCE according to the solar heat flux available in a day. And radiation heat transfer is allowed in the form of surface to surface radiation with participating medium. The inlet temparature of water,mass flow rate,atmospheric air temparature and wind velocity are the input parameters. The output temparature of water and the surface temparature of HCE are the output temparatures. The following material properties are given for thee solid and fluid boundaries.

Table: Material properties

7.1. Material properties:

Material	Density (kg/m^3)	Specific heat C_p (J/kg-k)	Thermal conductivity K (W/m-K)	Viscosity μ (Kg/m-s)
Water	998.2	4182	0.6	0.001003
Copper	8978	381	387.6	-
Air	0.0001245	1009	0.3095	0.00002181

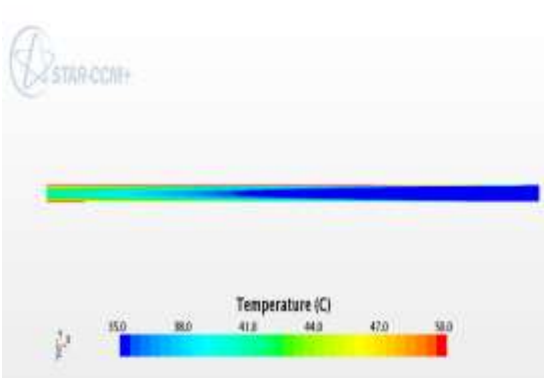

Fig 7.1: Temperature distribution in HCE

Table: Results comparison

Parameter	Experimental value	Simulation value
Inlet temperature	28	30
Mass flow rate	0.05	0.05
Wind velocity	-	0.5
Outlet temperature	33	28
HCE surface temperature	42	48

7.2 Sample calculation

Heat gain by the HCF = m C_P (T_o-T_i)

= 0.05x4182x (38-30)

= 627.3 w

Heat transfer coefficient ha= $4D_p^{-0.42}V_w^{0.5}$

= $4x0.025^{-0.42}x0.5^{0.5}$

= 13.317 w/ m^2 k

$Q_{CONVENTIONAL\ LOSSES}$ = $h_a \pi D_p (T_p-T_a)$

= 13.317x π x0.025(48-36)

= 12.55 w/m

$Q_{RADIATION\ LOSSES}$ = $\sigma €_p \pi D_p (T_p^4-T_a^4)$

= $5.67x10^{-8}x0.78x \pi x0.021x(48^4-36^4)$

= 0.011w/m

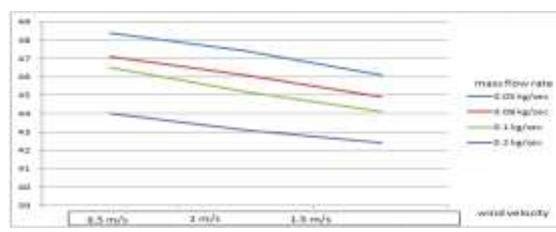

Fig 7.2: Surface temperature of the HCE

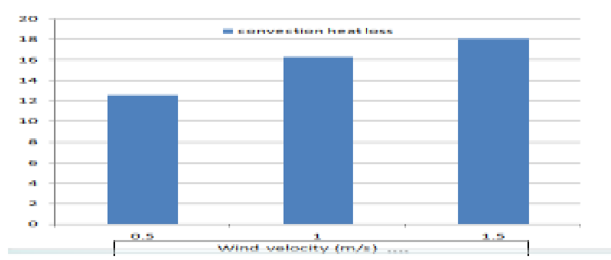

Fig 7.3: Convection heat loss with wind velocity

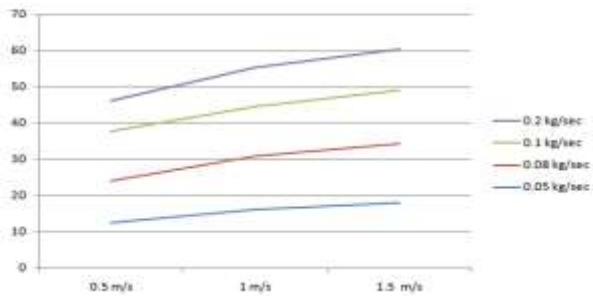

Fig 7.4: Total heat loss with wind velocity and mass flow rate

8. RESULT

The experimental study is done on the parabolic trough collector with different mass flow rate conditions and wind velocity. The heat collection element is modeled in catia and this flow is analyzed by using the star ccm software and these experimental and simulation losses are compared. The losses with varying wind velocity and mass flow rate are analyzed and these are discussed in the conclusion.

9. CONCLUSION

1) As the wind velocity increases the surface temperature of HCE is decreasing
2) The output temperature is inversely proportional to the mass flow rate of the HTF
3) As the wind velocity increases the heat losses are also increasing but in small amount
4) The convection losses are increasing as the surface temperature goes to higher range

10. FUTURE WORK

In this thesis bare copper tube is used as the HCE and water is used as the HTF fluid. In future work different HCE's can be used with different materials. And the HTF also can be altered by different organic fluids.

11. REFERENCE

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