MEE 552 Project Report

Design of Solar Rankine Cycle for Power Generation

Team Members

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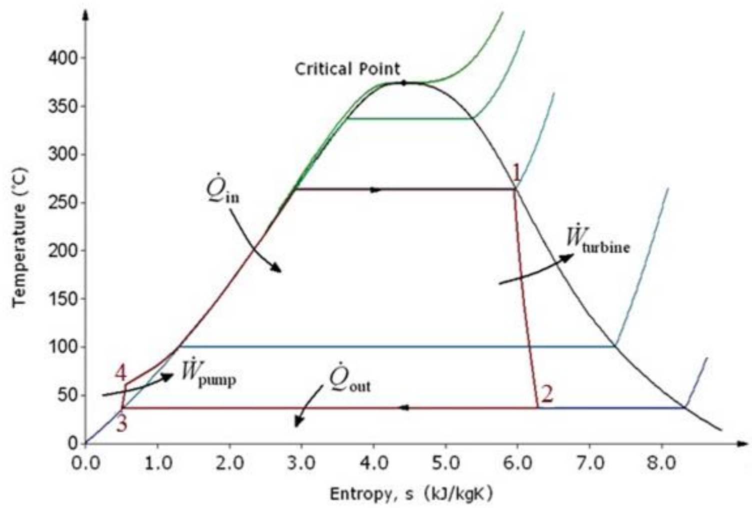
Introduction

This work aims to design a system that uses renewable source of energy, which can be used along with the existing conventional sources of energy to meet the increasing demand of power supply. Application of Solar energy to augment the process of power generation has been under consideration and also under use in some places for a long time. The power output was decided based on daily average usage per house for a small community of 10 houses.

Rankine Cycle:

The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work. The heat is supplied externally to a closed loop, which usually uses water as the working fluid.

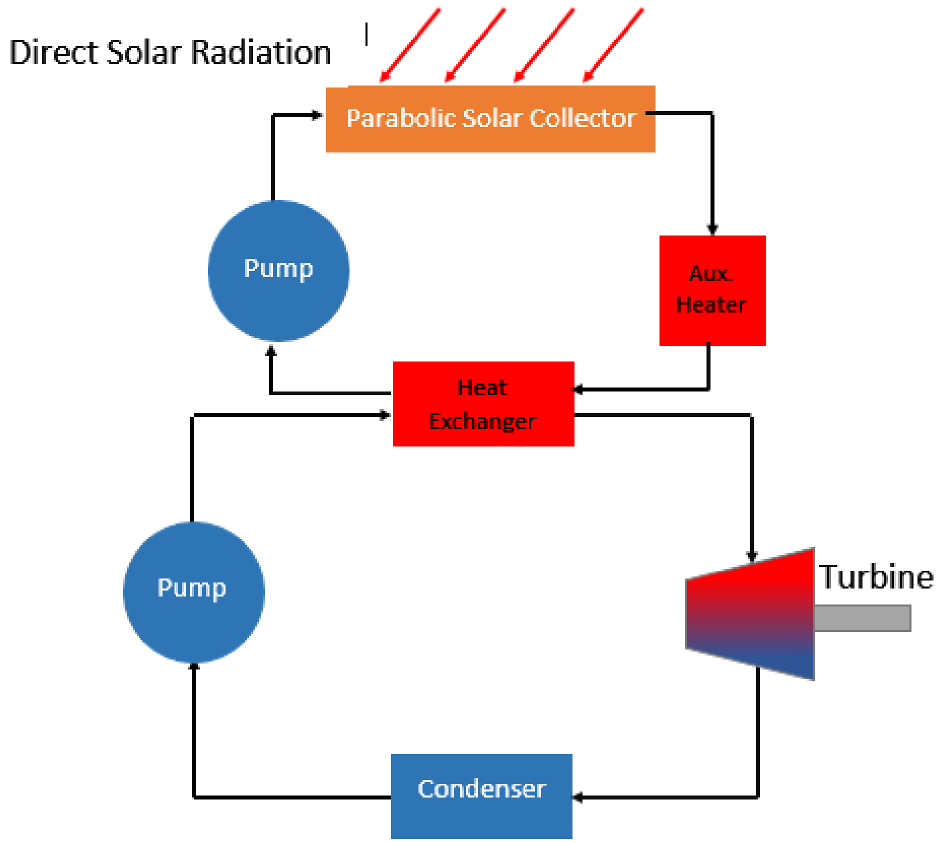


Process 1-2: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour

Process 2-3: The wet vapour then enters a condenser where it is condensed at a constant pressure to become a saturated liquid.

Process 3-4: The working fluid is pumped from low to high pressure. As the fluid is a liquid at this stage, the pump requires little input energy.

Process 4-1: The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a dry saturated vapour.



Project Schematic

The schematic of the Rankine cycle shown in figure above indicates the relative positioning of all the components. The boiler used to convert high pressure low temperature water to high pressure high temperature steam in standard Rankine Cycle is replaced by Heat Exchanger where the water gains the amount of heat required to increase its enthalpy.

Control Volume Analysis is carried out on all the components to obtain the enthalpy of the fluid at each state point. To ease the calculation procedure each time for different working temperatures, turbine and pump efficiencies a MATLAB code was written. The MATLAB program parametric equations to obtain the values of the pressure, enthalpy, entropy and specific volume at the working temperatures given by the user. The output of the MATLAB program gives Heat to be transferred to convert water to steam, Heat lost in the condenser, Work required to run the pump, Work given by the turbine, thermal efficiency of the cycle and the mass flow rate of the water/steam.

Control Volume Analysis on the Turbine:

Dryness fraction:

$$x_{2s} = \frac{s_{2s} - s_f}{s_{fg}}$$

Isentropic Enthalpy:

$$h_{2s} = h_f + x_{2s}h_{fg}\ kJ/kg$$

Isentropic Work:

$$w_{ts} = h_1 - h_{2s}\ kJ/kg$$

Work Done:

$$w_{ta} = w_{ts} * \eta_t$$

$$w_{ta} = (h_1 - h_2)\ kJ/kg$$

Mass flow rate:

$$m_s = \frac{Power}{w_{ta}}\ kg/sec$$

Control Volume Analysis on the Condenser:

Heat lost in Condenser:

$$Q_c = m_s * (h_2 - h_3)\ kW$$

Control Volume Analysis on the pump:

Isentropic work required:

$$W_{ps} = m_s * v_{f3} * (P_1 - P_2)\ kW$$

Actual pump work:

$$W_{pa} = \frac{W_{ps}}{\eta_p}\ kW$$

$$h_4 = h_3 + (W_{pa}/m_s)\ kJ$$

Control Volume Analysis of the Heat Exchanger:

$$Q = m_s * (h_1 - h_4)\ kW$$

Heat Exchanger:

The heat from solar radiation is used by the parabolic solar collector to heat Therminol VP-1. Therminol VP-1 is selected as the working fluid because of its high boiling point and high specific heat which results in greater rate of heat transfer.

To gain maximum heat exchange counter flow heat exchanger configuration is used. The tube of the shell-tube counter flow heat exchanger is selected as 1inch Schedule 20 steel tube. The area of the heat exchanger is calculated to obtain the required heat transfer rate to convert the water to high pressure high temperature steam. Working temperature of the Therminol VP-1 in the heat exchanger has been set to 100˚F and 250˚F.

$$Q_1 = Amount\ of\ heat\ supplied\ in\ the\ heat\ exchanger\ to\ the\ water$$

$$h_a = Enthalpy\ of\ therminol\ at\ 250^\circ\mathrm{C}$$

$$h_b = \ nthalpy\ of\ therminol\ at\ 100^\circ\mathrm{C}$$

Mass flow rate of Therminol-VP-1 is found by:

$$Q_1 = m_t * (h_a - h_b)\ \ kW$$

$$\Delta T_1 = Therminol\ inlet\ Temperature - Water\ outlet\ Temperature$$

$$\Delta T_2 = Therminal\ outlet\ Temperature - Water\ inlet\ Temperature$$

Log mean temperature difference is calculated as:

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}}$$

Properties of water were obtained from the data tables:

Density (ρ) and Dynamic Viscosity(μ) were obtained and used to calculate the Reynolds number and Nusselt Number.

$$Re = \frac{\rho * V * ID}{\mu}$$

$$Nu = 0.023 * Re^{0.8} * Pr^{0.333}$$

Heat transfer co efficient for the internal flow was later calculated from the obtained Nusselt Number

$$h_i = \frac{Nu * ID}{k}\ \frac{BTU}{hr.ft\text{^}2.^\circ C}$$

Internal flow heat transfer co efficient was used to calculate the overall heat transfer co efficient.

$$U = \frac{1}{\frac{1}{h_o} + \frac{r_o}{k} ln \frac{r_o}{r_i} + \frac{r_o}{r_i * h_i}}$$

Heat transfer rate is related to the area of heat exchanger as:

$$Q_1 = U * A * \Delta T_{lm}\ kW$$

Length of each tube is calculated as:

$$L = \frac{A}{\Pi * ID}\ feets$$

Thus by using the MATLAB program we can calculate the Heat exchanger area and the length of the tubes of heat exchanger for any operating conditions given by the user.

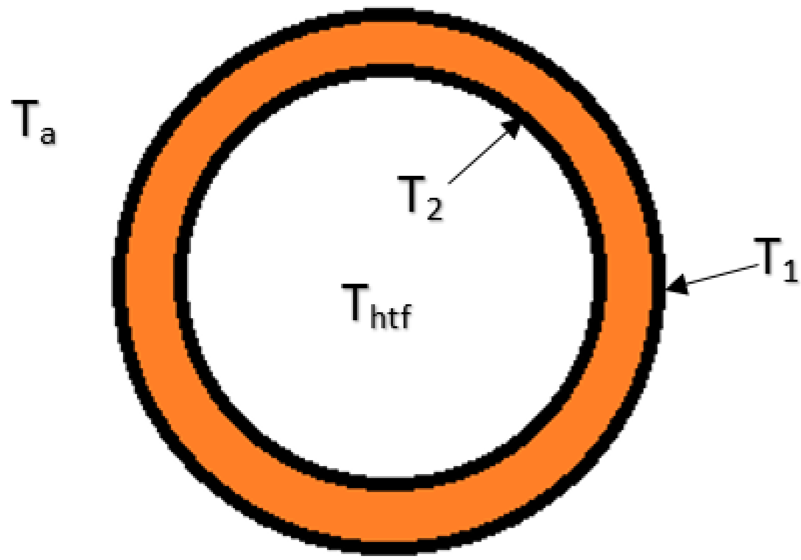
Parabolic Solar Collector

There are broadly two types of Solar Collectors, namely Flat Plate Solar Collector and Parabolic Solar Collector.

Flat plate solar collector collects whatever solar energy is falling on them. A parabolic solar collector on the other hand absorbs a concentrated solar radiation falling on it due to a parabolic mirror.

The collector part of solar collectors can be bare copper collector or a glass enclosed copper collector. For this project we have taken analysed both the types of collectors.

<u>Energy Conservation equations for Bare Copper Collector</u>



$$\frac{2\pi K l}{\ln(\frac{od}{id})}(T_1 - T_2) - \alpha G + \epsilon A \sigma (T_1^4 - T_a^4) + h_o A_o (T_1 - T_a) = E$$

…eq. (1)

$$\frac{2\pi K l}{\ln\left(\frac{od}{id}\right)}(T_1 - T_2) = h_i A_i \left(T_2 - T_{htf}\right)$$

….eq. (2)

Where,

$h_i \ = \ Heat\ Transfer\ Coefficient\ inside\ copper\ tube$

$h_o = Heat\ Transfer\ Coefficient\ outside\ the\ tube$

$\alpha, \epsilon \ = \ Absorptivity\ \&\ emissivity\ of\ copper$

$T_{htf} = \ Temperature\ of\ thermal\ fluid$

$T_a = \ Temperature\ of\ ambient\ air$

$E = \ Error$

Method of Solution

i) A sufficiently low value for T1 is guessed and then T2 is calculated based on T1 using equation 2.

ii) The error is calculated using equation 1.

iii) If the error is more than desired, T2 is incremented by a small amount and the process is repeated again.

iv) Iteration is continued till the required error value is reached.

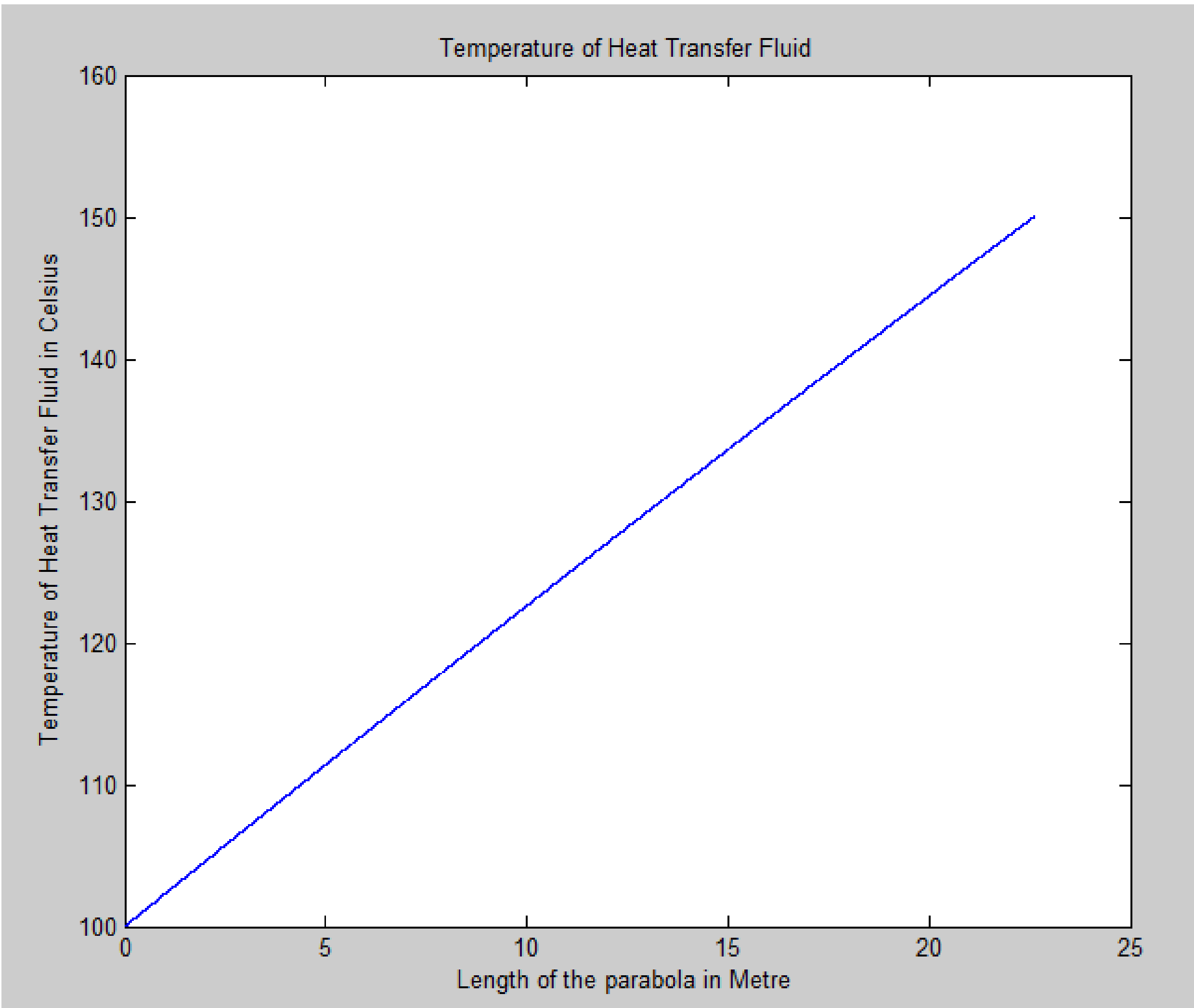
Results

The net length of the collector was found to be 72.78 metres.

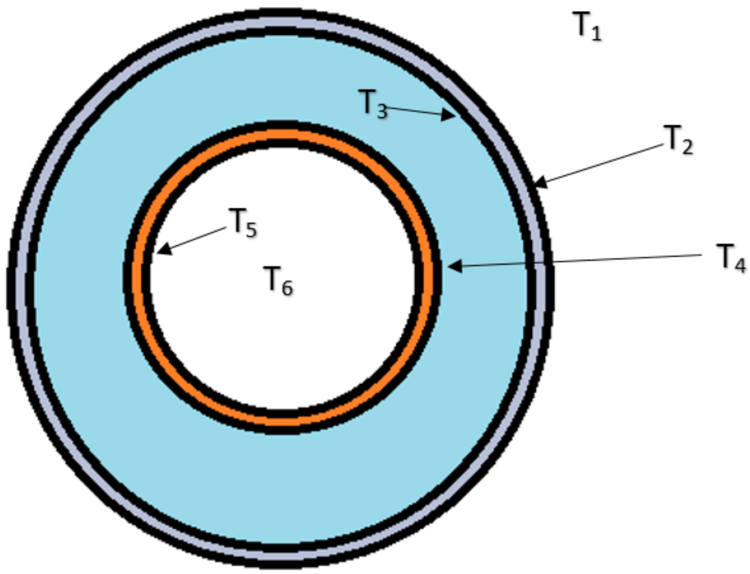
Efficiency was found to be approximately 57% for not so windy condition.

Bare copper collector is extremely sensitive to ambient condition. The efficiency reduces dramatically with high wind speed.

The following figure shows the temperature rise of the working fluid till 150 deg. C



Energy Conservation equations for Glass encased Copper Collector



$$\alpha_g G = \frac{2\pi k_g l}{\ln\left(\frac{OD_g}{ID_g}\right)}(T_2 - T_3) + h_o A_{og}(T_2 - T_1) \quad \text{....eq(3)}$$

$$\frac{2\pi k_g l}{\ln\left(\frac{OD_g}{ID_g}\right)}(T_2 - T_3) + \alpha_g \epsilon_c \sigma T_4^4 A_{oc} - F_{34}\epsilon_g \sigma T_3^4 A_{ig} + \alpha_g A_{ig} F_{33}\epsilon_g \sigma T_3^4 + \alpha_g (1 - \alpha_c)\tau G + F_{34}\alpha_g(1-\alpha_c)\sigma T_4^4 A_{ig} = E1 \quad \text{....eq(4)}$$

$$\frac{2\pi k_c l}{\ln\left(\frac{OD_c}{ID_c}\right)}(T_4 - T_5) = h_i A_{ic}(T_5 - T_6) \quad \text{....eq(5)}$$

$$F_{34}\alpha_c\sigma T_3^4 A_{ig} + \alpha_c\tau G - \frac{2\pi k_c l}{\ln\left(\frac{OD_c}{ID_c}\right)}(T_4 - T_5) - \epsilon_c\sigma T_4^4 A_{oc} = E2 \quad \text{....eq(6)}$$

$F_{34}, F_{33} = View\ Factor$

$\alpha_g, \alpha_c = Absorptivity\ of\ glass\ \&\ copper$

$\epsilon_g, \epsilon_c = Emittivity\ of\ glass\ \&\ copper$

$ID_g, OD_g = Inner\ \&\ outer\ diameter\ of\ glass$

$ID_c, OD_c = Inner\ \&\ outer\ diameter\ of\ copper\ tube$

$A_{ig}, A_{og} = Surface\ area\ of\ inner\ \&\ outer\ glass\ surface$

$A_{ic}, A_{oc} = Surface\ area\ of\ inner\ \&\ outer\ tube\ surface$

Method of Solution

i) A sufficiently low value for T2 is guessed and then T3 is calculated based on equation 2.

ii) This value of T2 and T3 is used to iterate and look for a converging value of T4 and T5(like in the case of bare copper collector).The equation for this task used is equation 5 and 6.

iii) A second error check is done based on the converged value of T4 and T5 using equation 4 .If the error is more than desired, T2 is incremented by a small amount and the process is repeated again.

iv) Iteration is continued till the required error value is reached .

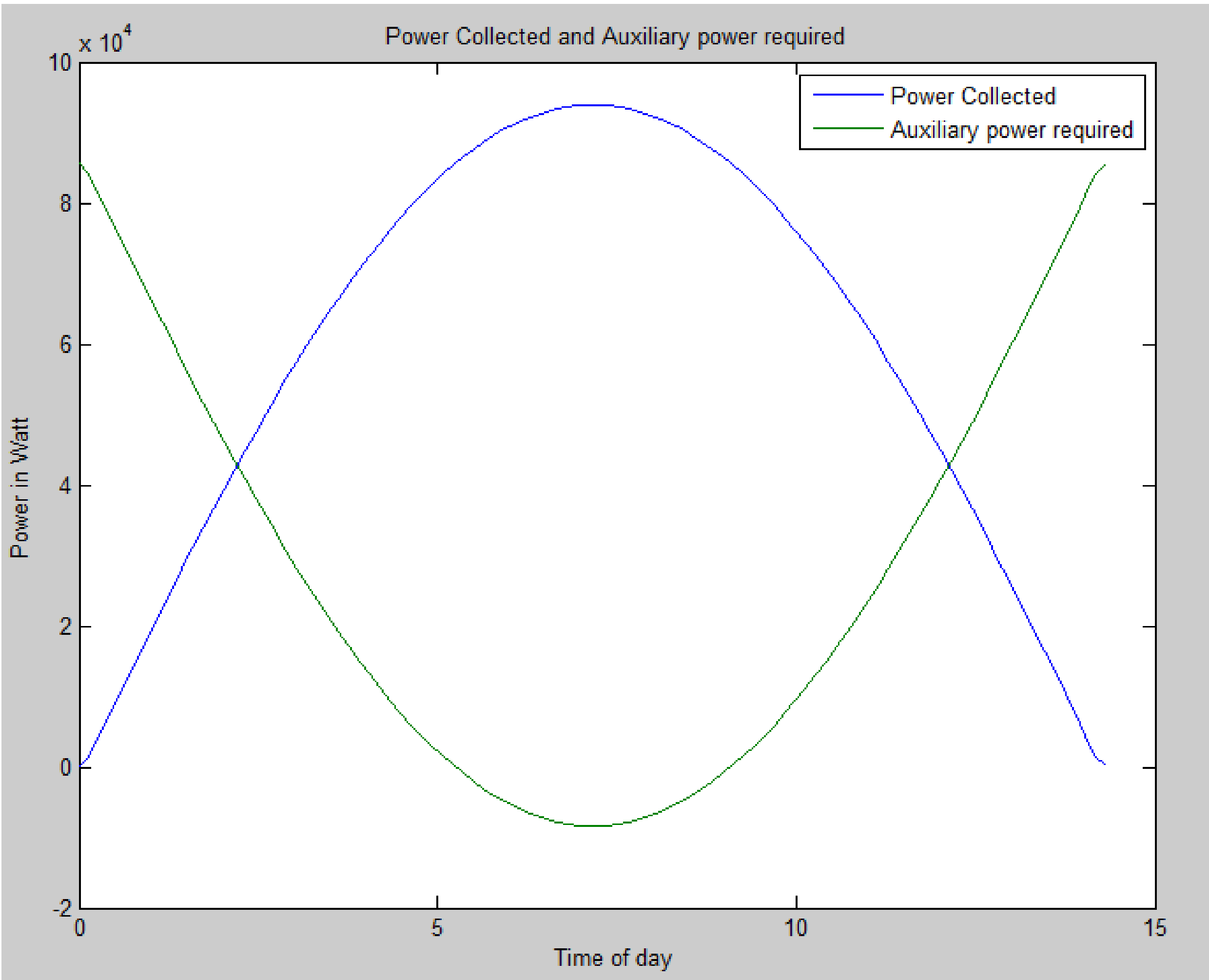
Results

The net length of the collector was found to be 67 metres.

Efficiency was found to be approximately 61.8%

This type of collector is not sensitive to ambient condition.

The following figure shows power collected and Auxiliary power needed for 120th day of the year:



Total energy collected over the day is 8.4883e+05 Wh

Matlab Codes

Matlab code for Rankine Cycle:

```
clear all;
close all;
prompt1 = {'Turbine inlet Temperature:'};
dlg_title1 = 'Enter Turbine inlet Temperature';
answer1 = inputdlg(prompt1,dlg_title1,[1,54]);
T= str2num(answer1{1});
prompt2 = {'Condenser Outlet Temperature:'};
dlg_title2 = 'Enter Condenser Outlet Temperature';
answer2 = inputdlg(prompt2,dlg_title2,[1,54]);
N= str2num(answer2{1});
prompt3 = {'Output Power'};
dlg_title3 = 'Enter required output power';
answer3 = inputdlg(prompt3,dlg_title3,[1,54]);
P= str2num(answer3{1});
prompt4 = {'Turbine Efficiency'};
dlg_title4 = 'Enter Turbine Efficiency';
answer4 = inputdlg(prompt4,dlg_title4,[1,54]);
n1= str2num(answer4{1});
prompt5 = {'Pump Efficiency'};
dlg_title5 = 'Enter Pump Efficiency';
answer5 = inputdlg(prompt5,dlg_title5,[1,54]);
n2= str2num(answer5{1});
% Parametric equations to calculate fluid properties
P1=(1358674.65234684)+(-81918.9477978889*T)+(2184.06388871094*T^2)+(-
33.7963722923486*T^3)+(0.334515098458539*T^4)+(-0.00219640839343630*T^5)+(9.56725318914008e-
06*T^6)+(-2.66603731765185e-08*T^7)+(4.31299435252114e-11*T^8)+(-3.08641855596400e-14*T^9);
Hf1=(-21439.1405015874)+(2801.49332285956*T)+(-161.258389106839*T^2)+(5.39129036120896*T^3)+(-
0.115209154083342*T^4)+(0.00163206205068476*T^5)+(-1.53277778610082e-05*T^6)+(9.20359790701528e-
08*T^7)+(-3.20634920543073e-10*T^8)+(4.93827158985212e-13*T^9);
Hg1=(-85639.5938356353)+(5335.43510949050*T)+(-142.750489135208*T^2)+(2.21808853407293*T^3)+(-
0.0220527836166511*T^4)+(0.000145499132652654*T^5)+(-6.37110863195540e-
07*T^6)+(1.78558132262391e-09*T^7)+(-2.90674492327435e-12*T^8)+(2.09435547083137e-15*T^9);
Sf1=(5952.74585923362)+(-793.633246414308*T)+(46.8107864469683*T^2)+(-
1.60321068747190*T^3)+(0.0351382315230426*T^4)+(-0.000511127922768881*T^5)+(4.93470884517824e-
06*T^6)+(-3.04932483316825e-08*T^7)+(1.09441268353320e-10*T^8)+(-1.73827157774209e-13*T^9);
Sg1=(1323.86657918412)+(-78.9726369871476*T)+(2.09658350204818*T^2)+(-
0.0323168966148672*T^3)+(0.000318685993821093*T^4)+(-2.08506566952388e-
06*T^5)+(9.05155892799680e-09*T^6)+(-2.51423511980662e-11*T^7)+(4.05505792643296e-14*T^8)+(-
2.89351737970358e-17*T^9);
Vf1=(-0.297811017221968)+(0.0351671415484247*T)+(-0.00181261529681278*T^2)+(5.36100414423644e-
05*T^3)+(-1.00019452659166e-06*T^4)+(1.21637974240135e-08*T^5)+(-9.59111213691121e-
11*T^6)+(4.68783128411355e-13*T^7)+(-1.26984147086200e-15*T^8)+(1.41093504377128e-18*T^9);
P3=(22867.0706363296)+(-2942.77495393833*N)+(167.371412327614*N^2)+(-
5.52199231772386*N^3)+(0.116488649253674*N^4)+(-0.00162962087579190*N^5)+(1.51207557355404e-
05*N^6)+(-8.97443394400482e-08*N^7)+(3.09206351142480e-10*N^8)+(-4.71252206203480e-13*N^9);
```

```
Hf3=(-21439.1405015874)+(2801.49332285956*N)+(-161.258389106839*N^2)+(5.39129036120896*N^3)+(-
0.115209154083342*N^4)+(0.00163206205068476*N^5)+(-1.53277778610082e-05*N^6)+(9.20359790701528e-
08*N^7)+(-3.20634920543073e-10*N^8)+(4.93827158985212e-13*N^9);
Hg3=(-28161.0808889896)+(3952.47245625836*N)+(-224.794489468813*N^2)+(7.41468625958310*N^3)+(-
0.156251655696109*N^4)+(0.00218180818301146*N^5)+(-2.01891113784764e-05*N^6)+(1.19394710245248e-
07*N^7)+(-4.09523812667777e-10*N^8)+(6.20811290493764e-13*N^9);
Sf3=(5952.74585923362)+(-793.633246414308*N)+(46.8107864469683*N^2)+(-
1.60321068747190*N^3)+(0.0351382315230426*N^4)+(-0.000511127922768881*N^5)+(4.93470884517824e-
06*N^6)+(-3.04932483316825e-08*N^7)+(1.09441268353320e-10*N^8)+(-1.73827157774209e-13*N^9);
Sg3=(-750.864718337800)+(98.9534183493047*N)+(-5.69568409253684*N^2)+(0.190091815680342*N^3)+(-
0.00405503527192328*N^4)+(5.73409375707987e-05*N^5)+(-5.37528892322635e-
07*N^6)+(3.22137567266224e-09*N^7)+(-1.12000000074295e-11*N^8)+(1.72134038434789e-14*N^9);
Vf3=(-0.297811017221968)+(0.0351671415484247*N)+(-0.00181261529681278*N^2)+(5.36100414423644e-
05*N^3)+(-1.00019452659166e-06*N^4)+(1.21637974240135e-08*N^5)+(-9.59111213691121e-
11*N^6)+(4.68783128411355e-13*N^7)+(-1.26984147086200e-15*N^8)+(1.41093504377128e-18*N^9);
x2=(Sg1-Sf3)/(Sg3-Sf3);                %Calculating H2%
H2s=(Hf3+(x2*(Hg3-Hf3)));
wta=(Hg1-H2s)*n1;
H2=Hg1-wta;
mw=P/wta;                              %Calculating mass flow rate of steam
Qc=mw*(H2-Hf3);                        %Calculating heat loss in condenser
wp=(Vf3*(P1-P3))/n2;
H4=Hf3+(wp);
disp('Mass flow rate of steam (Kg/sec)=');
disp(mw);
Qb=mw*(Hg1-H4);                        %Calculating heat gained in boiler
disp('Heat loss in condensor (KW)=');
disp(Qc);
disp('Heat Gained in Boiler (KW)=');
disp(Qb);
disp('Power Output of Turbine (KW)=');
disp(P);
nth=(mw*(wta-wp))/Qb;
%disp('Thermal Efficiency=');
%disp(nth);
```

Matlab code for Heat Exchanger:

```
clear all
clc
%---Variable Description----%
U=201.811;
disp('Enter Tube Diameter in inch')
Dt= input('');
Pd= Dt*0.0833;          %pipe diameter
```

```
% disp('Enter flow velocity in ft/sec')
% V= input('');
% Vd=V*0.3048;      %Inlet Velocity

%---Cold Side-Tube-----%
Mc=0.0349;
rho=1000;
Tt_in=(60*1.8)+32;
Tt_out=(120*1.8)+32;
Cpc=4186.3;
Cc=Mc*Cpc;
Delta_H1=2537.72;

%----Hot Side-Shell-----%
Mh=0.286;
Ts_in=(250*1.8)+32;
Ts_out=(100*1.8)+32;
Delta_H2=297;
%Ch=Mh*Cph;

%----Net Heat Exchange-----%
%Qnet=Cc*(Tt_out-Tt_in);
Qnet=Mh*(Delta_H2)*3.4121*1000;
disp('Net Heat Transfer in BTU/hr');
disp(Qnet);

%---Energy Equivalence----%
% Ts_out=Ts_in-Qnet/Ch;
% disp(Ts_out);
 disp('Enter Number of Tube Passes')         %Correction Factor Calculation
 i=input('');
 if i==1;
     F=1;
     disp('F=');
     disp(F);
 else
     R=(Ts_in-Ts_out)/(Tt_out-Tt_in);
    S=(Tt_out-Tt_in)/(Ts_in-Tt_in);
    P=((R^2)+1)^0.5;
    N=P*log((1-S)/(1-R*S));
    D=(R-1)*log((2-(S*(R+1-P)))/(2-(S*(R+1+P))));
    F=N/D;
    disp('F=');
    disp(F);
end

 %----LMTD calculation-----%
 dT1=Ts_in-Tt_out;
 dT2=Ts_out-Tt_in;
 dT=F*(dT2-dT1)/log(dT2/dT1);

% %----Surface Area Required----%
 Anet=Qnet/(U*dT);
disp('Area of the Heat Exchanger (ft^2)=');
disp(Anet);
```

```
 %---Length Calculation--
At=3.14*(Pd/2)^2;
Vd= Mc/(1000*At);        %Total Flow Area
disp('Flow Velocity (ft/sec)=');
disp(Vd);
L=Anet/(3.14*Pd);    %Length of Tubes
disp('Length of tube in feets=');
disp(L);
L1=L*0.3048;
disp('Length of tube in meters=');
disp(L1);
```

Matlab code for Bare Copper Collector:

```
clear all
clc

Tw=100+273;
T1=273;
Ta=30+273;

l=0.001;
m_dot=0.288;
%------Parabola Characteristic-------%
Lt=3;
Girr=684;
Gf=Girr*Lt*l;
%-----end----%
%---Tube characteristics-----%
id=0.01;
od=0.015;
K=385;

UAcond=2*pi*385*l/(log(od/id));
ab=0.7;
emi=0.7;
Gabs=ab*Gf;
%---End-------%
%----Thermal Fluid Characteristic------%
rho=1060;
v=m_dot*4/(rho*pi*(id)^2);

%-----end-----%
%------Ambient Conditions-----%
ha=60;
UAconv_o=ha*pi*od*l;
d=2;
counter=0;
qtotal=0;
while Tw<(200+273)
    T=Tw-273;

    cp=0.002414*T+5.9591e-6*T^2-2.9879e-8*T^3+4.4172e-11*T^4+1.498;
```

```
   cp=cp*1000;
%    k=-8.19477*10e-5*T-1.92257e-7*T^2+2.5034e-11*T^3-7.2974e-15*T^4+0.137;
    k=0.1;
   rho=-0.90797*T+0.00078116*T^2-2.367e-6*T^3+1083.25;
   gamma=exp(544.149/(T+114.3)-2.59578);
   vis=gamma*rho*1e-6;

   Pr=cp*vis/k;
   Re=rho*v*id/vis;

   Nu=0.023*Re^0.8*Pr^0.33;

   Htf=Nu*k/id;
   UAconv_i=pi*id*l*Htf;

while abs(d)>=0.001

    cond_ratio=UAcond/UAconv_i;
    T2=(cond_ratio*T1+Tw)/(1+cond_ratio);
    d1=UAcond*(T1-T2);
    d2=-1*Gabs+emi*(5.67e-8)*(T1^4-Ta^4)*pi*od*l+UAconv_o*(T1-Ta);
    d=d1+d2;
    T1=T1+0.001;
end
   q=UAcond*(T1-T2);
   T=Tw-273;
   cp=0.002414*T+5.9591e-6*T^2-2.9879e-8*T^3+4.4172e-11*T^4+1.498;
   cp=cp*1000;
   dT=q/(m_dot*cp);
   Tw=Tw+dT;
   counter=counter+1;

  qtotal=qtotal+q;
end
Length=counter*l
 qtotal
 Length*Girr
eta=qtotal/(Length*Girr*Lt)
```

Matlab code for Glass Encased Copper Collector:

Main Program

```
clear all
clc
```

```
qreq=8.5601e+04;
precicion=100;
n=120;
phi=0.731293;
Is=1367;
I=Is*(1+0.034*cos(2*pi*n/265.25));
I=I/2;
delta=23.45*pi/180*sin(2*pi*(284+n)/36.25);
sunset_angle=acos(-1*tan(phi)*tan(delta));
N=2*sunset_angle*180/(15*pi);
alpha=N/(180);
x=linspace(0,180,precicion);
q=ones(1,precicion);
h=alpha.*x;
eta=zeros(1,precicion);
for i=1:precicion

    Ir=I*sind(x(i));
    if Ir>=12
    [qtol,efficiency]= general(Ir);
    q(i)=qtol;
    eta(i)=efficiency;
    end
    if I<=12
        q(i)=0;
        eta(i)=0;
    end
end
figure(1);
qneed=qreq*ones(1,precicion);
qneed=qneed-q;

plot(h,q,h,qneed)
title('Power Collected and Auxiliary power required');
xlabel('Time of day');
ylabel('Power in Watt');
legend('Power Collected','Auxiliary power required')
totalenergy=trapz(h,q);
xyz=sprintf('Total Energy collected  = %d Wh',totalenergy);
text(20,30,xyz);

figure(3)
plot(h,eta)
title('Efficiency of Solar Collector');
xlabel('Time of day');
ylabel('Efficiency of Solar Collector');
%axis([0 h(10) 0.55 0.65])
```

Called Function

```
function [qtotal,etat]= general(ff)

T1=30+273;
T6=100+273;
```

```matlab
l=0.001;
Lt=3;
G=ff;
Gin=G*l*Lt;
%-----glass parameter------%
t=0.9;
abg=0.04;
eg=abg;
idg=0.02;
odg=0.021;
Kg=4;
Hg=100;
%-----copper tube parameter----%
abc=0.70;
ec=abc;
idc=0.01;
odc=0.015;
Kc=385;



%------View Factors-----%
Aoc=pi*odc*l;
Aic=pi*idc*l;
Aog=pi*odg*l;
Aig=pi*idg*l;

F34=Aoc/Aig;
F33=1-F34;
%----Thermal Fluid Characteristic------%
m_dot=0.288;
rho=1060;
v=m_dot*4/(rho*pi*(idc)^2);
%----constants----%
si=5.67e-8;
Cg=2*pi*Kg*l/(log(odg/idg));
Cc=2*pi*Kc*l/(log(odc/idc));
e1=2;
T2=T1;
pr2=0.01;
pr1=0.1;
b=0;
T4=T6;
counter=0;
Length=0;
qt=0;
while Length<(76.6500)

  T=T6-273;
  cp=0.002414*T+5.9591e-6*T^2-2.9879e-8*T^3+4.4172e-11*T^4+1.498;
  cp=cp*1000;
  %k=-8.19477*10e-5*T-1.92257e-7*T^2+2.5034e-11*T^3-7.2974e-15*T^4+0.137;
  k=0.1;
  rho=-0.90797*T+0.00078116*T^2-2.367e-6*T^3+1083.25;
  gamma=exp(544.149/(T+114.3)-2.59578);
  vis=gamma*rho*1e-6;
```

```
   Pr=cp*vis/k;
   Re=rho*v*idc/vis;
   Nu=0.023*Re^0.8*Pr^0.33;
   Hc=Nu*k/idc;

while abs(e1)>0.01

    T3=(-1*abg*Gin/(Cg))+T2+(eg*si*(T2^4-T1^4)*Aog/Cg)+(Hg*Aog*(T2-T1)/Cg);
    e2=2;
    c=0;
    T4=T6+pr2;
    while abs(e2)>0.001
        x=(Hc*Aic)/Cc;
        T5=(x*T6+T4)/(1+x);
        e2=(F34*abc*si*T3^4*Aig)+abc*t*Gin-Cc*(T4-T5)-ec*si*T4^4*Aoc;%+F34*(1-t-abg)*abc*si*(T4^4)*Aoc;
        T4=T4+pr2;
   end
    T4=T4-pr2;
    e1=+Cg*(T2-T3)+abg*ec*si*T4^4*Aoc-F34*eg*si*T3^4*Aig+F33*eg*si*T3^4*abg*Aig+abg*(1-
abc)*t*Gin+abg*(1-abc)*F34*si*(T3^4)*Aig;
    T2=T2+pr1;
end
   q=Cc*(T4-T5);
   dT=q/(m_dot*cp);
   T6=T6+dT;
   counter=counter+1;
   Length=l*counter;
   qt=qt+q;
end
qtotal=qt;

etat=qtotal/(Lt*Length*G);
end
```