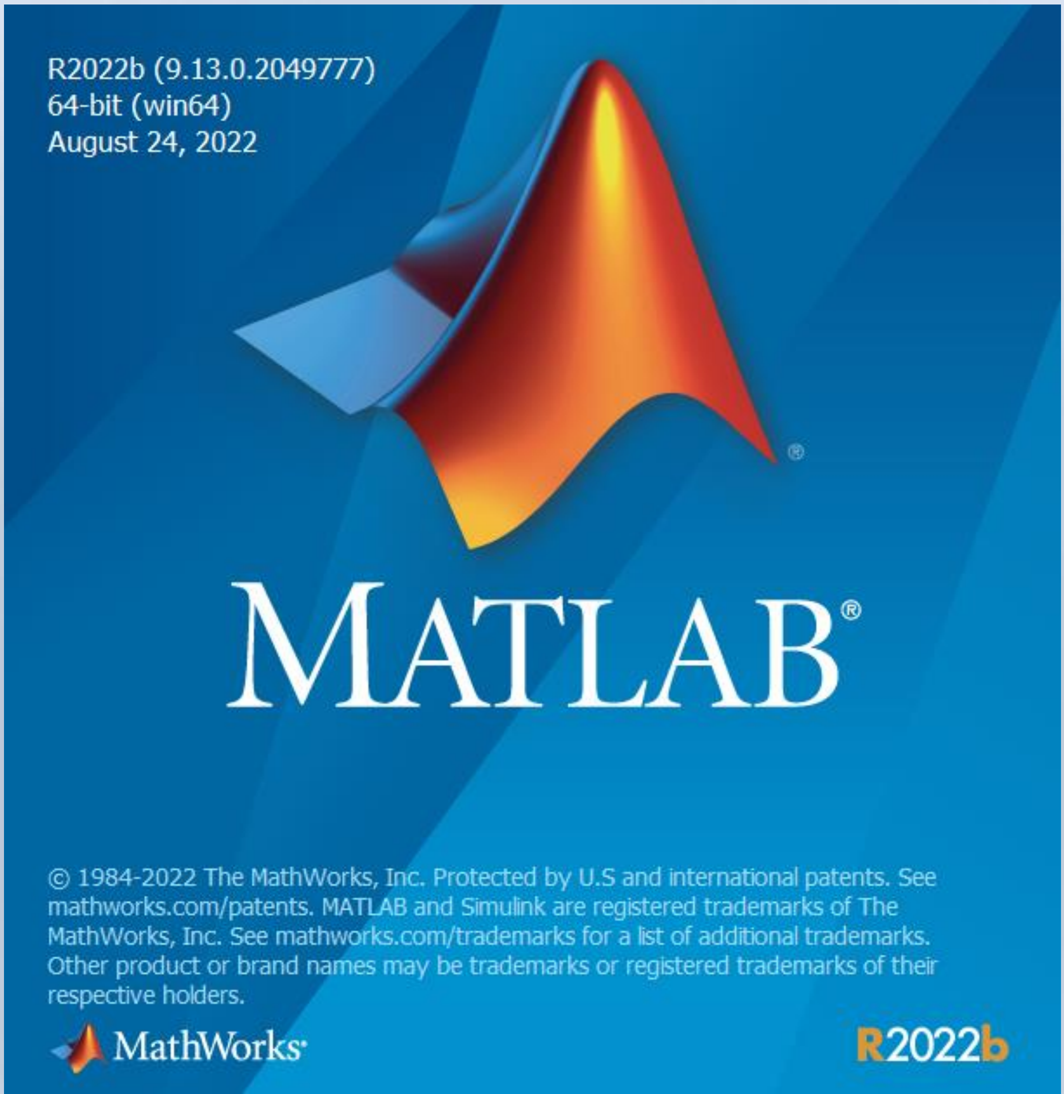
ME-214

Computer Programmings & Applications

Complex Engineering Problem (CEP)

Spring-2025

Department of Mechanical Engineering



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Solar Radiation Analysis on a Flat Plate Collector using MATLAB

This project aims to develop a **comprehensive MATLAB program** to analyze the variation of **solar insolation** on a flat plate collector surface throughout a day. The program enables users to input specific conditions such as the **day of the year (n)**, while geographic coordinates (latitude and longitude) are determined through Google Maps for location-specific accuracy. This allows a flexible and adaptable solution suitable for use in any region.

The key solar parameters and radiative components considered in this analysis include:

- **Declination angle (δ)**: Determines the tilt of the Earth's axis relative to the sun.
- **Hour angle (ω)**: Measures the sun's position relative to solar noon.
- **Angle of incidence (θ)**: Angle between the sun's rays and the collector surface.
- **Solar altitude (α_s)**: Vertical position of the sun in the sky.
- **Solar zenith (θ_x)**: Angular position of the sun in the sky.
- **Air Mass Ratio (m)**: Quantifies the atmospheric path length of sunlight.
- **Apparent Extraterrestrial Flux (A)**.
- **Optical Depth (k)**: Model the atmospheric attenuation.
- **Direct Beam Radiation (I^B)**
- **Diffuse Radiation ($I^D{}_C$)**
- **Reflected Radiation ($I^R{}_C$)**
- **Total Insolation on Collector (I_C)**: The cumulative radiation from all sources.

The developed MATLAB script computes these parameters on an **hourly basis** for a complete day and generates a plotted graph of **total insolation on the collector**, offering valuable insights into the optimal performance window. The calculations assume **clear sky conditions**, and **ground reflectance (ρ)** is set to a typical value of **0.2**.

(The calculations are on the day of 22 March hence, the graph and table too.)

```
clc; clear;
format long

%Inputs
latitude=input('Enter Latitude(degrees):'); %Latitude(eg:24.9537°N)
while latitude<-90 || latitude>90|| isnan(latitude)
    disp('Invalid latitude. Latitude must lies between -90 and 90.');
    latitude=input('Enter Latitude(degrees):');
end
longitude=input('Enter Local Longitude(degrees):'); %Local longitude(Longitude: 67.0007°E)
while longitude<-180 || longitude>180 || isnan(longitude)
    disp('Invalid longitude. Longitude must lies between -180 and 180.');
    longitude=input('Enter Longitude (degrees):');
end
rho=0.2; %Ground reflectance
beta=latitude; %Collector tilt
gamma=0; %Surface faces south

%Day-Month calculations
month=menu('CHOOSE A MONTH','January','February','March','April','May','June','July',...
    'August','September','October','November','December');
i=input('Day of Month:');
switch month
    case 1,if i>31, error('The day number is invalid for January'),end,n=i;
    case 2,if i>28, error('The day number is invalid for February'),end,n=31+i;
    case 3,if i>31, error('The day number is invalid for March'),end,n=59+i;
    case 4,if i>30, error('The day number is invalid for April'),end,n=90+i;
    case 5,if i>31, error('The day number is invalid for May'),end,n=120+i;
    case 6,if i>30, error('The day number is invalid for June'),end,n=151+i;
    case 7,if i>31, error('The day number is invalid for July'),end,n=181+i;
    case 8,if i>31, error('The day number is invalid for August'),end,n=212+i;
    case 9,if i>30, error('The day number is invalid for September'),end,n=243+i;
    case 10,if i>31, error('The day number is invalid for October'),end,n=273+i;
    case 11,if i>30, error('The day number is invalid for November'),end,n=304+i;
    case 12,if i>31, error('The day number is invalid for December'),end,n=334+i;
end

start_time=0; %Start time(midnight)
end_time=23; %End time(11 PM)

% Pre-allocate arrays for hourly values
Hours_of_day=(start_time:end_time)';
ST_arr=NaN(1,24)';                %Solar Time Hours_of_day
omega_arr=NaN(1,24)';             %Hour Angle (deg)
alpha_s_arr=NaN(1,24)';           %Solar Altitude (deg)
theta_z_arr=NaN(1,24)';           %Solar Zenith (deg)
SolarAzimuth_arr=NaN(1,24)';      %Solar Azimuth (deg)
theta_i_arr=NaN(1,24)';           %Angle of Incidence (deg)
m_arr=NaN(1,24)';                 %Air Mass ratio
Ib_arr= zeros(1,24)';             %Direct Beam Radiation (W/m^2)-DNI
```

```
Ibc_arr=zeros(1,24)';           %Beam Radiation on collector (W/m^2)
Idc_arr=zeros(1,24)';           %Diffuse Radiation on collector (W/m^2)
Irc_arr=zeros(1,24)';           %Reflected Radiation on collector (W/m^2)
Ic_arr=zeros(1,24)';            %Total Radiation on the collector (W/m^2)

%Store results for plotting
time_values=[];
Ic_values=[];

%Constant Calculations
delta=23.45*sind(360*((284+n)/365)); %Declination Angle (δ)
GMT=ceil(longitude/15); %Time zone offset
SL=GMT*15;
B=360/365*(n-81);
EoT=(229.2/60)*(0.000075+0.001868*cosd(B)-0.032077*sind(B)-...
    0.014615*cosd(2*B)-0.04089*sind(2*B)); %Equation of Time in minutes
A=1160+75*sind((360/365)*(n-275));
k=0.174+0.035*sind((360/365)*(n-100));
C=0.095+0.04*sind((360/365)*(n-100));

%Loop Calculations
for time=start_time:end_time
    index=time+1;
    ST=time+(EoT-(4*(SL-longitude))/60);ST_arr(index)=ST; %Solar Time
    omega=(ST-12)*15; omega_arr(index)=omega; %Hour Angle (Each hour=15° movement)
    %Incidence Angle Calculation (Theta_i)
    theta=sind(delta)*sind(latitude)*cosd(beta)-sind(delta)*cosd(latitude)*sind(beta)*...
        cosd(gamma)+cosd(delta)*cosd(latitude)*cosd(beta)*cosd(omega)+...
        cosd(delta)*sind(latitude)*sind(beta)*cosd(gamma)*cosd(omega);
    theta_i=acosd(theta); theta_i_arr(index)=theta_i;
    %Solar Altitude Angle (α)
    alpha_s=asind(cosd(latitude)*cosd(delta)*cosd(omega)+sind(latitude)*sind(delta));
    alpha_s_arr(index)=alpha_s;
    %Solar Zenith Angle (θz)
    theta_z=acosd(cosd(latitude)*cosd(delta)*cosd(omega)+sind(latitude)*sind(delta));
    theta_z_arr(index)=theta_z;
    if alpha_s>0
        %Solar Azimuth Angle (Azimuth)
        SolarAzimuth=sign(omega)*abs(acosd((cosd(theta_z)*sind(latitude)-sind(delta))/...
            (sind(theta_z)*cosd(latitude)))); SolarAzimuth_arr(index)=SolarAzimuth;
        m=1/sind(alpha_s); m_arr(index)=m;%Air Mass Ratio (m)
        Ib=A*exp(-k*m); Ib_arr(index)=Ib; %Direct Beam Radiation
        Ibc=Ib*cosd(theta_i); Ibc_arr(index)=Ibc;%Beam radiation on collector
        Idc=Ib*C*((1+cosd(beta))/2); Idc_arr(index)=Idc; %Diffuse radiation on collector
        Irc=rho*Ib*(sind(alpha_s)+C)*((1-cosd(beta))/2); %Reflected radiation on collector
        Irc_arr(index)=Irc;
        Ic=Ibc+Idc+Irc; Ic_arr(index)=Ic;
    else
        Ic_arr(index)=0;
    end
```

```
    time_values=[time_values;time];
    Ic_values=[Ic_values;Ic_arr(index)];
end

%For Table
variablenames={'Hour','SolarTime','HourAngle','SolarAltitude','SolarZenith',...
    'SolarAzimuth','IncidenceAngle','Air/Mass','IB','IBc','IDc','IRc','IC'};
Table_cal=table(Hours_of_day,ST_arr,omega_arr,alpha_s_arr,theta_z_arr,SolarAzimuth_arr...
    ,theta_i_arr,m_arr,Ib_arr,Ibc_arr,Idc_arr,Irc_arr,Ic_arr,'VariableNames',variablenames);
fprintf('\n\nHourly Data:\n')
```

Hourly Data:

```
disp(Table_cal);
```

Hour	SolarTime	HourAngle	SolarAltitude	SolarZenith	SolarAzimuth	IncidenceAngle
0	-0.581693706666667	-188.7254056	-63.6573154449331	153.657315444933	NaN	171.2745944
1	0.418306293333333	-173.7254056	-64.3185978027132	154.318597802713	NaN	173.7254056
2	1.41830629333333	-158.7254056	-57.6572469177566	147.657246917757	NaN	158.7254056
3	2.41830629333333	-143.7254056	-46.9645841113937	136.964584111394	NaN	143.7254056
4	3.41830629333333	-128.7254056	-34.5544603472743	124.554460347274	NaN	128.7254056
5	4.41830629333333	-113.7254056	-21.3948828129034	111.394882812903	NaN	113.7254056
6	5.41830629333333	-98.7254056	-7.90539725389337	97.9053972538934	NaN	98.7254056
7	6.41830629333333	-83.7254056	5.68682306692062	84.3131769330794	-87.3441084804617	83.7254056
8	7.41830629333333	-68.7254056	19.2060750470401	70.79392495296	-80.6712861903287	68.7254056
9	8.41830629333333	-53.7254056	32.4405425367033	57.5594574632967	-72.7965353683994	53.7254056
10	9.41830629333333	-38.7254056	45.0176864927345	44.9823135072655	-62.2501892912883	38.7254056
11	10.4183062933333	-23.7254056	56.1010910587477	33.8989089412523	-46.1713502901234	23.7254056
12	11.4183062933333	-8.72540559999999	63.6573154449331	26.3426845550669	-19.990582359448	8.72540559999999
13	12.4183062933333	6.27459440000001	64.3185978027132	25.6814021972868	14.6075323197238	6.27459439999993
14	13.4183062933333	21.2745944	57.6572469177566	32.3427530822434	42.7049887985856	21.2745944
15	14.4183062933333	36.2745944	46.9645841113937	43.0354158886063	60.1070439883903	36.2745944
16	15.4183062933333	51.2745944	34.5544603472743	55.4455396527257	71.309246432268	51.2745944
17	16.4183062933333	66.2745944	21.3948828129034	68.6051171870966	79.4956234546399	66.2745944
18	17.4183062933333	81.2745944	7.90539725389336	82.0946027461066	86.295323942413	81.2745944
19	18.4183062933333	96.2745944	-5.68682306692063	95.6868230669206	NaN	96.2745944
20	19.4183062933333	111.2745944	-19.2060750470401	109.20607504704	NaN	111.2745944
21	20.4183062933333	126.2745944	-32.4405425367033	122.440542536703	NaN	126.2745944
22	21.4183062933333	141.2745944	-45.0176864927345	135.017686492735	NaN	141.2745944
23	22.4183062933333	156.2745944	-56.1010910587478	146.101091058748	NaN	156.2745944

Air/Mass	IB	IBc	IDc	IRc	IC
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
10.0917437013069	227.312021844525	24.8437416280907	17.8019087269676	0.3845879709383	43.0302383259966
3.03982064690991	716.274388710747	259.89161843355	56.0949270866747	2.7489241039356	318.735469624161
1.86419660366871	867.315379087881	513.152142245341	67.9236808098878	5.00826373123927	586.084086786468
1.41377721433985	933.285289328395	728.10540318338	73.0901049668606	6.87814520424087	808.073653354481
1.20478602814396	965.576573472911	883.970169434679	75.6189923013388	8.22209465513394	967.811256391152
1.11587702213104	979.65046885015	968.312698562948	76.7211874202132	8.94673390646921	1053.98061988963
1.10960976409131	980.650252617476	974.775682166905	76.7994853440459	9.00220109971176	1060.57736861066
1.18362403059411	968.907977751693	902.879036201673	75.879890754585	8.38468760914603	987.143614565404
1.36811631810294	940.246895225755	758.01831051924	73.635302144609	7.13665649959438	838.790269163443
1.76307973248235	881.707177741742	551.585999997722	69.0507724787489	5.34459144350671	625.981363919978
2.7412759474776	751.937439470691	302.544850289944	58.8878738450647	3.13727546728178	364.569999602291
7.27072577300389	359.768215087622	54.5765197583472	28.1751967004826	0.737812885607338	83.4895293444371
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0
NaN	0	0	0	0	0

Explanation of Table (Output):

These calculations are performed for each hour of the day (from 00:00 to 23:00), and the results are displayed in the form of a Table. Given that the day of the year (n) for March 22 is calculated based on the script, let's break down what the output table values would represent for **March 22**. It'll go over the key calculations and their expected results on that particular day.

Assumptions:

*-**Latitude:*** You would input the latitude of the location (e.g., for a location in the Northern Hemisphere like 24.9537°N, as mentioned in input).
*-**Longitude:*** The local longitude for the location, which influences the Solar Time and GMT correction.
*-**Collector Tilt (β):*** This is set to the latitude value, so the collector is tilted based on the latitude.
*-**Surface Azimuth (γ):*** The surface faces south, meaning the azimuth is set to 0°.

For March 22:

-Hour:

Local time of day in hours, ranging from 0 (midnight) to 23 (11 PM). This represents the hour for which the solar radiation is calculated.

-Solar Time (ST):

Solar Time (ST) is calculated by adjusting for the Equation of Time (EoT) and the local longitude.

-Hour Angle (ω):

The hour angle increases by 15° per hour from solar noon. For example:
At solar noon (12:00 PM), the hour angle is 0°.
At 1 PM, the hour angle would be 15° (since the sun moves 15° per hour).
Similarly, at 6 AM, the hour angle will be -90°, indicating that the sun is 90° behind solar noon.

-Solar Altitude (α):

The solar altitude shows how high the sun is above the horizon.
On March 22, the solar altitude would be zero at sunrise and sunset, and it reaches a maximum value around solar noon (depending on the latitude of the location).

-Solar Zenith (θz):

When the solar altitude is high, the zenith angle will be low, and vice versa. The zenith angle will be large early in the morning and in the late afternoon when the sun is closer to the horizon.

-Solar Azimuth:

The solar azimuth angle shows the sun's direction relative to true north.
Around solar noon, the azimuth will be 0° (since the sun is directly south in the Northern Hemisphere), but it will change during the day as the sun moves across the sky.

-Incidence Angle (θi):

The incidence angle (θi) shows the angle between the sun's rays and the collector surface. The lower the angle, the more direct radiation the collector will receive.

-Air Mass (m):

The air mass ratio increases as the sun moves away from the zenith. At solar noon, the air mass ratio will be 1, and it increases in the early morning and late afternoon when the sun is lower in the sky.

-Direct Beam Radiation (IB):

This is the radiation coming directly from the sun. It is highest when the sun is near its zenith.

-Beam Radiation on Collector (IBc):

This is the amount of direct beam radiation that falls on the tilted collector surface.

-Diffuse Radiation (IDc):

This is radiation scattered by the atmosphere. It is typically higher when the sun is at a low altitude (near sunrise or sunset).

Reflected Radiation (IRc):

Reflected radiation depends on ground reflectance (ρ) and the solar altitude. More radiation is reflected at low sun angles (when the sun is near the horizon).

-Total Radiation (IC):

The total radiation on the collector is the sum of the direct beam, diffuse, and reflected radiation. It is highest around solar noon when the incidence angle is smallest.

Here is a simplified example for Solar Time (ST) and Total Radiation (IC) on a typical day like March 22:

-At 06:00 AM (morning):

The hour angle is around -90°.

The solar radiation (IC) would be low, because the incidence angle is large and the sun is just rising.

-At 12:00 PM (solar noon):

The solar altitude reaches its maximum value for the day.

The incidence angle is smallest (close to 0°), so the direct beam radiation (IB) is at its peak.

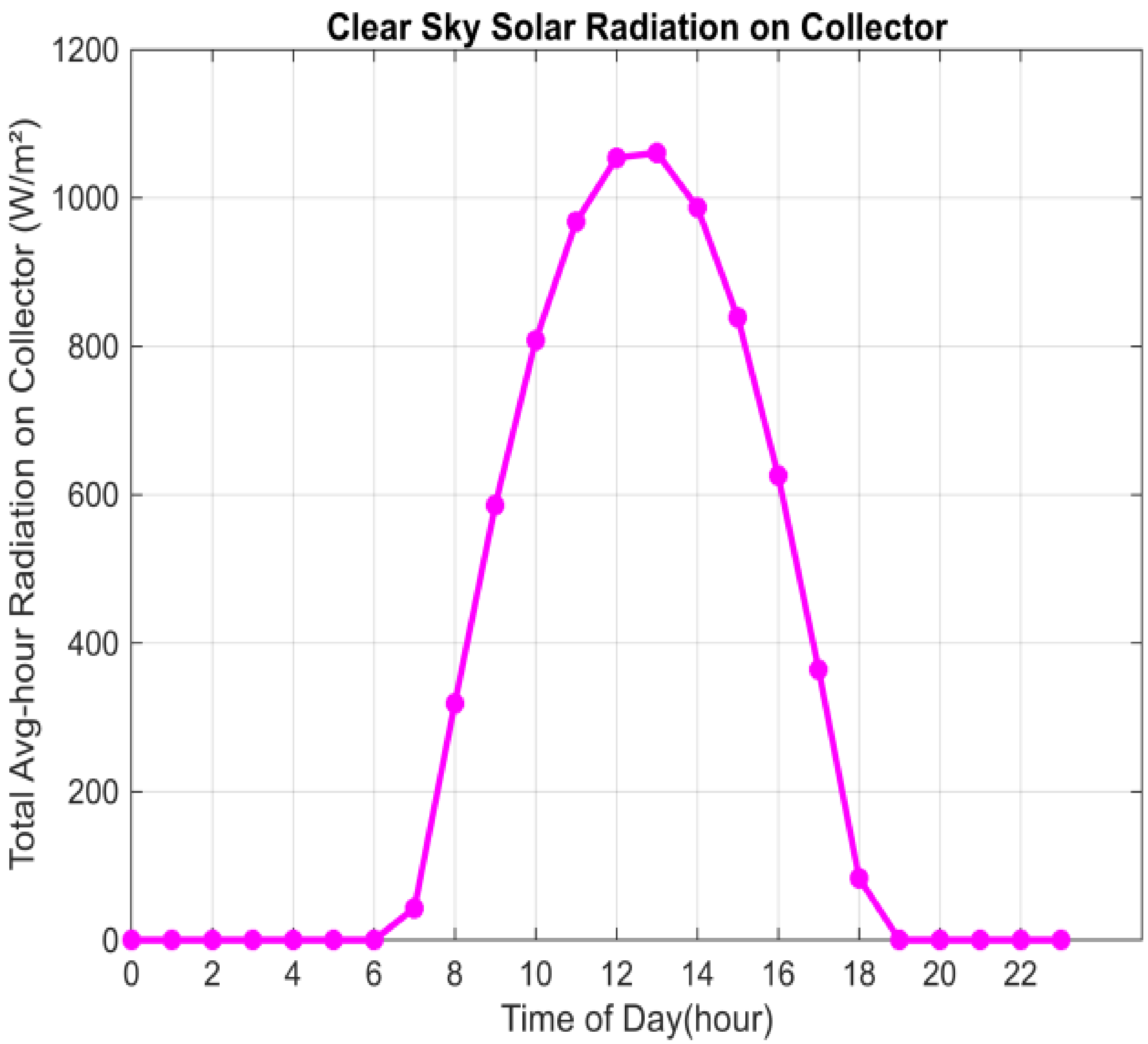
Total radiation on the collector (IC) will be at its maximum.

-At 06:00 PM (evening):

The sun will be lower in the sky, and the incidence angle will be higher again.

The solar altitude decreases, and the total radiation (IC) drops.

```
%Plot Results
figure;
plot(time_values, Ic_values,'m*-','LineWidth',2);
xticks(start_time:2:end_time);
xlabel('Time of Day(hour)');
ylabel('Total Avg-hour Radiation on Collector (W/m²)');
title('Clear Sky Solar Radiation on Collector');
grid on;
```



Graph:

X-Axis: The x-axis ranges from 0 to 23, representing each hour of the day (midnight to 11pm). This helps visualize how solar radiations varies throughout the day.

Y-Axis: The y-axis shows the total solar radiation (IC) received by the tilted solar collector, in(W/m^2)**.** It includes beam, diffuse and reflected radiations.

Key Observations:

-Solar Radiation at Sunrise and Sunset:

The graph starts at zero radiation at midnight (00:00) because the sun is not visible at night. As the sun rises, radiation gradually increases, peaking at solar noon (around 12:00), when the incidence angle is lowest, and the sun is at its highest point in the sky.

-Peak Radiation:

The radiation peaks when the sun is directly overhead (with an incidence angle close to 0°). This typically occurs around 12:00 PM (solar noon).

-Decline in Radiation in the Evening:

After solar noon, the radiation decreases as the sun moves lower in the sky, increasing the incidence angle and scattering more radiation through the atmosphere.

-Nighttime:

The radiation drops to zero at night (after sunset) because the sun is below the horizon.

-General Trend:

The total radiation on the collector exhibits a bell-shaped curve (kind of hyperbola) with a clear rise in the morning, a peak at solar noon, and a decline in the afternoon. This pattern is typical for clear-sky conditions, with the radiation varying depending on the solar altitude and incidence angle.

Conclusion:

The results presented in this analysis that it offers a comprehensive understanding of hourly solar radiation on a tilted flat plate collector, which is essential for the design and performance evaluation of solar energy systems. The table provides detailed information about the various solar angles and radiation components, while the graph visually demonstrates the daily variation of total radiation on the collector. This type of analysis is crucial for solar energy optimization, system sizing, and location assessment in both residential and commercial solar applications.

Rubrics for Complex Engineering Problem					
ME-214 Computer Programming and Applications					
Criterion	**Level of attainment**				
	Excellent (5)	**Good (4)**	**Fair (2)**	**Need Improvement (1)**	**Poor (0)**
Realization of Problems	Able to clearly comprehend the problem and develop a plan accordingly	Able to comprehend the problem and develop a plan with some deficiencies	Able to comprehend the problem and develop a plan with some deficiencies and inaccuracies	Able to comprehend the problem and develop a plan with major deficiencies and inaccuracies	Unable to comprehend the problem and develop a plan
Problem Solving Skills	Able to cover all aspects of the problem & properly carryout the calculations accurately	Able to cover many aspects of the problem & properly carryout the calculations accurately with minor deficiencies	Able to cover some aspects of the problem & properly carryout the calculations accurately with minor deficiencies and inaccuracies	Able to cover a few aspects of the problem & properly carryout the calculations accurately with major deficiencies and inaccuracies	Unable to cover any aspect of the problem
Usage of software	Able to use the software efficiently with effective programming techniques used throughout the program	Able to use the software sufficiently with effective programming techniques used in some parts of the program	Able to use the software sufficiently with effective programming techniques used in a few parts of the program	Able to use the software not sufficient enough to cater effective programming techniques	Unable to use software
Extraction of results and Presentation of work	Able to accomplish correct results the and present the results efficiently	Able to accomplish correct results and present the results sufficiently	Able to accomplish results with minor inaccuracies and present the results sufficiently with minor deficiencies	Able to accomplish results with major inaccuracies and present the results sufficiently with major deficiencies	Unable to accomplish the required results

Marks Obtained = ________ Teacher Signature: _______