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Analytical Study Of Average Monthly Efficiency of a Flat Plate Collector With Varying Solar Irradiation For Almora District Of Uttarakhand

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Abstract

One of the most important components of a solar system is the solar collector. The present work deals with the climatic conditions prevalent in Almora district of Uttarakhand. The study is made to find out the variation of solar radiation over months during years 2010 and 2011. The aforesaid data is then used to find out the average efficiency of a flat plate solar collector during each month.

Keywords: Efficiency, Flat Plate Collector, Irradiation

1. Introduction

Various types of solar energy systems for agricultural and marine products have been reviewed [2]. One of the most important components of a solar energy system is the solar collector. Various applications of the solar air collector are well documented [3]. Solar collectors can be used for drying, space heating , solar desalination, etc. A typical flat plate collector consists of an absorber, transparent cover sheets and an insulated box. The absorber is usually a sheet of high-thermal-conductivity metal with tubes or ducts either integral or attached. Its surface is painted or coated to maximise radiant energy absorption and in some cases to minimise radiant emission. The insulated box provides structure and sealing and reduces heat loss from the black or sides of the collector. The cover sheets, called glazing, allow sunlight to pass through to the absorber but insulate the space above the absorber to prevent cool air from flowing into this space. However, the glass also reflects a small part of the sunlight, which doesn't reach the absorber.

Charter et al. [3] proposed for collector testing is to operate the collector on the test stand, under conditions in which operation is nearly steady. In order to achieve the above conditions, water at constant temperature is supplied to the collector at a constant flow rate from the fixed head tank as the collector is rotated to face the sun to reduce the angle of incidence. The efficiency is then calculated from the carefully measured incident radiation, inlet and outlet temperature of the fluid, the ambient temperature and the flow rate of fluid through the collector.

The useful energy of the collector is given by

$$Q_u = m'C_p(T_0 - T_i)$$

Where m' is the flow rate of fluid through the collector, C_p is the specific heat of the fluid, T_o, T_i are outlet and inlet fluid temperature.

India can be divided roughly into six climatic zones ranging from extremely hot desert regions to severely cold, high-altitude regions, with a vast sea coast having a warm and humid climate. However, a large part of the country lies in the hot and dry region. (SUtana)

The present study is concentrated upon finding out the variation of solar radiation throughout the year in the district Almora of Uttarakhand.

2. Mathematical Formulation

The intensity of solar radiation for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by

$$R_a = \frac{24(60)}{\pi} G_{sc}\, d_r [\omega_s \sin(\Theta)\sin(\delta) + \cos\Theta\cos\delta\sin\omega_s \quad (2.1)$$

Where R_a= extra-terrestrial radiation
G_{sc} = solar constant = 0.0820 MJ/m^2/ min
d_r= inverse relative distance earth-sun
ω_s = sunset hour angle
δ = solar declination (rad)
Θ= latitude (rad)

The inverse relative distance earth-sun d_r and the solar declination δ are given by

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (2.2)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (2.3)$$

Where J is the number of the day in the year between 1 January and 365 or 366 (31 December).

The sunset hour angle, ω_s is given by

$$\omega_s = \arccos\,[-\tan(\Theta)\tan(\delta)] \quad (2.4)$$

As the acrcos function is not available in all computer languages, the sunset hour angle can also be computed using the arctan function:

$$\omega_s = \frac{\pi}{2} - \arctan\left[\frac{-\tan(\Theta)\tan(\delta)}{X^{0.5}}\right] \quad (2.5)$$

Where

$$X = 1 - [\tan(\Theta)]^2[\tan(\delta)]^2$$

And, X= 0.00001 if X< 0 and X=0

The daylight hours , N, are given by:

$N=(24/\pi)\omega_s$ (2.6)

Where ω_s is the sunset hour angle in radians.

If the solar radiation R_s is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (2.7)$$

Where

N= maximum possible duration of sunshine or daylight hour

R_s= solar or shortwave radiation

n = actual duration of sunshine

a_s = regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days(n=0). Its values is generally taken as 0.25

a_s+b_s = fraction of extraterrestrial radiaton reaching the earth on clear days (n=N). Its value is taken as 0.75

The calculation of the clear sky radiation R_{so} when n = N is required for computing net longwave radiation.

$R_{so}=(a_s+b_s)R_a$ (2.8)

Net solar or net shortwave radiation (R_{ns}) is calculated by

$R_{ns}= (1-\alpha)R_s$ (2.9)

Where α = albedo or canopy reflection coefficient which is 0.23 for the hypothetical grass reference crop

Net longwave radiation (R_{nl}) is calculated by the following correlation

$$R_{nl} = \sigma\left[\frac{T_{max,K}{}^4+T_{min,K}{}^4}{2}\right]\left(0.34-0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}}-0.35\right) \quad (2.10)$$

Where,

R_{nl}= net outgoing longwave radiation

σ = Stefan Boltzmann constant

$T_{max,K}$= maximum absolute temperature during the 24 hour period

$T_{min,K}$= minimum absolute temperature during the 24 hour period

e_a = actual vapour pressure

The net radiation (R_n) is calculated by the following formula

$R_n = R_{ns} - R_{nl}$ (2.11)

In steady state condition, the rate of energy absorbed by the plate per unit area should be equal to sum of rate of useful energy (Q_u) transferred to the fluid and the rate of energy lost (q_l) per unit area by the plate to surrounding.

$$q_{ab} = q_L + Q_u \quad (2.12)$$

$$q_{ab} = (\alpha\tau)I \quad (2.13)$$

$$q_L = U_L(T_p - T_a) \quad (2.14)$$

Where, U_L is overall heat loss coefficient.

The overall heat loss coefficient U_L is the sum of the top, bottom and edge loss coefficient, i.e.

$$U_L = U_t + U_b + U_e \quad (2.15)$$

The energy lost from the side of collector casing is exactly the same as that from the back if the thickness of edge insulation is the same as that of back insulation

$$U_e = U_b\left(\frac{A_e}{A_c}\right) \quad (2.16)$$

Where A_e is the edge area.

Heat is lost from plate to the ambient by conduction through the insulation and then subsequently by convection and radiation from the bottom surface casing. The bottom loss coefficient is given by

$$U_b = \left[\left(\frac{L_{in}}{K_{in}}\right) + \left(\frac{1}{h_b}\right)\right]^{-1} \quad (2.17)$$

Where h_b is the heat loss coefficient from the bottom, and is the sum of convective heat loss coefficient h_{bc} and radiative heat loss coefficient h_{br}. The values of h_{bc}, h_{br} can be calculated as in case of top cover. The suffix 'in' indicates insulation.

The top loss coefficient is given by the following expression

$$U_t = \left\{\left({}^1/_{h_1}\right) + \left({}^1/_{h_2}\right)\right\}^{-1} \quad (2.18)$$

And the instantaneous thermal efficiency of the collector is given by

$$\eta_i = \frac{Q_u}{A_p I} \quad (2.19)$$

Where A_p is the collector area and I is global radiation on the collector (W/m^2).

3. Parameters

There are basically two types of parameters that are being used for the whole analysis- Design Parameters and Climatic Parameters.

Design Parameters:

Transmissivity and absorptivity product ($\alpha\tau$) = 0.8

Mass flow rate of air through the collector (m') =0.03 kg/sec

Collector Efficiency factor (F) = $6 W/m^2\,{}^0C$

Collector heat removal factor (F_R) =0.787

Plate temperature (T_P) = 40 ^0C

Collector Area (A_P) = 1 m^2

Climatic Parameters for 2011:

Month	Average Temp.(^0C)	Sunshine hrs
January	9.1	7.06
February	11.38	6.09
March	14.98	7.8
April	17.73	7.48
May	22.63	7.56
June	23.7	4.34
July	24.68	3.01
August	24.38	3.65
September	23.85	6.08
October	19.85	8.18
November	15.02	6.99
December	10.18	7.22

Climatic Parameters for 2010:

Month	Average Temp (^{0}C).	Sunshine hrs
January	10.24	7.38
February	11.1	7.09
March	17.35	8.49
April	21.28	9.03
May	23.54	8.36
June	24.6	6.89
July	24.48	4.02
August	24.47	3.36
September	22.52	3.31
October	19.46	8.15
November	15.75	6.81
December	9.97	7.18

4. Results and Discussion

Figure 1 shows the the variation of solar irradiation throughout the year for Almora district of Uttarakhand for years 2010 and 2011. The intensity of solar radiation is low during the month of January and as the year progresses the value of solar radiation also increases and reaches the maximum by the month of May and again there is a decrease in the value of solar radiaton (except the month of October).

Figure 2 shows the variation of efficiency of the collector with months. It is seen from the figure 1 that as the year progresses there is an increase in solar radiation upto the month of May and consequently the efficiency also increases but after this with the passage of air the efficiency decreases because of decrement in intensity of radiation.

Table 1 :Solar Radiation Calculation Corresponding to 2010

Month	R_a (W/m^2)	R_s (W/m^2)	R_{so} (W/m^2)	R_{ns} (W/m^2)	R_{nl} (W/m^2)	R_n (W/m^2)
January	248	151	187	116	59	57
February	295	170	221	131	54	77
March	365	223	275	172	59	112
April	428	259	322	200	56	142
May	464	260	349	200	50	153
June	476	237	358	182	36	147
July	468	186	352	143	19	125
August	438	166	330	128	17	111
September	384	148	288	114	19	95
October	322	197	242	152	50	102
November	261	150	196	116	51	65
December	232	141	175	108	60	48

Table 2 :Solar Radiation Calculation Corresponding to 2011

Month	R_a (W/m^2)	R_s (W/m^2)	R_{so} (W/m^2)	R_{ns} (W/m^2)	R_{nl} (W/m^2)	R_n (W/m^2)
January	248	147	186	113	58	55
February	295	156	222	120	49	71
March	366	213	275	164	55	109
April	428	232	322	179	49	130
May	464	246	349	189	41	148
June	476	194	358	149	22	127
July	468	169	352	130	16	114
August	438	171	330	131	18	113
September	384	191	288	147	33	114
October	322	197	242	152	53	99
November	261	152	196	117	55	62
December	232	141	175	109	60	49

Table 3: Monthly Avg. Efficiency of Flat Plate Collector for the year 2010

S.No.	Month	Q_{ab}	Q_L	Q_u	η
1	January	120.8	178.56	0	0
2	February	136	173.4	0	0
3	March	178.4	135.9	42.5	0.1905
4	April	207.2	112.32	94.88	0.3663
5	May	208	98.76	109.24	0.4202
6	June	189.6	92.4	97.2	0.41012

7	July	148.8	93.12	55.68	0.29935
8	August	132.8	93.18	39.62	0.2386
9	September	118.4	104.88	13.52	0.0913
10	October	157.6	123.24	34.36	0.1744
11	November	120	145.5	0	0
12	December	112.8	180.18	0	0

Table 4: Monthly Avg. Efficiency of Flat Plate Collector for the year 2011

S.No.	Month	Q_{ab}	Q_L	Q_u	η
1	January	117.6	185.4	0	0
2	February	124.8	171.72	0	0
3	March	170.4	150.12	20.28	0.0952
4	April	185.6	133.62	51.98	0.2241
5	May	196.8	104.22	92.58	0.3763
6	June	155.2	97.8	57.4	0.2958
7	July	135.2	91.92	43.28	0.2561
8	August	136.8	93.72	43.08	0.2519
9	September	152.8	96.9	55.9	0.29267
10	October	157.6	120.9	36.7	0.1862
11	November	121.6	149.88	0	0
12	December	112.8	178.92	0	0

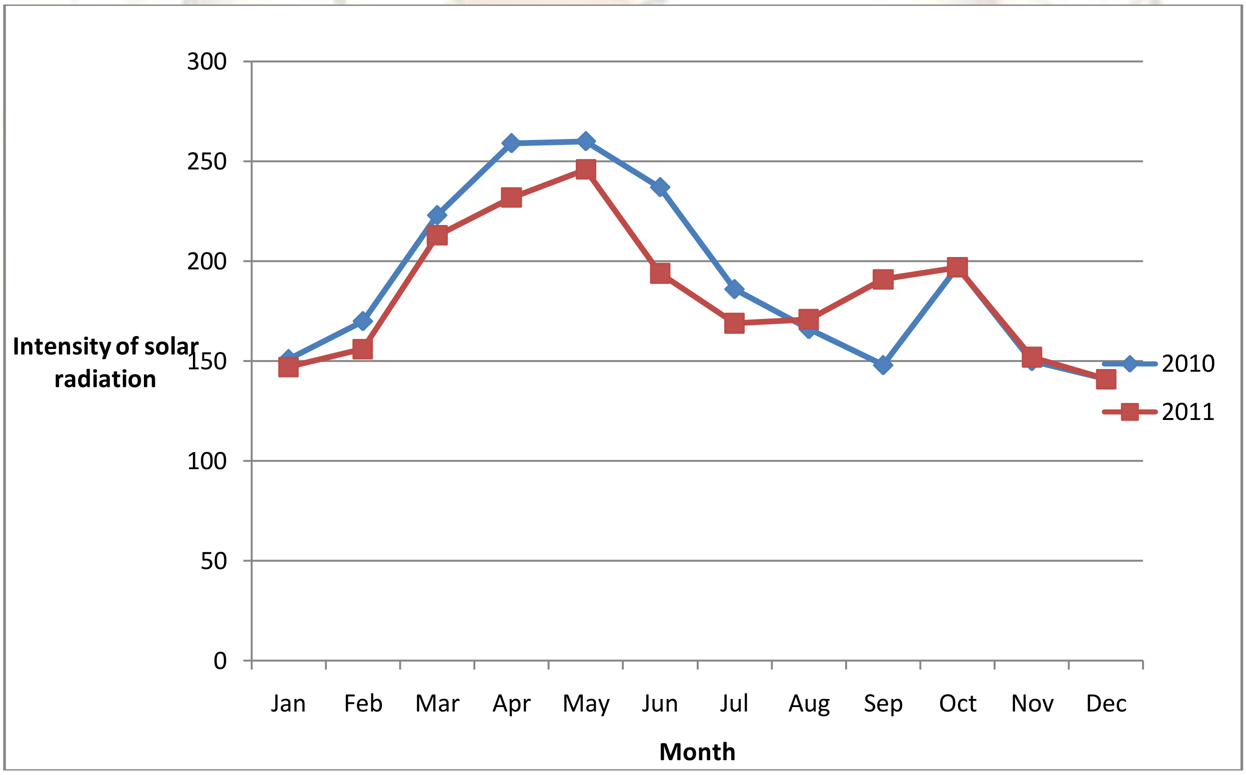

Figure 1: Variation of Solar Radiation Intensity throughout the year

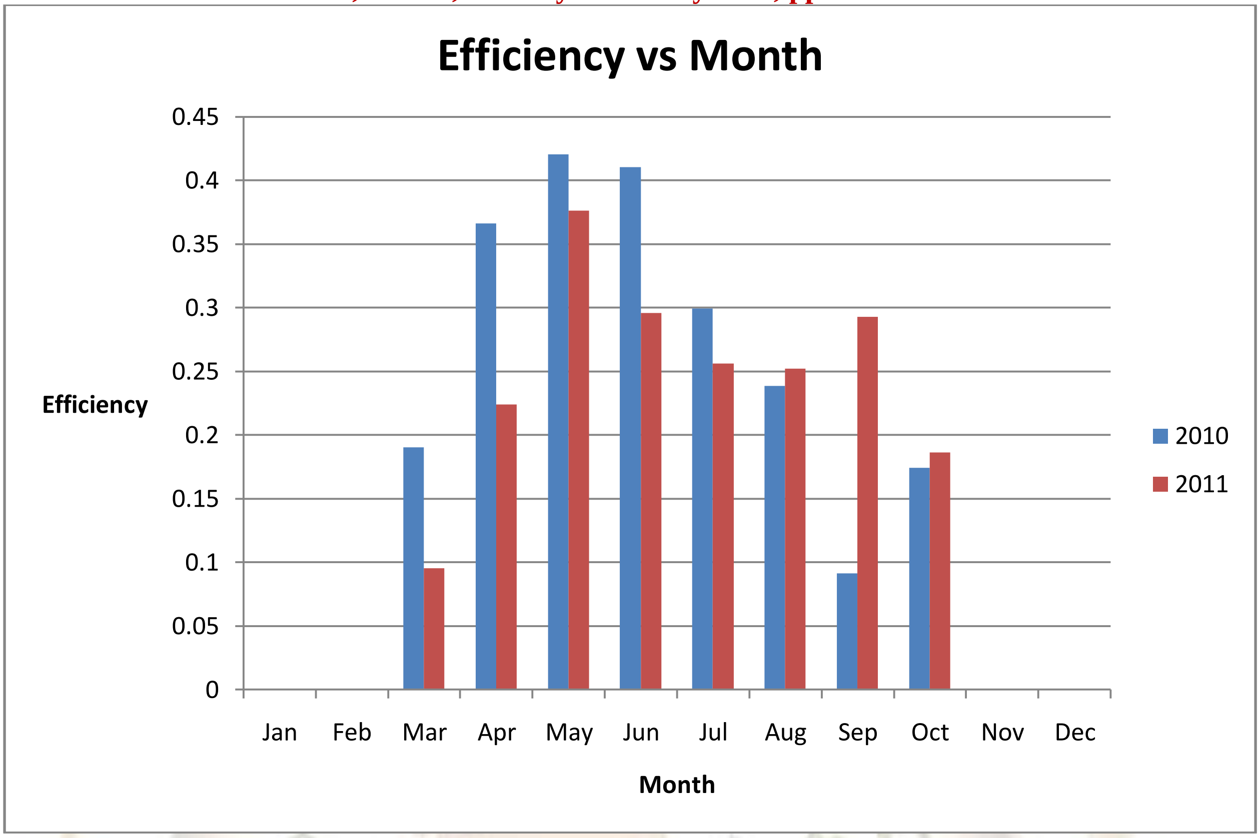

Figure 2: Variation of Collector efficiency throughout the year

5. Conclusion

The following conclusions can be drawn from the present work:

1. In the district Almora having a cold climatic zone the use of solar flat plate collector for various applications is very beneficial and clean.
2. During the winter season the efficiency of the solar collector is minimum due to the lower value of solar irradiation.
3. The ambient temperature is much lower during the winter seasons and the plate temperature is maintained at a much higher temperature, the heat loss to the atmosphere thus increases during this period and hence collector should not be operated during this period.

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