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Design of Solar Evacuated Tube Collector for Low Intensity Thermal Energy

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Abstract

In this paper to fulfil the requirement of low intensity thermal energy solar evacuated tube setup is designed. The number of parallel tubes in the setup is determined on the basis of mass flow rate required and pressure drop. To get higher target temperature the number of setup can be connected in series. In our study evacuated tube set up consists of ten tubes. The inner tube is made of copper coated with black and outer tube is made of borosilicate glass. The space between inner and outer tube is evacuated. The solar radiation falling on the setup is determined at tilt angles $\beta=\varphi-15^o$, $\beta=\varphi$, $\beta=\varphi+15^o$. It is found that maximum solar radiation is 5.31 MJ/m^2 at $\beta=\varphi+15^o$, while in same month it is 2.98 MJ/m^2at $\beta=\varphi-15^o$ and 3.59 MJ/m^2at $\beta=\varphi$. The maximum useful energy accounting thermal losses can be also computed in different seasons of year. It is found 4.35 kJ/s during summer season (February-March), 3.29 kJ/s during rainy season (June-September) and 3.69 kJ/s during winter season (October-January).

Keywords: Solar Energy, Evacuated tube collector, Global Solar Radiation, Beam Solar Radiation, Useful Heat, Ground albedo, Tilt angle, Heat removal factor.

INTRODUCTION

Power generation from conventional sources such as coal, oil and gases are constantly damaging our environment. The fossil fuels are adding hazardous pollutants such as sulphur dioxide (SO_2), Nitrogen oxides (NO_X), Carbon monoxide (CO) particulates and Carbon dioxide (CO_2). Apart from damaging environment, these fuels are also depleting in nature. Therefore renewable energy technologies got more importance and attention. Out of various renewable energy sources (solar energy, hydro energy, geothermal energy, wind energy, tidal energy etc.), solar energy is the most reliable renewable energy due to its abundance in nature and environment friendly. It is estimated that one hour of solar energy received by the earth is equal to total amount of energy consumed by humans in one year [1].Basically there are two different methods of harvesting solar energy depending on their needs. One is direct conversion of solar energy into electricity using photovoltaic solar cells and second is converting solar energy into thermal energy using solar collectors or concentrators [2].

In this paper solar thermal system is employed to obtain the useful energy from sun using evacuated tube collector. Many studies had been done in this area. Soteris [3] had studied various types of solar thermal collectors and their applications. Barlev et al. [4] provided the knowledge of concentrated collectors. Ho and Iverson [5] worked on Solar concentrating system. Mahdjuri [6] first introduced a tubular evacuated solar collector with rectangular performance characteristics. He introduced a heat pipe cycle to transfer heat from the absorber to the water tubing.

Evacuated tube solar collector is a device which is generally used to deliver heat for many applications air conditioning, water heating, thermal power plant, etc. Evacuated solar collectors are more attractive than any other of heating due to their high capability of heat extraction. These collectors are cost effective and most reliable with reasonably longer life time. Neeraj and Avdhesh [7] experimentally investigated and compared the circular fin type headers for an evacuated tube solar collector coupled with latent heat**,** storage device, where air was considered as a working fluid. They have observed that the outlet temperature in an evacuated tube solar air collector using circular fin and copper coil gave better compared with the ordinary solar evacuated tube collector.

STATEMENT OF PROBLEM

In this paper we want to design solar evacuated tube collector having inner diameter 58 mm and outer diameter 70 mm. the length of tube is taken 2000 mm. The inner copper tube is coated with black and outer glazing is borosilicate glass tube.

We are interested to determine the useful energy collected by solar evacuated tube collectors in different months of year forlocation New Delhi, India. First the solar radiation falling on the tilted surface is determined using Liu and Jordan model for different tilt angles. The useful solar radiation absorbed by tilted surface is computed. The mathematical modelling of evacuated tube solar collector is made and energy supplied by evacuated tube is calculated by accounting losses from collector. To simplify analysis it is assumed that heat transfer process is steady, solar intensity is constant throughout collector, specific heat of fluid is constant, axial heat transfer is negligible.

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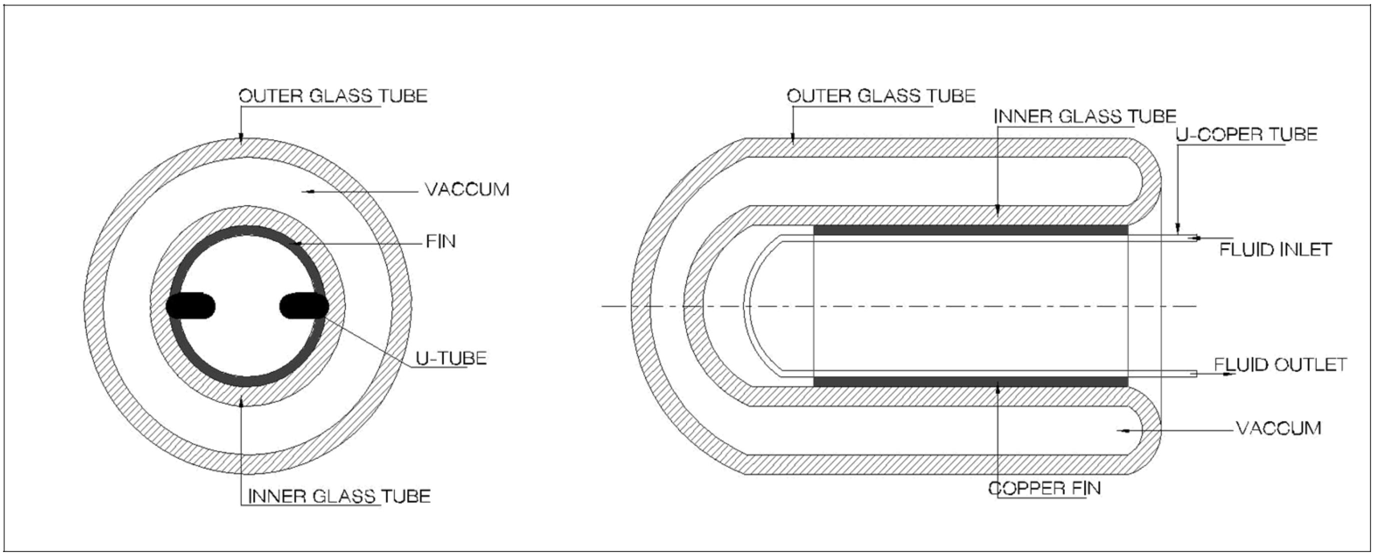

Figure 1.0 Evacuated tube collector

METEOROLOGICAL DATA

The measured meteorological data, for New Delhi (28.58° N, 77.19° E) viz. beam, diffuse solar radiation on horizontal surface, air temperature and wind speed is obtained from Indian Meteorological Department (IMD), Pune that has been compiled by Mani [8].

METHODOLOGY

Computation of solar radiation on tilted surface.

To estimate the solar energy on tilted surface LIU and JORDAN model [9] is used. According to this model solar radiation on tilted surface facing towards south is given as:

$$I_T = R_b I_b + R_d I_d + \rho_g R_g I_g$$

Where I_b is monthly mean hourly beam solar radiation, I_d is monthly mean hourly diffuse solar radiation, I_g is monthly mean hourly global solar radiation, and ρ_g = 0.2 (ground albedo)

$$R_b = {}^{\cos\theta}/_{\cos\theta_z}$$

$$R_d = {}^{(1+\cos\beta)}/_2$$

$$R_r = {}^{(1-\cos\beta)}/_2$$

$$\text{Cos } \theta = \text{Cos}(\varphi - \beta).\text{Cos}\delta.\text{Cos}\omega + \text{Sin}(\varphi - \beta)\text{Sin}\delta$$

$$\text{Cos } \theta z = \text{Cos}(\varphi).\text{Cos}\delta.\text{Cos}\omega + \text{Sin}(\varphi)\text{Sin}\delta$$

Whereβ, tilt angle; φ,latitude of location; δ, declination angle and ω hour angle

Declination angle and hour angle can be determined as follows:

Declination angle

$\delta = 23.45 \text{ Sin } [\frac{360}{365}(284 + \text{n})]$Here n is day of year

Hour angle,

ω = (Solar time − 12) ×15°

Mathematical modelling of solar evacuated tube collector [9]:

Solar energy absorbed by receiver surface of ETCsetup

$$S = (\tau\alpha)_{av} I_T$$

Where τ, is transmissivity and α, absorptivityand it is assumed that $(\tau\alpha)_{av}$= 0.72

The useful thermal energy for concentrating collectoris given as:

$$Q_u = F_R A_a \left[S - \frac{A_r}{A_a} U_L (T_i - T_a)\right]$$

Where A_a, aperture area; A_r, area of receiver (absorber) tube; U_L, overall heat transfer coefficient; T_i, inlet fluid temperature; T_a, ambient temperature

Heat removal factor

$$F_R = \frac{\dot{m}C_p}{A_r U_L}\left[1 - \text{Exp}\left(-\frac{A_r U_L D F^{/}}{\dot{m}C_p}\right)\right]$$

Mass flow rate of fluid

$$\dot{m} = \rho A v$$

Where A, cross-sectional area of inner tube; v, mean velocity of working fluid; ρ, density of working fluid; C_p, specific heat capacity; $F^{/}$, collection efficiency factor

For turbulent flow [10]

$$N_u = 0.027 R_e^{0.8} P_r^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14} = \frac{h_{fi} D_i}{K}$$

Where Reynolds number

$$R_e = \frac{\rho v D_i}{\mu}$$

μ, viscosity of working fluid; h_{fi}, convective heat transfer coefficient; K, thermal conductivity of fluid

Collection efficiency factor

$$F' = \frac{1/U_L}{\frac{1}{U_L} + \frac{D_o}{h_{fi} D_i} + \left[\frac{D_o}{2K_c} \ln\left(\frac{D_o}{D_i}\right)\right]}$$

Where D_i, D_o, diameter of inner tube and outer tube respectively; K_c, thermal conductivity of tube material

RESULT

The total solar radiation falling on the tilted surface has been calculated using Liu and Jordan model at tilt angle β=φ-15, β=φ, β=φ+15 for different months of year at New Delhi. These values are computed during a period of 10:30 am to 3:30 pm. The average solar radiation during these periods is plotted against month in Fig 2.0. The figure indicates that maximum value of solar radiation is obtained at tilt angle β=φ+15 for all months of year except August. The peak value of solar radiation is during month of May as indicated by graph.

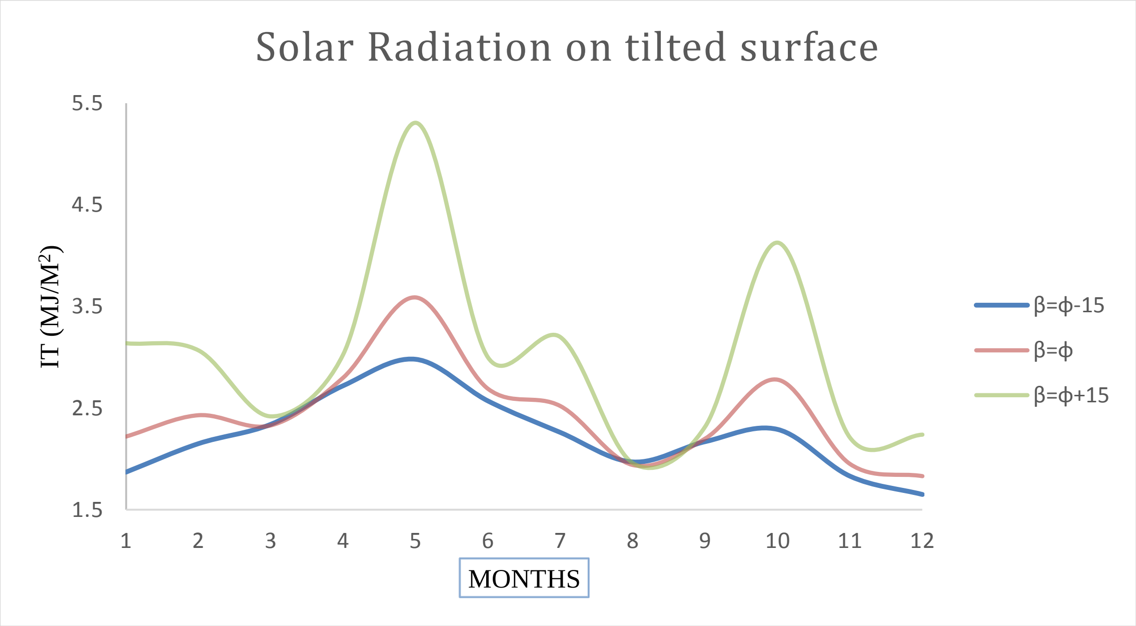

Figure 2.0: Average solar radiation falling on ETC setup at tilt angle β=φ-15, β=φ, β=φ+15 during a day in different months of year

Accounting the losses in evacuated tube collector the useful energy has been calculated for different months of year during 10:30 am to 3:30 pm. The average useful energy obtained in different month is plotted in Fig 3.0. The figure shows the similar trend of curves. This shows that useful energy obtained by collector is almost proportional to solar radiation falling on the surface, while the losses from collector are considered.

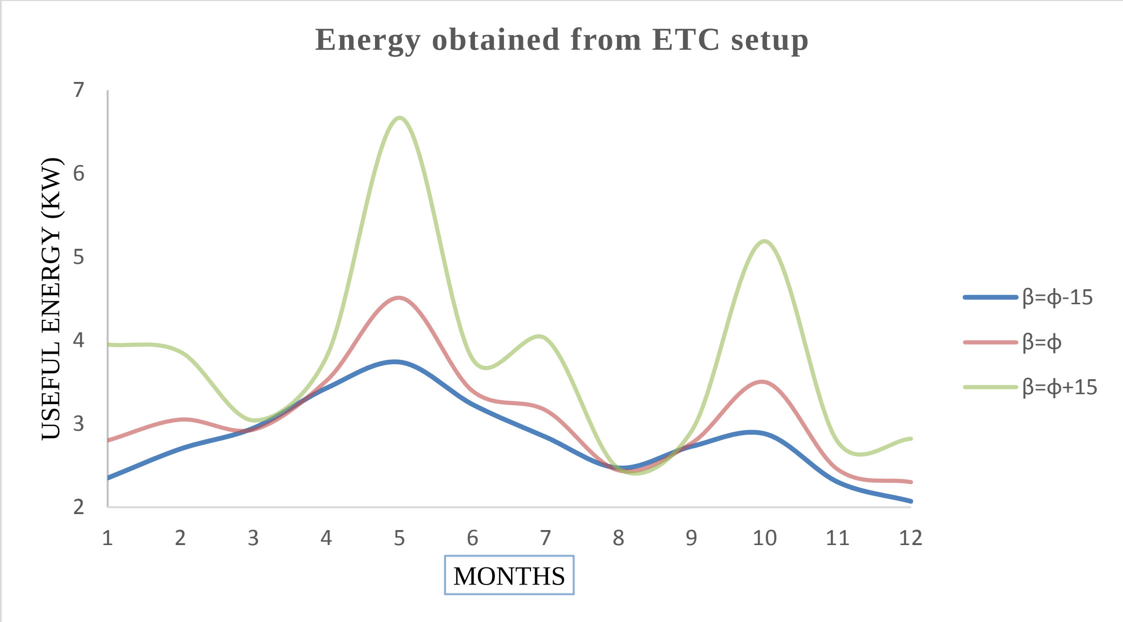

Figure 3.0: Useful energy obtained by ETC setup at tilt angle β=φ-15, β=φ, β=φ+15 during a day in different months of year

Table 1.0: Useful energy obtained by ETC setup during 10:30 am to 3:30 pm in different months of a year tilt angle β=φ+15º, β=φ, β=φ-15º

	Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	Time												
β=φ+15º	10:30	418.837	419.634	335.496	417.620	706.604	385.924	417.371	273.179	319.311	554.313	312.727	307.976
	11:30	453.975	445.499	365.433	450.800	714.835	405.671	446.612	293.106	347.885	581.981	342.422	346.722
	12:30	456.749	452.282	363.633	445.342	708.868	398.773	446.152	286.741	340.809	577.228	343.540	345.604
	13:30	427.524	414.946	324.509	405.730	664.844	368.710	414.036	258.109	309.823	534.679	301.971	307.976
	14:30	348.662	338.706	261.195	330.565	600.870	318.288	363.523	214.840	256.972	463.384	230.734	236.480

B=φ-15º				β=φ						
12:30	11:30	10:30	15:30	15:30	14:30	13:30	12:30	11:30	10:30	15:30
259.957	285.927	284.498	255.637	158.319	240.222	307.861	335.631	333.804	302.273	265.152
292.743	321.449	317.330	294.395	183.964	265.804	330.505	362.101	357.141	333.127	244.080
313.111	346.812	347.921	322.542	174.360	254.542	311.947	347.157	348.434	321.647	174.744
363.212	395.051	398.806	371.930	225.351	308.667	373.989	408.224	412.488	383.635	236.428
391.247	427.172	430.067	409.196	329.579	399.389	466.446	506.564	510.339	491.087	610.292
326.499	351.975	357.125	339.369	308.906	294.087	338.737	365.604	371.304	352.971	386.533
296.691	327.322	326.258	303.768	227.364	282.280	329.886	361.432	360.844	335.778	325.203
258.246	284.480	290.586	272.864	153.782	214.197	255.283	282.128	288.241	269.856	151.002
289.312	315.884	322.071	295.407	171.010	245.474	293.272	321.163	327.576	300.345	175.213
307.941	341.269	342.913	317.915	218.865	303.946	371.025	408.460	411.013	383.714	402.265
249.150	281.331	280.088	255.784	124.715	204.301	265.381	300.508	299.312	273.345	137.244
226.857	255.576	256.819	226.857	116.888	191.793	252.053	283.655	284.851	252.053	147.723

	13:30	199.883	233.919	258.031	302.232	330.200	284.391	252.375	217.975	243.696	247.878	192.669	171.992
	14:30	126.358	159.291	179.883	223.638	258.326	280.149	197.572	158.476	172.129	170.288	119.409	103.860
	15:30	255.637	294.395	322.542	371.930	409.196	339.369	303.768	272.864	295.407	317.915	255.784	226.857

CONCLUSION

It is found that that the total radiation and the useful energy observed on the tilted surface in different months of the year. We have calculated the total radiation and useful energy at three different tilt angles (β) i.e. at β=φ, β=φ+15 & β=φ-15. We found that the values calculated for total radiation and the useful energy varied as time change. When time varies from 10.30am to 15.30pm the values change as shown in the above three tables. The variation of useful energy can be shown in the graph. It can be clearly shown that the value of useful energy is more in the month of MAY and minimum in the month of DECEMBER for all three values of tilted angle.

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