Design of Solar Evacuated Tube Collector for Low Intensity Thermal Energy

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Abstract

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 concentrating 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 Avdesh [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.

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 (SO₂), Nitrogen oxides (NOₓ), Carbon monoxide (CO) particulates and Carbon dioxide (CO₂). 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].

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 for location 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.
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 \( \rho_g = 0.2 \) (ground albedo)

\[ R_b = \cos \theta \cos \theta_z \]

\[ R_d = (1 + \cos \beta) / 2 \]

\[ R_r = (1 - \cos \beta) / 2 \]

\[ \cos \theta = \cos(\varphi - \beta). \cos \delta. \cos \omega + \sin(\varphi - \beta) \sin \delta \]

\[ \cos \theta_z = \cos(\varphi). \cos \delta. \cos \omega + \sin(\varphi) \sin \delta \]

Declination angle
\[ \delta = 23.45 \sin \left[ \frac{360}{365} (284 + n) \right] \] Here n is day of year

Hour angle,
\[ \omega = (\text{Solar time} - 12) \times 15^\circ \]

Mathematical modelling of solar evacuated tube collector [9]:

Solar energy absorbed by receiver surface of ETC setup
\[ S = (\tau \alpha) \omega I_T \]

Where \( \tau \) is transmissivity and \( \alpha \) absorptivity and it is assumed that \( (\tau \alpha)_{\omega} = 0.72 \)

The useful thermal energy for concentrating collector is given as:
\[ Q_u = F_R A_d \left[ S - \frac{A_r}{A_a} U_L (T_i - T_a) \right] \]

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
\[ F_R = \frac{m C_p}{A_r U_L} \left[ 1 - \exp \left( -\frac{A_r U_L DF}{m C_p} \right) \right] \]

Mass flow rate of fluid
\[ \dot{m} = \rho A v \]

Where \( A \), cross-sectional area of inner tube; \( v \), mean velocity of working fluid; \( \rho \), density of working fluid; \( C_p \), specific heat capacity; \( F' \), collection efficiency factor
For turbulent flow [10]

\[ N_u = 0.027 \Re^{0.8} \Pr^{1/3} \left( \frac{\mu}{\mu_w} \right)^{0.14} = \frac{h_{fi}D_i}{K} \]

Where Reynolds number
\[ \Re = \frac{\rho v D_i}{\mu} \]

\( \mu \), viscosity of working fluid; \( h_{fi} \), convective heat transfer coefficient; \( K \), thermal conductivity of fluid

Collection efficiency factor

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

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 \( \beta = \phi - 15 \), \( \beta = \phi \), \( \beta = \phi + 15 \) 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 \( \beta = \phi + 15 \) 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 \( \beta = \phi - 15 \), \( \beta = \phi \), \( \beta = \phi + 15 \) 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 $\beta = \phi - 15$, $\beta = \phi$, $\beta = \phi + 15$ 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 $\beta = \phi + 15^\circ$, $\beta = \phi$, $\beta = \phi - 15^\circ$

<table>
<thead>
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<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
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<td>419.634</td>
<td>355.496</td>
<td>417.620</td>
<td>706.604</td>
<td>385.924</td>
<td>417.371</td>
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<td>319.311</td>
<td>554.313</td>
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<td>365.433</td>
<td>450.800</td>
<td>714.835</td>
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<td>414.036</td>
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<td>261.915</td>
<td>310.555</td>
<td>608.870</td>
<td>318.288</td>
<td>363.523</td>
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<td>Time</td>
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<td>300.508</td>
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<td>273.345</td>
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</table>

\[ \beta = \phi \]
CONCLUSION

It is found 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 (\(\beta\)) i.e. at \(\beta=\phi\), \(\beta=\phi+15\) & \(\beta=\phi-15\). 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.

REFERENCES


