Performance Analysis of Evacuated Tube Collector

Harsh Kadyan

Research scholar, Centre of Excellence for Energy and Environmental Studies
Deenbandhu Chhotu Ram University of Science & Technology, Murthal, (Sonepat) Haryana – 131039, India.

Abstract
To counter the energy crisis due to over dependence on conventional fossil fuels researchers are working on solar energy based systems. In domestic and industrial sector dependence of evacuated water heaters is increasing for ensuring uninterrupted supply of low temperature hot water. In this work the performance of ETC was evaluated following standard test procedure in the University. At this location adequate amount of solar radiation are available throughout year.

The result obtained from the test predicts that the maximum efficiency of the system, $\eta_{sys}$, is 51% and overall heat loss coefficient of the system during day time test, $U_{sys,d}$, found to 1.81 W/m²K.

Keywords: Evacuated Tube, Collectors, Thermal Analysis, Concentric-Tube, Flat Plate

INTRODUCTION

Presently, the energy crisis is predominant as conventional sources of power such as fossil fuels are depleting at a quicker rate. Also, the utilization of these fuels, adversely have an effect on our environment ensuing in global warming, ozone layer depletion, acid rain etc [1]. Hence, there is a necessity to shift the center of attention closer to different non-conventional and renewable electricity sources. Solar power finds its utility over various fields. [2-3]

The world market for solar water heaters has increased substantially in the last decade. As a result, there have been large-scale trends of new-technology and improved-quality products [4]. The evacuated tube solar collectors operate better in comparison to flat plate solar collectors, in unique for high temperature operations. [5]. However, previously, it provided no actual competition for flat plate solar collectors, due to the fact of difficulties in manufacturing and maintenance of the vacuum seal. [6]

The supply of thermal energy required by using most of the water heating processes can range from 70-120°C. [7] which can ideally be produced by using evacuated tube collectors which can without difficulty obtain this range and have the delivered gain of a excessive performance. [8] With the recent advances in vacuum technology, evacuated tube collectors can be reliably mass produced. [9-10]. it was identified that the creation of vacuum between the absorber and the cover of a solar collector would result in a considerable improvement in collector efficiency due to reduction in heat loss via convection and conduction. [11-12].

Each evacuated tube consists of two glass tubes. The outer tube is made of extremely sturdy transparent borosilicate glass that is in a position to resist impact from hail up to 38 mm in diameter. The internal tube is additionally made of borosilicate glass, but lined with a one-of-a-kind selective coating (ALN/AIN-SS/CU).

SITE DETAILS

The experiment will carried out at Deen Bandu Chhotu Ram University of Science and Technology Murthal, Haryana (longitude=77° 07' E, latitude=29° 03' N), which had Sunny day, partially cloudy and scattered cloud day some times. During the testing time, the collector faced south direction at a tilt angle equal to latitude of Murthal.
Radiation data for the test region

<table>
<thead>
<tr>
<th>Month</th>
<th>Radiation (kWh/m²/Day)</th>
<th>Month</th>
<th>Radiation (kWh/m²/Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5.46</td>
<td>July</td>
<td>3.71</td>
</tr>
<tr>
<td>February</td>
<td>5.94</td>
<td>August</td>
<td>4.08</td>
</tr>
<tr>
<td>March</td>
<td>6.39</td>
<td>September</td>
<td>4.83</td>
</tr>
<tr>
<td>April</td>
<td>5.93</td>
<td>October</td>
<td>4.54</td>
</tr>
<tr>
<td>May</td>
<td>5.35</td>
<td>November</td>
<td>4.65</td>
</tr>
<tr>
<td>June</td>
<td>3.87</td>
<td>December</td>
<td>4.99</td>
</tr>
</tbody>
</table>

Specifications of ETC:

The evacuated tube collector containing ten tubes was selected for this study. The collector is of direct flow type with tube length of 1800 mm having outer diameter is 57.90 mm and inner is 43.25 mm having three layer coating. The exposed area of single tube is 0.164 m² and gross aperture area is 1.31 m². The structure for collector is aluminum powder coated galvanized iron made having 1.58 mm thickness having no leakage at 0.2 kg/cm² pressure as found in static pressure leakage test. The detail specifications of the ETC are follows:

<table>
<thead>
<tr>
<th>Type of collector</th>
<th>Evacuated Tube Collector, direct flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube length</td>
<td>1800 mm</td>
</tr>
<tr>
<td>Inner diameter of each tube</td>
<td>43.25 mm</td>
</tr>
<tr>
<td>Outer diameter of each tube</td>
<td>57.90 mm</td>
</tr>
<tr>
<td>Gap between two tube</td>
<td>22.08 mm</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>10</td>
</tr>
<tr>
<td>Details of selective coating</td>
<td>Graded AL-N with Copper</td>
</tr>
<tr>
<td>Exposed area (gross) of a single tube (D*L), m²</td>
<td>0.164 m²</td>
</tr>
<tr>
<td>Gross aperture area of the collector, m²</td>
<td>1.31 m²</td>
</tr>
<tr>
<td>Aperture length</td>
<td>1670 mm</td>
</tr>
<tr>
<td>Aperture Width</td>
<td>78402 mm</td>
</tr>
<tr>
<td>Reflector below the tubes</td>
<td>Not Provided</td>
</tr>
</tbody>
</table>

Testing Procedure for ETC

The testing procedure adapting for the following test is ASHARE standard 93 followed by many countries [1] and has been adopted by an Indian standard IS 12933 (part5) [12]. The standard specifies that the collector shall be tested under clear sky conditions in order to determine efficiency. On any given day data is recorded under steady state conditions for fixed values of mass flow rate ‘m’ and inlet water temperature ‘T_i’. For each set of fixed values, it is specified that an equal number of tests be conducted symmetrically before and after solar noon. For eg. If data of five set is recorded then the time of recording should be 11:00 am, 11:30 am 12 noon, 12:31 pm and 13:00 pm, Theses set of reading at given time and intervals eliminate any biasness because of transient effects.
As per standard test procedure the data was recorded for four inlet temperatures on different days and total sixteen data sets were obtained. The efficiency of the ETC was calculated using the standard Hottelier equation [13] and the calculated values of the efficiency are shown in Table 2. Further, while testing the collector is considered to be operating under steady state conditions, if the deviations in the experimental parameters is within permissible limits. The experimental parameters recorded during the test are shown in Table 3 and were within permissible limit.

Table 2. Test Results

<table>
<thead>
<tr>
<th>Date of Test</th>
<th>Tsid °C</th>
<th>Tsfd °C</th>
<th>Average Ambient Temp. Tad °C</th>
<th>Average Solar Radiation, GT W/m²</th>
<th>(1+2)/2</th>
<th>ΔT</th>
<th>X</th>
<th>% ƞ</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.07.2017</td>
<td>42.9</td>
<td>66.3</td>
<td>33.6</td>
<td>635</td>
<td>54.60</td>
<td>21.00</td>
<td>0.03</td>
<td>0.47</td>
</tr>
<tr>
<td>27.07.2017</td>
<td>46.5</td>
<td>68.2</td>
<td>34.0</td>
<td>626</td>
<td>57.35</td>
<td>23.35</td>
<td>0.04</td>
<td>0.44</td>
</tr>
<tr>
<td>28.07.2017</td>
<td>53.2</td>
<td>74.4</td>
<td>33.2</td>
<td>646</td>
<td>63.80</td>
<td>30.60</td>
<td>0.05</td>
<td>0.42</td>
</tr>
<tr>
<td>30.07.2017</td>
<td>59.5</td>
<td>80.2</td>
<td>34.6</td>
<td>630</td>
<td>69.85</td>
<td>35.25</td>
<td>0.06</td>
<td>0.42</td>
</tr>
<tr>
<td>01.08.2017</td>
<td>64.2</td>
<td>85.6</td>
<td>35.1</td>
<td>652</td>
<td>74.9</td>
<td>39.8</td>
<td>0.06</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 3. Experimental Parameters.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time</th>
<th>Ambient Temp. °C</th>
<th>Average Global Radiation (I) W/m²</th>
<th>Average Temp. of water in tank °C</th>
<th>Average Wind Speed m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:40</td>
<td>33.1</td>
<td>515</td>
<td>42.9</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>9:10</td>
<td>34.3</td>
<td>594</td>
<td>43.9</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>9:40</td>
<td>34.6</td>
<td>630</td>
<td>45.2</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>10:10</td>
<td>33.2</td>
<td>650</td>
<td>44.7</td>
<td>1.7</td>
</tr>
<tr>
<td>5</td>
<td>10:40</td>
<td>32.8</td>
<td>700</td>
<td>46.4</td>
<td>2.2</td>
</tr>
<tr>
<td>6</td>
<td>11:10</td>
<td>34.4</td>
<td>710</td>
<td>47.8</td>
<td>1.2</td>
</tr>
<tr>
<td>7</td>
<td>11:40</td>
<td>34</td>
<td>680</td>
<td>51.2</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>12:10</td>
<td>34.2</td>
<td>670</td>
<td>52.5</td>
<td>2.3</td>
</tr>
<tr>
<td>9</td>
<td>12:40</td>
<td>33.3</td>
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<td>53.1</td>
<td>4</td>
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<td>60.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSIONS

Figure 1 shows the thermal efficiency of the evacuated tube collector. The efficiency curve shows the negative slope indicating that as the temperature of the inlet water increases the thermal efficiency of the collector decreases. If the thermal efficiency curve is extended towards the left and it touches the vertical axis then the point of intersection shows the point of maximum efficiency for the given collector.

Extending the curve on right side and the point where it touches the horizontal axes then point of coincide at horizontal axes indicates zero thermal performance. The point of zero thermal performance depends on the slope of the curve. Greater the slope of the curve earlier it will coincide the horizontal axes. Therefore, it is concluded from the discussions that for larger range of efficiency the slope of the curve should be gentle.

Figure 1. Efficiency curve for a commercial evacuated tube collector

The test results obtained are summarised below:

- Efficiency, ηc of the collector is found equal to 51%
- Overall heat loss coefficient of the system during day time test, Usys,d, found to 1.81 W/m²K.
- Percentage system efficiency at standard test conditions Ts = 50°C, Tad = 25°C, GT=700 W/m²) is found 0.43 as calculated above.
- Average amount of energy collected (Q) during the period of day time test corresponding to standard test conditions (Kwh) is 2.76.

CONCLUSIONS

Prescribed standards worldwide for testing the solar thermal collectors are unique and very precise in predicting the thermal performance of the solar collectors. The results obtained from the tests can be used for further designing and improvements in the evacuated collectors for any location globally and also for particular applications.

REFERENCES


