PERFORMANCE EVALUATION OF EVACUATED SOLAR TUBE COLLECTOR USING NON-EDIBLE OIL AS WORKING FLUID

Dattatray Galhe[1], Dr. Amol Ubale[2], Dr. S. Chakradhar Goud[3]

[1] *Research Scholar, Mechanical Engineering, Shri JJT University, Rajasthan, India*
[2] *Associate Professor, Mechanical Engineering, Zeal College of Engineering, Pune, India*
[3] *Professor, Mechanical Engineering, Shri JJT University, Rajasthan, India*

ABSTRACT

The rate of drying increases with the rise in drying air flow rate at constant drying air temperature, as one of the solar collector applications, and hence the drying time decreases with the increase in the flow rate of drying air. As a result of the air flow rate, the drying rate doesn't vary much; this effect is less significant than the temperature of the dry air. It is often found that the drying rate decreases occasionally, which can be improved by forced air circulation. The configuration of the Solar Collector System is therefore very critical, since it is based on the primary operating fluid temperature and flow rate. The scope for designing a successful Evacuated Tube Solar Collector (ETSC) Device is therefore open. The heat obtained by the collector depends on the operating fluid's characteristics. Non-edible (engine oil) is used in this research work as a main working fluid rather than traditional water / air working fluid. To improve the solar system's effectiveness, it is therefore important to research its results. In this work, the efficiency of both working fluids (engine oil and air) is analyzed and compared both experimentally and analytically. For different residential, rural, manufacturing and food drying uses, this powerful device can be used.

Keyword: - *Flat Plate Collector; Phase Change Material; Evacuated Solar Tube Collector; Non-edible Oil; Thermal Efficiency*

1. INTRODUCTION

Today, environmental change and energy crises are very critical issues of sustainability. The use of solar energy is thus used to fuel, produce electricity, dry fields, etc. The energy conversion zero-emission project needs time and resources to move forward. Green energy conversion is a catalyst for it. Solar dryers have been shown to be used efficiently for the drying of farm crops.[5] These dryers may be designed to reduce the strain of traditional energy supplies, such as fossil oil, electricity, etc. In order to maximise their supply, functionality as well as market demand, many agricultural products such as grape, potato, jetropha seeds, chilies etc. need drying.[8] Among these, certain fruits, such as the protection of grapes by drying, are also a major industry in many parts of the world, offering stronger exports. So such a company can be a major factor in exporting the economy. Drying of crops by traditional or non-conventional methods provides goods for longer lives without losing their consistency. [18] The drying time for some plants in conventional dryers is about two weeks. Sometimes, owing to any or other factors, such as cloudy conditions or unseasonable showers, the successful drying days are increased and the consistency of the dried goods is affected. [20] The natural convection solar flat plate collector has recently been proposed by some researchers to solve this problem. But it is observed in certain kinds of solar collectors that the average performance is about 20 percent. There is, however, space to enhance the functionality of the collector. The increase in efficiency can be done by using force convection instead of normal convection. Literature shows that ETC solar collectors have better thermal efficiency than natural convection using forced convection. As the evacuated tube collector (ETC) minimises the loss of convection heat, the construction of an effective ETC solar system with usable tube forms requires more thorough research. [7]

2. METHODOLOGY

Solar system design is based on solar ETSC system development. The experimental evaluation of the solar collector includes examining the solar collector's collected data, to assess its output and connections between each part of the device.[29] The research work was performed in four stages, Phase (1) Collecting literature to clarify the context, Phase (2) Design and Fabrication of ETSC system, Phase (3) Experimentation on system, Phase (4) Calculation and Result

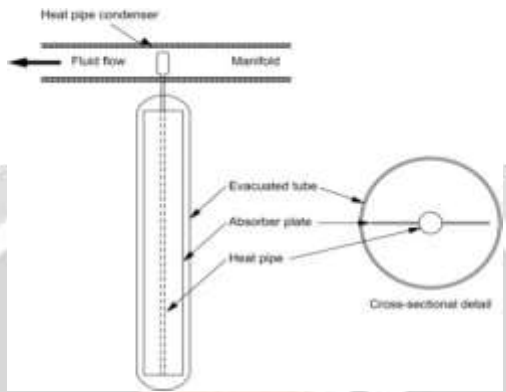

Fig -1 Cross Section of Evacuate Tube Collector [32]

3. EXPERIMENTAL SETUP

The evacuated tubes, connected at the top and sealed at the bottom of the coaxial borosilicate glass tubes, contain a vacuum. The exterior tube is a transparent tube called a tube with a width of 4.7 cm and a length of 180 cm. The inner tube called the Absorber Tube has a diameter of 3.7 cm. The width is 0.16 and 0.2 cm for the inner and outer tubes respectively. The inner tube holds the solar-heated fluid Engine oil. [24] The inner tube is coated with an appropriate material for dark absorption (aluminium nitrite) for the detection and delivery of the solar radiation incident to the working fluid. The closed volume between the external and internal tubes is used as a thermal insulator, primarily due to convection and conduction, thereby eliminating thermal loss. Thus, the trapped solar energy consumed and transferred to the working fluid (green house phenomenon) is prohibited from escaping backwards to the atmosphere. [16]

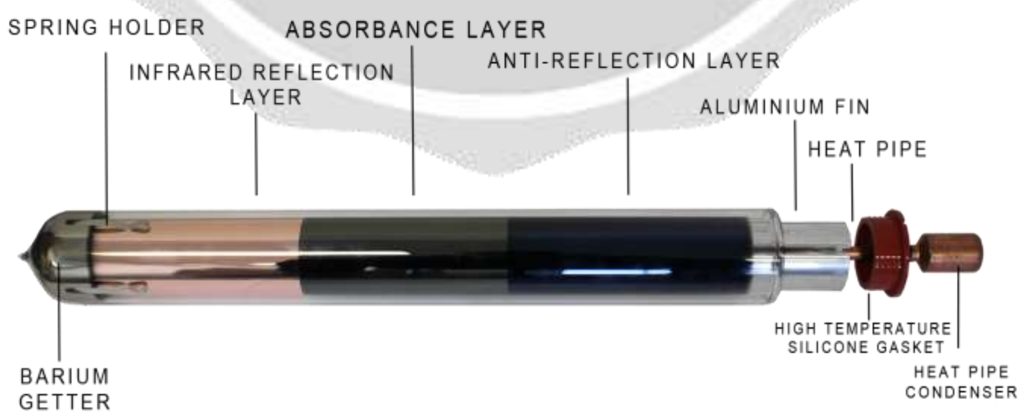

Fig. 2 Evacuate Tube Collector [32]

For this experiment, an adjustable frame is designed. The frame is made up of Aluminium. It is designed such that angle of the evacuated tubes mounted on the frame can be changed as required.

Frame of the Evacuated tube solar collector was done under considerations of environmental and equipment parameters. We have taken 5 possible evacuated tubes (4.7 cm in diameter) of length 180 cm which gives us the area for actual working for our study. We had first enlisted the possible materials for designing frame on basis of parameters such as weight, temperature, density, surface roughness, air flow rate and at last cost of the material (per meter). The possible materials were Stainless Steel, Iron, Galvanized Iron and Aluminium. [13]

As a fact, the Aluminium material is light in weight and not high in cost. On the other hand, the Galvanized Iron was also low in cost and strength was also considerable. The Stainless Steel has high cost that's why it was out of consideration. We selected the Aluminium material for our frame construction. The design of frame was first made with the help of the CAD software. [23] As the construction of earlier frames, which were likely to be fixed for same angle from the fixed bottom and the Solar collector were only fixed to attend the radiations of the sun at that angle only. This probably decreases the surface area that to be attended by the radiations and affects the efficiency of the working solar collector. For overcoming this situation, we constructed a frame which can be turned with the help of rotating links. [29]

The outer body of heat exchanger or header is made up of stainless steel. This header has 5 holes of diameter of 48mm on it to place the evacuated tube. Open end of these tubes are in these holes and the close ends have support through the frame. [13]

4. MATHEMATICAL DESIGN PROCEDURE AND CALCULATIONS

If air is passed through pipe surrounded by fluid having temperature higher than ambient temperature the air will take the heat from them. The oil filled in the evacuated tubes and the header (heat pipe) is heated by the solar energy falling on the system. Energy falling on tubes is absorbed by the vacuum present between the inner and outer tube and given to the oil (non-edible oil) filled within it. The energy balance equation is given as,

$$(Qo)\ abs = mo * Cpo * \Delta T \qquad (1)$$

where mo is mass of oil, Cpo is specific heat of oil and ΔT is the temperature difference between the inlet oil temperature and outlet oil temperature.

The mass of oil is calculated by,

mo= [(Volume of tubes) * (density of oil)] / [3600* Sunshine hours]

where, Volume of tubes = π * r2 * L * N

N is the no. of tubes used

Heat stored by oil is transferred to the pipe from which air is passing. The heat gained by the air is given by,

$$(Qa)abs= ma * Cpa * \Delta T \qquad (2)$$

Where, ma is air passing through the pipe, Cpa is the specific heat of air, ΔT is the temperature difference between the air inlet and outlet temperature.

The mass of air is calculated by,

$$ma = \rho * Vair * A$$

where, ρ is density of air, Vair is the velocity of air and A is the area of tube

Efficiency of the heat gained by the oil due to the solar radiation falling on the tubes is given by,

$$\eta oil= [(Qo)abs] / (Ac * Ig) \qquad (3)$$

Total area of the collector that is exposed to sun (Ac) is,

Ac= (π/2) * D * L * N

where, D and L are diameter and length of the tube in m, N is number of tubes and Ig is the total global solar radiations falling on the tubes.

Efficiency of heat gained by the air flowing through the pipe fixed in the header due to increased temperature of the oil is given by,

$$\eta air= [(Qa)\ abs] / [(Qo)abs] \qquad (4)$$

I. calculations

(i) Volume of tubes,

$$V = \pi * r^2 * L * N$$

$$V = \pi * 0.019^2 * 1.8 * 5$$

$$\boldsymbol{V = 0.0102\ m^2}$$

(ii) Mass of oil in tubes,

$$m_o = \rho_O * V$$
$$m_o = 834 * 0.0102$$
$$\boldsymbol{m_o = 8.51\ kg}$$

(iii) Mass flow rate of air,

$$m_a = \rho_a * A_a * v$$
$$m_a = 1.225 * 0.05067 * 1.32$$
$$\boldsymbol{m_a = 8.19 * 10^{-4}\ kg/s}$$

(iv) Heat gained by the oil,

$$(Qo)abs = \frac{m_o * Cpo * \Delta T}{3600 * S}$$
$$(Qo)abs = \frac{8.51 * 16400 * 12}{3600 * 8}$$
$$\boldsymbol{(Qo)abs = 58.51\ J/s}$$

(v) Thermal efficiency of oil,

$$\eta_{oil} = \frac{(Qo)abs}{I_G * Ac} * 100$$
$$\eta_{oil} = \frac{58.51}{682 * 0.6644} * 100$$
$$\eta_{oil} = \mathbf{12.83}\ \%$$

(vi) Heat gained by air,

$$(Qa)abs = m_a * Cp * \Delta T$$
$$(Qa)abs = 8.19 * 10^{-4} * 1005 * 12$$
$$\boldsymbol{(Qa)abs = 9.88\ J/s}$$

(vii) Thermal Efficiency of air,

$$\eta_{air} = \frac{(Qa)abs}{(Qo)abs} * 100$$
$$\eta_{air} = \frac{9.88}{58.51} * 100$$
$$\eta_{air} = \mathbf{16.99}\ \%$$

Using above sample calculations the result table is prepared for readings taken from 10 am to 5 pm.

5. RESULT AND DISCUSSION

Using above equations analytical values for outlet temperature at outlet is calculated and compared with actual readings obtained through experimental setup.

Table- I: Percentage error calculated for analytical and experimental results

Time (hrs)	Solar Radiation	Collector Outlet Temp (Actual) (0C)	Collector Outlet Temp (Actual) (0C)	%Error
10:00	682	82	85.4	3.9881
11:00	715	93	96.3	3.4267
12:00	721	109	112.7	3.2830

13:00	691	120	123.4	2.7552
14:00	638	120	118.1	1.6088
15:00	621	117	120.2	2.6622
16:00	552	81	84.3	3.9145
17:00	501	75	72.5	3.4482

Average % Error is 3.1358 % which is well in acceptable limit. Hence results are validated.

With higher mass flow speeds, but on one side, it reduces losses; in the other, the air outlet temperature decreases and, in essence, increases the interceptor region. For an effective use of the solar-evacuated tube collector, less mass flow rate with moderate air transport diameter is therefore needed. To achieve more steady flow, the interception region of the collector must be improved to allow greater mass flow rates.

6. CONCLUSION

Experiments on a design plan for an evacuated solar tube collector were conducted to detect its use for high-temperature air. The experimental results suggest that motor oil is less comestible and less efficient as a working solvent, for example, than air. Results have shown that the efficiency of non-edible oil as working fluid is lower for the first two hours though gradually rising from 1.5 per cent to 39 per cent before 5 pm. Non-edible oil has been found to be an effective heat transfer medium between the internal surface of the evacuated tube and the external surface of the tube.

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