To Improve the Thermal Performance of Heat Pipe in Evacuated Tube Solar Collector

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***Abstract*-This paper discuss about the design of Evacuated Tube Solar Collector (ETSC) to fulfill the basic daily residential requirement of hot water consumption. Generally, during a day period when full availability of the solar radiations the ETSC charge continuous as most of the upper part of tube are directly absorbed solar radiation but the lower part of tube where solar radiations is not fall directly; and hence tube heating is not uniform. Therefore, the efficiency of ETSC is lower. In this paper design of curved shape reflector sheet is prepared which is used for increasing the temperature of lower part of tube and hence the efficiency of ETSC is measured.**

Keywords: Evacuated Tube Solar Collector, Phase Change Material, Efficiency.

I INTRODUCTION

The consumption of conventional resources of energy is very high, so these resources are continuously depleting day by day. The development of renewable energy is important for the future to balance global energy resources as it is a never-ending resource. Among renewable energy sources, solar energy has a high potential, especially for use in heat production via solar thermal collectors. Solar collectors are devices that are used to harness the energy from the sun, convert the income solar radiation into useful heat energy, being the key element in solar energy utilization systems. The solar thermal collectors absorb the incident solar energy to heat up the running water through the tubes. Evacuated tube solar collectors (ETSC) are increasingly in use worldwide because of their high thermal efficiency and high working temperature. The evacuated tubular solar collector consists of glass vacuum sealed tubes. The conductive and convective losses are reduced by the presence of vacuum medium in ETSC. [1]. Reports an analytical investigation of the new compact design of evacuated heat pipe solar water heater integrated with latent heat storage tank. This device has a set of evacuated heat pipe solar collector arrays directly connected to a tank, which is filled by paraffin wax as the phase change materials (PCM). The materials in which energy is stored in a form of latent heat are called phase change materials (PCMs), since the heat exchange takes place in the PCM through the phase change from solid to liquid and vice versa. There are different types of PCMs concerning its organic or chemical base, melting temperature ranges, and reaction sensitivity with the other materials. Some studies were performed to investigate the effect of the PCM integration with the solar system's storage tank, or as a separate storage unit, on the system's performance. Among the PCMs, paraffins have certain desirable properties for thermal energy storage. paraffins have a suitable melting point and relatively high latent heat. [2]. Furthermore, paraffins are non-toxic and harmless to the environment. Therefore, they are often used as the PCM in thermal energy storage supplied with solar energy. Experimental analysis also carried in shell and tube thermal energy storage using PCM. [3].

Energy output temperatures can be increased by decreasing the area from which heat losses occurs. This is done by employing concentrators to reflect and concentrate the solar radiation back to the absorbers. Concentrators can be reflectors or refractors, can be cylindrical or surfaces of revolution, can be continuous or segmented. There are two types' concentrators: non imaging collectors with low concentration ratio and linear imaging collectors with intermediate concentration ratio. Concentrators can have concentration ratio from low values less than unity to high values of the order of 10^5. [4]. Concentrated solar power with parabolic trough allows obtaining a higher operating temperature. [5] The effect of parabolic reflector, PCM and mass flow rate of water in evacuated tube solar collector assembly was determined experimentally in this paper.

II METHODOLOGY

In an evacuated heat pipe solar collector, the end section of the heat pipe is inserted into the manifold. Section of evacuated tubes absorbs solar energy and then transfer it to the heat pipes. The insulated reservoir tank is filled up with the PCM (paraffin wax). Moreover, the finned pipes are employed inside the manifold in order to exchange the heat from the phase change material to the supply water. The cylindrical parabolic reflector is used to reflect the solar radiation to the back and sides of each tube. The aluminum reflector sheet has the reflectivity around 90-95% which reflects the maximum heat over the below portion of ETSC. An ETSC with reflector involves of the following heat transfer processes: i) Absorption of solar energy, ii) Charging process of PCM. iii) Discharging process of PCM to the cold supply water.

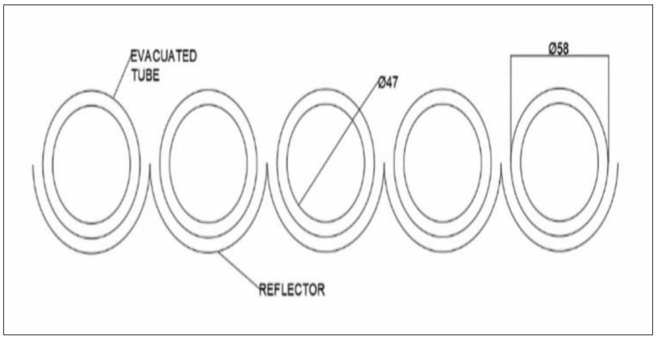

Fig. 1. ETSC with cylindrical parabolic reflector

Cylindrical parabolic reflector consists of a polished thin aluminum sheet curved into desired shape, to reflect maximum solar radiations. Evacuated tube is placed at focal point of the reflector as shown in Fig.1. Each tube is provided with the reflector and are placed at the focal point of the respective reflector. Support structure is fabricated using steel for providing mechanical support to whole system. Concentration ratio is an important parameter used to describe the amount of solar energy concentrated by cylindrical parabolic reflector. Concentration ratio is defined as the ratio of area of aperture of the reflector to the surface area of absorber tube. [6].

$$C=\frac{A_r}{A} \quad (1)$$

Where, C is concentration ratio, A_r is the area of aperture of the reflector (m^2), A is the area of absorber tube (m^2). Collector efficiency is expressed as the ratio of solar energy collected divided by the solar energy available. The collector efficiency is calculated from the equation:

$$\eta = \frac{\dot{m}C_p(T_i - T_o)}{IAN} \quad (2)$$

Where, N = number of tubes =5, C_p= specific heat of water =4179.6 J/kg.K, I= solar radiance =915 W/m^2, A= area of single evacuated tube. Fig. 2 shows Schematic diagram of actual reflector sheet of the proposed heat pipe solar water heating system. The system mainly consists of heat pipe solar collector, water storage tank, thermocouples, pump, flow meter, pipes and fitting, valves. The basic principle adopted in the construction of the parabolic solar reflector is that when parallel rays of light from the Sun close to and parallel to the principal axis are incident on a concave or parabolic shaped mirror, they converge or come together after reflection to a point F on the principal axis called the principal focus.

Fig. 2 Schematic diagram of actual reflector sheet.

When the Evacuated tube, solar parabolic plate collector, mounting stand are integrated the required assembly appears. The evacuated tube acts as an absorber and absorbs all the solar radiations falling on it. As this tube is placed at the focal line of the designed parabolic collector, it absorbs all the reflected radiations too. This increases the temperature of the air. Four thermocouple wires are used to measure the temperature of inlet, heat pipe, wax and outlet. These thermocouple wires are connected to digital temperature indicator that indicates the temperature sensed. A portion of the solar radiation which strikes the glass of HPSC is absorbed and used to vaporize the working fluid inside the heat pipes and the remainder is dissipated back into the environment. The vapor inside the heat pipes rises towards the condenser section where transfers its heat to the solar working fluid through the manifold, condenses, and returns to the evaporator section, and the cycle continues. The solar working fluid, which is circulated using a pump, enters the manifold at low temperature and its temperature rises as it passes along the manifold. Heated water is extracted from the top of the storage tank.

III DESIGN CALCULATION

Design of ETSC is made as per the required outlet temperature: The following parameters are design and selected: Dimensions and Properties of Components: 1) Glass Tube: The material used is borosilicate glass. The outer diameter = 58mm, Inner diameter=47mm, and length, L=1.8m. The thermophysical properties of borosilicate glass are as: Density (ρ) =2.23 kg/cm^3, Thermal conductivity, k =1.14 W/m.K, Specific heat, C_p=0.83 J/kg.K. 2) Reflector: D=70mm**,** L=1.8m**,** Reflectivity=90%**.** 3) Heat pipe: The material used for heat pipe is copper material. The outer diameter =30mm, Inner diameter=26mm, Length, L=2 mm, Thermal conductivity, k=385 W/m.K. 4) Acetone: The boiling point=56ºC, Density=784.78kg/m^3, Thermal conductivity =k_l = 0.1667K, Specific heats, C_{pl}=2.14kJ/kg.K, C_{pg}=1.29 kJ/kg.K 5) Finned Tube: The copper fins materials selected. The outer diameter = 24mm, Inner diameter = 20mm, Length, L = 490mm, width B=12mm, thickness, t=2mm, Number of fins = 3. 6) Wax: Melting point =60°C, Mass = 25kg, Density = 900 kg/m^3, Thermal conductivity = k_s = 0.24W/m.K, Specific heats, C_{pl}=1.69 kJ/kg.K, C_{pg} = 2.1 kJ/kg.K. 7) Water: The specific heatC_{pl}=4.187 kJ/kg.K.

i) Calculation of Acceptance Area: The acceptance area is calculated as follows:

$$A_a = \left(\pi \times \frac{D_1}{2} \text{xL} - \text{D} \times \text{L}\right) = \left(\pi \times \frac{0.07}{2} \text{x}1.7 - 0.058 \times 1.7\right)$$

= 0.088m^2.

Calculation of Area: $A_r = \pi \times \text{D x L} = \pi \times 0.058 \text{ x } 1.7$ = 0.3m^2.

Calculation of Concentration ratio: $C = \frac{Ar}{A} = \frac{0.088}{0.3} = 0.267$.

Reflector's Heat Intensity: I = 1000xA_a=88 W.

Reflector intensity =88x0.9=71.06 W.

Heat Input (From Sun to Tube): The absorbed solar power by tube = S = $(\tau\alpha)$ G A_r = 0.85×1000×0.3 = 255 W.

Total absorbed solar power = S + Reflector intensity = 255+71.06 = 326.06 W.

Heat Transfer from tube to heat pipe,

$Q_{Conv} = Q_{o\,Cond} + Q_{loss}$ … (Assuming Q_{loss} = 0)

$$326.06 = \frac{2 \times \pi \times k \times l \times \Delta T}{ln\left(\frac{R_2}{R_1}\right)}$$

$$326.06 = \frac{2\times\pi\times385\times1.7\times\Delta T}{ln\left(\frac{0.03}{0.026}\right)}$$

$\therefore \Delta T = 0.011$°C.

ii) Heat Transfer from heat pipe to acetone: The heat transfer from heat pipe to acetone and it is given as: $Q_{i\,Cond} = Q_{o\,Cond}$

$$= \frac{2 \times \pi \times k \times l \times \Delta T}{ln\left(\frac{R_2}{R_1}\right)} = mC_{pl}\,\Delta T$$

$$\frac{2\times\pi\times385\times1.7\times0.011}{ln\left(\frac{0.03}{0.026}\right)} = 100 \times 10^{-3} \times 2.14 \times 10^3 \times \Delta T$$

$\therefore \Delta T = 1.477$°C.

iii) Heat Transfer from Acetone to Heat pipe: Similarly, the heat transfer from Acetone to heat pipe is given as,

$Q_{i\,Cond} + Q_{LH} = Q_{o\,Cond}$

$$mC_{pg}\,\Delta T + m\times\text{latent heat} = \frac{2\times\pi\times k\times l\times\Delta T}{\ln\left(\frac{R_2}{R_1}\right)}$$

$$100\times2.14\times1.477+\frac{100\times518}{3600} = \frac{2\times\pi\times385\times0.3\times\Delta T}{\ln\left(\frac{0.03}{0.026}\right)}$$

ΔT_{hp}= 0.04°C.

iv) Heat Transfer from Heat pipe to wax: The heat transfer from heat pipe to wax is, here N is the number of pipes required,

$$Q_{i(Hp)} = Q_{o(wax)} = N \times \frac{2\times\pi\times k\times l\times\Delta T}{ln\left(\frac{R_2}{R_1}\right)} = \left(mC_{ps}\,\Delta\,T\right)_{wax} =$$

$$5 \times \frac{2\times\pi\times385\times0.3\times0.04}{ln\left(\frac{0.03}{0.026}\right)} = 10\times 2.1 \times 10^3 \times \Delta T$$

$\therefore \Delta T = 0.047$°C

v) Heat Transfer from Wax to Finned tube: The heat transfer from Phase change material wax to finned is given as,

$$Q_{i(cond)} + Q_{LH} = Q_{o(cond)}$$

$$(mC_{pl}\Delta T) + m\times \text{latent heat} = \frac{2\times\pi\times k\times l\times\Delta T}{\ln\left(\frac{R_2}{R_1}\right)}\;10\times1.6\times10^3\times0.047 + \frac{10\times190\times10^3}{3600}$$

$$= \frac{2\times\pi\times385\times0.49\times\Delta T}{\ln\left(\frac{0.024}{0.02}\right)}$$

$\therefore \Delta T = 0.115$°C.

vi) Heat Transfer from Finned tube to water: Finally the heat transfer from finned material to the water is given as,

$$Q_o = Q_i$$

$$\frac{2\times\pi\times k\times l\times\Delta T}{\ln\left(\frac{R_2}{R_1}\right)} = m\,C_p\Delta T = \frac{2\times\pi\times385\times0.49\times0.115}{\ln\left(\frac{0.024}{0.02}\right)} = 0.00167 \times 4187 \times (T - 30)$$

Therefore, T = 136.92°C. This is the obtained output temperature of water.

IV CONCLUSION

The complete theoretical design calculation of evacuated solar tube collector with reflector has done. And based on the design procedure the maximum outlet temperature of water obtained is 136.92ºC in the evening when the mass flow of water is 1.67×10^{-6} m^3/s and the efficiency is during that time period obtained is 25.98%.

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