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Performance Analysis of Water-in-glass Evacuated Tube Solar Water Heater

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Abstract:

It is necessary to develop a technique of receiving and storing solar energy efficiently. Extensive research work is taking place worldwide in the area of Solar Water Heaters. The project aims at studying the performance of water-in-glass evacuated tube solar water heater and to analyze the results obtained from the experimentation, which involves tilting evacuated tube at different angles and measuring the temperature of water in the tank over the period of time. Temperature is sensed by a suitable temperature sensor and those values are recorded manually. Those recorded values then used to obtain relationships between the inclination angle, temperature attained in the tank. A MATLAB code is used to plot temperature characteristics and calculate heat transfer coefficient. It also involves the determination of Heat gain and Heat loss from the tube at various angles of inclination during operation and suggesting the appropriate inclination angle with an efficiency point of view.

Keywords **—Evacuated tube collector, Solar water heater, Tube tilt angle, Thermal Performance**

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I. INTRODUCTION

Solar energy, being plenteous and widespread in its convenience, making it one amongst the foremost enticing sources of energy. Tapping this energy won't solely facilitate in bridging the gap between demand and provider of electricity however shall conjointly economize within the long run.

A solar water heating plant (SWHS) could be a device that creates out there the thermal energy of the incident radiation Water in the tubes is heated by solar radiation, rises to the storage tank and is replaced by colder water from the tank for use in varied applications by heating the water. Circulation of water from the tank through the collectors and back to the tank continues automatically due to the thermosiphon principle[1]SWH collector tilt angle has significant effects on a system's daily collectible radiation and daily solar heat gain, as the thermosiphon effect and flow patter varies with inclination.[2] Due to round shape of evacuated tube it collects almost all energy it may happen that the effect remains insignificant. [3]

II. CONTRUCTIONAL FEATURES

1.**Storage tank**

It is a tank that stores water and comes like a water tank from an external water source. The outer cylindrical surface is covered by high-tech insulating material (rock wool or mineral wool) to reduce heat losses from the heated water in the inner tank heated by the solar tube heater. Rock wool is a manmade fibre and has many outstanding characters such as non-combustible, non-toxic, low thermal conductivity, long service life, etc. At the top of the frame and tubes is the storage tank. The tube's top open end is attached to the storage tank. 7-8 litres of the tank volume is used for the 58D1800L model

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Fig. 1 Storage tank

2.Evacuated tube

Borosilicate glass evacuated tube is 47 mm in diameter and 1800 mm in length. The vacuum tubes are made up of a double wall glass tube with a center space containing the heat pipe. The vacuum wall presence prevents any convection or conduction losses. A barium getter is used to keep the vacuum between the two glass layers. This getter is exposed to high temperatures during manufacturing, causing the bottom of the evacuated tube to be covered with a pure barium layer. During storage and operation, this barium layer actively absorbs any CO, CO_2, N_2, O_2, H_2O, and H_2 gassed from the tube, thus helping to maintain the vacuum.

3. Experimental Setup

The trigonometric formulae were used to decide the height of the tank accordingly stand was designed.The whole system required a structure strong enough to hold up cylinder at various angles. Rubber ring type end support was used to support fragile end of evacuated tube.

Fig.2Experimental Setup

III EXPERIMENTAL PROCEDURE

1.Empty tube test-

Before taking actual readings it is necessary to check whether the setup is healthy or not. To do that test was done on the empty tube .forleak-proof setup it is expected the temperature to reach above 200°C. Our max temperature attained was 210°C .

2Determination heat loss coefficient-

Water was heated to 56.69 ^{0}Cand allowed to cool down for 2 hours . The given formula derived from newton's law of cooling was used to calculate heat loss coefficient .

$$U_{loss} = \frac{\rho\, V_T C_f\ (T_f - T_i) \ln\left\{\frac{T_i - T_0}{T_f - T_0}\right\}}{(t2 - t1)}$$

U_{loss} = heat loss coefficient.
ρ = Density of water.=1000kg/m^3
C_f= Specific heat capacity=4.187 kJ/kg
T_f= Final temperature.=56.69 ^{0}C
T_i= Initial temperature.=54.41 ^{0}C
T_f= final time.
Ti = initial time
T_f–Ti=7200sec

$$U_{loss} = 2.263\ \mathrm{W}/m^2$$

3.Temperature characteristics test

Temperature readings at set angles were taken every 5 minutes from 10 am to 5 pm.

IV. MATHEMATICAL MODELLING AND FLOW CHART OF MATLAB CODE

1Heat transfer coefficient:

After calculating heat loss coefficient for overall system next task is to find heat transfer coefficient inside the system. To find this we must use specifications of the tube provided which give us heat loss coefficient of the tube. After that using electrical analogy of the heat transfer heat loss coefficient of the tank is calculated. The thermal network for it is as given as follows.

$$\frac{1}{U_{sys}A_{sys}} = \frac{1}{h_{tank}A_{tank}} \Big\| \frac{1}{h_{tube}A_{tube}}$$

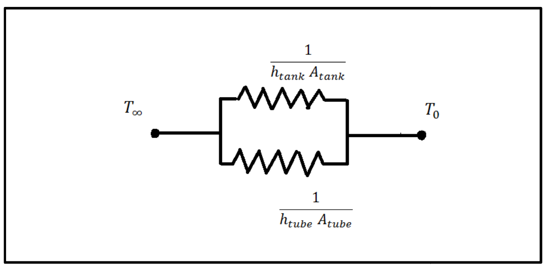

Fig. 3 Resistance network for system

Resolving the equations we get

$$h_{tank} = \left(\frac{U_{sys}A_{sys} - h_{tube}A_{tube}}{A_{tank}}\right)$$

The above equation gives us the value of heat loss coefficient for the tank only which will further be used to evaluate heat transfer coefficient of the liquid inside the tank in order to plot performance for various angles. h_{tank}will be considered as U_o from now onwards. Here K_i is the thermal conductivity of the insulation. All the specifications of tank are respectively as specified in the table.

$$\frac{1}{U_oA_o} = \frac{1}{h_oA_o} + \frac{\ln\left[\frac{r_o}{r_i}\right]}{2\pi K_i t} \Big\| \frac{t}{K_iA_{si}} + \frac{1}{h_\infty A_i}$$

In the above correlation h_o is the heat transfer coefficient of the outside air, which can be found from ambient air temperature (T_o) and instantaneous wind velocity (V_w). Only unknown ish_∞. We get heat transfer coefficient inside the tube.

2. Heat gain of the system

When ETC tube is exposed to the radiations it heats the water inside the tube and gains heat and start convicting it to the tank by thermosiphon effect. Heat transferred over given period of the time by the system can be found by a simple correlation as given by

$$Q_u = m_sC_p(T_2 - T_1) + \int_{t1}^{t2} U_{loss}A_{tank}(T_0 - T_0)\, dt$$

Where m_s mass of the fluid inside the system which from calculations comes out to be 8.73 kg with a tolerance of 20 gms. $C_p$is the specific heat of water. Every other quantity is known. U_{loss}andA_{tank} are constant with time.

IV. RESULT AND ANALYSIS:

1.Variation of nusselt number :

Nusselt number is important to calculate the nature of flow and convection coefficient inside the bulk fluid. Nusselt number is directly proportional to the convection coefficient and it represents the ratio of heat convected to heat conducted through the fluid. It means that heat conducted increases with time and temperature. It also shows that for given three inclinations, the 45-degree inclination is showing higher nusselt numbers for the given temperature. Hence it provides that when the inclination is increased it increases the random motion of fluid particles and slightly higher turbulence.

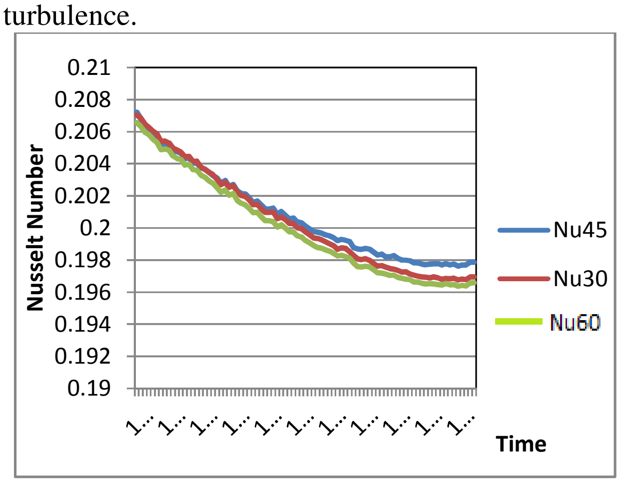

Fig. 4 Variation of Nusselt number with inclinations

2. Variation of Rayleigh number with inclinations

Rayleigh number is deciding criteria between laminar and turbulent flow. For fluid and liquids its value is 10^9. From results obtained its value is always less than critical value. Hence flow is laminar only.

Again for various inclinations increment in Rayleigh number for 45 degree system is higher as compared to 60 and 30 degree. Because of weight and less flux heat, it slows down motion of fluid but since at higher inclination better mixing of fluid because of thermal currents.

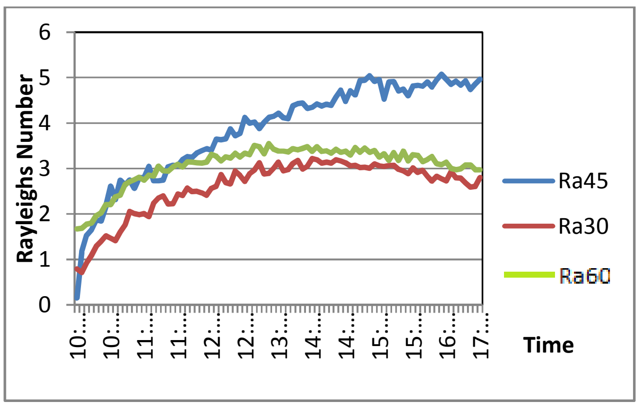

Fig 5 Variation of Rayleigh number with inclination

3.Temperature variation behaviour

The temperature variation graph shows that for inclination of 45 degree the temp attained is maximumas the thermosiphon effect and gravity effect both are optimised.

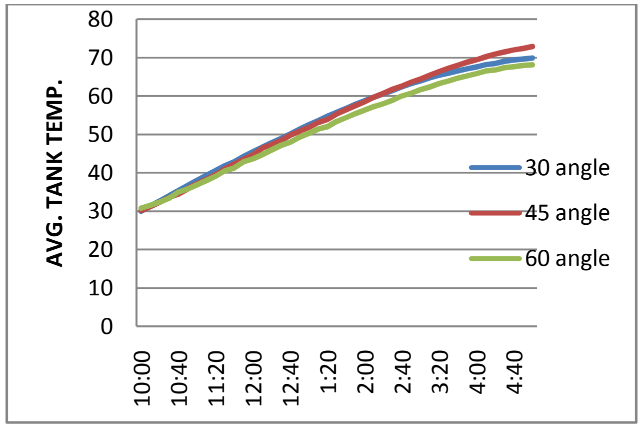

Fig. 6 temperature characteristic

V. CONCLUSION

The temperature characteristics obtained as a result of the experiment show that the performance varies with respect to angle of inclination. The data collected during the experiment shows the highest values of water temperatures for lesser inclination angles (30 degree) at earlier stages of the experiment.For 30 degree system it is seen that temperature at the open end of the tube is maximum as compared to other locations. Hence for lower angles stagnation zone inside the tank is more dominant**.** On the other hand, for 45 degree system the initial variation shows higher departure of temperature for closed end of tube as compared to other locations. Hence stagnation zone is more dominant inside the tubes at higher angles. From temperature readings it is confirmed that at higher angles stagnation zone exists inside the tube and for lower inclinations stagnation zone exist inside the tank**.**

Lower values of Rayleigh number signify laminar flow inside the system for natural convection and these currents are high in 45 degree system

FUTURE WORK

Simulation of the Test Setup can be carried out to validate the results by using CFD software.

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