Study of Influence of Tilt Angle and Flow Rate on the Performance of Evacuated Tube Solar Collector

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***Abstract*— Solar collectors are the most widely used device to convert solar radiation into heat. In conventional applications they can provide energy for domestic hot water or space heating in combination with low water temperature systems. Testing of thermal efficiency and performance of the evacuated tube solar collectors are addressed and discussed in the present work. In order to investigate the performance of evacuated tube solar collector, an experimental set-up has been constructed. The set up consists of fifteen evacuated tubes and manifold channel. The manifold channel consists of a hollow pipe (square pipe) in center through which water flows. Thermocouples were used to measure the inlet and outlet water temperature and pyranometer was used to measure solar radiation intensity. The temperature difference and efficiency were studied with different water flow rates at different tilt angles with horizontal. The tilt angles that have been used were 15° and 30° with the horizontal, and the various flow rates were 300 ml/min, 400 ml/min, 500 ml/min. The set of readings were taken for 6 different days at regular interval of time (30 minute) for each tilt angle of the evacuated tube solar collector at each flow rate. All the readings were tabulated and standard efficiency curves have been plotted. The conclusion is made from the graphs and data obtained. From the graphs it has been observed that at 15° tilt angle, flow rate 500 ml/min gives a better performance compare to other two flow rates. Similarly, at 30° tilt angle also flow rate 500 ml/min gives better performance among the applied flow rates. It is cleared that tilt angle has not so much influence on the performance. But at tilt angle 30° the performance is slightly higher than the 15° tilt angle.**

Keywords*— *Solar collectors, Evacuated tube collectors, Tilt angle

I. INTRODUCTION

plate collectors. For a concentrator system the cost per unit area of the solar collecting surface is therefore potentially Sun is the primary source of energy to earth. Humans learnt the use of solar energy since prehistoric times. Basically, all the forms of energy in the world as we know it are solar in origin. Oil, coal, natural gas and woods were originally produced by photosynthesis processes, followed by complex chemical reactions in which decaying vegetation was subjected to very high temperature and pressure over a long period of time. Even the wind and tide energy have a solar origin since they are caused by difference in temperature in various regions of the earth. The main advantage of solar energy is it is clean and do not cause any environment pollution. The major problem presently the world is facing is Global warming and it is getting worse day by day because of the increment of greenhouse gasses e.g- CO, HC, NOx etc. which are exhausted from the combustion of fossil fuel. The growing concern about the environmental effects and the escalate on oil prices in last two decades along with the continuously increasing energy demand had lead to higher attention on solar technologies [1–6]. Solar water heating has been extensively studied and it has been reported that it can supply about 70% of sanitary water heating demand on residential and commercial facilities [7]. The most common models for low to medium temperature applications are the single glazed flat plate solar collector and the evacuated tube solar water heater due to their simplicity, high efficiency and low cost of maintenance and operation [1,8]. China is one of the biggest manufacturers and consumers of evacuated tube solar collector water heater. On 2012 a solar collector area of about 250,000,000 m2 for residential water heating was installed in this country, 90% of which was evacuated tube solar collector water heater [8]. India has also set a mid-term goal of a solar collector area of 300,000,000 m2 by 2020 [9-10]. This would mean a continuous growth of solar water heater manufacturing not only for the chinese market but also for its commercialization overseas. Solar thermal collectors are special kinds of heat exchangers that convert solar radiation into internal energy of the transport medium. This is the most important component in any solar thermal system. A solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. A convenient way to classify solar collectors is according to their models of movement; i.e. stationary, single-axis tracking and two-axis tracking. The stationary solar collectors are permanently fixed in position and do not track the sun. There are two general types- the flat plate collector and concentrating (focusing) collector. Focusing collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors use optical system in the form of reflectors or refractors.

The main advantages of concentration systems over flat plate collector types are that the reflecting surfaces requires less material and are structurally simpler than flat less than that for flat plate collectors. Owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment or vacuum insulation to reduce heat losses and improve collector efficiency are economically feasible. Because the temperature attainable with concentrating system

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is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat plate collectors.

Morrison et al.[11] evaluated the characteristics of water-in-glass evacuated tube solar water heaters including assessment of the circulation rate through single-ended tubes. A numerical model of the heat transfer and fluid flow inside a single-ended evacuated tube had been developed assuming no interaction between adjacent tubes in the collector array. Lamnatouet al.[13] presented an evacuated tube collector solar dryer for drying apples, carrots, and apricots experimentally. The mass flow number, along with the maximum collector and fluid exit temperatures, was studied in relation to the minimum entropy generation. Results show that the outlet air temperature was appropriate for drying the agriculture products without preheating of air. Roonak Daghigh and Abdellah Shafieian[14]carried out a study to theoretically and experimentally evaluate the performance of asolar water heating system with evacuated tube heat pipe collector. First, a mathematical model was presented according to thermal and exergy analysis to analyze the collector performance and then the given system was constructed and experimentally tested according to a real consumption pattern. The obtained results showed that the optimal numbers of collector pipes were reported to be 15. Also, a direct association was found between hot water consumption and system performance. Many researchers have experimentally used the evacuated tube for the heating of water and heating of air with intermediate fluid. The objective of the current experiment is to study the performance of evacuated tube solar collector at different water flow rates and at different tilt angles.

II. EXPERIMENTAL SETUP

The aim of this experimental work is to study the thermal performance of an evacuated tube solar water heater with different tilt angles and flow rates. The experimental setup of ETC solar collector based on one ended glass evacuated tube is shown in Fig 1. It consists of a header with fifteen one ended glass evacuated tube which are mounted on an adjustable stand.

Fig. 1: Evacuated tube solar water heater

The length of the evacuated tube is 1500 mm. Outer diameter of the evacuated tube and absorber tube are 57 mm and 47 mm, respectively. Each evacuated tube filled with water. The collector is inclined with an angle of 15° and 30° relative to horizontal. The flow rates maintained are 300 ml/min, 400 ml/min, 500 ml/min.

A. Evacuated tube Solar collector

The evacuated tube consists of two borosilicate glass tubes. The outside of the inner tube is coated with a solar selective coating, as show in Fig. 2[11]. The annular space between the outer tube and inner tube is evacuated to minimize the heat loss. The evacuated tube can effectively minimize the heat loss through thermal conduction and convection. Therefore, the average water temperature in the storage tank in this case is higher than most other solar water heating systems under the same conditions. The operation of these evacuated tube solar collectors are highly influenced by the tilt angle of the tube respect to the ground as it will affect the total irradiance on the absorber and the natural convection heat transfer[15].

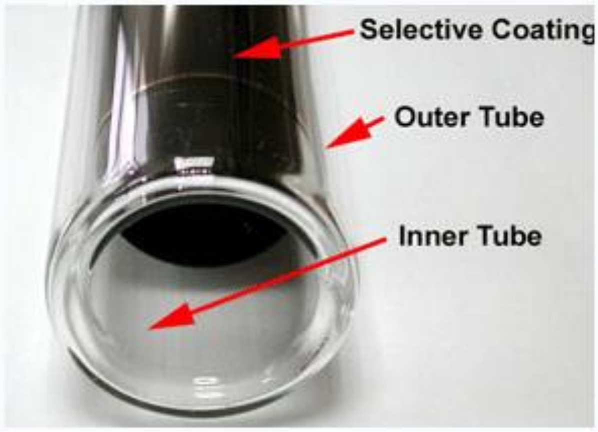

Fig. 2: Evacuated tube with single-phase open thermosiphon

Fig. 3 shows the working principle of a evacuated tube solar collector. Cold water flows into the inner tube. There, they absorb heat from the solar radiation. The hotter water rises through the tube to enter the storage tank. At the same time the cold water at the bottom of the tank flows into the tubes. Such circulation and convection flow will continue as long as the solar radiation sustains [12].

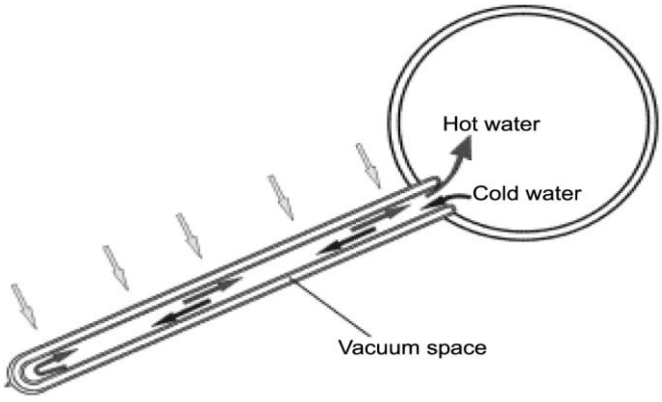

Fig. 3: Working principle of single-phase thermosiphon solar collector

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B. Header

The header used in this system is of square rectangular shape. The header contains fifteen holes in which the evacuated tubes are attached. Open end of the evacuated tubes are fitted in these holes and the closed ends are supported by the frame.

C. Measuring Devices

The different parameters are measured for calculating the thermal performance of the evacuated tube solar water heater are the following:

1. The inlet and outlet temperature of the water
2. Solar radiation intensity

Copper constant thermocouples are used to measure the inlet and outlet water temperature. Pyranometer is used to measure solar radiation intensity.

D. System operation

Initially, the tap water was supplied to the evacuated tube solar collector and then expose to the sun. This tap water circulates by thermosyphon from evacuated tube to header. Cold water flows into the inner tube. There, they absorb heat from the solar radiation. The hotter water rises through the tube to enter the storage tank. At the same time the cold water at the bottom of the tank flows into the tubes.

Then the different measured parameters are noted at a interval of 30 min. The three various flow rates are implemented on three different days at 15° tilt angle, then the procedure is repeated for another three days at 30° tilt angle.

III. RESULT AND DISUSSION

The main parameter to describe the solar collector performance is the instantaneous efficiency η. The collector efficiency is defined in steady-state conditions as:

$$\eta = \frac{Q_{out}}{Q_{in}} \quad (1)$$

Where Qout is the useful heat power (output) provided from the collector to the working fluid (water) and Qin is the input heat flux provided by the solar radiation. The useful heat power Qout is obtained as:

$$Q_{out} = mc_p(t_{out} - t_{in}) \quad (2)$$

Where m is the mass flow rate of working fluid flowing through the tube, tin & tout are the inlet and outlet temperatures of fluid respectively and Cp is the specific heat of the working fluid.

The input heat flux Qin is defined as:

$$Q_{in} = G.A_c \quad (3)$$

Where G is the global solar irradiance and Ac is the reference area of the collector. To describe the collector efficiency is so necessary to define reference area. The reference area Ac is defined as:

$$A_C = \frac{\pi dl}{2} \times \text{no. of tubes} \quad (4)$$

Where d and l are the tube diameter and length respectively and no. of tubes used is 15.

The data that has been obtained in the experimental work were analyzed. The efficiency curves of the tube collector for different tilt angle at different flow rates have been plotted with respect to the time of the day.

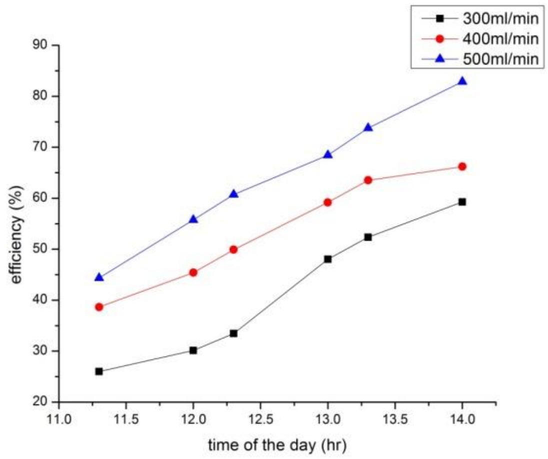

Fig. 4: Efficiency curves for 15^0 tilt angle of the tube collector for different flow rates

The efficiency curves for 15° tilt angle of the tube collector for different flow rates was shown in the fig 4. It was clearly observed that the efficiency of the tube collector has increased with increase in flow rate. In the present work, the efficiency of the collector was determined for three different flow rates. It can be observed that the maximum efficiency of the collector was obtained at flow rate of 500 ml/min was 83.53%. Again efficiency of the collector was kept on increasing with the passage of time for all three flow rates. It may be due to the fact that with passage of time pre heating of the collector tubes comes into play.

It case of 30° tilt angle of the tube collector (fig 5) again it can be seen that efficiency of the tube collector was kept on increasing due course of time. The similar fact to the previous case can also be applied here. Similar to the previous case, the maximum efficiency of the tube collector was obtained at flow rate of 500 ml/min, which was 83.53%.

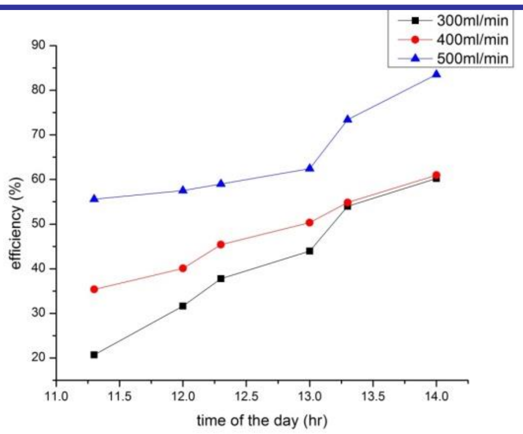

Fig. 5: Efficiency curves for 30o tilt angle of the tube collector for different flow rates

From the below graphs the maximum efficiency of the tube collector was found at the flow rate of 500 ml/min for both the tilt angles of the collector. The comparison of the efficiencies of the tube collector has been made at the flow rate of 500 ml/min for the both tilt angle in fig 6. It was clear from the curves the maximum efficiency of the tube collector was obtained at 30° tilt angle of the collector tubes, which was 83.53%.

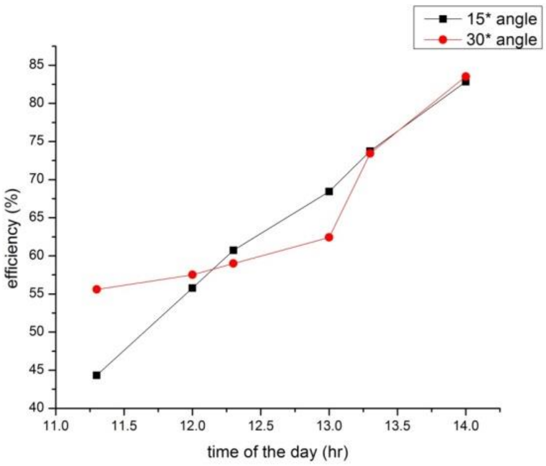

Fig. 6: Comparison of the efficiency of the collector at the flow rate of 500ml/min for 15o and 30o tilt angles

IV. CONCLUSION

In the present work the influence of tilt angle and flow rate on the evacuated tube solar collector was observed. The experiment on the performance on different flow rates and tilt angle has been carried out. The different flow rates implemented are 300 ml/min, 400 ml/min, 500 ml/min, with tilt angles 15° and 30° with the horizontal. The observation is taken in six different days. Experimental results revealed that the collector fluid flow rate had significant effects on the thermal performance of evacuated tube solar water collector. Results showed that the temperature difference of the water and thermal efficiency of evacuated tube solar collector is better with flow rate 500 ml/min compare to flow rate 300 ml/min and 400 ml/min. Results also showed that performance of the evacuated solar collector is not so much influenced by tilt angle, but at tilt angle 30° the collector performance slightly higher than at tilt angle 15° with the horizontal.

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