

Effect of Inclination Angle on Temperature Characteristics of Water in-Glass Evacuated Tubes of Domestic Solar Water Heater

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Abstract - The water-in-glass evacuated tube is an integral part of evacuated tube solar water heater. Solar water heaters with evacuated tube collectors perform better than that of flat plate collector. The usage of evacuated tube collectors is increasing day by day. The space requirement for mounting these collectors in congested cities is a problem faced by solar industry. Mounting the collectors on the wall in vertical orientation will be the easiest solution for the problem. For flat plate collectors it is essential that the inclination of the collectors should be based on the latitude of that place for better performance. But for evacuated tube collectors, there is no proof that the performance will be best for particular angle of inclination. This paper discusses the experimental study conducted on the evacuated tube collectors mounted at different angles of inclination. The temperature characteristics obtained as a result of the experiment show that the performance does not vary with respect to angle of inclination.

Index Terms— Water in-Glass Evacuated Tube, Solar Water Heater, Angle of Inclination, Collector Mountings

I. INTRODUCTION

Morrison et al (2004) analyzed the water-in-glass evacuated tube. In his research findings he has mentioned that evacuated tube solar collectors perform better than flat plate collectors during high temperature operations. Water-in-glass tube collector seems to be a better option for domestic utilization because of its simplicity and low cost. The water-in-glass evacuated tubes are manufactured in large quantity in China and Europe. Many solar water heater manufacturers in India are importing the evacuated tubes from China. The market for solar water heaters with evacuated tube collector is growing swiftly because of low cost and better performance. The space required for mounting a 100 LPD solar water heater is 30m². In a multi-storied apartment, if the resident in the ground floor want to use solar water heater, he has to use the terrace of the building for mounting the collectors. The hot water has to travel through the long pipe line. The resident has to spend more money for plumbing works. Also, there will be a significant energy loss when the water travels through the long pipe. If the terrace is occupied for some other purpose like advertisement hoarding, television antenna, etc., it will be difficult for mounting the solar water heater. In order to avoid all those problems, it is essential to study the performance of the evacuated tube at various angles of inclination. If the performance remains same for all angles of

inclination, it will be easy to mount the collectors. Runsheng Tang et al (2011) studied the thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt angles. The team conducted the experiment at two different angles 22° and 46°. There is no significant variation in daily thermal efficiency. But this study does not provide the data for other angles of inclination, particularly 0° and 90°. The present study is carried out to find the temperature characteristics of the evacuated tube at tilt angles, viz. 0°, 15°, 30°, 45°, 60° and 90°. Obviously this idea of angles on the basis of application will create a greater impact on this environmental concerned world. The main reason why solar heaters are not preferred is the price and complexity. But when it is apparent that one can go on with any angles and less complexity which in turn means low pricing will increase the number of users to switch from electric water heaters to solar. Literatures state that the collectors should face the south direction to receive sunlight for maximum period of time. This factor is also taken into consideration. The experiment is conducted with the tubes facing south direction as well as north direction. The results are interesting and they raise question on literatures' statement.

II. EVAUCATED TUBES

The evacuated tubes used in this experiment are supplied by a solar water heater manufacturer. The tube is made of borosilicate glass. The diameter of the tube is 47mm and the length is 1500mm. Figure 1 shows the detail parts of the evacuated tube.



Fig 1 Evacuated tube

The vacuum tubes consist of a double wall glass tube with a space in the centre which contains the heat pipe. The sun's radiation is absorbed by the selective coating on the inner glass surface, but prevented from re-radiating by the silvered innermost lining. This is in effect like a one-way mirror which has been optimized for infra-red radiation. In fact it is very efficient, of the sun light's energy hitting the tube's surface, 93% is absorbed, whereas only 7% is lost through

reflection and re-emission. The presence of the vacuum wall prevents any losses by conduction or convection - just like a thermos flask. Because of this, the system will work even in very low temperatures, unlike traditional flat plate collectors. In order to maintain the vacuum between the two glass layers, a barium getter is used. During manufacture this getter is exposed to high temperatures which cause the bottom of the evacuated tube to be coated with a pure layer of barium. This barium layer actively absorbs any CO, CO₂, N₂, O₂, H₂O and H₂ out gassed from the tube during storage and operation, thus helping to maintaining the vacuum. The barium layer also provides a clear visual indicator of the vacuum status. The silver colored barium layer will turn white if ever the vacuum is lost.

III. MOUNTING ARRANGEMENT FOR EVACUATED TUBES

The whole system required a structure strong enough to hold up all the tubes at various angles at the same time. So a wooden stand is designed with appropriate dimensions which would provide the necessary inclinations needed. The stand mounting can accommodate 20 tubes at a time. Trigonometric rules are followed in designing the tube mounting. The notches to be positioned within the outer frame are calculated based on the Figure 2.

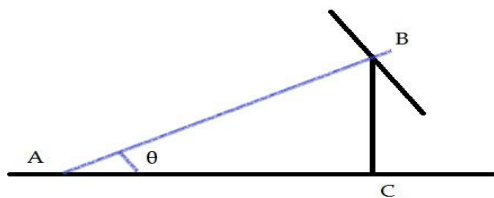


Fig. 2 Trigonometry diagram

In the above given schematic diagram the line BC denotes the vertical height required and the slanting line AB denotes the evacuated solar tube. AB is the tube length and the angles are varied such that 0°, 15°, 30°, 45°, 60° and 90°. Vertical height BC and horizontal distance AC are calculated using below sine and cosine laws.

$\text{Sin } \theta = \text{BC} / \text{AB}$

$\text{BC} = \text{AB Sin } \theta$

$\text{Cos } \theta = \text{AC} / \text{AB}$

$\text{AC} = \text{AB Cos } \theta$

The values of AC and BC are calculated from the above relations and are tabulated below.

Table 1 Mounting Stand Specification

Angle	AC	BC
0°	1.50 m	-
15°	1.44 m	0.39 m
30°	1.29 m	0.75 m

45°	1.06 m	1.06 m
60°	0.75 m	1.29 m
90°	-	1.50 m

The design specifications are adopted for the fabrication. The structure is entirely made of wood so that it can be easily carried to the building terrace. In order to make the stand water resistant, a separate thinner coating is sprayed over it. The fabricated mounting stand is shown in Figure 3. The stand is positioned so that it faces the south direction.



Fig 3 Mounting Stand

IV. INSTRUMENTATION

Temperatures are to be measured in three places of the tube, viz., top, middle and bottom. The type of thermocouple used in the experiment is a Fe/Con contact type thermocouple with the maximum measuring capacity of 400°C. The thermocouple is calibrated with a series of minor experiments and checked for errors.

V. EXPERIMENTATION

The basic experimentation is to record the temperature readings of the water in the evacuated tubes at particular time intervals. The time intervals were chosen from a frequency of about once in an hour to once in half an hour. Initially the experiment is conducted with tubes facing the south direction and later towards the north direction.



Fig 4 Experimental set-up

Figure 4 gives the view of experimental set-up. The experiment is conducted on clear sun-shine day with average direct radiation of 650 W/m². The solar radiation is measured with the help of pyr heliometer available in the solar radiation monitoring station. The readings are taken continuously for every one hour from 10.00 a.m. to 3.00 p.m.

VI. RESULTS OF THE EXPERIMENTS

The temperature characteristics are plotted based on the observed readings from experimental set-up facing south direction.

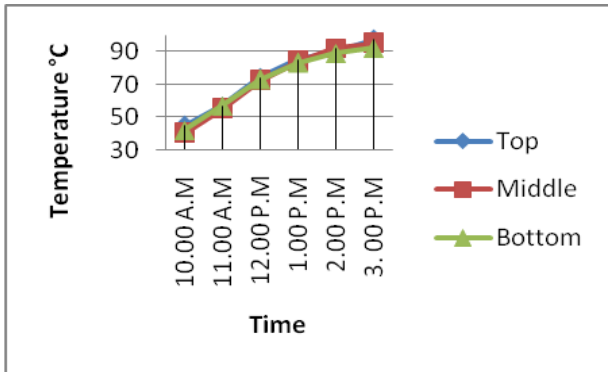


Fig 5 Temperature characteristics at 0° inclination

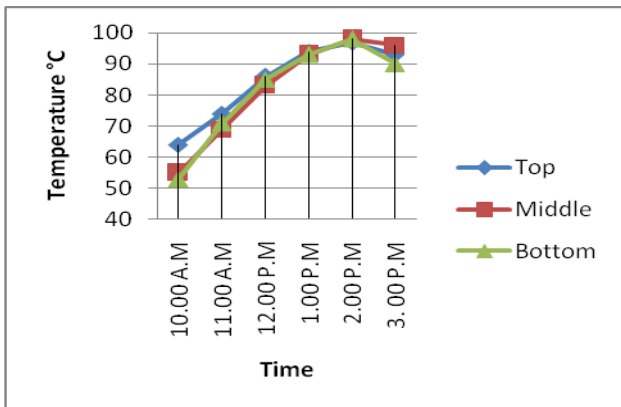


Fig 6 Temperature characteristics at 15° inclination

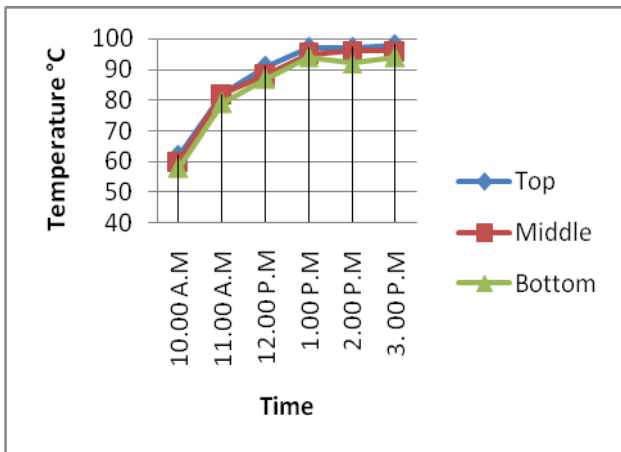


Fig 7 Temperature characteristics at 30° inclination

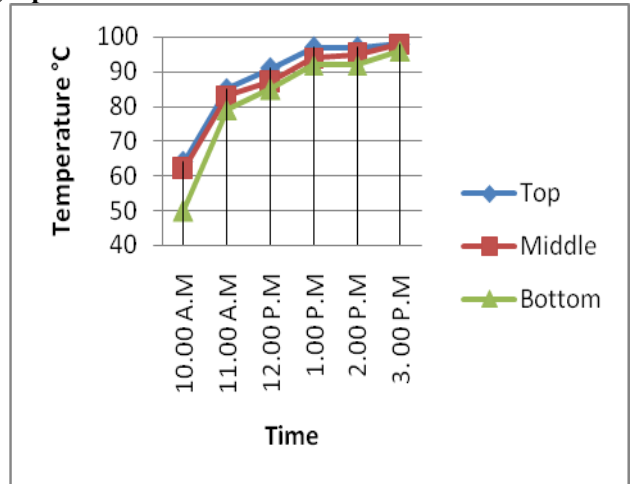


Fig 8 Temperature characteristics at 45° inclination

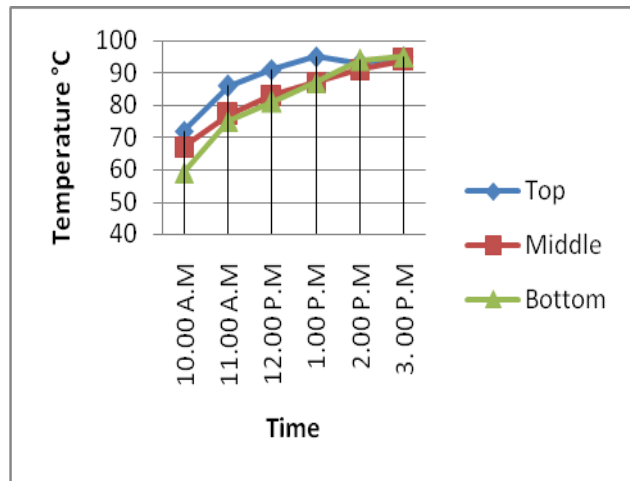


Fig 9 Temperature characteristics at 60° inclination

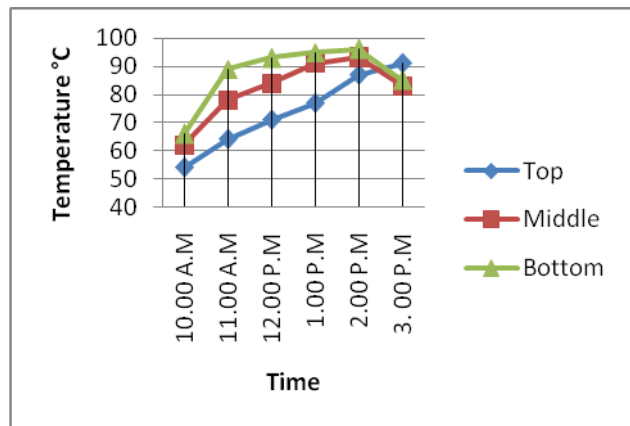


Fig 10 Temperature characteristics at 90° inclination

VII. DISCUSSION ON RESULTS

For 0°, 15°, 30°, 45° and 60° of inclinations, the temperature of water in the top portion of the tube is higher than that of middle and bottom. This is because of buoyancy effect produced due to density difference. But in case of 90° inclination, the temperature of water in the top portion of the tube is slightly less than that of bottom. This is because of the convection heat transfer from water to air. This loss will be

eliminated when tubes are integrated with the tank. The whole system is analyzed to give a future decision which will be revolutionary rewriting the conventional rules and regulations of the evacuated tube solar water heater. This angular and direction based analysis might be a simple analysis but the beneficiary output is great. Imagine yourself living in a tightly populated zone, where you cannot afford much of floor space to actually place a solar water heater for your energy purpose. The two main hindrances for this are the angular position and direction. If both the hindrances are removed, it will be easier for handling the evacuated tube solar water heater. The peak temperatures occur during 12 noon and 2 P.M. The permissible limit of temperature for a human body is 40°C. As far as the objective of the paper is concerned there is no significant variation in the temperature because of inclination angles. In future, the evacuated tube water heaters will be mounted over vertical walls of the apartments. The output of the project will be very useful for the solar water heater industries. Also, the experiment is conducted by changing the experimental set-up facing north direction which is an unconventional one. But there is no significant variation in the temperature readings. Because of the round shape of the evacuated tubes, they have the capability of receiving major amount of solar radiation. The heat losses are minimized in the tubes to a larger extent. So, the inclination angle does not produce significant changes in the temperature characteristics.

VIII. CONCLUSION

The system ensures the practical stability of the evacuated solar tube water heater that this will work in conditions that are not conventional. The experimentation clearly proves that neither the angle of inclination nor the facing direction has an imposing effect over the temperature characteristics of the evacuated tube. The thermosyphon movement of fluid inside the water-in-glass evacuated tube is not at all affected by the inclination angle. The convective heat loss co-efficient may vary according to the inclination angle. Since radiative heat transfer is employed in evacuated tubes, the convective heat loss co-efficient cannot create a significant temperature drop.

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