Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 10; April-June, 2015 pp. 77-81

http://www.krishisanskriti.org/jmsme.html

Thermal Analysis of Evacuated Tube Collector having different Shapes of Flow Passages inside the Tube

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Abstract—*In this article, the thermal performance of evacuated tube solar water heater having different shapes of flow passages inside the tube is evaluated. For this, three solar water heaters (SWH) are fabricated. In SWH1, simple evacuated tube with no auxiliary arrangement inside the tube is used, while in SWH2 and SWH3 two different artificial arrangements for separating hot and cold fluid streams inside the tubes is developed. Using these three SWH's two experiments were performed at 22^0 and 45^0 collector tilt angle under the same atmospheric conditions. It was found that in experiment 1, at 22^0collector tilt angle, the efficiency of all the three solar water heaters is approximately same while in experiment2, at 45^0 collector tilt angle the, the efficiency of SWH1, SWH2 and SWH3 is 44.17 %, 47.69 % and 47.25 % respectively thus the thermal performance of SWH is improved at 45^0 collector tilt angle with auxiliary arrangements inside the tube.*

Keywords*: Evacuated tube collector, solar water heater, collector tilt angle, flow passages, thermal performance*

1. INTRODUCTION

Evacuated tube collector is a type of non concentrating collector. It has better performance than flat plate collector for high temperature operation because of reduced convection heat loss due to the vacuum envelop around the absorber tube. At present the glass evacuated has become the key component in solar thermal utilization, especially; they are proved to be very useful in residential application that requires higher temperatures because of its lower heat loss.So the evacuated solar collectors are widely used to supply the domestic hot water or heating. In evacuated tube two layers of hot and cold fluid are formed which helps in transferring the heat from the tube to tank. So, the flow pattern inside the tube is of big importance for the thermal performance of the collector tube.

Morrison et. al [1] In this paper, the performance of a water-in-glass evacuated tube solar pre-heater is investigated using the International Standard test method ISO 9459-2 for a range of locations. Factors influencing the operation of water-in-glass collector tubes are discussed and a numerical study of water circulation through long single-ended thermosyphon tubes is presented. Preliminary numerical simulations have shown the existence of inactive region near the sealed end of the tube which might influence the performance of the collector.

Kim and Seo [2] the thermal performance of a glass evacuated tube solar collector is numerically and experimentally investigated. The solar collector considered in this paper consists of a two layered glass tube and an absorber tube. Air is used as the working fluid. Four different shapes of absorber tubes are considered, and the performances of the solar collectors are studied to find the best shape of the absorber tube for the solar collector. Theperformance of a solar collector is affected by the shape of the absorber, incidence angle of solarirradiation, and arrangement of collector tubes. The results obtained from the simplified model arevery different from those from the collector model, which considered not only beam and diffuseirradiation but also shade due to adjacent tubes.

Budihardjo et al. [3] Experimental and numerical investigations were undertaken to develop a correlation for natural circulation flow rate through single ended water-in-glass evacuated tubes mounted over a diffuse reflector. The circulation flow rate was correlated in terms of solar input, tank temperature, collector inclination and tube aspect ratio. The sensitivity of the flow rate correlation to the variation in circumferential heat flux distribution was also investigated. Further numerical simulation shows that when the heat input is concentrated on the top circumference of the tube, as is the case with collectors mounted over a diffuse reflector, the effect of circumferential heat flux distribution on the circulation flow rate through the tubes is not significant; therefore the correlation could be used to predict the flow rate at any time of day. Different flow structures are observed in the tube when a concentrating reflector is used underneath the collector.

Tang et. al [4] In this paper, a detailed mathematical procedure is developed to estimate daily collectible radiation on single tube of all-glass evacuated tube solar collectors based on solar geometry, knowledge of two dimensional radiation transfer. Results shows that the annual collectible radiation on a tube is affected by many factors such as collector type, central distance between tubes, size of solar tubes, tilt and azimuth angles, use of diffuse flat reflector (DFR). Unlike the flat-plate collectors, all-glass evacuated tube solar collectors should be generally mounted with a tilt-angle less than the site latitude in order to maximize the annual energy collection. For most areas with the site latitude larger than 30˚ T-type collectors should be installed with a tilt-angle about 10˚ less than the site latitude, whereas for H-type collectors without DFR, the reasonable tilt-angle should be about 20˚ less than the site latitude.

Ma et. al [5] The thermal performance of the individual glass evacuated tube with solar collector U tube is investigated by analytical method. The solar collector considered in this study is a two-layered glass evacuated tube, and the absorber film is deposited in the outer surface of the absorber tube. The heat loss coefficient and heat efficiency factor are analyzed using one-dimensional analytical solution. And the influence of air layer between the absorber tube and the copper fin on the heat efficiency is also studied. To evaluate the thermal performance of the glass evacuated tube solar collector, not only should the heat efficiency be considered, but also the surface temperature of the absorbing coating is an important parameter. And the efficiency increases with increase of solar radiation intensity, but it reaches gradually to a constant.

Tang et. al [6] To performance comparative studies, two sets of water-in-glass evacuated tube solar water heater (SWH, in short) were constructed and tested. Both SWHs were identical in all aspects but had different collector tilt-angle from the horizon with the one inclined at 22˚ (SWH-22) and the other at 46˚ (SWH-46). Experimental results revealed that the collector tilt-angle of SWHs had no significant influence on the heat removal from solar tubes to the water storage tank. Experiments also showed that, for the SWH-22, the cold water from the storage tank circulated down to the sealed end of tubes along the lower wall of tubes and then returned to the storage tank along the upper wall of solar tubes with a clear water circulation loop; whereas for the SWH-46, the situation in the morning was the same as the SWH-22, but in the afternoon, the cold water from the storage tank on the way to the sealed end was partially or fully mixed with the hot water returning to the storage tank without a clear water circulation loop

2. EXPERIMENTAL SETUP

In the experimental setup, three solar water heaters namely SWH1, SWH2 and SWH3 are developed. The photograph of the experimental setup at 45^0 and 22^0 is shown in Fig. 1.The different components used in experimental setup are mentioned below –

2.1 Evacuated tube collector

2.2 Storage tank

2.3 Insulation

2.4 Parting wall

Fig. 1: Photograph of systems at 45^0 and 22^0

2.1 Evacuated tube collector

The test sections of the evacuated tubes used in this system are shown in Fig. 2(a) and 2(b). Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass and between them vacuum ($P \leq 5x10^{-2}$ Pa) is present. The tube has inner and outer diameter as 47 mm and 58 mm respectively and length of the tube is 1800 mm. The outer tube is transparent which allows light rays to pass through with minimal reflection. The inner tube is coated with a special selective coating of aluminum nitride (Al-N/Al) with excellent features such as solar radiation absorption and minimal reflection properties.

(a) (b)

Fig. 2: Schematic diagram of evacuated tube (a) side view of evacuated tube (b) front view of evacuated tube

2.2 Storage tank

Three containers having dimension (250mm×90mm×300mm) are used as storage tanksas shown in Fig. 3(a) and 3(b). The 40 mm thick insoflex insulation is applied on its outer surface to reduce the heat losses.

(a) (b)

Fig. 3: (a) Photograph of curved insulated surface tank (b) Photograph of concentric circular insulated surface tank

2.3 Insulation

Insoflex is used as insulation material to reduce the heat losses from the tank and also inside the tube of SWH2 and SWH3 to separate the hot and cold fluid streams. It has very low thermal conductivity of 0.0374 W/mK. Thus it acts as a good insulation material.

2.4 Parting wall

To stop the mixing of cold and hot water of in the storage tank of SWH2 and SWH3, parting walls are used. These are made up of sheet metal on which insoflex insulation is applied. These walls have holes whose shape depends upon the shape of cold flow passage. The photograph of parting wall of SWH2 and SWH3 are shown in Fig. 4(a) and 4(b).

(a) (b)

Fig. 4: (a) photograph of parting wall of SWH2
(b) photograph of parting wall of SWH3

In SWH1 a simple evacuated tube is fitted in the storage tank. In SWH2 a curved insulating wall is fitted inside the collector tube as shown in Fig. 5(a). In SWH3 an insulated tube is placed concentric to the evacuated tube as shown in Fig. 5(b). While making the two flow passages inside the tube care has been taken so that area of cross section for both the passages is almost equal.

Insulated boundary is formed using insoflex and PVC. In SWH2 a curved section of PVC of 2 mm thickness is taken and insoflex insulation of thickness 2.5 mm is pasted on its concave side using ethylene vinyl acetate (fevicol) and then it is inserted inside the evacuated tube. Due to elastic property of PVC it makes a tight contact with inner glass tube. To keep it in proper position inside the evacuated tube and maintaininguniform space for both the passages,8 steel supports of length 19 mm at a distance of 10cm are used on its convex side as shown in Fig. 6(a). While in SWH3 a PVC pipe of 31 mm inner diameter and 2mm thickness having 2.5 mm insoflex insulation around its outer surface is placed concentrically inside the evacuated tube. Thus the tube and space between PVC tube and glass tube makes two flow channels as shown in Fig. 6(b). The arrangements are inserted upto depth of 1600 mm from tube opening leaving a space of approx 200 mm at the bottom of tube. To extend the channel from tube opening to required height in the storage tanks a detachable insulated boundary (parting wall) are used in the storage tank of SWH2 and SWH3.

(a) (b)

Fig. 5: (a) Curved insulated surface (b) concentric circular insulated surface

(a) (b)

Fig. 6: (a) Position of support on curved insulated surface (b) Position of supports on concentric circular insulated surface

For the experiments, four temperature sensors (thermocouple) were set in each system. These thermocouples are used to monitor the temperature profile of water inside the tube and the storage tank. In SWH1 and SWH2, one thermocouple was set at lower side, one at upper side of tube opening and one at the bottom of the tube as shown in Fig. 7 and Fig. 8. In SWH3 one PT 100 sensor was set at insulated tube opening, one at upper side of collector tube opening and one at bottom of evacuated tube as shown in Fig. 9. One thermocouple was used at upper surface of the water in the storage tank of all the three SWHs. All data were recorded manually at intervals of 10 min. Before experiments, all temperature sensors and RTD were calibrated to an absolute measuring error of0.1 ºC

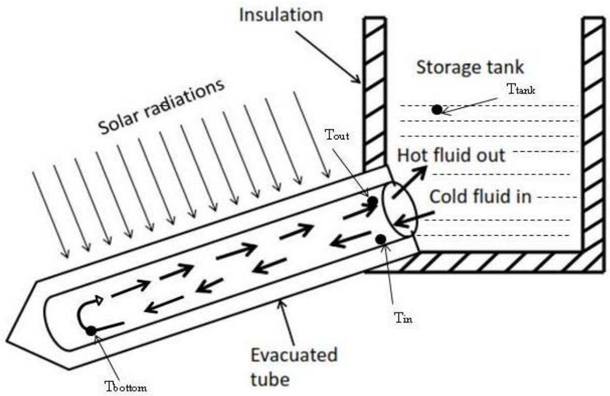

Fig. 7: Schematic diagram of SWH1

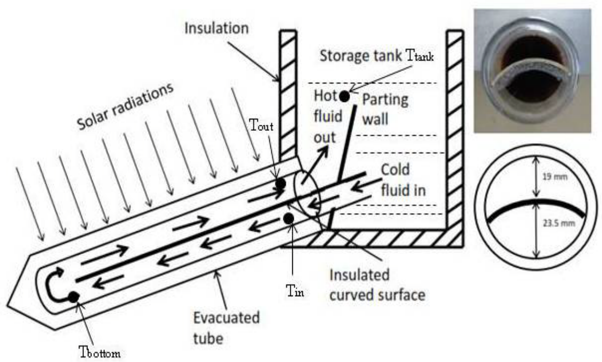

Fig. 8: Schematic diagram of SWH2

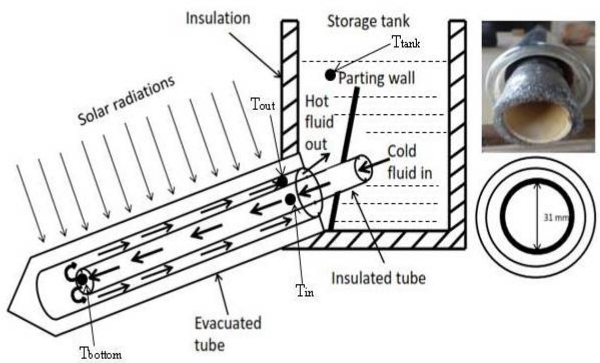

Fig. 9: Schematic diagram of SWH3

3. MEASURING DEVICES AND INSTRUMENTS

All the temperatures are measured with RTD PT100 thermocouples which are connected with a digital temperature indicator that shows the temperature with a resolution of 0.1^{o}C.

4. SYSTEM OPERATION

This exercise includes two experiments of all three systems. In each experiment the collector of each system is inclined at same particular angle and their performance is compared.

To examine solar systems are to be identical in performance, each solar tubes is tested with storage tank inclined at 45º angle of their inclination and exposed to same atmospheric conditions. Eight liters of water is filled in each system and exposed to solar radiations from 09:00 hr. to 15:00 hr. At 15:00 hr the water in each storage tank is stirred and its temperature is measured. There was maximum temperature difference of 0.3ºCbetween the three systems. This ensures that our tubes and storage tanks are almost identical in performance.

Before every experiment tubes are cleaned properly from inside and fitted in the storage tanks with their respective auxiliary arrangement thus making two different physical channel in SWH2 and SWH3. In the early morning water at the same temperature from well stirred water tank is filled ineach SWH. First the tubes of all the SWHs are filled with water and then a fix quantity of 8 litre of water is filled in each storage tank. All the systems are exposed to solar radiations at 09:00 hr to 15:00 hr and readings are taken at an interval of 10 min. At15:00 hr lid of each storage tank is removed and insulating walls are also removed. After that water in each system is stirred well and its final temperature is measured.

5. THERMAL ANALYSIS AND DISCUSSIONS

The evacuated tubes are exposed to solar radiations from 09:00 hr to 15:00 hr. During this period the energy is absorbed by the evacuated tubes and is transferred to the water inside the tube which further transfers this energy to the water in the storage tank by thermosiphon.

The solar radiation intensity received at the aperture area of the evacuated tube collector during the experiment is calculated by the formula:

$$Q_{in} = I \times A \times t$$

In the above equation average solar intensity during month of November is taken.

Aperture of the evacuated tube collector is given as:

$$A = 2 \times D \times L$$

The output energy i.e. energy stored by the water in the storage tank is given as:

$$Q_{out} = m \times c \times (T_{final} - T_{initial})$$

Efficiency of the system is given as below:

$$\eta_{system} = \frac{Q_{out}}{Q_{in}}$$

The efficiency of the solar water heaters in experiment 1 i.e. at collector tilt angle of 22^0 is shown in Fig. ure 10. The efficiency of SWH1, SWH2, and SWH3 are 48.4 %, 48.8 % and 48.5 % respectively.

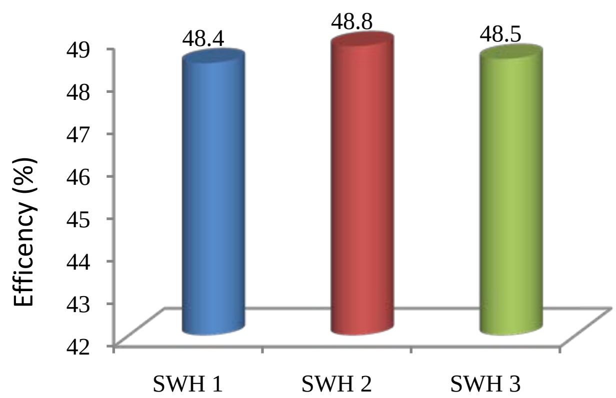

Fig. 10: Efficiency of solar water heaters in experiment 1

The efficiency of the solar water heaters in experiment 2 i.e. at collector tilt angle of 45^0 is shown in Fig. ure 10. The efficiency of SWH1, SWH2, and SWH3 are 44.17%, 47.69 % and 47.25 % respectively.

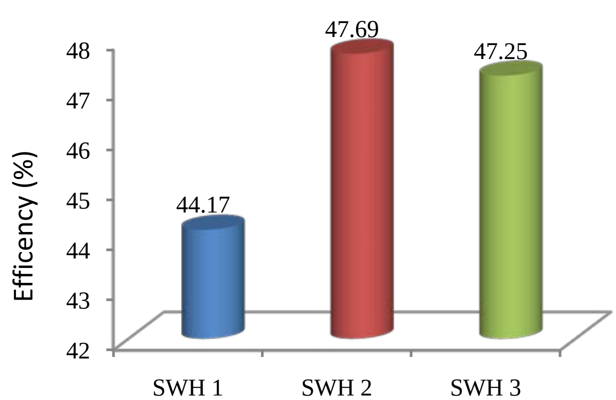

Fig. 9: Efficiency of solar water heaters in experiment 2

6. CONCLUSIONS

In experiment 1, at 22^0 inclination of collector tube there is no significant difference in efficiency in all the three system. Due to this low angle of inclination of collector tubes, hot and cold fluid steams are separated inside the tube and this result in clear circulation loop in all the three SWHs. The auxiliary arrangement made in SWH2 and SWH3 has no significant role in separating hot and cold fluid stream. There was minor increment of efficiency in SWH2 and SWH3 as compared to SWH1 i.e. 0.4% and 0.1 % respectively.

While in experiment 2, at 45^0 inclination of collector tube, there is clear circulation loop in SWH1 up to noon hours but in after noon hours hot and cold fluid start mixing with each other and there is no clear circulation loop. While such problem is not encountered in SWH2 and SWH3 due to presence of insulated boundary between hot and cold fluids. The efficiency in SWH2 and SWH3 are found to be 3.52 % and 3.08 % respectively more as compared to SWH1.

Nomenclature

Q_{in} Solar radiations received by evacuated tube collector, J

I Average solar radiation Intensity, W/m^2

A Aperture area of by evacuated tube collector, m^2

t time, hr

D Diameter of evacuated tube collector, m

L Length of evacuated tube collector, m

Q_{out} Energy stored by the water in storage tank, J

C Specific heat of water, kJ/kg ℃

m Mass of water in storage tank, kg

T_{final} Final temperature of water in the storage tank, ℃

$T_{initial}$ Initial temperature of water in the storage tank, ℃

η_{system} Efficiency of the system

REFERENCES

[1] Morrison G.L., Budihardjo I., Behnia M., 2004, "Water-in-glass Evacuated Tube Solar Water Heaters", Solar Energy, vol. 76, pp 135-140.

[2] Kim Y., Seo T., 2007, "Thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tubee", Renewable Energy, vol. 32, pp 772-795.

[3] Budihardjo I., Morrison G.L., Behnia M., 2007, "Natural circulation flow through water-in-glass evacuated tube solar collectors", Solar Energy, vol. 81, pp 1460-1472.

[4] Tang R., Gao W., Yu Y., Chen H., 2009, "Optimal tilt-angles of all-glass evacuated tube solar collectors", Energy, vol. 34, pp 1387-1395.

[5] Ma L., Lu Z., Zhang J., Liang R., 2010, "Thermal performance analysis of the glass evacuated tube solar collector with U-tube", Building and Environment, vol. 45, pp 1959-1967.

[6] Tang R., Yang Y., 2014, "Nocturnal reverse flow in water-in-glass evacuated tube solar water heaters", Energy Conversion and Management, vol. 80, pp 173-177.