Theoretical and Experimental Analysis of V-Trough Solar Collector based on Water Heating System

Gupta Raghuvir[1] and Desai Chinmay[2]

Chhotubhai Gopalbhai Patel Institute of Technology, Bardoli, India
xyz, desai.chinmay@utu.ac.in

Abstract. There are various types of solar water heater system available in the commercial market to fulfill different customers demand, such as flat plate collector, concentrating collector, evacuated tube collector and integrated collector storage. The aim of this research work is to improve the thermal performance of V-trough solar water heater system using a cost effective cum easy fabrication of the system. Here we are going to integrating the solar absorber with the easily fabricated V-trough reflector can improve the performance of solar water heater system. In my present work, optical analysis, experimental study and cost analysis of the stationary V-trough solar water heater system are presented in detail for the middle class family (i.e. 6-7 persons) at the best economical cost of Rs.12,000/- getting final temperature of 70-80°C. For this we are going to improve the thermal performance of V-trough solar water heater system by changing its Aperture area; and the angle between the Incident reflector and Absorber plate.

Keywords: V-trough collector, Solar water heater, Solar collector, Solar absorber, Solar concentration.

1 Introduction

There is an abundance of solar irradiance on earth and the easiest way of harnessing the solar energy is to directly convert it into useful thermal energy. Solar Energy is an unlimited source of renewable energy. Solar Energy, if utilized, shall not only bridge the gap between demand and supply of electricity but shall also save money since running cost of appliances working on solar energy is negligible shall also help in reducing pollution and maintenance of echo balance[1].

Solar water heating is now an advanced technology. Wide spread utilization of solar water heaters can reduce a significant portion of the conventional energy being used for heating water in homes, factories and other commercial & institutional establishments. Internationally the market for solar water heaters has expanded significantly during the last decade. Solar Water Heating System is not a new name in India now. The technology is easily available in our country and in use in almost all mega cities [1].

Solar Water Heater (SWH) is a typical device that converts the solar energy into thermal energy to heat up a heat transfer fluid such as water, non-freezing liquid or air for domestic usage. Solar water heating (SWH) or solar hot water (SHW) systems comprise several improvements and many established renewable-energy technologies that have been well recognized until many years. SWH has been widely used in Australia, Austria, China, Cyprus, Greece, India, Israel, Japan and Turkey [1].

Ilhan Ceylan et al (2012)[16] studied that Energy and energy analyses of a temperature controlled solar water heater, TCSWH was experimentally analyzed at 40°C, 45°C, 50°C and 55°C and it was also compared with the thermosiphon system. A detailed comparison was performed by calculating stored energy, storage tank water temperatures, storage tank water amounts and system efficiencies for both systems.

According to K.K. Chong, K.G. Chay et al (2012)[24] a cost-effective cum easy fabricated V-trough solar water heater system using the forced circulation system is proposed. The experimental result has shown very promising results in both optical efficiency of V-trough reflector and the overall thermal performance of the solar water heater. The novel stationary V-trough solar water heater with the maximum solar concentration ratio of 1.8 suns has been proposed to improve the thermal efficiency of the whole system. The advantages of the new proposal are that easy to be fabricated, cost-effective and high thermal efficiency.

2 DESIGN AND CONSTRUCTION OF V-TROUGH SOLAR WATER HEATER

V-trough Solar Water Heater is a type of forced circulation system. It mainly consists of stationary V-trough collector (i.e. A flat absorber plate and V-trough reflector), circulating pump, storage tank and thermocouple.

The V-trough Solar Water Heater with high thermal efficiency can be easily constructed and installed in the rural area for the middle class people. It can help to reduce the dependency on the fossil fuel especially in the developing countries were the cost of fuel is increasing day by day.

The prototype of V-trough solar water heater was been constructed in the Uka Tarsadia University campus which is located in Bardoli, India with the latitude of 21.12°N and longitude of 73.12°E.

The following is the details which describes about the each component of V-trough Solar Water Heater.

A. V-trough Collector

The solar collector is made from two major parts: a flat absorber plate and V-trough reflector. The V-trough reflector was constructed using two rectangular facet mirrors with a dimension of 12 cm (width) * 100 cm (length) * 0.4 cm (thickness) each and inclined according to the experiment requirement of the angle (i.e. 110°, 120°, 130°) related to the absorber plate. To optimize the optical performance, the V-trough reflector was aligned horizontally along east-west direction. Ideally the V-trough reflector should be south facing and inclined at the angle of equal to the local latitude. However, in order to simplify the mechanical structure of the prototype with a very minimum effect to the overall performance, we decided to place the V-trough reflector in horizontal.

The absorber plate was fabricated by joining a brass sheet with a dimension according to the experimental requirement [i.e. 120cm, 140cm, 160cm (width); 100cm (length); 1mm (thickness) to three equally distant copper pipes with outer diameter of 1.0 cm each.

The copper pipes were brazed to the top surface of the brass sheet for maximizing the exposure area of the copper pipes to the solar radiation. The brass sheet was selected as a supporting base because of its good thermal conductivity and high tensile strength. Both the brass sheet and copper pipe have thermal conductivities of 110.8 W/(mK) and 401 W/(mK) respectively. The top surface of the absorber plate was painted in black color as to maximize the absorptivity to solar irradiance.

B. Storage tank

Storage tank of prototype SWH was simply a standard plastic container with a dimension of 42 * 39 * 20 cm3 capable of storing at least 20 L of hot water for domestic usage. Two holes were drilled where one hole was at the bottom of the tank for the connection to the absorber inlet and the other hole was at the top part of the water tanks side wall for the connection to the absorber outlet. Aluminum foil were utilized to enhance the heat insulation of the water tank from convective and radiation losses respectively due to their easy availability, cost effectiveness and light weight.

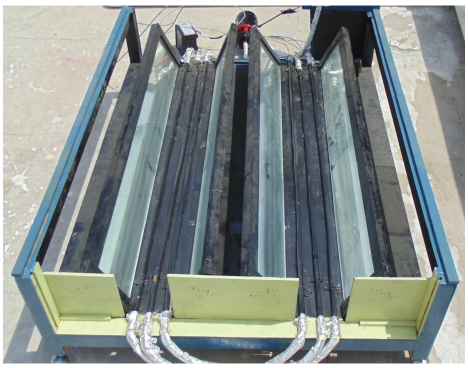

Fig. 1. Picture to show the prototype of V-trough solar water heater

Fig. 2. Picture to show how storage tank was constructed with the use of plastic container and insulating materials

C. Water circulating pump The pump was been use to circulate the water from the tank to the copper pipe and back to tank with the flow rate of 5.88lit/min and having the head of 3m, having the dimension of 13*13cm.

D. Solar power meter

Solar power meter is use to get the value of global solar irradiation for the specific time and day in W/m2.

E. Digital Thermocouple

Digital thermocouple is been used to read the inlet and outlet water temperature in the storage tank.

Fig. 3. Picture to show the pump

Fig. 4. Picture of solar power meter

Fig. 5. Picture of digital thermocouple

3 RESULTS AND DISCUSSION

V-trough solar water heater performance test was been conducted on the geographical location of Bardoli (latitude 21.12 °N, longitude 73.12°E). The collector was instrumented with K-type thermocouples, thermometer and solar power meter for measuring the temperature of moving water from the inlet and outlet of the collector; the ambient temperature; and the incident solar radiation in W/m2. Here the performance test of prototype V-trough collector was carried out for different width of the brass sheet (wb) (i.e. 12cm, 14cm, 16cm); and the angle between reflective and absorber plate (Φ) (i.e. 50° , 60° , 70°) for different days during the May month of 2014.

- Total amount of solar energy radiated on the aperture area over a test Interval Δ t is given by,

$$Q_{incident} = I_{ave} * A_{ap} * \Delta t \tag{1}$$

- The collector thermal energy,

$$Q_{col} = m * c_{water}(T_{f\_heating} - T_{i\_heating}) \tag{2}$$

where, $T_{f\_heating}$ and $T_{i\_heating}$ are the final and initial water temperature in the storage tank for the heating period within the interval time Δ t respectively (K).

- The collector thermal efficiency,

$$\eta_{thermal} = \frac{m * c_{water}(T_{f,heating} - T_{i,heating})}{I_{ave} * A_{ap} * \Delta t}$$

where A_{ap} is aperture area (m^2), C_{water} is specific heat capacity of water (4187 J/kg K), m is the mass of the water (20 kg), time interval of 30min (1800 second).

From all the measurement results have shown a common characteristic where the water temperature in the storage tank increases directly proportional to the global solar irradiation. The graphs of global solar irradiance slowly increase from the lowest value at 10.00 a.m. to the maximum value at the solar noon and then they slowly decrease after the solar noon and so on. The highest achievable temperature is 79°C on 12th April 2014 and 81°C on 2nd May 2014 respectively. This temperature is achieved for the brass sheet with the width of 12cm and; the angle between absorber and reflective plate as to be 60° respectively.

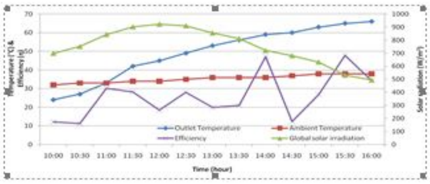

Fig. 6. Experimental reading on 11th April 2014, $w_b = 12$cm & $\Phi = 50°$

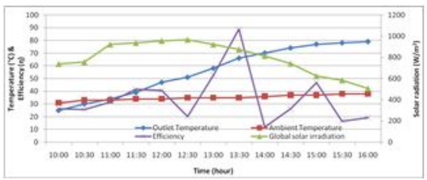

Fig. 7. Experimental reading on 12th April 2014, $w_b = 12$cm & $\Phi = 60°$

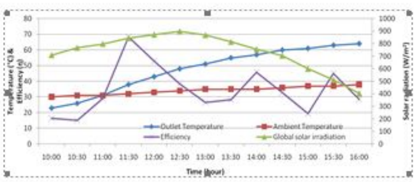

Fig. 8. Experimental reading on 14th April 2014, $w_b = 12$cm & $\Phi = 70°$

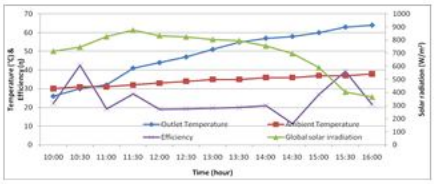

Fig. 9. Experimental reading on 15th April 2014, $w_b = 14\text{cm} \quad \& \quad \Phi = 50^\circ$

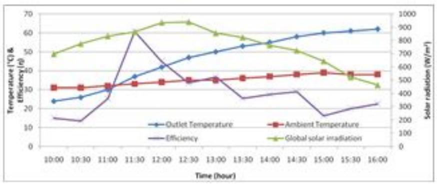

Fig. 10. Experimental reading on 16th April 2014, $w_b = 14\text{cm} \quad \& \quad \Phi = 60^\circ$

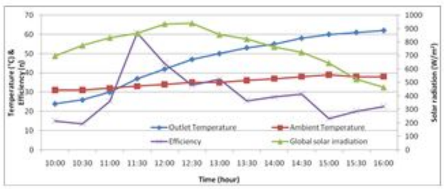

Fig. 11. Experimental reading on 17th April 2014 $w_b = 14\text{cm} \quad \& \quad \Phi = 70^\circ$

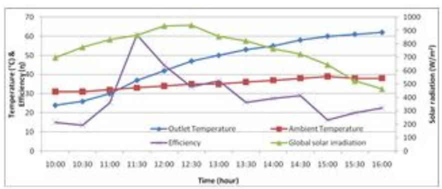

Fig. 12. Experimental reading on 18th April 2014, $w_b = 16\text{cm} \quad \& \quad \Phi = 50^\circ$

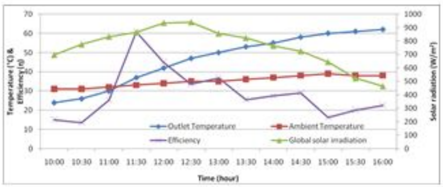

Fig. 13. Experimental reading on 19th April 2014, $w_b = 16\text{cm} \quad \& \quad \Phi = 60^\circ$

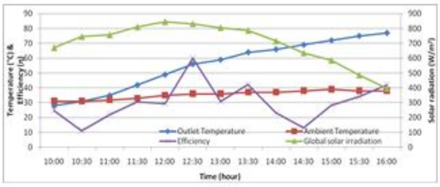

Fig. 14. Experimental reading on 21st April 2014, $w_b = 16\text{cm} \quad \& \quad \Phi = 70^\circ$

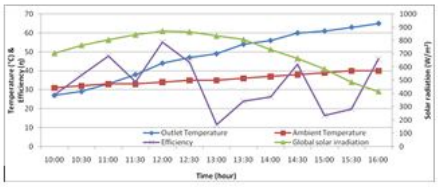

Fig. 15. Experimental reading on 22nd April 2014, flat plate collector

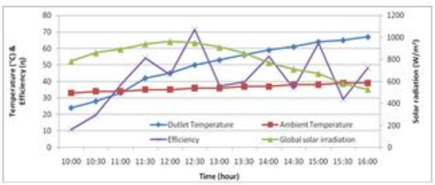

Fig. 16. Experimental reading on 1st May 2014, $w_b = 12\text{cm} \quad \& \quad \Phi = 50^\circ$

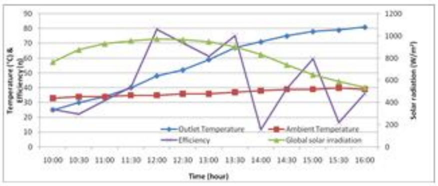

Fig. 17. Experimental reading on 2nd May 2014, $w_b = 12\text{cm} \quad \& \quad \Phi = 60^{\circ}$

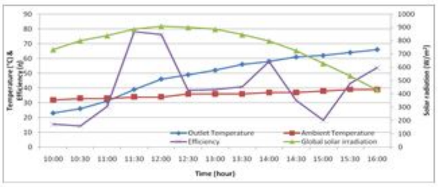

Fig. 18. Experimental reading on 3rd May 2014, $w_b = 12\text{cm} \quad \& \quad \Phi = 70^{\circ}$

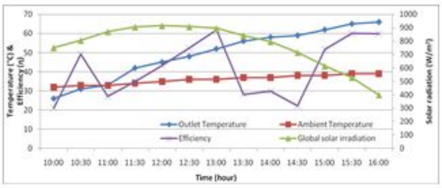

Fig. 19. Experimental reading on 5th May 2014, $w_b = 14\text{cm} \quad \& \quad \Phi = 50^{\circ}$

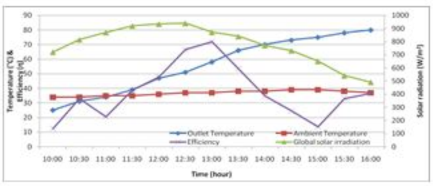

Fig. 20. Experimental reading on 6th May 2014, $w_b = 14\text{cm} \quad \& \quad \Phi = 60^{\circ}$

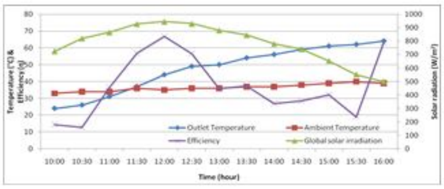

Fig. 21. Experimental reading on 7th May 2014, w_b = 14cm & $\Phi = 70°$

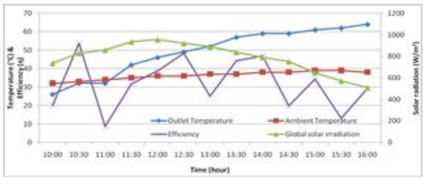

Fig. 22. Experimental reading on 8th May 2014, w_b = 16cm & $\Phi = 50°$

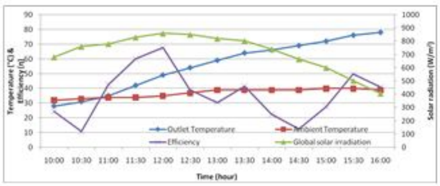

Fig. 23. Experimental reading on 9th May 2014, w_b = 16cm & $\Phi = 60°$

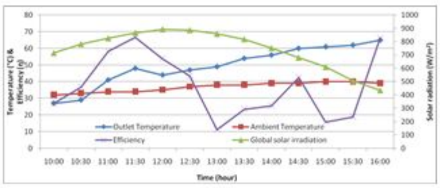

Fig. 24. Experimental reading on 10th May 2014, w_b = 16cm & $\Phi = 70°$

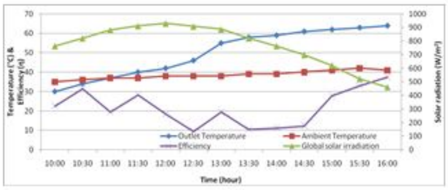

Fig. 25. Experimental reading on 12th May 2014, flat plate collector

4 CONCLUSION

In the present course of work an attempt had been made to design and fabricate V-Trough solar collector based on water heating system. Proposed water heating system was kept under studies for the reading of 1 month and had an analysis over it.

From the collected data (i.e. inlet water and outlet water temperature of storage tank, ambient temperature, global solar irradiation) efficiency of the proposed solar water heating system was been calculated for each day.

Following conclusions can be drawn from the present study:

- Proposed system is manufactured with all component at the cost of Rs.12,000/-.
- As the angle between reflective plate and the absorber plate increases its aperture area increases; which increases the amount of solar irradiation over the absorber plate at a proper angle (i.e. 60°).
- For the maximum amount of collector thermal efficiency, the reflective width and the absorptive width should be same and the angle between them should be 60°.

References

1. E O Falayi and A B Rabiu. Solar Radiation Models and Information for Renewable Energy Applications. Solar Radiation. InTech 2012.
2. Greentech knowledge solution. Solar water heaters in India: market assessment studies and surveys for different sector and demand segment. Submitted to Ministry of New and Renewable Energy 2010.
3. Tanvi Shanghavi. Indian Solar market: Potential and Opportunities. 2012.
4. Soteris A Kologiros. Solar thermal collectors and application. Progress in Energy and Combustion science 2004; 231-295.
5. Kalogirou S. The potential of solar industrial process heat application. Applied Energy 2003; 76: 337-361.
6. Winston R. Solar concentrators of novel design. Solar energy 1974; 16: 89-95.
7. Spate F, Hafner B, Schwarzer K. A system for solar process heat for decentralised applications in developing countries. Proceedings of ISES Solar World Congress 1999.

8. Kalogirou S, Eleftheriou P, Lloyd S, Ward J. Design and performance characteristics of a parabolic-trough solarcollector system. Applied Energy 1994; 47: 341354.
9. Francia G. Pilot plants of solar steam generation systems. Solar Energy 1968; 12: 5164.
10. Mills DR. Solar thermal electricity - Solar energy: the state of the art 2001: 577651.
11. Smyth M, Eames PC, Norton B. Integrated collector storage solar water heaters. Renewable and Sustainable Energy Reviews 2006; 10: 503-538.
12. Chen Bo-Ren, Chang Yu-Wei, Lee Wen-Shing, Chen Sih-Li. Long term thermal performance of a two-phase thermosyphon solar water heater. Solar Energy 2009; 83: 1048-1055.
13. Jaisankar S, Radhakrishnan TK, Sheeba KN. Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes. Solar Energy 2009; 83:1943-1952.
14. Kumar R, Rosen MA. Thermal performance of integrated collector storage solar water heater with corrugated absorber surface. Applied Thermal Engineering 2010; 30: 1764-1768.
15. Kumar Rakesh, Rosen Marc A. Integrated collector-storage solar water heater with extended storage unit. Applied Thermal Engineering 2011; 31: 348-354.
16. Ilhan Ceylan. Energy and exergy analyses of a temperature controlled solar water heater. Energy and Buildings 2012; 47: 630635.
17. Varun and Siddhartha. Thermal performance optimization of a flat plate solar air heater using genetic algorithm. Applied Energy (India) 2010; 87: 1783-1789.
18. S N Singh. Optimization of Solar (PV) Home lighting in Literacy House with integration of LEDs and Social impact in Indian Rural Society. 2012.
19. Pitak Khlaichom Kawin Sonthipermpoon. Optimization of Solar Tracking System Based On Genetic Algorithm. 2010.
20. A C Mintsa, Do Ango, M Medale. Optimization of the design of a polymer flat plate solar collector. Solar Energy (France) 2013; 87: 64-75.
21. Tao Tao, Zheng Hongfei, He Kaiyan, Abdulkarim Mayere, A new trough solar concentrator and its performance analysis. Solar Energy (China) 2011; 85: 198-207.
22. Xue Xiaodi, Zheng Hongfei, He Kaiyan, Chen Zhili, Tao Tao, Xie Guo. Experimental study on a new solar boiling water system with holistic track solar funnel concentrator. Energy (China) 2010; 35: 692-697.
23. Ljiljana T Kostic, Zoran T Pavlovic. Optimal position of flat plate reflectors of solar thermal collector. Serbia Energy and Building 2012; 45: 161-168.
24. K K Chong, K G Chay, K H Chin. Study of a solar water heater using stationary V-trough collector. Renewable Energy (Malaysia) 2012; 39: 207-215.
25. Sanjay Kumar Sharma. Fabrication and Experimental Investigation of V-Trough Flat Plate Collector in Hot Climatic Conditions of Rajasthan: A Case Study of Jaipur. 2013.

About Authors

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Donec varius dapibus metus eget ultrices. Nulla sagittis mauris rutrum, blandit augue eget, laoreet augue. Phasellus enim odio, sagittis in mi sed, fringilla mollis odio. Phasellus quis purus ultricies, tempor purus at, tempus quam. Donec ultricies, ligula ac pretium porttitor, nibh nunc. Integer eros nibh, cursus at est sed, volutpat tristique justo. Donec ornare facilisis lorem, id feugiat elit pellentesque at. Nulla odio mauris, luctus sed faucibus id, dignissim dictum velit. Morbi vehicula velit at massa tristique rhoncus.

Phasellus quis purus ultricies, tempor purus at, tempus quam. Donec ultricies, ligula ac pretium porttitor, nibh nunc. Integer eros nibh, cursus at est sed, volutpat tristique justo. Donec ornare facilisis lorem, id feugiat elit pellentesque at. Nulla odio mauris, luctus sed faucibus id, dignissim dictum velit. Morbi vehicula velit at massa tristique rhoncus.