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Experimental Analysis of Solar Water Heater Using Pulsating Heat Pipe

[1]D. A. More and [2]P. R. Pachghare
[1] M.Tech (2nd Year Thermal Engineering), [2]Assistant Professor,
[1,2]Mechanical Department, Government College of Engineering, Amravati (M.S), India

Abstract-- Solar energy is used for solar water heater in domestic and industrial purpose. Pulsating heat pipe is a fast responding, flexible and high performance thermal conducting device. The CLPHP system described in this study relies on the natural forces of gravity and capillary action and does not require an external power source. The flat plate collector consisted of a 2 mm thick sheet of Aluminum covered by a glass enclosure with a collecting area of 1*0.5 m^2 , an evaporator located on the collecting plate, and a condenser inserted into a water tank. A length of 0.003 ID copper tubing was bent into multiple turns at critical points along its path and used to channel the working fluid throughout the system. Water was used as the working fluid. Efficiency evaluations were conducted during daylight hours over a two month period and included extensive monitoring and recording of temperatures with type-K thermocouples placed at key locations throughout the system. The results confirmed the anticipated fluctuation in collector efficiency dependant on the time of day, solar energy irradiation; ambient temperature and flat plate mean temperature. An efficiency of approximately 44% was achieved, which correlates with the efficiency of the more expensive available solar water heater. The CLPHP system offers the additional benefits of corrosion free operation.

Keywords – *Solar Water Heater, Closed Loop Pulsating Pipe, Solar Radiation.*

I. INTRODUCTION

Typically, conventional solar collectors (SC) use water pipes attached to the collecting plate where water circulates either naturally or forcibly and transfers the heat it collects to a storage tank. Some of the shortcomings of this type solar collectors system include the extra expense of a pump and the power needed to operate it, the extra space required for any natural circulation system, the corrosion effect of water, and the limited quantity of heat transferred by the fluid. Heat pipes offer a promising solution to these problems. Heat pipes working under gravity with the condenser located above the evaporator do not require external power because capillary action functions to return the heat transfer fluid to the evaporator. This type of heat pipe system is often referred to as a gravity assisted heat pipe, a wickless gravity assisted heat pipe or a closed loop pulsating heat pipe. Numerous experiments have been conducted over the years on these systems; some examples of the findings are elucidated here. With respect to the closed two-phase thermosyphon, Soin et al. [1,2] investigated the thermal performance of a thermosyphon collector containing boiling acetone and petroleum ether, and presented the effect of insolation and the liquid level on the collector performance. Schreyer [3] experimentally investigated the use of refrigerant R11 in a thermosyphon solar collector for residential applications. It was found that, for two identical collectors, the instantaneous peak efficiency of a boiling refrigerant charged collector was 6% greater than that of a hydraulic fluid circulating solar collector. Akyurt [4] designed and manufactured numerous heat pipes. Each heat pipe was incorporated into a prototype solar water heater. An extensive testing program lasting for more than a year revealed that the heat pipe perform satisfactorily as heat transfer elements in solar water heaters. H. M. Hussein, M. A. Mohmad [5] And Hussein [14] investigated theoretically and experimentally a thermosyphon flat plate solar collector. The transient thermal behavior of a wickless heat pipe flat plate solar collectors was analyzed with regard to various parameters. The results revealed that the pitch distance limited the selection of an absorber plate to one having a high value of thermal conductivity. Also, from the theoretical analysis, it was concluded that the condenser section aspect ratio and the heat pipe inclination angle had a significant effect on the condensation heat transfer coefficient inside the inclined wickless heat pipes. Esen and Yuksel [6] fabricated a two phase thermosyphon solar collector with heat pipes and studied experimentally various phase-change fluids to evaluate the effect of insolation and mass of fluid on the collector performance. It was found that such a collector can be successfully used, especially during cold, cloudy and windy days. Mathioulakis and Belessiotis [7] presented the results of a theoretical and experimental investigation of the energy behavior of a new type of solar collector employing a heat pipe filled with ethanol.

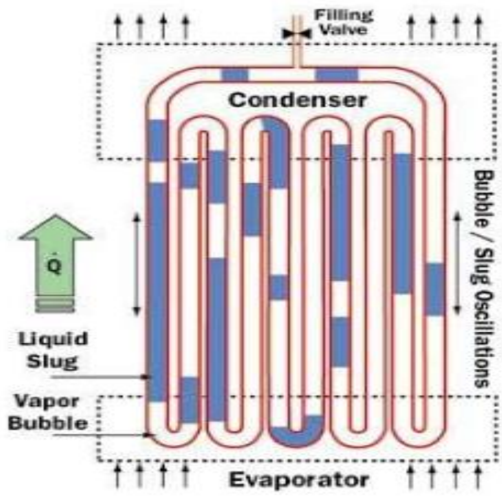

Figure1: Close loop pulsating heat pipe

The energy behavior of the system was characterized by high instantaneous efficiencies up to 60%. Also Pachghare [8], Kandekar [9] has deep studied on the pulsating heat pipe. And they gives the pulsating heat pipe is efficient and fast thermal response device. And we can use it as heat transfer device.

As seen from these extensive literature reviews, very few experiments or tests have been conducted on closed loop pulsating heat pipe solar collectors. The CLPHP displays numerous advantages; the main advantage being large quantities of heat can be transported through a small cross-section area. The CLPHP shown in Fig. 1 is a very effective heat transfer device; its structure is simple and it has fast thermal response. It consists of a long capillary tube bent into many turns; the evaporator, adiabatic and condenser sections are located at these turns. However, there is no wick structure to return the condensate liquid from the condenser to the evaporator section. Heat is transported from the evaporator section to the condenser section by the pulsation of the working fluid moving in an axial direction in the tube. The inner diameter of the pipe is important. It must be small enough so that under operating conditions liquid slugs and vapor plugs can be formed. If the diameter is too large, the liquid and vapor inside the tube will become stratified and oscillating heat pipe operation cannot be established. Rittidech et al. [10] investigated the effect of inclination angles, evaporator lengths and working fluid properties on the heat transfer characteristics of closed-end oscillating heat pipe at normal operating condition, Further, Pachghare [11] et al. Gives the art of state of pulsating heat pipe, Rittidesh et al. [12] presented a correlation to predict the heat transfer characteristics of a closed-end oscillating heat pipe at normal operating condition. As the criterion to find the maximum inner diameter of a CEOHP, Maezawa et al. [13], presented that under the condition where the vapor bubble is formed alternately with the liquid plug within the tube, the pipe diameter should depend on the properties of the working fluid as:

$$d = 2 * \sqrt{\frac{б}{g * (\rho l - \rho v)}}$$

The primary objective of the current work is to study the thermal performance of a CLPHP solar collector.

II. CLPHP DESIGN AND PRODUCTION

The size and position of the CLPHP system can be arranged to conform to the environment in which it will be located.

A. The CLPHP

The CLPHP in this experiment was designed and developed from a 0.00301 m inside diameter copper tubing. The 32 m CLPHP tubing was divided into two sections, i.e. the evaporator, 1 m long, and condenser, 0.40 m long. The distribution of the tubing is shown in Fig. 1. Water was selected as the working fluid, and a filling ratio of 50% of the total volume of tube was used. The tube arrangement was aligned at an inclination angle of 41 degrees from the horizontal plane, in Twelve turns. The condenser section was inserted in a water tank. The evaporator section occupied the collecting plate with an area of 1.00 m * 0.5 m, and the collecting plate was covered by a glass plate.

B. The collecting plate

A 2 mm thick Aluminum sheet 1.00 m in length was used to make a collecting plate with 1* 0.5 m2 test area. When considering solar energy irradiation and the performance of, CLPHP, it was determined that Twelve turns in the tubing of the CLPHP were sufficient for the area provided. The collecting plate was roove to size and pressed to make room for the tubing which was attached in place to the plate surface. The plate was then painted black.

C. The assembly

As shown in Fig. 2, the wooden box made to house the plate had a 5 cm thick layer of insulation at the backside and a 4 mm glass plate with 2.5 cm air gap at the front side that was fitted and sealed with silicone glue.

III. TEST RIG

The prototype was installed into a test rig, as shown in Fig. 3. Solar energy was absorbed by the CLPHP through the solar collector, and then was transferred to the condenser. The temperatures were measured using type-K thermocouples. The temperatures were recorded at three points on the collecting plate surface, and represented the

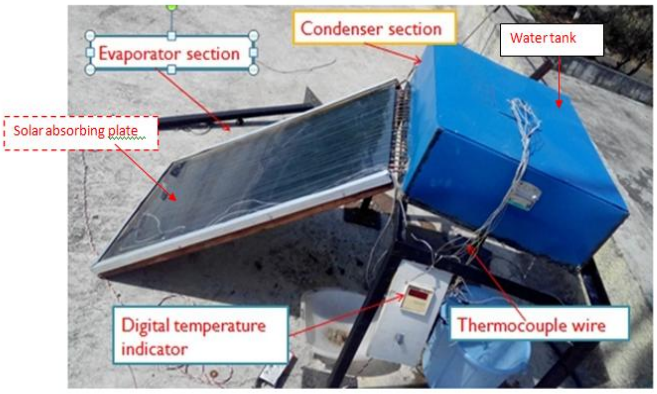

Figure 2: Experimental assembly

plate surface profile. Their average value was taken as the average plate temperature (Tp). The. Three thermocouples on condenser section, one for water temperature and one for ambient temperature. Take the value of instantaneous solar radiations (I) from standard laboratory. Day-long experiments were carried out from 09:00 a.m. to 18:00 p.m., and data were recorded at half hour intervals. The experiments were performed throughout March 2016. On each day, the hot water storage tanks were completely drained in the morning and refilled with cold water. The controlled parameter was the water flow rate at 6 l/hr. The tests were performed on March 25, 2016 and April 1, 2016.

IV. RESULT AND DISCUSSION

The quantity of heat transferred to the water with in the tank can be calculated by water temperature variation, taking into account the water flow rate and its specific heat:

$Q = M_w * Cp * (T_o - T_i)$

The cumulative collection efficiencies (g) can be expressed as a ratio of the amount of heat stored in the tank to the total amount of solar energy irradiation on the collector for the same period of time, i.e.,

$$g = \frac{Q}{IA}$$

In this experiment two representative tests were chosen to analyze the system performance. The first was conducted on March 25, 2016 and the second on April1, 2016. The results of these studies are show in Figs. 3-8. The following points can be noted: Fig. 4 and fig 3 shows the daily changes of the ambient conditions for both experiments. Values of ambient temperature (Ta) and solar energy irradiation (I) are shown. Ambient temperatures reached 37 ^{0}C and 44 ^{0}C , while the solar energy irradiation reached 625 and 639 W/m2. The heat transfer capability of the CLPHP is a function of the difference in temperature between the high temperature source and the low temperature sink, which is represented in Fig. 5 as the difference between the plate temperature (Tp) and the water temperature (Tw). Fig. 6 shows the heat absorbed by water with time, And fig. 7 shows the solar collector plate efficiency (g) with time. It shows the heat absorb and efficiency is increases as ambient temperature and incident radiation increases.

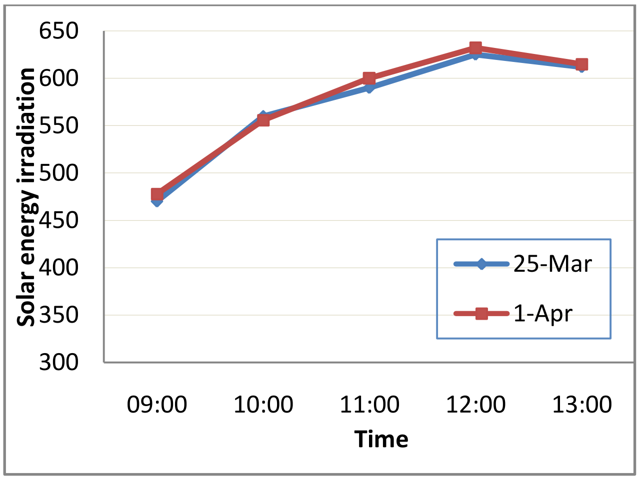

Figure 3: Solar energy irradiation Vs Time

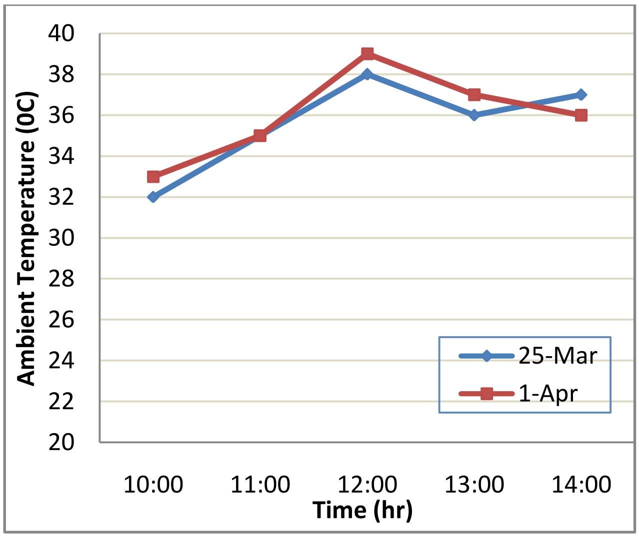

Figure 4: Ambient Temperature Vs Time

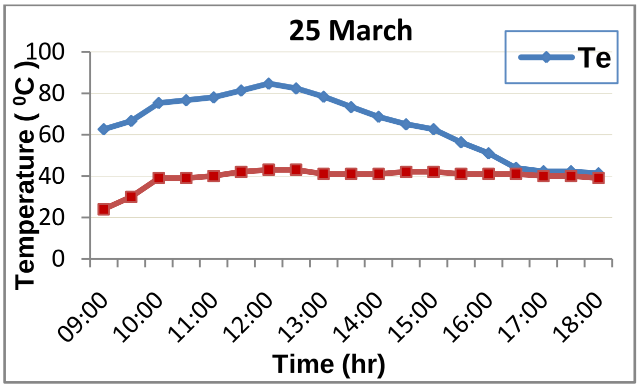

Figure 5: Evaporator temperature and Water temperature Vs Time 25 March

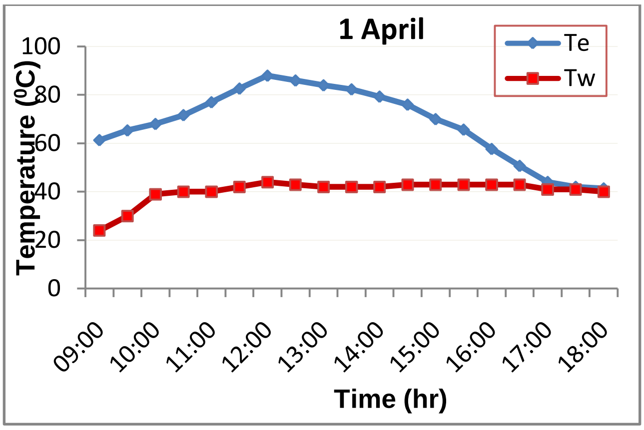

Figure 6: Evaporator temperature and Water temperature Vs Time for 1 April

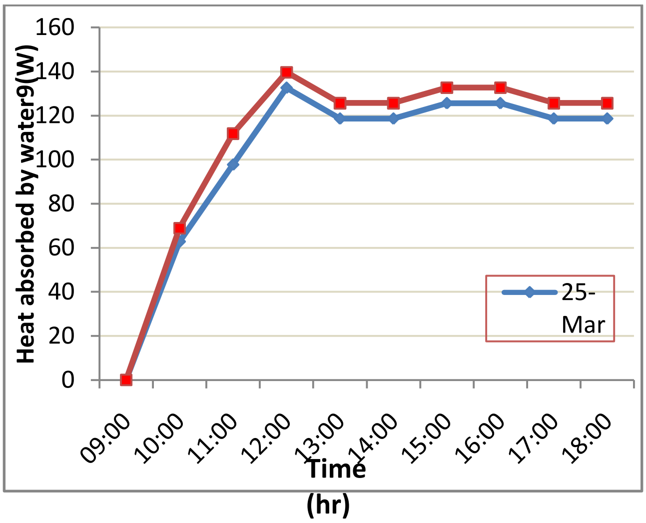

Figure 7: Heat absorbed by water Vs Time

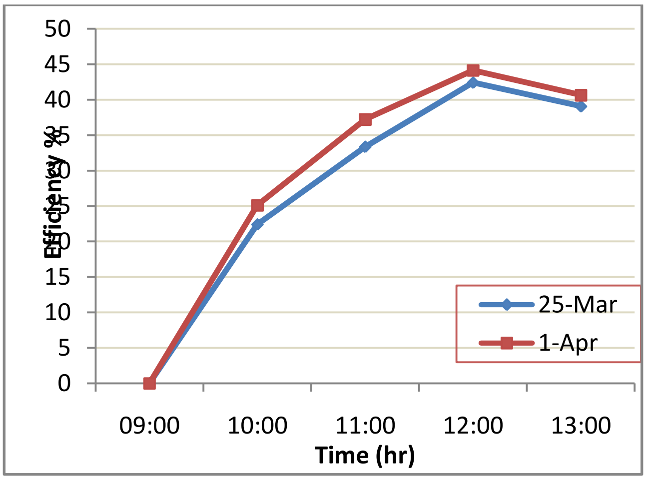

Figure 8: Efficiency of solar plate Vs Time

Efficiencies calculated from the above formula given in the definition of efficiency of our solar water heater at various time for 25 March and 1 April. We have calculated efficiencies at time 9:00, 10:00, 11:00, 12:00, 13:00. Figure 8 shows the efficiencies of solar water heater at various time on 25 March and 1 April. At 9'oclock the heat absorbed by water is nearly zero, therefore the efficiency of our system is zero. As time passes, the incident radiation also increases, therefore the heat added to the system is increases, the efficiency also increase. At 12o'clock the incident radiation is highest and observe efficiency is also highest, it is 43 % on 25 March and 44% on 1 April.

CONCLUSION

In this study, we designed and built an experimental prototype of a CLPHP solar collector to investigate its performance. An evaluation of the system proved its performance to be comparable with the performance obtained from a available solar water heater. An efficiency of about 44% was attained which is directly comparable to that of the solar water heater available in the market. Other advantages of the system include simple construction, corrosion free operation and elimination of winter icing problems.

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