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Performance Analysis of Two Phase Thermosyphon Solar Water Heater

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ABSTRACT

Solar energy is recognized as one of the most promising alternative energy options. On sunny days, solar energy systems generally collect more energy than necessary for direct use. Therefore the design and development of solar energy systems is of vital importance and nowadays one of the greatest efforts in solar research. This project investigates experimentally the thermal performance of a two-phase thermosyphon water heater. Different heat transfer mechanisms, including natural convection, nucleate boiling and film wise condensation , are observed in the two phase thermosyphon solar water heater while solar radiations varies. The proposed system achieves characteristics efficiency higher than the conventional systems by reducing heat loss for the two-phase thermosyphon solar water heater.

Keywords - Thermosyphon, solar energy, natural convection, nucleate boiling, film wise condensation.

1. INTRODUCTION

Natural convective and forced convective solar water heaters have been considered and developed in recent years. The temperature stratification in forced convective solar water heaters is not serious because the water in the tank is mixed with water pumps; however this system cannot be used when the pump or electromagnetic valve fails. Our project investigates the performance of the two phase thermosyphon solar water heater. This project undergoes different heat transfer mechanisms including natural convection, geyser boiling, nucleate boiling, film wise condensation are observed in the two phase thermosyphon solar water heater while solar radiation varies. The energy storage material is water because it is much flexible when compared to other storage materials. Some of the other storage materials paraffin wax and etc. this project used alcohol (methanol) as working fluid. Here the working fluid is methanol its boiling point is $65^{o}C$ and hence it can change its phase even when there is very less solar radiations. Hence it is more convective when compared to other working fluids. The amount of alcohol is filled with an adequate amount of working with the calculated amount. Here the double pipe heat exchanger is used for the heat exchanging process. After absorbing the solar radiations the working fluid inside the thermosyphon because boiled and produces gaseous working fluid which heats the water. Here two non-return valve are used in order to avoid the return motion of the gases state back to the alcohol. When the storage material attains higher temperature when compared to the solar radiations absorbed, there is the change of reverse process and hence instead of evaporation film condensation will takes place. In order to avoid the return motion the check valve is used.

Wen –shing lee *et al* studied the thermal performance of latent heat storage in a two phase thermosyphon solar water heater , which utilizes the phase change heat transfer mechanisms of boiling and condensation also it eliminates drawbacks found in the conventional solar water heater such as unstable thermal storage in case of pump (or) electromagnetic valve failure and charges and discharges ability of the conventional storage systems relies on the system piping design, and therefore only two functions, energy storage and energy release, are available in the operating modes. They used ethyl alcohol as working fluid. They studied the thermal behavior of tricosane (paraffin wax 116), water, sodium acetate ($NaCH_3COO.3H_2O$) used as energy storage materials and it results tricosane provides better advantage to be the energy storage material in the latent heat storage system. Also they examined that the system gives optimum charge and discharge performance under 40% alcohol fill ratio with tricosane used as energy storage material.

Performance of large solar water heating system Thermosyphon mode by Tiwari *et al* is two large solar water heating systems (non-pressure type), each having 1000 liter capacity, have been installed at IIT New Delhi and their performances have been studied under the thermosyphon mode between the collectors and the storage tank. A simple transient analysis of the system, incorporating the effect of withdrawal of hot water from the storage tank, has been developed. The effect of stratification in the storage tank has been studied experimentally. It is found that the experimental observations are in good agreement with the theoretical results obtained by the present model.

2. EXPERIMENTAL SETUP

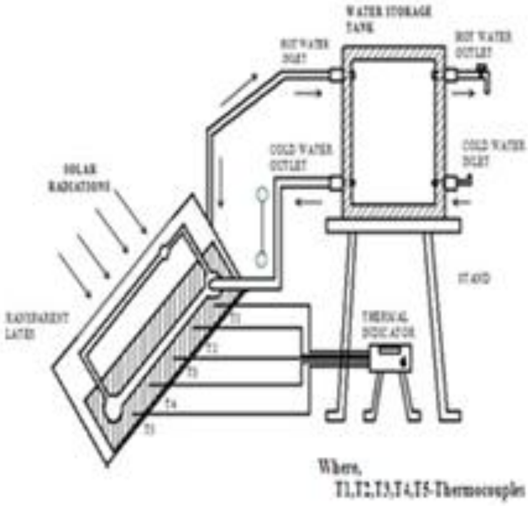
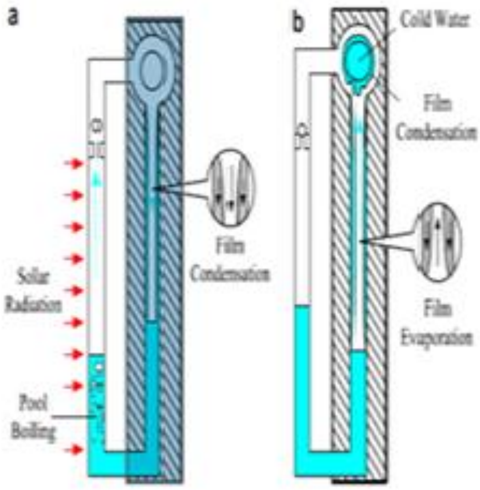


Fig.1 Thermosypon solar water heater



(a) Charge mode
(b) Discharge mode

Fig.2 Film Condensation & Evaporation

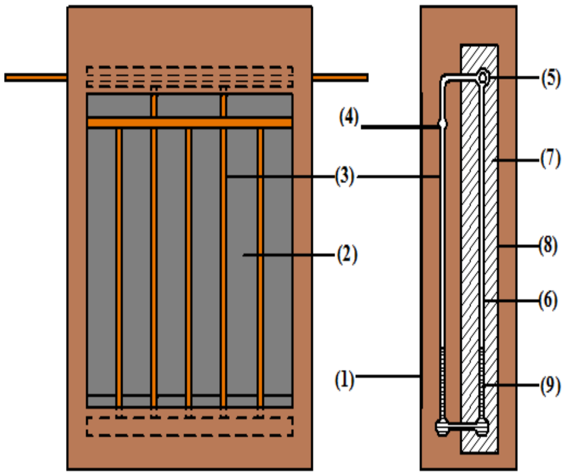
3. COMPONENTS DESCRIPTION

3.1 Transparent plate

It is used to absorb the solar radiations and brittle. It is easily breakable when limited number of stress is given. It is cheap and it is easily available. It is used in vehicles, houses, etc..,

3.2 Vertical Copper tubes

The dimension of the tube is inner tube is 11.7mm and outer diameter tube is 12.7mm. The copper tube is a good absorber of heat. It does not release much amount of heat. It is malleable, ductile, very good conductor of electricity, excellent conductor of heat, resistance to corrosion. It is reddish orange in color. Its melting is 1083.4^{o}c boiling point is 2567^{o}C.



1. Transparent Plate, 2.Collector, 3.Collector Tubes, 4. Check Valve, 5.Double Pipe Heat Exchanger, 6. Parallel-Fin Tubes, 7.Energy Storage Material, 8.Energy storage Tank, 9.Working Fluid

Fig.3 Collector Tank of Two Phase Thermosyphon Solar Water Heater

3.3 Horizontal Copper tubes

The dimension of the tube is inner tube is 17.4mm and outer diameter tube is 19mm. The copper tube is a good absorber of heat. It does not release much amount of heat. It is malleable, ductile, very good conductor of electricity, excellent conductor of heat, resistance to corrosion. It is reddish orange in color. Its melting is 1083.4^{o}C boiling point is 2567^{o}C.

3.4 Energy storage tank

The material used for storage tank is mild steel. The storage tank is filled with pure distilled water. The dimension is 800mm x 600mm x 60mm. It is malleable and ductile. The storage tank is braced with copper.

3.5 Working fluid

The working fluid is methyl alcohol. The melting point is 175K and boiling point is 338K. The density of methyl alcohol is 0.7918g/cm^3. The molar mass is 32.04g/mol. The molecular formula is CH_3OH.

3.6 Check valves

The number of check valves used here is two. The ball is made of Teflon and it can able to withstand the temperature generated. Its thread is half an inch. It can open or release the vapour at a pressure of 10mbar.

3.7 Energy storage material

The energy storage material is pure distilled water. The molecular mass of water is 18.01g/mol. The density is 1000kg/mol. The structure is hexagonal in shape. The amount of water used is 20-25 liters. The work of this energy storage medium is to condense the alcohol for further process is repeated.

4. WORKING PRINCIPLE

Solar energy is the basic source of the solar water heater. The solar radiations get collected in the transparent plate transfers the heat to the copper tubes which are placed vertically. These copper tubes are filled with methyl alcohol and when the solar radiations fall on the copper tubes the alcohol which is filled in the tubes get evaporated. Now it passes through the check valves. The work of check valve is to allow only the vapor and it resists the opposite flow. In the double pipe heat exchanger, the water gets heated and it is received in the storage tank. The storage medium makes the hot vapor to condense and sent to the bottom of the copper tubes. Now the cycle is repeated and the water gets heated. The heater comprises an energy storage tank and a two-phase closed thermosyphon loop. The energy storage tank is filled with water. The thermosyphon loop includes three parts:

(1) Parallel-fin tubes vertically disposed inside the energy storage tank,

(2) Vertical collector tubes located outside the tank with check valves mounted on the top, and

(3) A double pipe heat exchanger situated at the upper region inside the storage tank.

The thermosyphon loop is filled with an adequate amount of working fluid, alcohol. The figure shows the function in which the system operates to store heat. Having absorbed solar radiation, the working fluid inside the thermosyphon becomes boiled and produces gaseous working fluid, which flows upward and passes through the check valves. Then the vapor flows downward into the parallel-fin tubes. The vapor undergoes film condensation on the inner wall of the fin tubes and releases heat to the water.

Following that, the condensed working fluid flows downward along the inner surface of the parallel-fin tubes under gravity, and finally into the collector tubes to complete the charge cycle. The heat stored in the energy storage material will be released when cold water enters the internal tube of the double-pipe heat exchanger. The process of heat transfer from the energy storage material to the cold water entering the double-pipe heat exchanger is as follows. First, the vapor working fluid transfers heat to the cold water through the internal tube of double-pipe heat exchanger and condenses into liquid form on the outside of the internal tube. After that, when the condensed liquid working fluid flows down along the inside wall of parallel-fin tubes, the fluid will absorb heat from the energy storage material and part of this fluid will be evaporated by film evaporation.

Meanwhile, the liquid working fluid in the lower part of the parallel-fin tube evaporates due to decrease in vapor pressure by condensation and absorbs heat from the energy storage material. Through the steps described above, the discharge cycle of heat stored in the storage to the cold water is completed. The collector and the check valve are made of copper, and the transparent plate is made of transparent polycarbonate plastics. The check valves in the innovative system can prevent the thermosyphon from operating reversely to release the stored heat. As the system stores more thermal energy during the energy storage period, the temperature of the water inside the storage tank becomes higher. When solar radiation decreases, the temperature of the collector may be lower than that of water in the tank.

If the system operates without the check valve design, the working fluid inside the fin tubes may absorb the stored heat to produce vapor. The vapor flows into the collector tubes to condense and release the heat to the surroundings. The energy storage material and the fill ratio of working fluid is 40% alcohol for the optimal charge and discharge efficiency. In this study, the long-term outdoor thermal performance of the two-phase thermosyphon solar water heater using water as energy storage material is carried out.

5. DESIGN CALCULATION

5.1 Design calculation of heat exchanger:

Formula:

$$1/U = (r_1/r_2)*(1/h_1) + (r_2/k)\ln(r_2/r1)+(1/h_2)$$

Radius:

r_2 = 12.7/2=6.35mm = 0.00635mm

r_1 = 11.7/2=5.85mm = 0.00585mm

Thermal conductivity:

k = 386 w/mK

Dimension of storage tank:

Length, L = 800mm = 0.8m

Diameter, D = 400mm = 0.4m

Heat transfer co-efficient:

$h_1 = 2500 W/m^2K$

$h_2 = 250 W/m^2K$

Formula substitution:

(1/U) = (.00043419) + (0.0000012429) + (0.004)

(U) = 225.4571 W/m^2K

Area:

A = π*D*L

A = π*12.7*.0008

A = $0.031919 m^2$

Log mean temperature difference

$dT = T_1-T_2/\ln(T_1/T_2)$

dT = 27.63°C =

dT = 300.63 K

Heat transfer rate:

Q = UAdT

Q = 225.4571*0.031919*300.634

Q = 2163.472W

5.2 Design calculation for storage tank

Volume of storage tank

$V = \pi/4*D^2*L$

= (3.14*0.4*0.4*0.8)/4

V = $0.100m^3$

V = 1000 liters

Area of storage tank

A = 0.8*0.7

A = $0.56 m^2$

5.3 Design calculation for energy storage material

Volume of copper inside the tank

$V = \pi/4(D^2)*0.8+2*\pi/4(d^2)*0.5+7*(\pi/4)*(0.025)$

V = (0.00022682+0.00012668+0.000022168)

= $0.000375668m^3$

V = 0.3757 liters

M = 0.375kg

5.4 Design calculation for wooden box

Volume of wooden box

V = 0.9*0.8*0.08

V = $0.0576 m^3$

6. ENERGY STOREAGE FOR THE TIME INTERVAL OF 10.30 A.M – 5.00 P.M

Energy stored in the storage tank

$Q_w=M_wC_{pw}(T_f -T_i)$

= 100x4180(40.42-16.64)

Q_w= 2090000 J

Energy storage in the collector body

$Q_b=M_bC_{pb}(T_f-T_i)$

=27x 0.875(40.42-16.64)

Q_b=561802.5 J.

Total heat loss in the system body

$Q_l= U_t(T -T_a)$

= 10 x (28.53-24)

Q_l=45.3 J

The energy balance equation

$Q_c=Q_w+Q_b+Q_l$

=(2090000) + (561802.5) - (45.3)

Q_c= 2651757.2 J

Mean system temperature

$T= (T_i+T_f)/2$
= (16.64+40.42)/2

T= 28.53 ^oC

The collector efficiency

$\eta_s = Q_w/(H_tA_c)$

= $(2090000x100)/ (0.56x5.4x10^6)$

η_s = 69.11%

7. HOURLY BASED COLLECTOR EFFICIENCY

TIME	Q_w (J)	Q_c (J)	η (%)
10.30-11.30	297950	298010.5	9.85
10.30-12.30	435890	436001.675	14.41
10.30-1.30	844192	844516.525	27.92
10.30-2.30	1285601	1286156.52	42.51
10.30-3.30	1747240	1748040.45	57.78
10.30-4.30	2090000	2651757.2	69.11

8. COMPARISON

System	Collector Type	Efficiency
Closed Thermosyphon system		69.315
Proposed closed Thermosyphon system		63.5
System A	Evacuated Tube	57.9
System B	Flat Plate Collector	50.2

9. RESULTS AND DISCUSSIONS

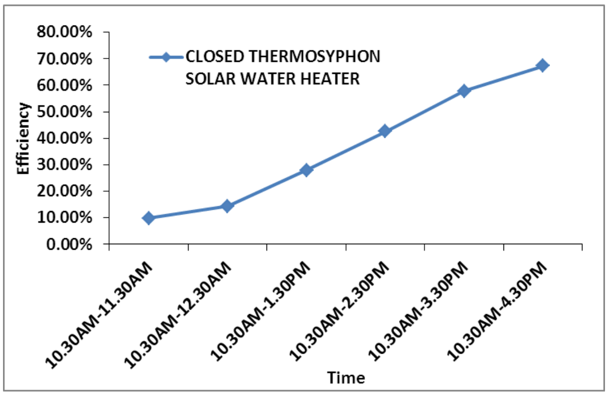


Fig.4 Closed thermosyphon solar water heater time vs. efficiency

The figure shows the temperature profiles of the collector at the upper and lower locations, TPU and TPL, on sunny day. The variations in solar radiation and water temperature at the top of the storage tank, T1, are also illustrated. The working fluid in the thermosyphon is alcohol with a fill ratio of 40%. Since the wall thickness of the collector tubes is 0.2 mm, the collector temperatures, TPU and TPL, are equal to the temperatures of the vapor and liquid working fluid inside the thermosyphon, respectively. As shown in this figure, different flow patterns inside the thermosyphon exist with changes in solar radiation. It can be divided into three regions, which are natural convection, geyser boiling, and nucleate boiling.

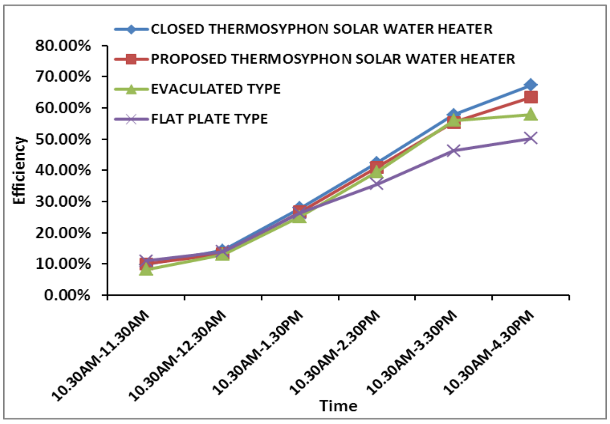


Fig.5 Comparison between four solar water heater systems

When the collector temperatures are less than the water temperature at the top of storage tank, T_1, the check valves are closed by gravity to prevent the thermosyphon from operating reversely. In this way, the heat transfer mechanism inside the thermosyphon becomes natural convection due to the lower solar radiation. Figure demonstrates the temperature distributions of water inside the storage tank under sunny weather condition. Since the natural convection is the main heat transfer mechanism in the thermosyphon, no heat is transferred to the storage tank. The temperature of water in the energy storage tank is kept constant at 24°C. During regions geyser boiling, and nucleate boiling, the boiled working fluid produces vapor which flows into the fin tubes and transfers the absorbed heat to storage tank. This results in increasing water temperatures in the storage tank. As the check valves close during the last hour of the experiment, the heat transfer mechanism in the thermosyphon becomes natural convection again and the water temperatures were kept constant till the end of the experiment.

10. CONCLUSION

The thermal performance of the two phase thermosyphon solar water heater is demonstrated through the hourly performance tests. The thermal behavior of the system is determined by the measured temperature distribution of both collector and water inside the storage tank under local climatic condition. The results show that the proposed solar water heater provides better thermal performance than the conventional system. Owing to the superior heat transfer mechanism of boiling and condensation in the thermosyphon the proposed system not only reduces the heat loss between the collector and the surroundings, but also enhances the thermal storage density

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