Heat Transfer Analysis of Two Phase Closed Thermosyphon using Aqueous Solution of n-Butanol

M. Karthikeyan, S. Vaidyanathan, B. Sivaraman
Mechanical Engineering, Annamalai University, Annamalai Nagar – 608002, India

ABSTRACT

Two phase closed thermosyphon is proved to be a good heat transfer device. A large amount of heat is transferred from evaporator section to condenser section with relatively a small temperature difference. In this paper, the heat transfer of two phase closed thermosyphon is analysed experimentally with different inclinations and heat input. For this experiment, two copper thermosyphons of length 1000 mm, inner diameter 17 mm and outer diameter 19 mm are designed. Both are charged with 60 ml of working fluid with an evaporator length of 400 mm and condenser length of 450 mm. One thermosyphon is charged with de-ionized water (DI) and the other with aqueous solution of n-butanol. It is found that the heat transfer coefficient of aqueous solution of n-butanol is higher than that of de-ionized water.

Keywords: Boiling heat transfer coefficient, Condensation heat transfer coefficient, Thermal resistance, Two phase closed thermosyphon

NOMENCLATURE

di Inner diameter of heat pipe (m)
hc Heat transfer coefficient in condenser (W/(m² °C))
he Heat transfer coefficient in evaporator (W/(m² °C))
m Mass flow rate of water in condenser (kg/s)
Cpl Specific heat of water (J/kg °C)
I Current (A)
Le Length of evaporator section (m)
Lc Length of condenser section (m)
Qav Heat transfer rate (W)
Q1 Inlet heat by evaporation (W)
Q2 Outlet heat by condensation (W)
R Thermal resistance (°C /W)
T1 Inlet water temperature of condenser (°C)
T2 Outlet water temperature of condenser (°C)
Tv Vapour temperature (°C)
Twc Average temperature of condenser section (°C)
Twe Average temperature of evaporator section (°C)
V Voltage (v)

1. INTRODUCTION

A two-phase closed thermosyphon is a wickless heat pipe and a heat transfer device with high thermal performance. It is a closed container filled with little amount of working fluid. Here, the heat is supplied to the evaporator section (lower section) which causes the working fluid inside the pipe to vapourize and evaporate. The generated vapour then moves upwards to the condenser section (upper section). The condensed liquid goes down along the surface of the tube wall due to gravitational force. The foremost benefit of two phase closed thermosyphon is that, no mechanical pumping is needed and therefore cheap and trustworthy. The thermosyphon has been proved to be a promising heat transfer device with very high thermal conductance. A two-phase closed thermosyphon is used to transfer a large amount of heat at a higher rate with a small temperature difference.

The two-phase closed thermosyphon is widely used because of their simple structure when compared to other types of heat pipes. In practice, the effective thermal conductivity of thermosyphon exceeds nearly 200–500 times that of copper. Therefore, thermosyphons are being used in many applications such as heat exchangers, cooling of electronic components, solar energy conversion systems, spacecraft thermal control, cooling of gas turbine rotor blades, etc. [1]. D. Ristoiu [2] described the effect of
the fluid property in the heat transfer characteristics of the inclined thermosyphon (0 – 90 degree) by taking into account the filling ratio. They used copper thermosyphon and three kinds of working fluid (Alcohol, acetone and water) and filling ratios 50%, 30% and 15%. The experiment was conducted by gradually increasing the temperature of heating oil from near room temperature to a certain high level (dry out) and the interior flow phenomenon and corresponding heat transfer rate was recorded simultaneously. Their result revealed that there exist a range of inclination angle at which thermosyphon shows a better performance than the vertical position i.e the critical heat transfer rate is higher and the thermal resistance is lower. Qi Baojin [7] investigated experimentally to study the heat transfer characteristics of titanium/water and copper/water two phase closed thermosyphon. Their experiment showed that the heat transfer coefficient in condenser of titanium/water is about 2-3 times more than that of copper/water. They also concluded that the mixed condensation mode with dropwise and filmwise condensation coexisting on titanium surface is higher than compared to that of copper. Behrooz Mirzaei Ziapour [4] predicted the vapour flow thermal resistance effects on the heat transfer characteristics of a two phase closed thermosyphon by using an enhanced FORTRAN code combined with EES software. They validated that their present model was simple and efficient for designing two phase closed thermosyphon in both transient and steady regimes than the classical Runge-Kutta method. Yong Joo Park [5] investigated the heat transfer characteristics of a copper two phase closed thermosyphon with Copper Ferrous as working fluid in the range of 50 – 600W heat flow rate and 10 – 70% fill charge ratio. Their results showed that the heat transfer coefficient of the evaporator section increased with the increase of the power. The effect of the filling ratio was negligible for both the smooth and grooved surface. On the other hand, the heat transfer coefficient showed some enhancement with increase in the filling ratio in the condenser section by the expanded working fluid pool. S.H. Noie [6] studied the applications of two phase closed thermosyphon and states that they are increasing in heat recovery systems due to their high effectiveness. He has taken the input heat transfer rate in the range of 100 – 900W, filling ratio in the range of 30% to 90% and aspect ratios as 7.45, 9.8 and 11.8. It has been concluded that the thermosyphon operates at its best for optimum filling ratio for a certain aspect ratio. Nicola di Francescantonio[7] carried out the experiment using quartz cuvette and glass tubes filled with binary mixtures and water. The thermal performance of the heat pipes filled with binary mixtures has better performance than the heat pipes filled with water. This is because binary mixtures have a non linear dependence of the surface tension to that of temperature. Raffaele Savino [8] investigated the surface tension driven effects in wickless heat pipes with aqueous solutions of alcohols. Flow visualization and numerical simulation of bubbles behavior and boiling pattern in transparent capillaries show the potential advantages of using self rewetting fluids. Yoshiyuki Abe [9] described the results of microgravity experiments on thermal management device namely wickless heat pipe with dilute aqueous solutions of high carbon alcohols. Most of the liquids show a decrease in the surface tension with increasing temperature but the self rewetting fluids show an increase in the surface tension with increase in temperature. This unique character allows for a spontaneous liquid supply to the hotter interface by thermocapillary flow. When liquid phase change takes place, additional Margoni effect due to concentration gradient by the evaporation of alcohol rich in composition of the aqueous solutions is induced. Therefore a strong liquid inflow to dry patch is expected at three – phase liquid interface. One of the main application of self rewetting fluids in space is thermosyphon in which condensate spontaneously returns to evaporation section by enhanced Margoni effect. Zhang [10] promoted the use of working fluids for heat pipe systems like dilute alcohol solutions (range between 0.0005 and 0.008 moles per litre) which exhibit a non-linear dependence of the surface tension with temperature and a positive gradient with increasing temperature in a suitable range of temperatures and concentrations. At low concentration, the aqueous solutions behave like positive binary mixtures [11]. It is important that only a small amount of the long-chain alcohols, order of $10^{-3}$ mole per litre, is needed to change the surface tension characteristics of water without affecting other bulk properties of water [12].

In this paper, two phase closed thermosyphon of copper container is taken and experiments are conducted for various inclinations and different heat inputs. The objective of this project is to analyse about the heat transfer performance of two phase closed thermosyphon using De Ionized water and aqueous solution of n-butanol.

2. EXPERIMENTAL SETUP

A schematic view of the experimental system is shown in fig. 1 and the thermocouple experimental locations is shown in fig. 2. To carry out the experiment, a thermosyphon of copper container with a 19 mm outer diameter, a total length of 1000 mm and a wall thickness of 1 mm are taken. The thermosyphon is charged with 60 ml of working fluid which approximately corresponds to the amount required to fill the evaporator section. The length of the evaporator section, adiabatic section and condenser section are 400 mm, 150 mm and 450 mm respectively. A wattmeter with the required power range and a variac has been incorporated into the electric heater circuit to evaluate the required heat to be supplied to an electric heater, with an uncertainty of ± 1 W, which in turn energizes the evaporator section. The wall temperature distribution of the two phase closed thermosyphon is measured using six copper constantan (T type) thermocouples with an
uncertainty of ± 0.1 °C. In addition to that, three more thermocouples are located in condenser surface and one in adiabatic surface. The condenser section which is 450 mm long as mentioned earlier has 34 mm outer diameter and 30 mm inner diameter concentric tube. It acts as a cooling water jacket and is used at the condenser end to remove the heat from the pipe. The thermosyphon has the ability to transfer more amount of heat. As a result of it, a sudden rise in the wall temperature would damage the thermosyphon when the heat is not released properly at the condenser. Therefore, cooling water is dispersed first through the water jacket before supplying heat to the evaporator. Flow rate of cooling water from the water tank to the water jacket in the condenser is measured by using a rotameter with ± 1% accuracy. The flow rate is kept constant at 0.08 kg/min. The inlet and outlet temperatures of the cooling water are measured by using two more copper constantan thermocouples. The two phase closed thermosyphon is completely insulated with the glass wool. The amount of heat loss from the evaporator and condenser surface is negligible. The vacuum pump model BABA – 1-25 and 1/4 HP is used for evacuating the thermosyphon.

2.1 Experimental Procedure

To conduct the experiments, two identical two phase closed thermosyphons of same dimensions mentioned above are used. One is charged with de-ionized water and other with aqueous solution of n-butanol. Before filling up the working fluid, the thermosyphon is evacuated using the vacuum pump to remove the dissolved gases. After evacuation, the thermosyphon is filled with 60 ml of the working fluid. The evaporator section is heated using the required power supply with the help of auto transformer. The power input to the two phase closed thermosyphon is gradually raised to the desired power level. The surface temperatures at six different locations along the evaporator section of two phase closed thermosyphon are measured at regular time intervals until the two phase closed thermosyphon reaches the steady state condition. Similarly, adiabatic wall temperatures, water inlet and outlet temperatures in the condenser region are measured. Once the steady state is reached, the input power is turned off and cooling water is allowed to flow through the condenser inorder to cool the two phase closed thermosyphon and to make it ready for further experimental purpose. Again, the power is increased to the next level and the two phase closed thermosyphon is tested for its performance. This experimental procedure is repeated for different heat inputs namely 40W, 50W, 60W, 70W and 80W and for different inclinations of thermosyphon namely 15°, 30°, 45°, 60°, 75° and 90° with respect to horizontal direction. The output heat transfer rate from the condenser is calculated by applying an energy balance to the condenser flow. The vacuum pressure in the inner side of the two phase closed thermosyphon is monitored by vacuum gauge which is attached to the condenser end of the two phase closed thermosyphon.

3. RESULTS AND DISCUSSION

3.1 Effect of Thermal Resistance

![Fig. 1 Schematic diagram of experimental setup](image1)

![Fig. 2 Thermocouple locations](image2)

![Fig. 3 Thermal resistance distribution for various heat input for 15° inclination](image3)
The thermal resistance of the thermosyphon is calculated by using the following expression:

\[ R = \frac{(T_w - T_{wc})}{Q_i} \]  

(1)

Fig. 3 to 8 shows the effect of heat input on thermal resistance of two phase closed thermosyphon at various angle of inclinations for both de-ionized water and aqueous solution of n-butanol. It is clear from the figures that the thermal resistance of two phase closed thermosyphon gets deteriorated for both working fluids when the angle of inclination and heat input increases. This is a typical characteristic of the thermosyphon in which evaporation takes place on the surface of a liquid pool in low heat flux and nucleate boiling in a higher heat flux. As a result of it, thermal resistance drastically reduces with higher heat input [9]. At lower inclination of thermosyphon and higher heat input, the difference between the thermal resistance of de-ionized water and aqueous solution of n-butanol is nearly 20%, whereas at lower heat input their difference is nearly 35%. The thermal resistance of aqueous solution of n-butanol is less than the de-ionized water for all the variables.

### 3.2 Effect of Boiling Heat Transfer Coefficient

The boiling heat transfer coefficient for various heat flux at 15° inclination is shown in Fig. 9.
The heat transfer capacity of evaporator section for two phase closed thermosyphon is determined by heat transfer coefficient $h_e$ which is evaluated by using the following equation [3]

$$h_e = \frac{Q_{av}}{\pi d_1 L_e (T_{we} - T_v)}$$  \hspace{1cm} (2)$$

where

$$Q_{av} = \frac{Q_1 + Q_2}{2}$$ \hspace{1cm} (3)

The rate of heat transfer to the evaporator section is obtained from the relation given below [3]

$$Q_1 = I \times V$$ \hspace{1cm} (4)

The rate of heat removal from the condenser section is calculated from the following relation [3]:

$$Q_2 = m \times C_{pl} (T_o - T_i)$$ \hspace{1cm} (5)

Experimental results of DI water and aqueous solution of n-butanol at different heat flux levels in evaporator section are plotted and compared. As shown in the fig. 9 to 14, all values of $h_e$ for the tested two phase closed thermosyphon increase with the increment of heat flux. The heat transfer coefficient of aqueous solution of n-butanol is higher than that of de-ionized water because the aqueous solution of n-butanol has good heat transfer characteristics than the DI water. The heat transfer coefficient of evaporator of aqueous solution of n-butanol is nearly 55% higher than that of DI water in 75° inclination and 80 W heat input.
3.3 Effect of Condensation Heat Transfer Coefficient

The heat transfer capacity of condenser section for two phase closed thermosyphon is determined by heat transfer coefficient $h_c$ which is evaluated by using the following equation [3]

$$h_c = \frac{Q_{av}}{\Pi d_i L_c (T_v - T_{wc})} \quad (6)$$

Experimental results of DI water and aqueous solution of n-butanol at different heat flux levels in condenser are plotted and compared. As shown in the fig. 15 to 20, all values of $h_c$ for the tested two phase closed thermosyphon increases with the increment of heat flux. The heat transfer coefficient of aqueous solution of n-butanol is higher than that of de-ionized water. The heat transfer coefficient of condenser section is slightly lower than that of the heat transfer coefficient of evaporator section for all the variables. It is due to the vapour phase of working fluid moving from evaporator section to condenser section through the adiabatic section of the thermosyphon. While moving, it is obvious that the vapour phase of working fluid has an impact over the inner wall of the thermosyphon. Because of this impact filmwise condensation starts in the adiabatic section. It is concluded that the rate of heat transfer is reduced due to this filmwise condensation which occurs before the condenser section. The heat transfer coefficient of condenser of aqueous solution of n-butanol is nearly 32%
higher than that of DI Water in 15° inclination and 80 W heat input.

4. CONCLUSION

The heat transfer performance of two phase closed thermosyphon is analysed experimentally for various angle of inclinations and heat inputs of the de-ionized water and the aqueous solution of n-butanol working fluids. The following conclusions are made from the results obtained:

- Thermal resistance is indirectly proportional to the heat input i.e., thermal resistance decreases with the increase of heat input
- Heat flux has significant effect on the performance of two phase closed thermosyphon. The heat transfer coefficient increases with heat flux
- The boiling heat transfer coefficient is slightly higher than the condensation heat transfer coefficient
- Performance of two phase closed thermosyphon with aqueous solution of n-butanol is better than that of two phase closed thermosyphon with de-ionized water

REFERENCES


