Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

ISSN: 2229-712X

Elixir Mech. Engg. 63 (2013) 18309-18314

Analysis on heat transfer characteristics of inclined two phase closed thermosyphon using aqueous solution of n-hexanol

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ARTICLE INFO

Article history:

Received: 2 September 2013;

Received in revised form:

29 September 2013;

Accepted: 3 October 2013;

Keywords

Heat transfer coefficient,

Overall heat transfer,

Thermal conductance,

Two phase closed thermosyphon.

ABSTRACT

Two phase closed thermosyphon are often used in heat exchanger equipments because of their high heat transfer capabilities without external power requirements. In the current study, the heat transfer characteristics of two phase closed thermosyphon is analysed experimentally for various angle of inclinations and heat inputs. To carry out the experiment, two copper thermosyphons of length 1000 mm, inner diameter 17 mm and outer diameter 19 mm are taken and charged with 60 ml of working fluid with an evaporator length of 400 mm and condenser length of 450 mm. One of the thermosyphon is charged with de-ionized water (DI) whereas the other is charged with aqueous solution of n-hexanol. The heat transfer coefficient of thermosyphon filled with aqueous solution of n-hexanol shows a better result when compared to thermosyphon filled with de-ionized water.

Nomenclature

A_c	Condenser lateral surface (m^2)
A_e	Evaporator lateral surface (m^2)
A	Cross sectional area of thermosyphon (m^2)
h_c	Heat transfer coefficient in condenser ($W/m^2\ °C$)
h_e	Heat transfer coefficient in evaporator ($W/m^2\ °C$)
m	Mass flow rate of water in condenser (kg/s)
C	Thermal conductance (W/K)
C_{pl}	Specific heat of water (J/kg °C)
I	Current (A)
L_e	Length of evaporator section (m)
L_c	Length of condenser section (m)
R	Thermal resistance (K/W)
Q_{av}	Heat transfer rate (W)
Q_1	Inlet heat by evaporation (W)
Q_2	Outlet heat by condensation (W)
T_i	Inlet water temperature of condenser (°C)
T_o	Outlet water temperature of condenser (°C)
T_v	Vapour temperature (°C)
T_{wc}	Average temperature of condenser section (°C)
T_{we}	Average temperature of evaporator section (°C)
U	Overall heat transfer coefficient ($W/m^2\ °C$)
V	Voltage (v)

Introduction

Two-phase closed thermosyphon is a gravity assisted wickless heat pipe. At the bottom there exists a liquid reservoir. The thermosyphon is a heat transfer device with very high thermal conductance and thermal performance. It is a closed container filled with little amount of working fluid. Here, the heat is applied to the evaporator section which is at the lower end of the thermosyphon. Heat supplied in the evaporator section causes the working fluid inside the thermosyphon to vapourize and evaporate. The generated vapour then moves upwards to the condenser section which is at the upper end of the thermosyphon. The condensed liquid goes down along the surface of the tube wall due to gravitational force. The primary benefit of using two phase closed thermosyphon is that further additional mechanical pumping shall not be needed because of which it is cheaper and reliable. 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 its simplicity when compared to other types of heat pipes. In practice, the effective thermal conductivity of thermosyphon exceeds nearly 200–500 times than 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].

M. Premalatha [2] examined the effect of heat transfer characteristics of wickless solar heat pipe for various working fluids and different inclination angles. The better performance of thermosyphon was in the vertical position compared to other range of inclination angles. Qi Baojin [3] investigated experimentally to study the heat transfer characteristics of titanium/water and copper/water two phase closed thermosyphon. Their experiment results 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. In recent days, it was found that the aqueous solutions were dependent of surface tension on temperature without affecting the bulk properties of the liquid.

Oron [4] studied such impact in thin liquid layers. It was noted that only a small amount of the long-chain alcohols, order of 10^{-3} mole per litre, was needed to change the surface tension characteristics of water without affecting other bulk properties of water. Hussain [5] studied the effect of working fluid and mixture ratio of two fluids water and acetone on the performance of wickless heat pipe. From the experiments it was inherited that performance of thermosyphon is more effective when pure

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liquid is used than mixture. Noie [6] probed the heat transfer characteristics of a two phase closed thermosyphon for a range of heat transfer rates, system pressure, aspect ratios and filling ratios. The experimental results of boiling and condensation heat transfer coefficients were compared to the existing correlations. A new correlation was used to predict the boiling heat transfer coefficient.

Wei Guo [7] explored the axial conduction through a thermosyphon wall for two numbers of two phase closed thermosyphon. One of the thermosyphon had a thermal break within the adiabatic section which resisted the axial conduction. It was found that the axial conduction caused an increase in the overall heat transfer coefficient. Janusz [8] studied the heat transfer characteristics of two phase closed thermosyphon heat exchanger where the evaporator part comprised of smooth, corrugated and porous coated tubes. The results indicated that the effective performance was obtained for the evaporator bundle consisted of porous coated tubes than the smooth or corrugated tubes. Amatachaya [9] looked into the thermal performance of two cross sectional geometries of thermosyphon (circular and flat) for various filling ratio, aspect ratio and heat input rates. They inferred from the experiments that the higher average wall temperature in the evaporator section was for a flat thermosyphon than that of circular thermosyphon. It was also observed that the maximum heat input had a notable influence on heat flux for each and every aspect ratio.

Payakaruk [10] conducted experiments to discover out the effect of Bond numbers, Froude numbers, Weber numbers and Kutaleladze numbers on the heat transfer rate and thermal resistance. The thermosyphons used were of copper material and R22, R123, R134a, ethanol and water were used as working fluids. Different filling ratios, aspect ratios were also considered. The experiments were taken for various inclination angles and heat input. It was concluded that the filling ratio has no effect whereas the properties of working fluid affects the heat transfer characteristics. New correlation was employed to predict the heat transfer characteristics. Ku II Han [11] developed a mathematical model to predict the performance of two phase closed thermosyphon with various internal grooves. The experiment was conducted with methanol as the working fluid. The effects of number of grooves, operating temperatures, heat flux, boiling heat transfer characteristics were considered. The boiling heat transfer showed better performance in the thermosyphon having internal grooves than that of plain thermosyphon. Meyer [12] inspected the thermal performance characteristics of two phase closed thermosyphon filled with R134a and Butane as the working fluids. The experiment was taken for different inner diameters, lengths and inclinations. It was brought to a close note that the heat transfer rate reached maximum for a lower temperature difference when the inclination was in vertical position. Abe [13] discussed about the various applications of self rewetting fluids in heat transfer characteristics.

In the present study, two numbers of two phase closed thermosyphon of copper container is taken. The experiments are conducted for different inclinations namely 15^{o}, 30^{o}, 45^{o}, 60^{o}, 75^{o}, 90^{o} and a range of heat inputs as 40W, 60W, 80W, 100W and 120W. The intension of this work is to investigate the heat transfer coefficient and overall heat transfer coefficient of two phase closed thermosyphon using De Ionized water and aqueous solution of n-hexanol.

EXPERIMENTAL SETUP

Fig. 1(a) represents the schematic view of the experimental setup and the locations of the thermocouple are shown in fig. 1 (b). The experimentation is done by taking two numbers of two phase closed thermosyphon. The thermosyphon is of copper container with 1000 mm of total length, 19 mm outer diameter, 17 mm inner diameter and a wall thickness of 1 mm are taken. One of the thermosyphon is charged with 60 ml of De Ionized water and the other with aqueous solution of n-hexanol. The working fluid charged approximately corresponds to the amount required to fill the evaporator section.

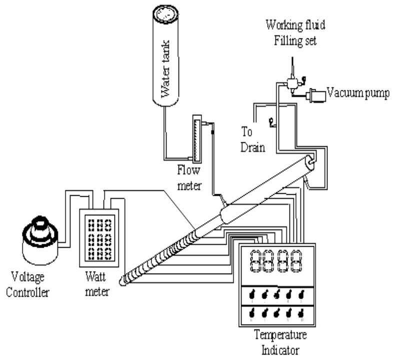

Fig. 1(a) Schematic diagram of experimental setup

The length of the evaporator section, adiabatic section and condenser section are 400 mm, 150 mm and 450 mm respectively. The evaporator section is heated by the electric heater. This is provided by the wattmeter of required power range along with the variac. The necessary heat to be supplied to the electric heater is calculated with an uncertainty of ± 1 W. Six copper constantan (T type) thermocouples with an uncertainty of ± 0.1 °C are used to measure the wall temperature distribution of the two phase closed thermosyphon. In addition to this, three more thermocouples are located in condenser section and one in adiabatic section. The condenser section has an additional concentric tube which is of 34 mm outer diameter and 30 mm inner diameter. This is used as a cooling water jacket to remove the heat from the thermosyphon.

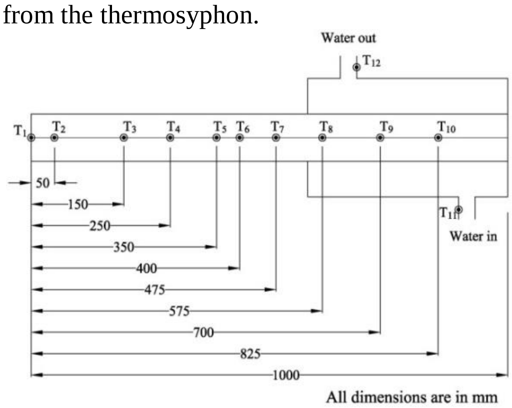

Fig. 1 (b) Thermocouple locations

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 section. Therefore, cooling water is dispersed first through the water jacket before supplying heat to the evaporator section. Flow rate of cooling water from the water tank to the water jacket in the condenser section 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 section and condenser section is negligible. The vacuum pump model BABA – 1- 25 and 0.25 HP is used for evacuating the thermosyphon.

Experimental Procedure

Two identical two phase closed thermosyphons of same dimensions mentioned above are used to conduct the experiment. One of the thermosyphon is charged with de-ionized water and other with aqueous solution of n-hexanol. The thermosyphon is evacuated using the vacuum pump to remove the dissolved gases within it before filling up with the working fluid. 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 40 W, 60 W, 80 W, 100 W and 120 W and for different inclinations of thermosyphon likely 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.

RESULTS AND DISCUSSION

OVERALL HEAT TRANSFER COEFFICIENT

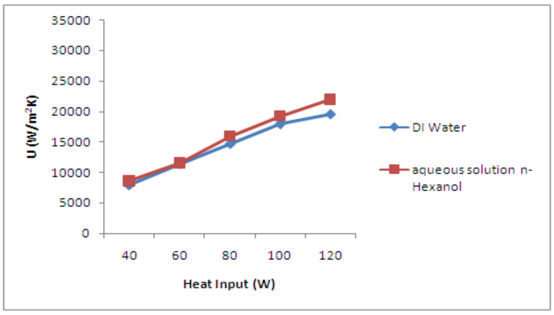

Fig. 2 Overall heat transfer coefficient for various heat input at 15° inclination

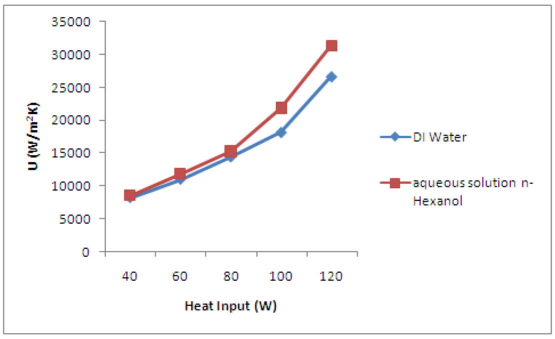

Fig. 3 Overall heat transfer coefficient for various heat input at 30° inclination

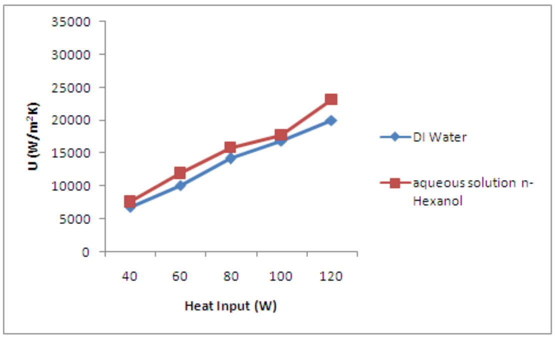

Fig. 4 Overall heat transfer coefficient for various heat input at 45° inclination

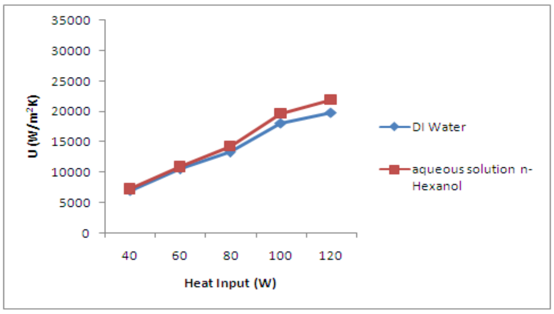

Fig. 5 Overall heat transfer coefficient for various heat input at 60° inclination

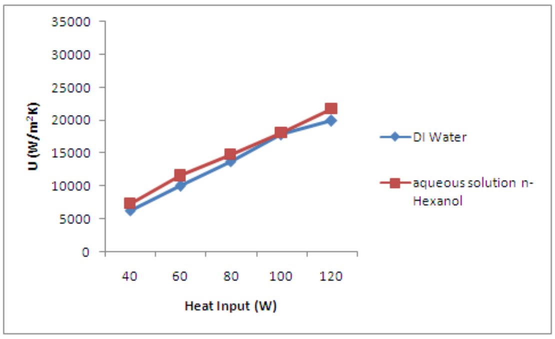

Fig. 6 Overall heat transfer coefficient for various heat input at 75° inclination

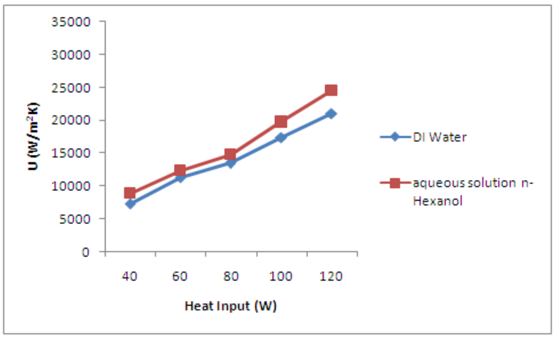

Fig. 7 Overall heat transfer coefficient for various heat input at 90° inclination

The overall heat transfer coefficient of the thermosyphon is calculated by using the following expression [14]

$$U = \frac{Q_1}{A(T_{we} - T_{wc})} \qquad (1)$$

The overall heat transfer coefficient for various input heat transfer rates are studied and evaluated for all the inclinations. Fig. 2 to 7 shows the effect of overall heat transfer coefficient of two phase closed thermosyphon for both de-ionized water and aqueous solution of n-hexanol. The overall heat transfer coefficient ranges around 6200 to 26650 W/m^{2}K when de-ionized water is used as working fluid. When aqueous solution of n-hexanol is used as working fluid, it ranges around 7200 to 31000 W/m^2K. The increase is due to the increased heat transport capacity of the aqueous solution of n-hexanol. The maximum overall heat transfer coefficient is obtained when heat input is 120 W and at vertical direction. The overall heat transfer coefficient of aqueous solution of n-hexanol is higher than the de-ionized water for all the conditions.

Heat transfer coefficient in evaporator section

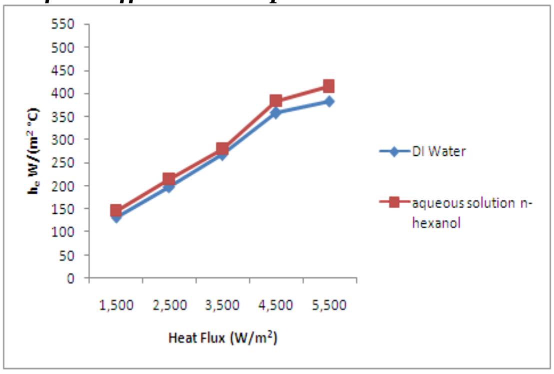

Fig. 8 Evaporator Heat transfer coefficient for various heat flux at 15 ° inclination

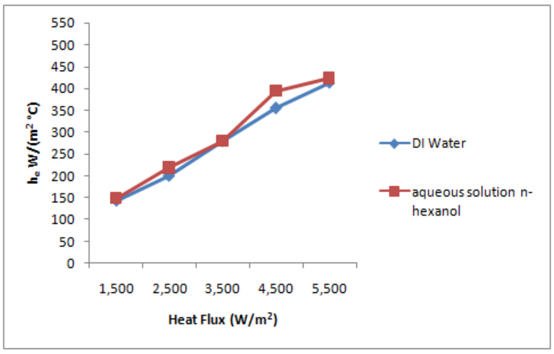

Fig. 9 Evaporator Heat transfer coefficient for various heat flux at 30 ° inclination

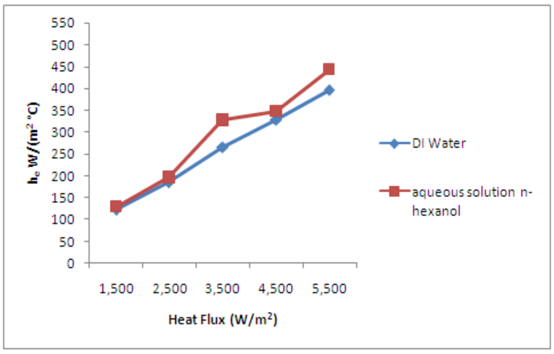

Fig. 10 Evaporator Heat transfer coefficient for various heat flux at 45° inclination

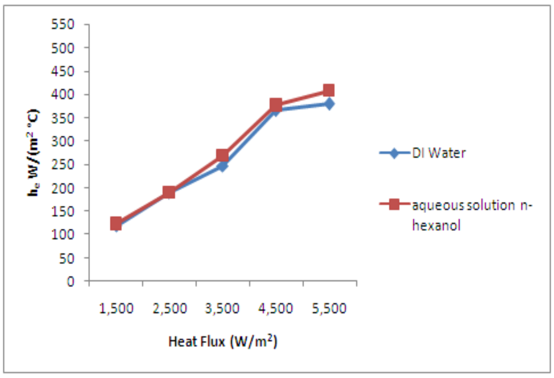

Fig. 11 Evaporator Heat transfer coefficient for various heat flux at 60° inclination

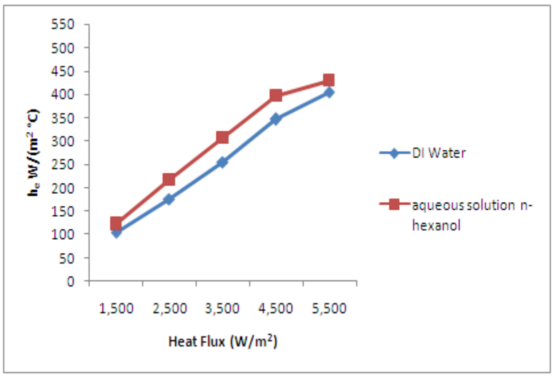

Fig. 12 Evaporator Heat transfer coefficient for various heat flux at 75 ° inclination

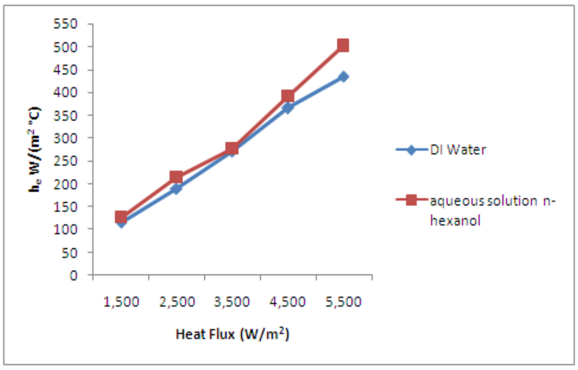

Fig. 13 Evaporator Heat transfer coefficient for various heat flux at 90 ° inclination

The evaporator heat transfer coefficient for two phase closed thermosyphon is determined by heat transfer coefficient h_e from the measured data of wall temperature and vapour temperature. The evaporator heat transfer coefficient of the section is calculated by using the following equation [3]

$$h_e = \frac{Q_{av}}{A_e\,(T_{we} - T_v)} \qquad (2)$$

where

$$Q_{av} = \frac{Q_1 + Q_2}{2} \qquad (3)$$

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

$$Q_1 = I \quad V \qquad (4)$$

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

$$Q_2 = m\, C_{pl}\,(T_o - T_i) \qquad (5)$$

Fig. 8 to 13 depicts the evaporator heat transfer coefficient for two phase closed thermosyphon which is determined by the h_e from the measured data of wall temperature and vapour temperature (equivalent to the wall temperature of adiabatic section). All the values of h_e for two phase closed thermosyphon increases with increment of heat flux. The heat transfer coefficient of aqueous solution of n-hexanol is higher than that of de-ionized water because aqueous solution of n-hexanol has good heat transfer characteristics than the DI water. The maximum heat transfer coefficient of evaporator of aqueous solution of n-hexanol obtained is 503 W/m^2C when the power input is 120 W and at angle of inclinations 90°.

Heat transfer coefficient in the condenser section

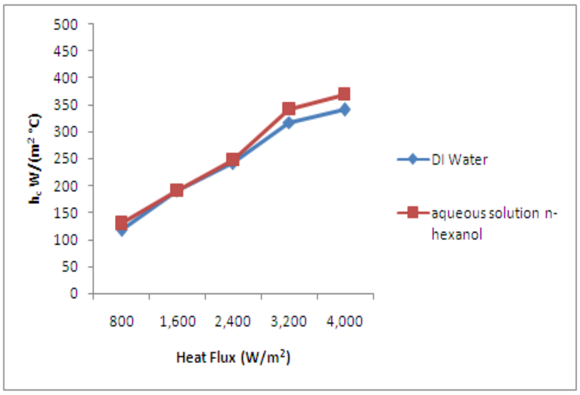

Fig. 14 Condenser Heat transfer coefficient for various heat flux at 15° inclination

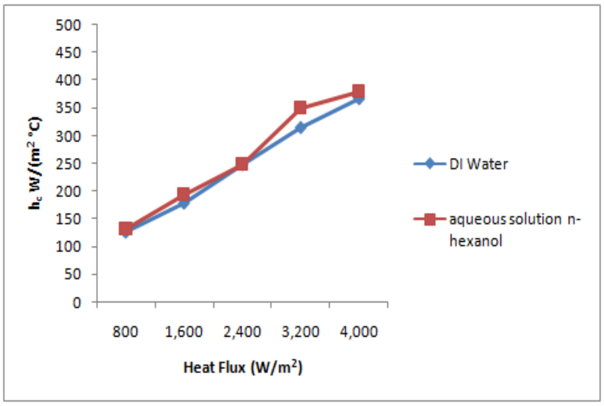

Fig. 15 Condenser Heat transfer coefficient for various heat flux at 30° inclination

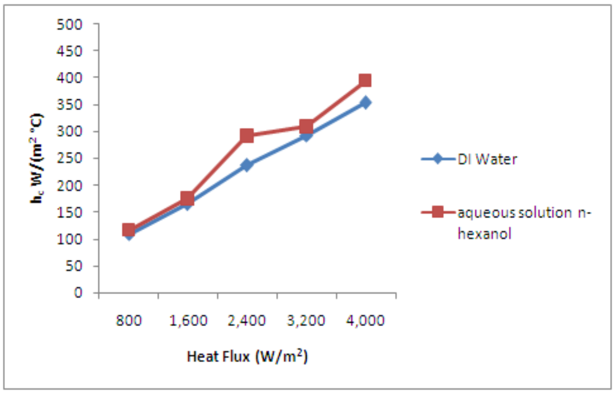

Fig. 16 Condenser Heat transfer coefficient for various heat flux at 45° inclination

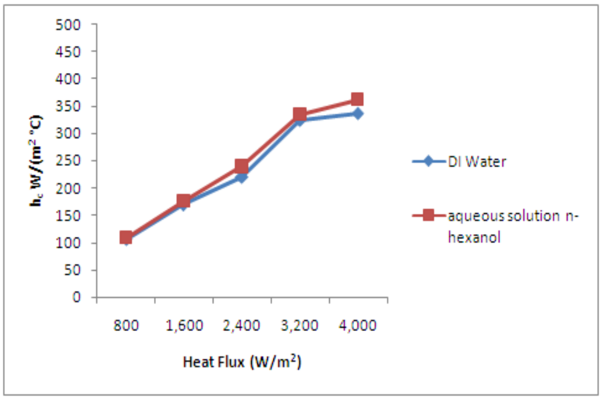

Fig. 17 Condenser Heat transfer coefficient for various heat flux at 60° inclination

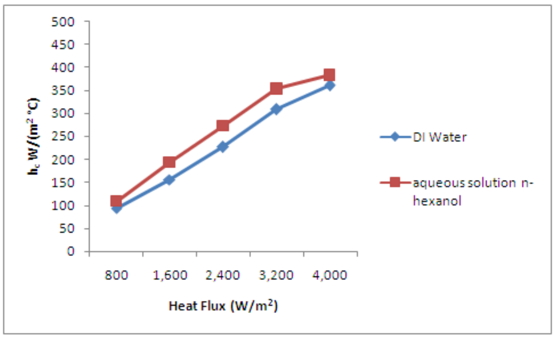

Fig. 18 Condenser Heat transfer coefficient for various heat flux at 75° inclination

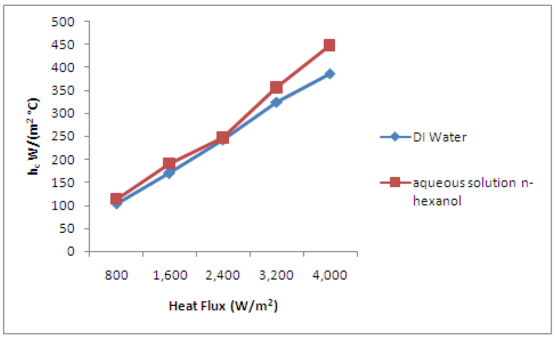

Fig. 19 Condenser Heat transfer coefficient for various heat flux at 90° inclination

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

$$h_c = \frac{Q_{av}}{A_c\,(T_v - T_{wc})} \tag{6}$$

The experimental results of DI water and aqueous solution of n-hexanol at different heat flux levels in condenser section are plotted and compared. As shown in the fig. 14 to 19, all the 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-hexanol is higher than that of de-ionized water. Since the vapour phase of working fluid moves from evaporator section to condenser section through the adiabatic section of the thermosyphon, the heat transfer coefficient of condenser section is lower than that of the heat transfer coefficient of evaporator section for all the variables to some extent. It is noticable that the vapour phase of working fluid has an impact over the inner wall of the thermosyphon when moving and due to this impact, filmwise condensation starts in the adiabatic section. As a result of it, the rate of heat transfer is reduced before the condenser section. The maximum condenser heat transfer coefficient of aqueous solution of n-hexanol obtained is nearly 447 W/m^{2}C when the heat input is 120 W and at angle of inclination 90°.

Thermal Conductance

The thermal conductance C is evaluated by the equation given below [15]

$$C = \frac{1}{R} \tag{7}$$

where

$$R = \frac{(T_{we} - T_{wc})}{Q_1} \tag{8}$$

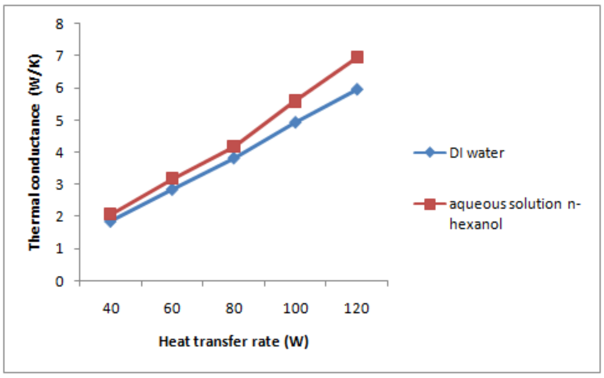

Fig. 20 Thermal conductance distribution for various heat input at 90° inclination

The heat transfer characteristics of two phase closed thermosyphon shows better results for 90° angle of inclination. Fig. 20 shows the thermal conductance for deionized water and aqueous solution of n-hexanol at 90° angle of inclination. The thermal conductance gets progress for both the working fluids with increase of heat input. The maximum thermal conductance acquired is nearly 7 W/K which is for aqueous solution of n-hexanol at 120 W.

CONCLUSION

The heat transfer characteristics of two phase closed thermosyphon is analyzed experimentally for a range of inclinations and heat inputs of the de-ionized water and the aqueous solution of n-hexanol working fluids. The conclusions of this study can be summarized as follows:

- Overall heat transfer coefficient of two phase closed thermosyphon increases with increase of heat input for both the working fluids and the maximum is obtained for aqueous solution of n-hexanol
- Effect of heat flux has more impact on the performance of two phase closed thermosyphon. When the heat flux increase, the heat transfer coefficient also increases
- The condensation heat transfer coefficient is slightly lower compared to that of the boiling heat transfer coefficient
- Thermal conductance is directly proportional to the heat input i.e thermal conductance increases with increase of heat input
- Two phase closed thermosyphon with aqueous solution of n-hexanol has better performance than the deionized water

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