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PERFORMANCE INVESTIGATION OF ELLIPTICAL THERMOSYPHON WITH DIFFERENT WORKING FLUID AND FILL VOLUME AT VERTICAL POSITION

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ABSTRACT
A utilization of thermal energy via effective heat transfer device is most important task in the today modern era. Due to very high thermal conductivity two phase closed thermosyphon has proven as effectual tool to transfer the thermal energy. In current work the thermal performance of vertically orientated elliptical geometry two phase closed thermosyphon was investigated for different working fluid and fill volume. Thermosyphons are manufactured of commercial stainless steel tube with 2.54 cm OD and 2.24 cm ID and deformed to have elliptical cross section of 3.0 x 1.9 cm using special dies. During the experimentation acetone, methanol ethanol and water are used as working fluid with fill volume of 8, 10, 12 and 14 cc. Fill volume and type of working fluid has significant impact on the performance of thermosyphon. Experimental results indicate that wall temperature along the length of acetone charged thermosyphon was higher as compared with other working fluids. The 10 cc water charged thermosyphon shows 21% and 24% increase in heat transfer rate compared with acetone charged thermosyphon at 450 W and 650 W heat input respectively.

Keywords: Thermosyphon, Working Fluid, Wall Temperature, Fill Volume

INTRODUCTION
Energy is one of important factor of present epoch. A proper utilization of thermal energy via effective heat transfer effective device is also significant as being saving of electrical energy. For enhancement of heat transfer a variety of passive and active augmentation techniques are used. The introduction of heat pipe was first conceived in 1942.[1] In two phase closed thermosyphon heat transfer occurs as a result of evaporation and condensation of working fluid. Due to very high thermal conductivity two phase closed thermosyphon is proven as the effectual tool to transfer the thermal energy.

Jouhara and Robinson [3] investigated performance of small diameter two phase closed thermosyphon charged with water, FC-84, FC-77 and FC-3283 as working fluid. The water charged thermosyphon indicates better performance in terms of thermal resistance and maximum heat transport capabilities. Sarafraz et al. [6] examined nanofluid fouling effect on thermal performance of a thermosyphon. Instabilities in performance over the time are observed due to fouling on wick structure and internal wall of evaporator with water-based TiO_2 nanofluid. Lataoui and Jemni [7] investigated heat transfer characteristics of stainless steel two phase closed thermosyphon. Water, ethanol and acetone are used as working fluid. Experimental evaporator heat transfer coefficient obtained for ethanol charged stainless steel thermosyphon closely matches with predicated evaporator heat transfer coefficient. Whereas reasonable agreement between experimental and predicated evaporator heat transfer coefficient was obtained for stainless steel thermosyphon charged with water and acetone as working fluid. Alammar et al. [8] found that geyser boiling phenomena occurs for shorter duration in the high fill ratio water charged copper two phase closed thermosyphon as compared with small fill ratios thermosyphon. Kim et al. [9] studied the performance of water charged copper two phase closed thermosyphon for different inclination angles and filling ratios. A best thermal performance for two phase closed thermosyphon was obtained at 30º inclination angle and 50% filling ratio. Das et al. [10] observed lower temperature distribution along the wall of graphene nanofluid charged two phase closed thermosyphon as compared to deionised water charged thermosyphon. It was also observed that for both the working fluids thermal resistance of two phase closed thermosyphon reduces with increase in the power input irrespective of the inclination angle. Gallego et al. [11] examined the thermal performance of glass thermosyphon charged with Al_2O_3-water based nanofluids. As compared with water, the efficiency of two phase closed thermosyphon improved up to 14.8% due to use of Al_2O_3 nanofluids at 0.1 weight concentration, 45% filling ratio and 60 W power input. Kaya Metin [12] investigated thermal performance of copper two phase closed thermosyphon using nanofluid containing CuO nanoparticles. The performance enhancement of two phase closed thermosyphon was observed due to the use of CuO/water nanofluids as compared with pure water. For weight concentration of 1% CuO/water nanofluids, approximately 10% enhancement was observed. While for 2% CuO/water nanofluids, approximately 18.5% enhancement was observed. Robinson [13] observed failure of the sapphire tube thermosyphon charged with water as working fluid, due to liquid hold-up in the condenser section and subsequent falling liquid film and evaporator dryout. Qian et al. [14] investigated thermal performance of carbon steel two phase closed thermosyphon charged with single and hybrid nanofluids. The best thermal performance was obtained for hybrid nanofluid of 25% Al_2O_3 + 75% TiO_2 –H_2O and single nanofluid TiO_2 –H_2O as compared with distilled water. Suresh kumar et al. [15] observed that for different heat inputs, efficiency of the two phase closed thermosyphon increases due to the use of Al_2O_3/water nanofluid as compared with distilled water. Choi and Lee [16] investigated thermal performance of copper thermosyphon with cellulose nanofiber fluid as the working fluid. Due to use of nanofiber fluid a minimum improvement of 14.3% was observed in the critical heat flux whereas boiling heat transfer coefficient improved by up to 71.74%, as compared with water. Kim et al. [17] examined flow visualization and heat transfer in the two phase closed thermosyphon charged with water, acetone, and HFE7100 as working fluid. A semi-cylindrical channel was made of a copper block and the flat face of the channel was covered with Pyrex glass to observe behavior of the working fluid inside the two phase closed thermosyphon. Due to increase in the heat flux, a local dry-out was observed for water. The entrainment was observed for HFE7100. The condensation heat transfer coefficient for water was higher as compared with acetone and HFE7100. Beal et. Al [18] observed that thermal resistance of two phase closed thermosyphon reduces due to decrease in the surface tension of working fluid.

The literature indicates that predominance work has been performed to investigate thermal performance of circular cross section geometry thermosyphon. Whereas still relatively limited amount of work was observed on different geometries two phase closed thermosyphon such as elliptical, semi-circular, flat etc. It was also observed that converting the circular geometry into elliptical increases surface area to volume ratio and hence improves the performance of thermosyphon. The present works aims to evaluate thermal performance of elliptical thermosyphon at vertical position using different working fluid.

EXPERIMENTAL WORK

An experimental setup has been prepared to evaluate thermal performance of stainless steel two phase closed thermosyphon. Figure 1 shows schematic experimental setup. It consists of two phase closed thermosyphon under test, heater, constant level water tank, cooling water flow circuit and instrumentation. Thermosyphons are manufactured from stainless steel tube with 2.54 cm OD and 2.24 cm ID. To obtain elliptical cross section of 3.0 x 1.9 cm, these thermosyphons are deformed with special dies. The working length of each thermosyphon was 0.8 cm. Length of evaporator and condenser section was 0.35 cm, whereas the length of adiabatic section was 0.1 cm. A condenser section of thermosyphon was surrounded by stainless steel water cooling jacket. A 1000 W electrical heater was used to supply the heat input at evaporator section. Electrical power input to the heater was controlled via variable voltage transformer with an accuracy ± 1%. A 40 mm thick glass wool was provided around evaporator, adiabatic and condenser section as an insulation to avoid the heat loss to the surrounding.

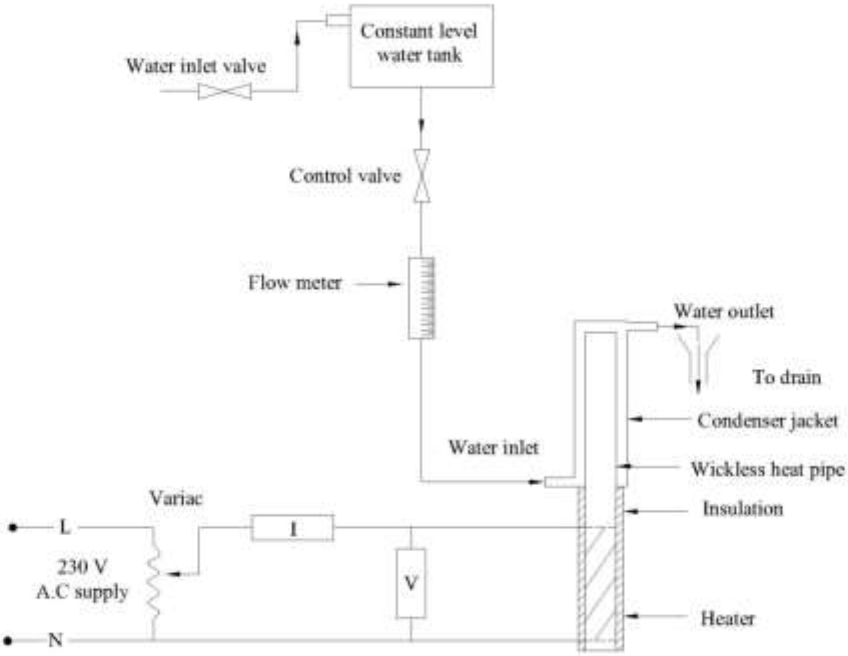

Figure 1 Schematic Diagram of Experimental Setup

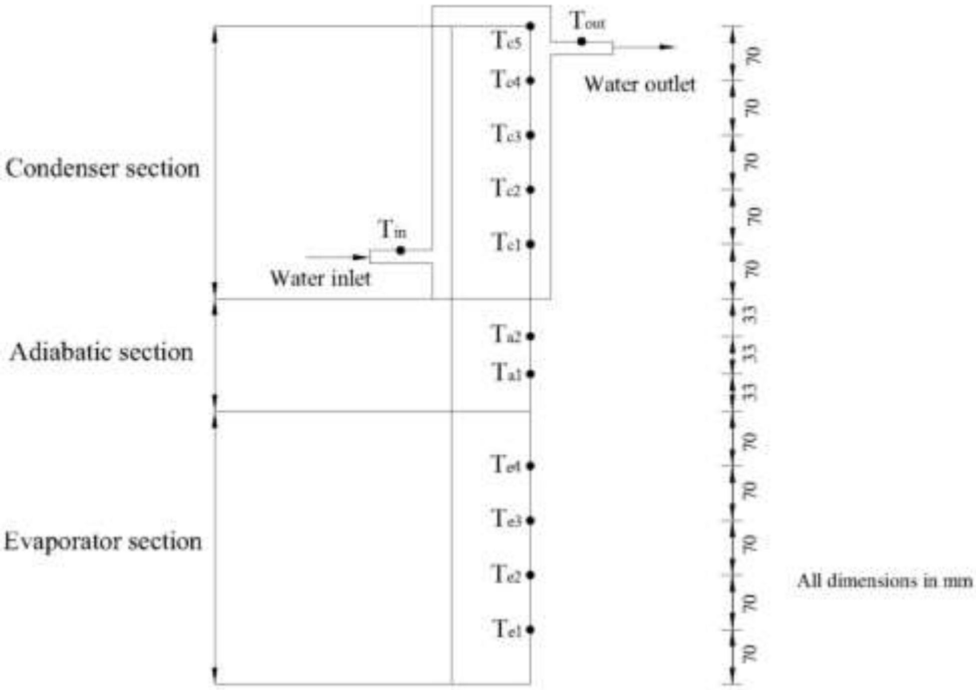

Figure 2 Locations of Thermocouples

The temperature distribution along the length of the thermosyphon was recorded by PT 100 thermocouples with an accuracy ±0.1°C. Figure 2 shows locations of thermocouples. Eleven thermocouples are used to measure the surface temperature of thermosyphon. Two separate

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thermocouples are used at inlet and outlet of condenser section to measure the temperatures of cooling water supplied to condenser jacket with accuracy ±0.1 °C. The cooling water to the jacket was supplied from a constant head water reservoir tank measured by Rotameter (Eureka 0.2-1.6 l/min, with ± 3% accuracy). The coolant water flow rate was kept constant.

The uncertainty existing in heat input to evaporator, temperature recording and heat flow rate at condenser are determined by equation (1), (2) and (3) respectively.

$$\frac{\delta P}{P} = \sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2} \tag{1}$$

$$\delta_{\nabla T} = \sqrt{\left(\frac{\partial \Delta T}{\delta T_1}\delta T\right)^2 + \left(\frac{\partial \Delta T}{\delta T_2}\delta T\right)^2} \tag{2}$$

$$\frac{\delta Q_c}{Q_c} = \sqrt{\left(\frac{\delta \dot{m}_w}{\dot{m}_w}\right)^2 + \left(\frac{\delta \Delta T}{\Delta T}\right)^2} \tag{3}$$

Fixed Parameters:

Material of thermosyphon : Stainless Steel

Evaporator length : 0.350 cm

Adiabatic length : 0.100 cm

Condenser length : 0.350 cm

Coolant mass flow rate : 30 lit/hr.

Variable Parameters:

Working Fluid: Water, Ethanol, Methanol and Acetone

Fill volume : 8cc, 10 cc, 12 cc and 14 cc

Heat input : 450 W and 650 W

RESULTS AND DISCUSSION

A series of experimentation are carried out to record temperature response along the outside wall surface of thermosyphon. The temperature was also recorded at inlet and outlet of the condenser cooling jacket for analyzing the performance of elliptical two phase closed thermosyphon.

- *Temperature Distribution along the Outside Wall Surface*

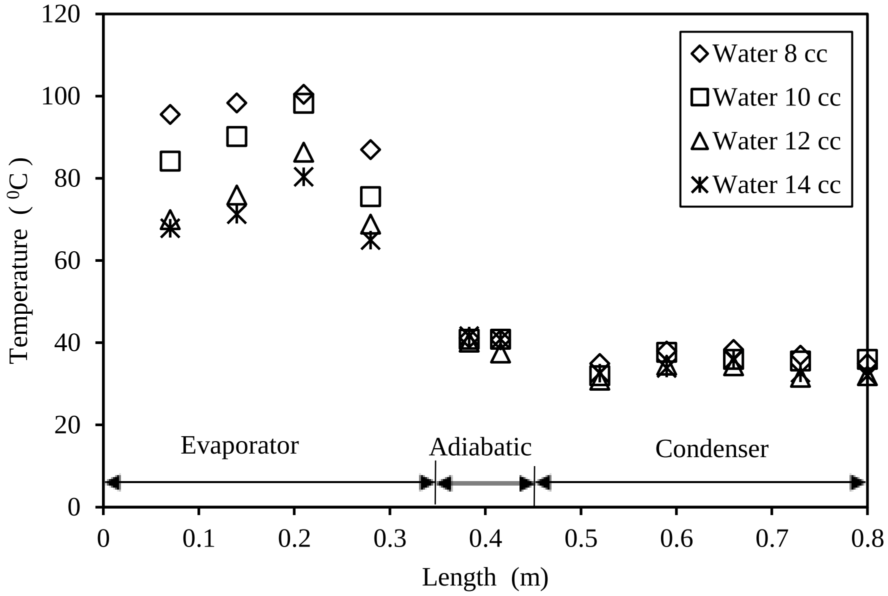

Figure 3 Temperature distributions along the outside wall surface for water at 450 W

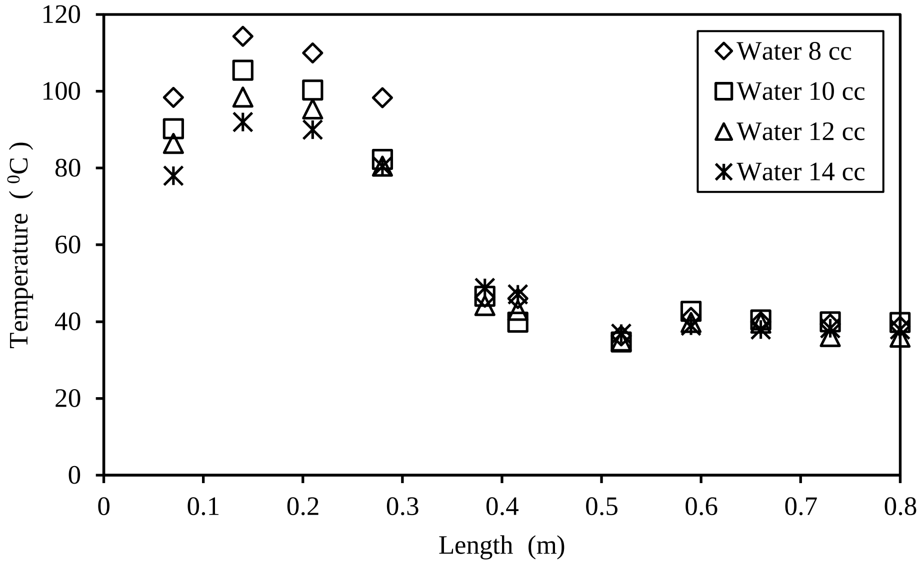

Figure 4 Temperature distributions along the outside wall surface for water at 650 W

Figure 3 and 4 represents variation of temperature along the length of thermosyphon with water as working fluid. It was observed that wall temperature increases as the fill volume decreases. For a small fill volume evaporation rate of working fluid increases, tends to increase the wall temperature. In adiabatic section almost isothermal behavior was observed for all the fill volume. An insulation provided at adiabatic section avoid the heat loss to surrounding, hence no heat is added or rejected in adiabatic section results in constant temperature. In condenser section, wall temperature increases towards the end where the coolant outlet pipe was located. The increase could be due to the gain of heat by coolant water flowing from inlet to outlet section of condenser. For circular geometry water charged wickless heat pipe similar trends have been reported by Jouhara and Robinson [3], Kannan and Natarajan [4], Alzadehdakhel et al. [5].

The temperature distributions along the wall surface of ethanol charged thermosyphon is as shown in figure 5 and figure 6. Due to heat supply, maximum temperature was observed in the evaporator section of thermosyphon for all fill volume. Similar to water charged thermosyphon, almost isothermal behavior was observed in the adiabatic section, while in the condenser section wall temperature increases towards the end of thermosyphon.

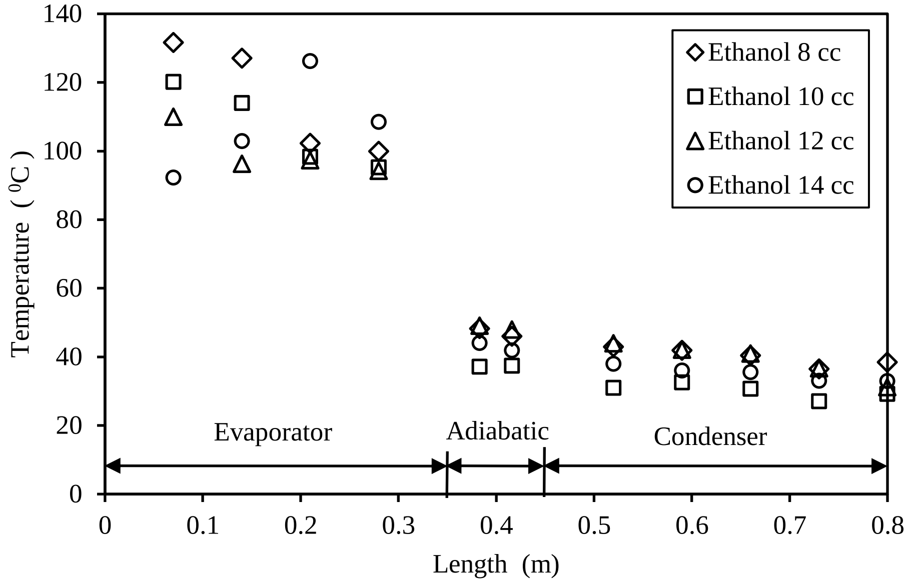

Figure 5 Temperature distributions along the outside wall surface for ethanol at 450 W

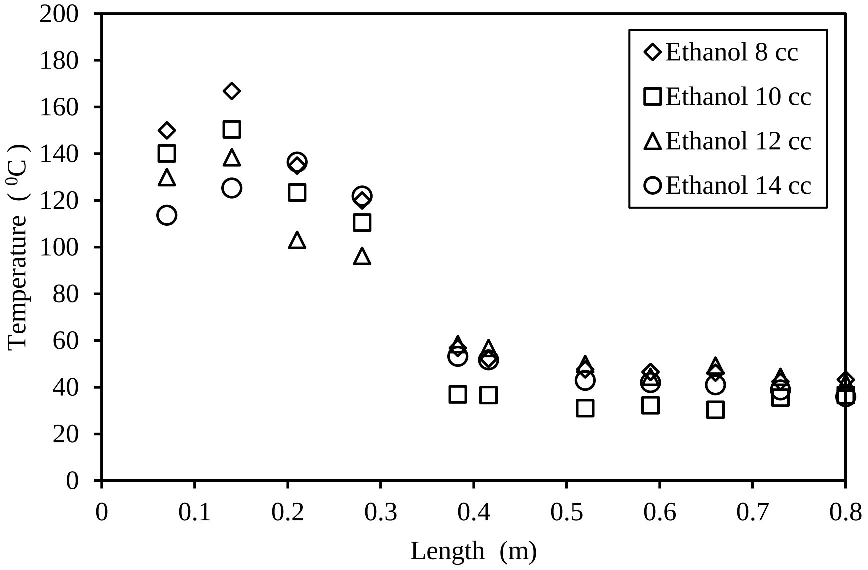

Figure 6 Temperature distributions along the outside wall surface for ethanol at 650 W

The 8 cc ethanol thermosyphon indicates maximum temperature in the evaporator section at the heat input of 650 W. Dry out effect was observed for 8 cc ethanol charged thermosyphon at 650 W heat input results higher wall temperature in the evaporator section of thermosyphon. Due to the dry out lower wall temperatures was observed in the condenser section, that result decrease in the thermal performance of thermosyphon.

Figure 7 and 8 shows temperature distributions along the wall surface of methanol charged thermosyphon. A methanol charged thermosyphons indicates higher wall temperature compared with water charged thermosyphons for same heat input. Latent heat of methanol is less than water results in increased wall temperature. For small fill volume (8 cc) thermosyphon dry out of evaporator section was observed at 650 W heat input results in the increased temperature at evaporator section. The condensate from condenser section was not able reach to the evaporator section within the required duration due to resistant of vapour formed in evaporator section tends to results in dry out at evaporator. For circular geometry wickless heat pipe with methanol as a working fluid similar trend has also been reported by Cho and Han [2].

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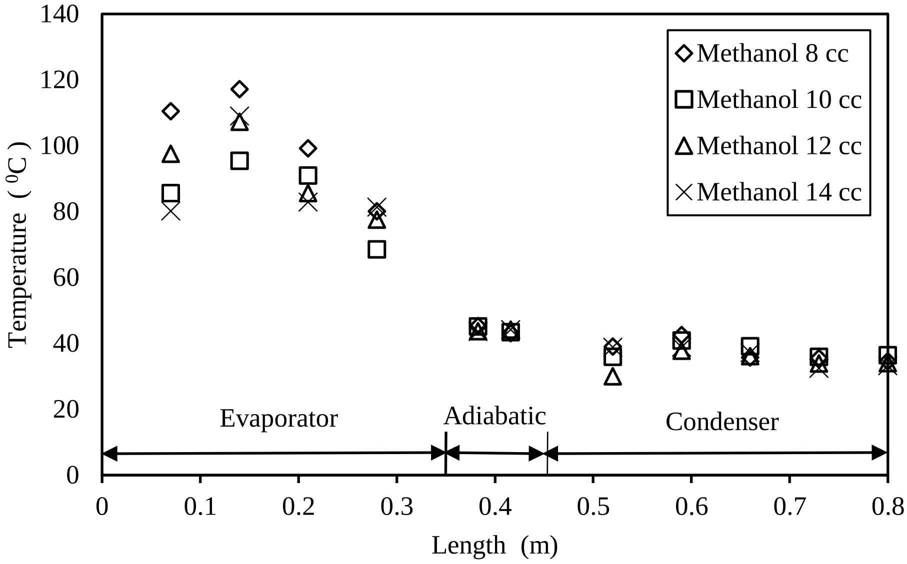

Figure 7 Temperature distributions along the outside wall surface for methanol at 450 W

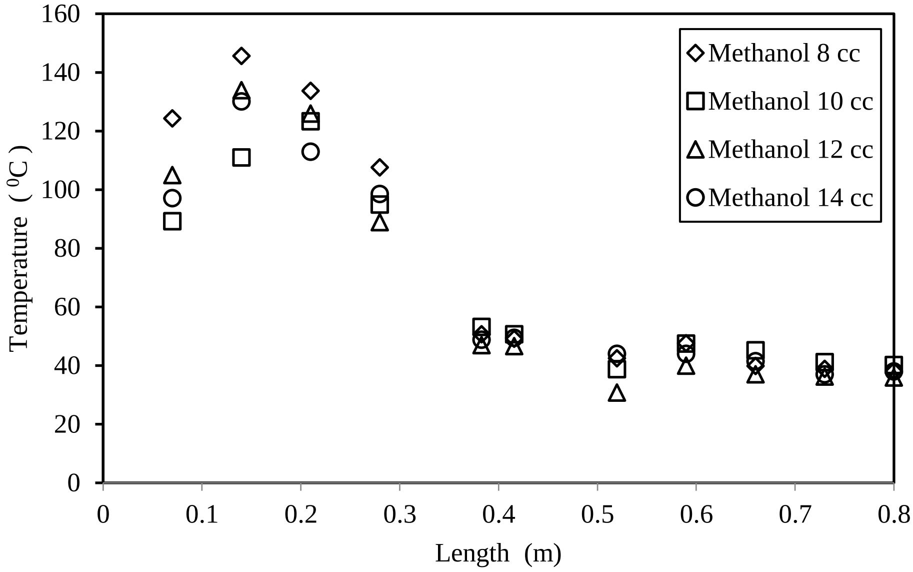

Figure 8 Temperature distributions along the outside wall surface for methanol at 650 W

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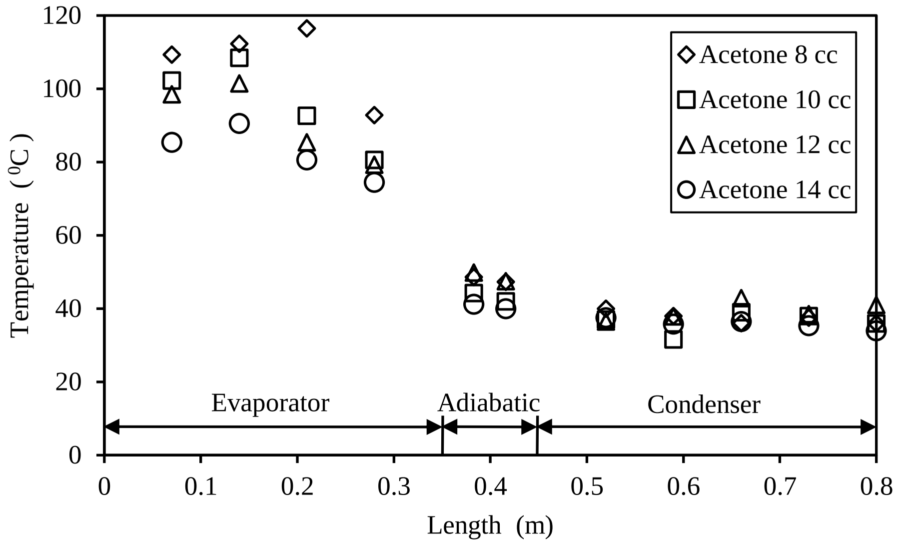

Figure 9 Temperature distributions along the outside wall surface for acetone at 450 W

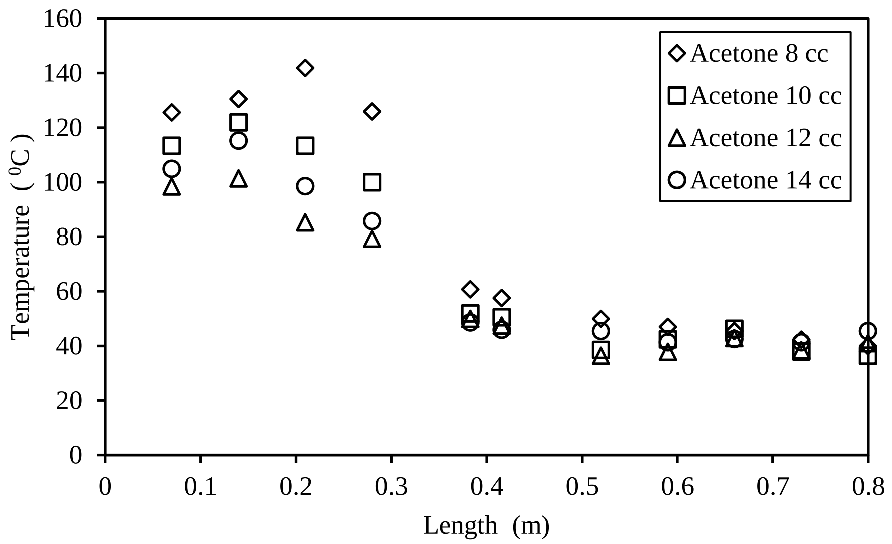

Figure 10 Temperature distributions along the outside wall surface for acetone at 650 W

A variation of temperature along the length of thermosyphon with acetone as working fluid is shown in figure 9 and figure 10. The wall temperatures in acetone charged thermosyphon was higher as compared with other working fluids. A lower latent heat of vaporization of acetone compared with water, ethanol and methanol results in higher wall temperatures. For 8 cc and 10 cc thermosyphon dry out condition is observed due to higher wall temperature.

- *Effect of fill volume on heat transfer rate at condenser section*

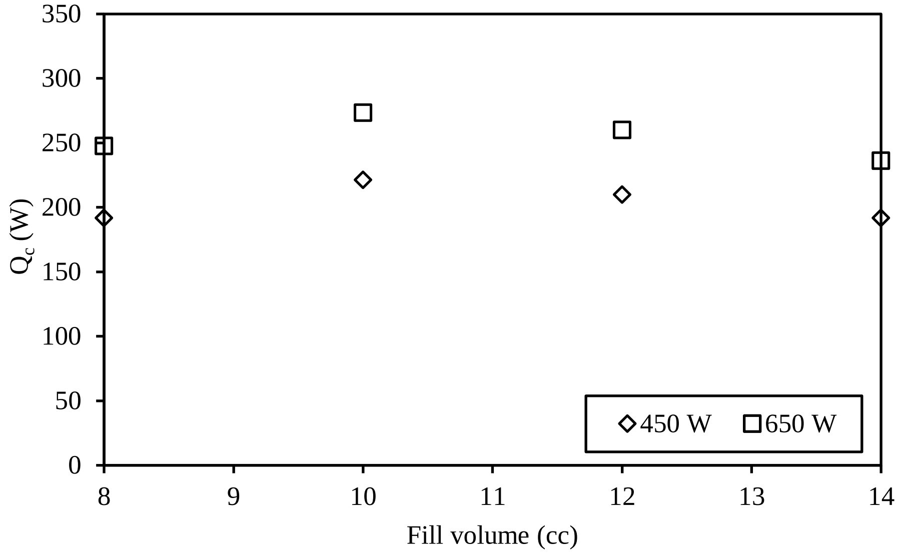

Figure 11 Condenser heat transfer rate at different fill volume for water charged thermosyphon

Figure 11 represents condenser heat transfer rate for water charged thermosyphon at different fill volume. The increase in heat input also increases the heat transfer rate at condenser section. Water charged thermosyphon indicates maximum condenser heat transfer rate at 10 cc fill volume. For higher fill volumes flooding may occur in the thermosyphon results in the decrease of condenser heat transfer rate. While at low fill volume of 8 cc, the dry out condition may occur in the thermosyphon results in the decrease of condenser heat transfer rate. Fill volume of 10 cc, was observed to be optimum fill volume for water charged thermosyphon where maximum condenser heat transfer rate occurs at both the heat inputs.

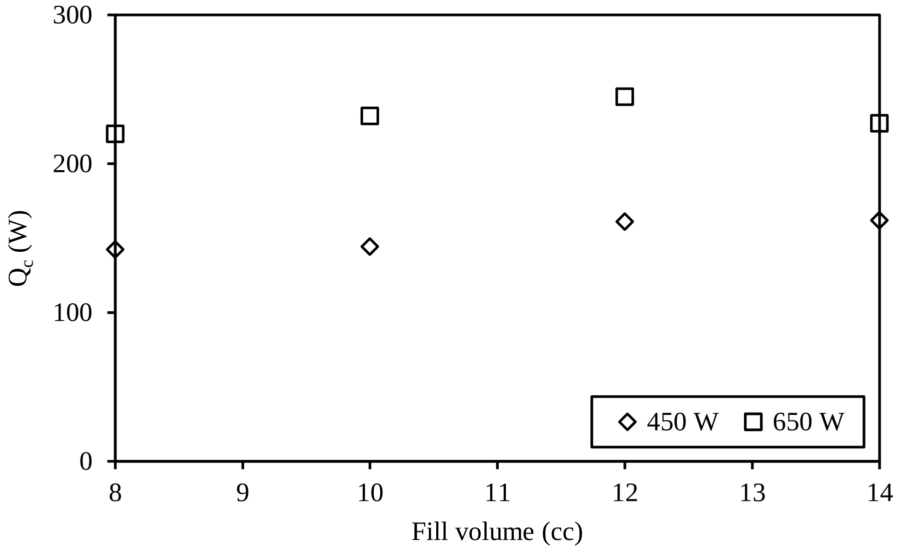

Figure 12 Condenser heat transfer rate at different fill volume for ethanol charged thermosyphon

Condenser heat transfer rate at different fill volume for ethanol charged thermosyphon is as shown in figure 12. A heat transfer rate at condenser section increases with increase in the fill volume up to 12 cc, further increase in the fill volume reduces the condenser heat transfer rate. Similar to water charged thermosyphon flooding and dry out may occur in the 14 cc and 8 cc ethanol charged thermosyphon respectively, results in the reduced heat transfer rate. For both the heat inputs similar trend was obtained.

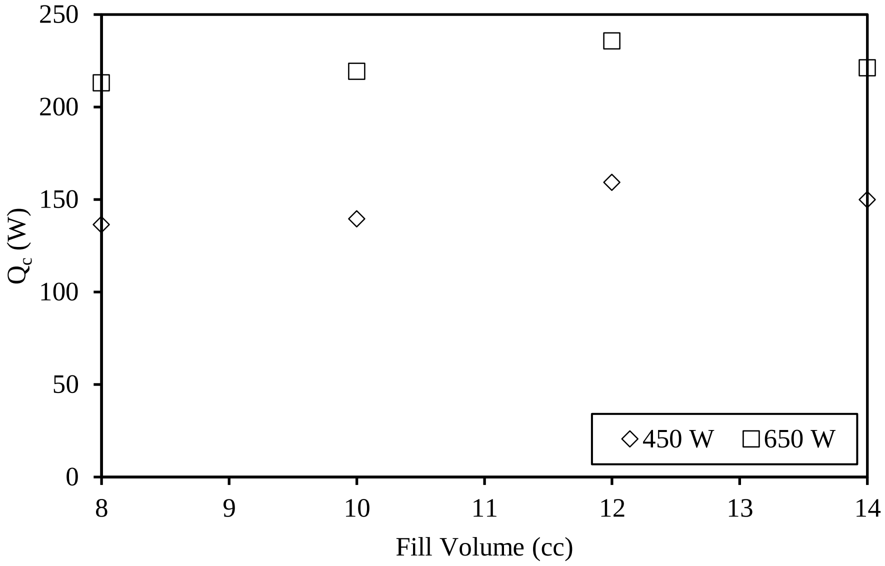

Figure 13 Condenser heat transfer rate at different fill volume for methanol charged thermosyphon

Figure 13 represents condenser heat transfer rate for methanol charged thermosyphon at different fill volume. As thermo-physical properties of ethanol and methanol closely matches, a trend of curve obtained for methanol charged thermosyphon was almost similar ethanol charged thermosyphon. Fill volume of 12 cc was observed to be optimum fill volume for methanol charged thermosyphon where maximum condenser heat transfer rate occurs at both the heat inputs.

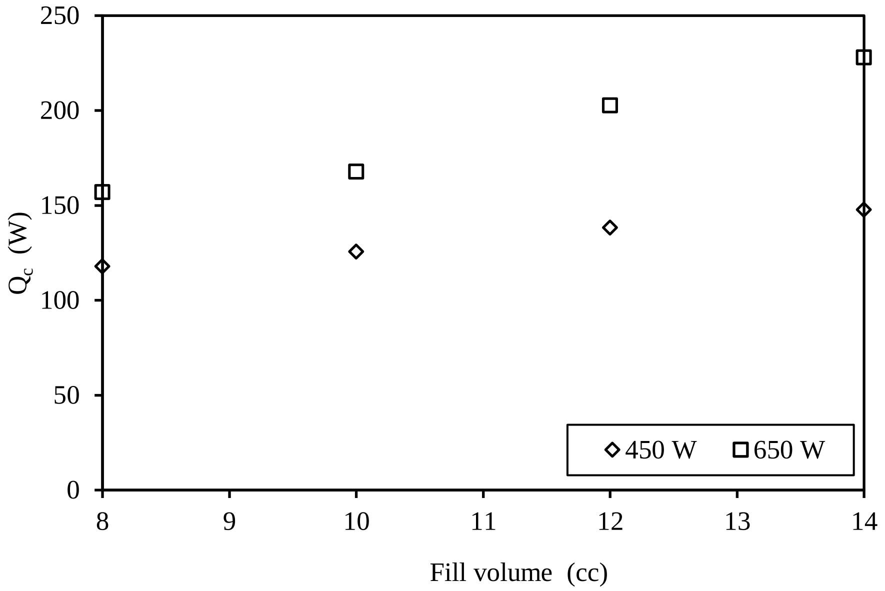

Figure 14 Condenser heat transfer rate at different fill volume for acetone charged thermosyphon

Condenser heat transfer rate at different fill volume for acetone charged thermosyphon is as shown in figure 14. A heat transfer rate at condenser section increases with increase in the fill volume. Similar trend was observed for both the heat inputs. Fill volume of 14 cc was observed to be optimum fill volume for acetone charged thermosyphon where maximum condenser heat transfer rate occurs.

- *Heat transfer rates at condenser for different working fluids*

The thermal performance of thermosyphon for different working fluids is as shown in figure 15 and figure 16. A heat transfer rate for water charged thermosyphon was found to be higher as compared with other working fluids. The latent heat of vaporization for water is higher as compared with other working fluid leads to absorb more amount heat in the evaporator section for the same heat input. Whereas due to lower latent heat of vaporization, minimum heat transfer rate was observed for acetone charged thermosyphon. A heat transfer rate of ethanol and methanol charged thermosyphon closely matches with each other due to their thermo-physical properties.

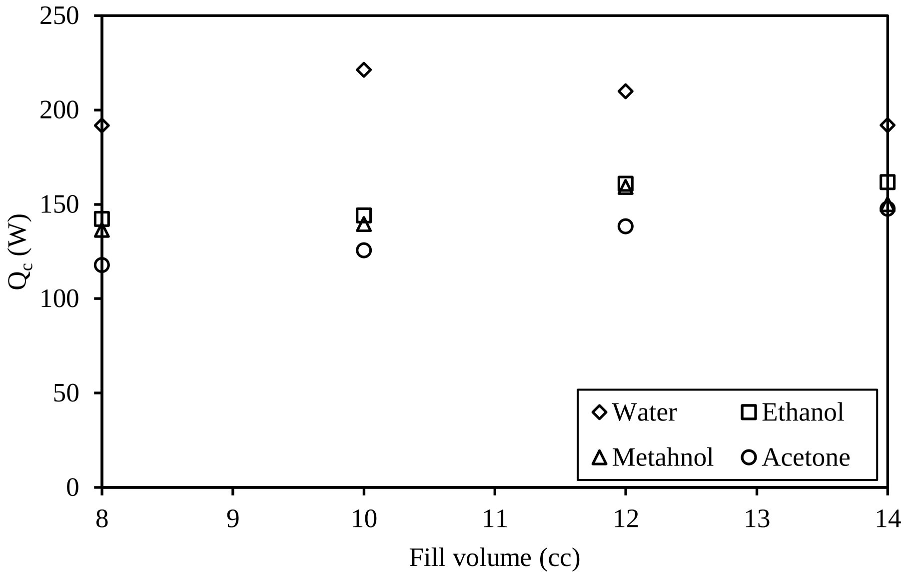

Figure 15 Effect of working fluid on heat transfer rate at 450 W

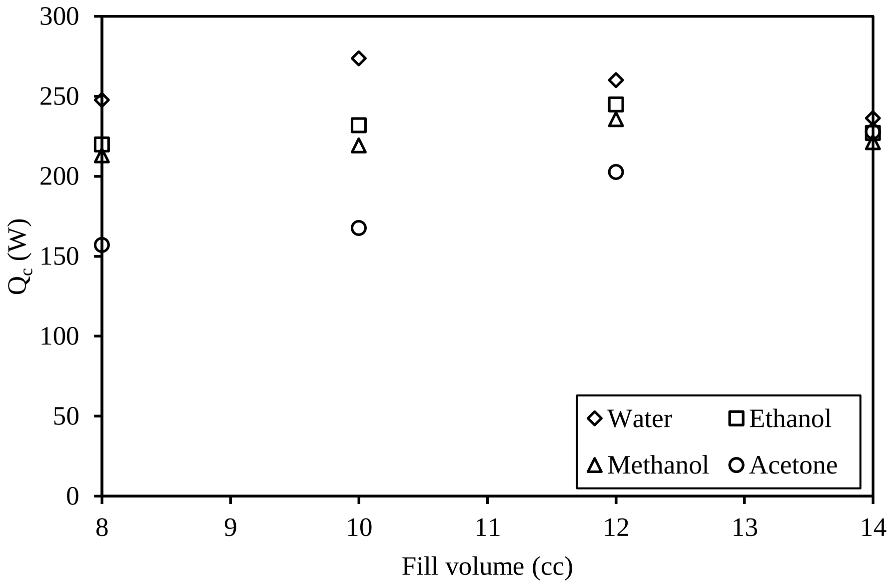

Figure 16 Effect of working fluid on heat transfer rate at 650 W

CONCLUSIONS

The experimental set up was prepared to evaluate the thermal performance of elliptical two phase closed thermosyphons. The series of experiments were performed and following conclusions were drawn:

1) Fill volume and type of working fluid has significant impact on the performance of thermosyphon.

2) As the fill volume decrease the wall temperature increases for all the working fluid. The wall temperature was almost isothermal in adiabatic section; while in condenser section it increases towards the end where the coolant outlet pipe was located. The wall temperature in acetone charged thermosyphon was higher.
3) Optimum fill volume for water and acetone charged thermosyphon was 10 cc and 14 cc respectively where the maximum heat transfer rate at condenser section occurs. While for ethanol and methanol charged thermosyphon, optimum fill volume was obtained at 12 cc.
4) A heat transfer rate at condenser section for water charged thermosyphon was higher as compared with all other working fluid. The 10 cc water charged thermosyphon shows 21 % and 24 % increase in the heat transfer rate compared with acetone charged thermosyphon at 450 W and 650 W heat input respectively

These stainless elliptical thermosyphons are suitable for waste heat recovery heat exchanger applications due to less corrosion and saving in area.

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