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Investigation of the Thermosyphon Performance for Different Working Fluids

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ABSTRACT

This study investigated a thermosyphon performance using different types of working fluids. Gravity assisted heat pipe of 15mm diameter, and 300 mm long with a thermal capacity of 240W was designed, fabricated and tested. An experimental setup was built to test the thermosyphon performance. For each performance test, the thermosyphon was filled with different working fluids including water, methanol and acetone. The thermosyphon was filled with 30% of working fluid fill ratio. The temperature distribution along the heat pipe was measured and recorded using thermocouples. The thermosyphon performance was evaluated based on the value of the heat transfer coefficient and the thermal resistances. At 30% fill ratio, the acetone had transferred the largest heat with 61.59 W.

Keywords: *heat pipe, thermosyphons, heat recovery, heat exchanger.*

Introduction

A heat pipe is a heat transfer device that can transfer large quantities of heat energy with a small temperature difference between the hot to the cold region. The heat pipe is a simple device that can rapidly transfer heat from one location to another. Sometimes it is also referred as "superconductors" as it possesses extra large heat transfer capacity and rate with minimal heat loss. The heat pipe is made from sealed aluminium or copper container. The inner part of the heat pipe contains a capillary wick. A small amount of

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saturated water is inserted into the tube and acts as a working fluid [1]. The heat pipe can be divided into 3 sections which are an evaporator at one end, a condenser at the other end and an adiabatic section in the middle. The evaporator absorbs heat and vaporises the working fluid at high temperature. The vapour rises and flows to the cooler condenser effectively transferring the latent heat of vaporisation. This process is assisted by buoyancy forces [2]. Both heat pipes and thermosyphons have the same working principle. However, for a thermosyphon, condensate returns to the hot end by gravity whereas for a heat pipe by capillary action of a wick [3]. Therefore for a heat pipe, the location of the evaporator is not restricted and can be placed anywhere, but for a thermosyphon, it must be located below the condenser.The quality and type of fluid usually determine the performance of the heat pipe. Different types of fluids such as water are used depending on their applications.

Experimental Set-up

The thermosyphon was fabricated using a copper tube that had 300 mm length, 15 mm outer diameter with 2 mm thickness as shown in Figure 1. A pressure gauge was installed at the top side of the heat pipe to monitor the inner pressure of the thermosyphon. An air valve also was welded and installed to allow excess air to be released when the working fluid at boiling point.

A water heater model EJK-E0811 (GR) of 230 V and, 1000W capacity was used for providing the required heat source at the evaporator. The evaporator and the adiabatic sections of the heat pipe were insulated using polystyrene foam to minimise the heat loss through these portions.

Figure 1: The dimension of the fabricated heat pipe.

A 120 x 100 mm box that containing water jacket acted as a condenser. The heat from the condenser section of the heat pipe is cooled by the cold water in the jacket. The inlet and outlet temperatures of cooling water were measured to determine the rate of heat transfer. To minimise the heat loss to the surrounding, the condenser was insulated with an aluminium foil.

The K-type thermocouple wires were used as the temperature sensors (thermocouples numbering are shown in Figure 2, the position of thermocouple 1 is in the water heating section. The position of thermocouples 2, 3, and 4 are respectively 50, 150 and 250 mm from the base of the heat pipe, while the thermocouple 5 is in the cooling water section. The thermocouples 6 and 7 measure the inlet and outlet temperatures of and the cooling water. A simple 8-channel digital temperature indicator was used to measure all the temperatures.

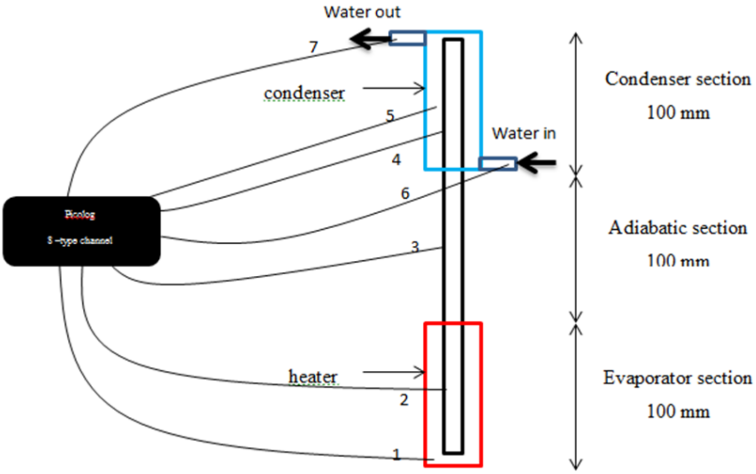

Figure 2: The schematic diagram of the experimental setup.

Experimental Procedures

Prior to the testing, the thermosyphon was filled with the working fluid and was vacuumed at 0.6 bars. The test then started by turning on the electric heater to heat the water in the evaporator section as shown in Figure 2. The heat from the water heater is transferred via the thermosyphon before been rejected to the cooling water in the condenser section. To monitor the temperatures changes at various locations, 7 thermocouple wires were attached to the thermosyphon using tape, and they were connected to a data logger. The transient test was conducted on the heat pipe, in which heater was put on the temperature rise and observed at regular intervals till the steady state was achieved. The testing was repeated with others two working fluid including methanol and acetone. All the temperature reading, the seven points on the heat pipe surface were taken for all three working fluids after reaching steady state condition. Various plots were drawn to study the performance of the in- house designed thermosyphon.

Figure 3: The actual experimental test bench.

Result and Discussion

The thermosyphon performance is evaluated using the overall thermal resistance and is calculated as follows:

$$R = \frac{T_e - T_c}{\dot{Q}} = \frac{T_2 - T_4}{Q} \tag{1}$$

where R (°C/W) is the overall thermal resistance, Te (T_2) and Tc (T_4) are the wall temperature of evaporator and condenser, respectively. The heat transfer rate was determined via the amount of energy transfer to the cooling water at the condenser section (Figure 2). The heat transfer rate was calculated as follows:

$$\dot{Q} = \dot{m} c_p (T_{w,out} - T_{w,in}) \tag{2}$$

Where $\dot{m}$ (kg/s) is the water mass flow rate, $T_{w,out}$ and $T_{w,in}$ are the outlet and inlet of the cooling water temperature, respectively. The specific heat of water, c_p is assumed constant during the experiment because of small temperature rise.

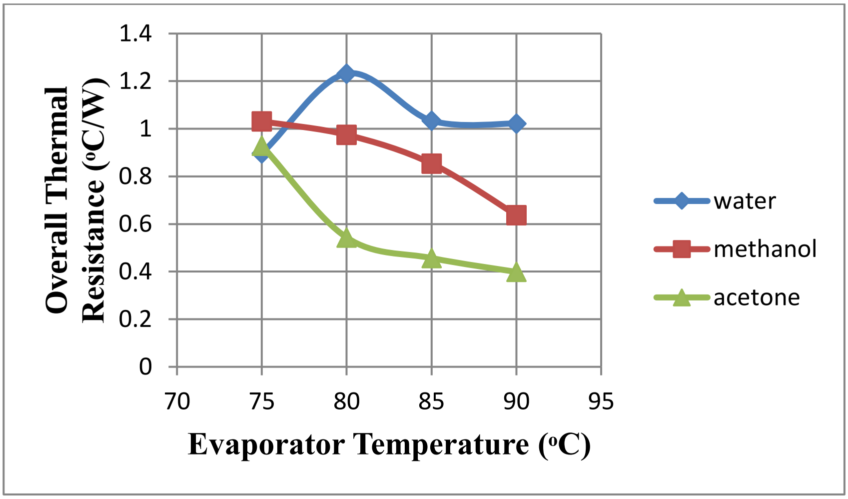

Figure 4: The overall thermal resistance versus evaporator temperature

Figure 4 shows the changes of the overall thermal resistance of the thermosyphon with increasing evaporator temperature. It is obvious that with the increase of the heat transfer flux or evaporator temperature, the overall thermal resistance of the thermosyphon for all working fluids decreased significantly. Acetone has shown the lowest overall thermal resistance within the evaporator temperature range because it has the lowest latent heat of vaporisation with a saturated boiling temperature of 57°C. At a lower evaporator temperature, the liquid acetone has quickly changed into a vapour. For other liquids like methanol and water, the evaporation process takes longer time because they have higher vaporisation latent heat and boiling points. A faster phase changes from liquid-vapour-liquid for acetone produces a low thermal resistance compared to other liquid.

The heat transfer coefficient, h for the thermosyphon is calculated as follows:

$$h = \frac{\dot{Q}}{A(T_2 - T_4)} \tag{3}$$

where the A is the mean surface area of the thermosyphon, T_2 and T_4 are the evaporator and condenser surface temperature, respectively. Figure 5 exibits the heat transfer coefficient, h against the input temperature. The heat transfer coefficient shows an increment trend with rising evaporator temperature. The accetone has the highest heat transfer coefficient followed by methanol and water. Accetone has the lowest heat of vaporization compared to methanol and water. The heat of vaporization for water and methanol are larger than acetone, therefore, the acetone reach the vapor temperature faster and start to change its phase [4]. Due to this reason, the acetone produced the highest heat transfer rate compared to the other liquids in the temperature range from 75 - 90°C.

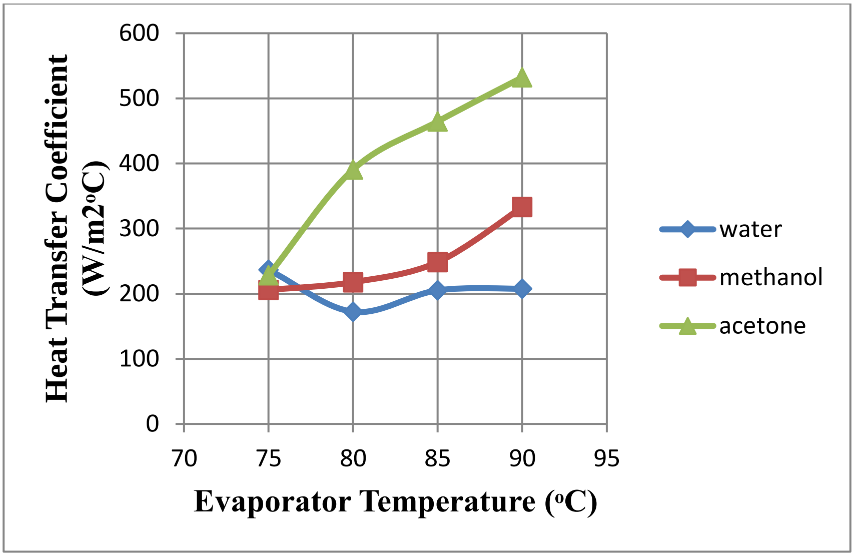

Figure 5: The heat transfer coefficient versus evaporator temperature

Figure 6 shows the heat transfer rate versus evaporator temperature. As expected, the acetone had shown the largest heat transfer rate followed by methanol and water. The acetone heat pipe produced the largest heat transfer rate due to having the lowest thermal resistances (between 0.9°C to 0.4 °C) and highest heat transfer coefficient (220 to 540 W/m2). Water has a high vaporisation latent heat (2.453 x 106 J/kg) and high boiling point (99°C) compared to acetone (0.539x106 J/kg at 57°C) and methanol (1.178 x 106 J/kg at 65°C) [5].Due to the higher saturation temperature for water and lower for acetone, less vapour exists in the water thermosyphon. Acetone could produce more vapour plugs before entering the condenser and subsequently, releases more heat [6].

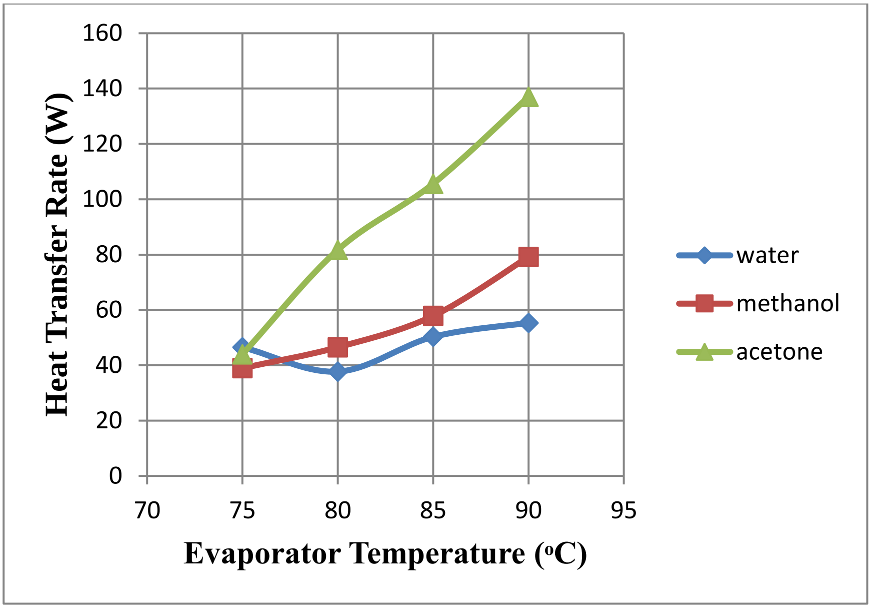

Figure 6: The heat transfer rate versus evaporator temperature

Conclusion

In this paper, an experiment to assess the performance of a thermosyphon using different working fluids was conducted. An in-house thermosyphon was designed and built. The 300 mm long thermosyphon was fabricated using a hollow copper tube with 15 mm diameter and 2 mm thickness. An experimental set-up was developed to test thermal performance of the thermosyphon consisting of a heating and cooling section. During each test, the thermosyphon was filled with 30% of working fluids using a different type of liquids including water, methanol and acetone. The study concludes that:

1. The thermal resistance of the thermosyphon decreases with increasing evaporator temperature regardless of the working fluid used.
2. Acetone was identified as the best working for the designed thermosyphon because it has the smallest thermal resistance and the highest heat transfer coefficient compared to other liquids.

3. Acetone and methanol thermosyphons would be suitable for lower heat dissipation applications due to having lower saturation temperature and dry-out limitations.
4. Water filled thermosyphon could be suitable for higher temperature application because having higher boiling and critical temperature, latent heat, and surface tension.
5. Further investigation is needed to investigate the effect of different fill ratio with broader temperature range.

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