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Research Article

Heat transfer characteristics of thermo-syphon: Case study of modifying inclination angle of evaporator and condenser sections

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Abstract - Experiments were carried out to study the heat transfer characteristics of a thermosyphon when modifying the evaporator and condenser sections to be oriented at 0, 60 and 90 degrees with respect to the 70 degree inclination of the adiabatic section (Z shaped). The thermosyphon was made of copper tube with an outer diameter of 15.87 mm and 300, 450 and 600 mm total lengths. The evaporator, adiabatic and condenser sections were equal in length. R-134a, ethanol and distilled water were employed as the working fluids with a 50% filling ratio by evaporator volume. The evaporator section was heated by hot water at 60, 70 and 80 °C, whereas 20 °C cool water was supplied to the condenser section. The test was conducted at various inclination angles, i.e., 0, 20, 40, 60, 70, 80, 90, 110, 130, 150, 170 and 180 degrees. The results show that the heat flux significantly depends on the working temperature. R-134a had the best performance followed by ethanol and distilled water. The heat flux decreased with an increase in the total length. When increasing the orientation angles of the evaporator and condenser sections, the heat flux rose due to the assistance of gravity. The maximum heat flux was 26.85 kW/m^2 with the lowest thermal resistance of 0.065 °C/W. In addition, the optimal tested orientation angle was in the range of 40-110 degrees with respect to the horizontal plane.

Keywords: Thermosyphon, heat transfer characteristic, modify, inclination angle

1. Introduction

A thermosyphon is a wickless heat pipe, which is also known as a gravity-assisted heat pipe. It contains a small amount of working fluid for heat transfer (Shabgard *et al*., 2014). In addition, for basic principle (see Fig. 1), heat is supplied to the evaporator where the working fluid pools inside, and is changed into vapor. Then, the temperature and pressure cause the vapor to flow toward the condenser. The vapor adjacent to the condenser releases its latent heat and condenses into liquid, after which it returns to the evaporator owing to gravity (Fadhl *et al*., 2013).

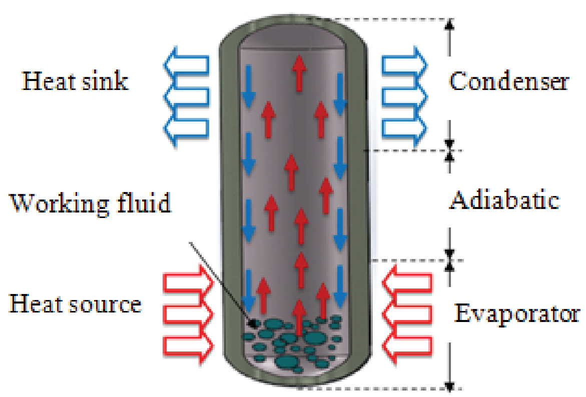

Figure 1. Schematic of thermosiphon.

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A thermosyphon is regarding as a highly effective heat transfer device, which can be found in many applications, for instance heat exchanger, electronic cooling or power generation, etc. The heat transfer performance of the thermosyphon is affected by many factors, such as, section length, working fluid, filling ratio, inclination angle and heat input. These factors have been studied by numerous investigations that aimed to enhance its performance (Jiang *et al*., 2014).

Previous experiments found that a thermosyphon works well when oriented at 60-90 degrees. Researchers have attempted to improve the performance by modifying the inclination angle of the evaporator and condenser sections to 0, 60 and 90 degrees with respect to the 70 degree inclination of the adiabatic section, as illustrated in Figure 2.

2. Experimental and procedure

The tested thermosyphon was made of copper tube with a 14.06 mm inner diameter and 15.87 mm outer diameter. The length of the evaporator, adiabatic and condenser sections were equal, and varied at 100, 150 and 300 mm. The evaporator and condenser sections were modified to be oriented at 0, 60 and 90 degrees with regard to the 70 degree inclination of the adiabatic section (see Fig. 2.).

Distilled water, ethanol and R-134a were used with a filling ratio of 50% of the evaporator volume. Experiments were performed at various inclination angles, namely 0, 20, 40, 60, 70, 80, 90, 110, 130, 150, 170 and 180 degrees. The entire surface of the tested thermosyphon was wrapped with insulating material to prevent heat loss.

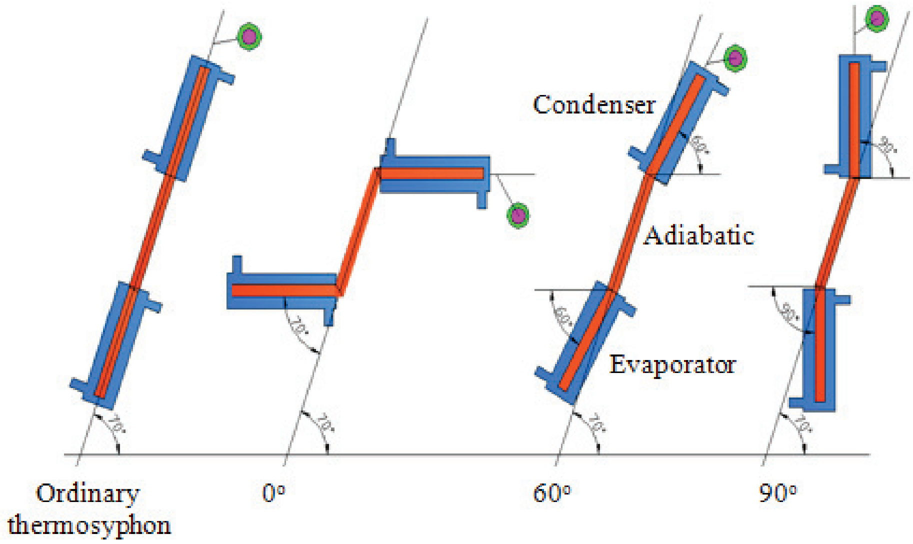

Figure 2. Thermosyphon with modified evaporator and condenser sections oriented at 0, 60 and 90 degrees vs. conventional thermosyphon.

The test rig is shown in Figure 3 and consists of a thermosyphon, a hot bath, a cool bath, flow meter and data acquisition. The evaporator section was heated by hot water at 60, 70 and 80 °C from the hot bath (Thermo Fisher Scientific EX-35 with ±0.01°C), while the condenser section was cooled with circulated water at 20 °C from the cold bath (EYELA CA-112CE cold bath with ±2°C). The mass flow rate of the water jackets of both the evaporator and condenser were controlled by a floating rotameter at the rate of 0.4 l/min. There were four thermocouples of type-K installed at the inlet-outlet for both the evaporator and condenser, as can be seen in Figure 4, and temperature probes were installed on three points on each of the outer surfaces (3x3 = 9 points). All installed thermocouple points were monitored and recorded by a data logger (Yogokawa MV1000 with ±0.7°C accuracy).

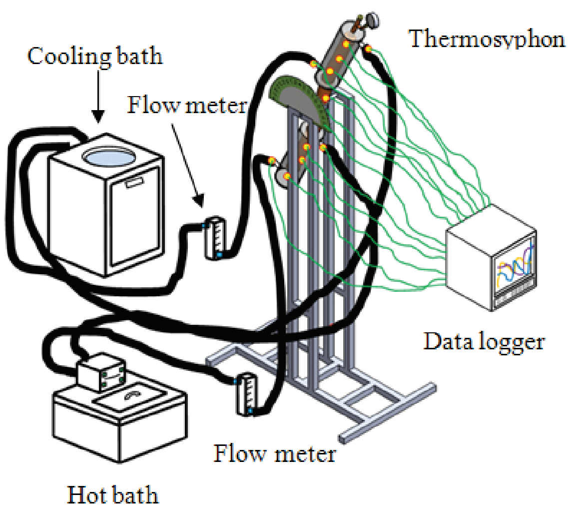

Figure 3. Schematic diagram of test rig.

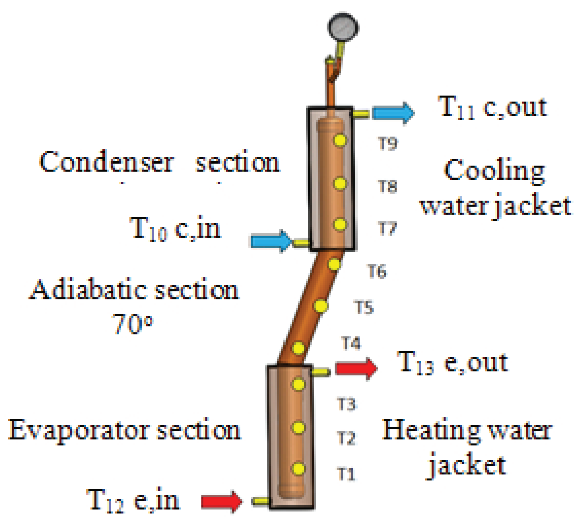

Figure 4. Installed thermocouple point.

The experiment begins by supplying the hot water and cool water at the desired temperatures to the water jackets. The flow rate was controlled to be 0.4 l/min. The temperature was recorded with the data logger for 10 minutes or until the temperature was stable. Calculate the heat transfer rate at the condenser using the following (On-ai *et al*., 2013):

$$Q_{cool} = m_{cool} Cp_{cool} \left(T_{c,out} - T_{c,in}\right) \quad (1)$$

Where, Q_{cool} is the heat transfer rate (W), m_{cool} is the mass flow rate of the cooling water (kg/s), Cp_{cool} is the specific heat of the cooling water (J/kg.°C) and $T_{c,out} - T_{c,in}$ is the temperature difference of the inlet and outlet of the condenser (°C).

The heat transfer rate from the evaporator section is examined using the same approach, and is given by:

$$Q_{hot} = m_{hot} Cp_{hot} \left(T_{e,in} - T_{e,out}\right) \quad (2)$$

The rate of heat transfer per unit area or heat flux (W/m²) is express as (Jiao *et al*., 2008):

$$q_c = \frac{Q_{con}}{A_c} \text{ and } A_c = [\pi r^2 + (2\pi r \times L_c)] \quad (3)$$

$$q_e = \frac{Q_{evap}}{A_e} \text{ and } A_e = [\pi r^2 + (2\pi r \times L_e)] \quad (4)$$

Where, A_c and A_e are the heat transfer areas of 0.00518, 0.00767 and 0.0106 m² at the section lengths of 100, 150 and 200 mm (L_c and L_e), respectively.

The thermal resistance could be evaluated using the following equation (Park *et al*., 2002):

$$R_{th} = \frac{T_{Evap} - T_{con}}{Q_e} \quad (5)$$

Where, $T_{evap} - T_{con}$ is the temperature difference between the average wall temperature of the evaporator and condenser sections. Q_e is the heat transfer (W) in the evaporator section that can be calculated by similar methods as Q_c.

Above all, the thermal performance can be defined as follows (Cengel, 2002):

$$\eta_{ther} = \frac{q_c}{q_e} x100\% \quad (6)$$

3. Results and Discussion

3.1 Effect of working temperature

The experimental results showing the effect of the working temperature on the heat flux are in Figure 5. It can be seen that when the working temperature at the evaporator section increases, the heat flux increases as well, due to the direct effect of the heat causing the fluid to boil. At 80 °C for the working temperature, the highest heat flux at each tested orientation was achieved.

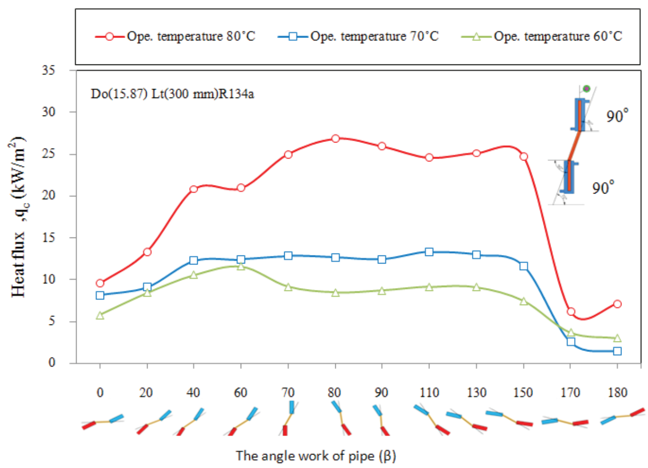

Figure 5. Effect of working temperature on heat flux at various tested angles (R-134a).

3.2 Effect of working fluid

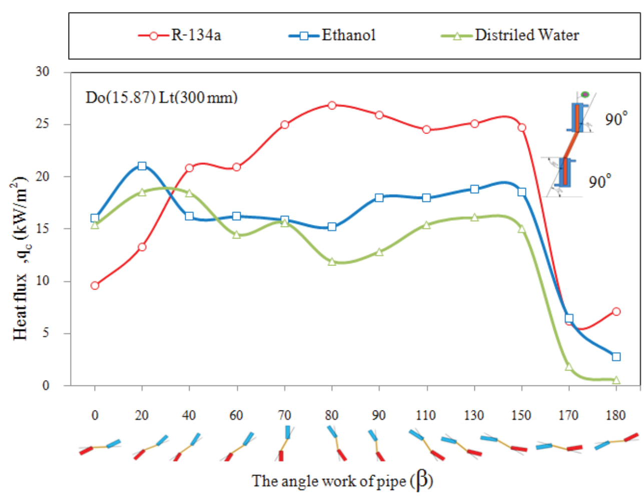

Figure 6. Effect of working fluid on heat flux at various tested angles (working temp. = 80°C).

Figure 6 presents the heat flux with different working fluids tested at various orientation angles. The figure indicated that R-134a is an excellent medium when compared with ethanol and distilled water.

3.3 Effect of total length

The experiments also investigated the effect of the total length of the theremosyphon on the heat flux. The length of the thernosyphon was varied at 300mm, 450mm and 600mm. The results are shown in Figure 7, and they are difficult to classify owing to the tested conditions only covering small differences in the aspect ratio. However, when considering all the tested orientations, the length of 300 mm obtained the highest heat flux.

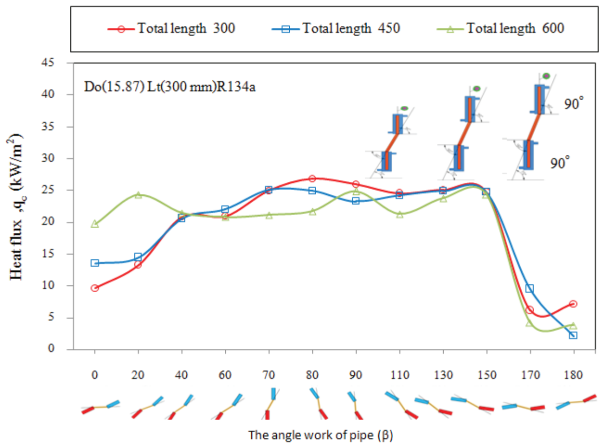

Figure 7. Effect of evaporator length on heat flux at various tested angles (working temp. = 80°C).

3.4 Effect of inclination angle of evaporator and condenser

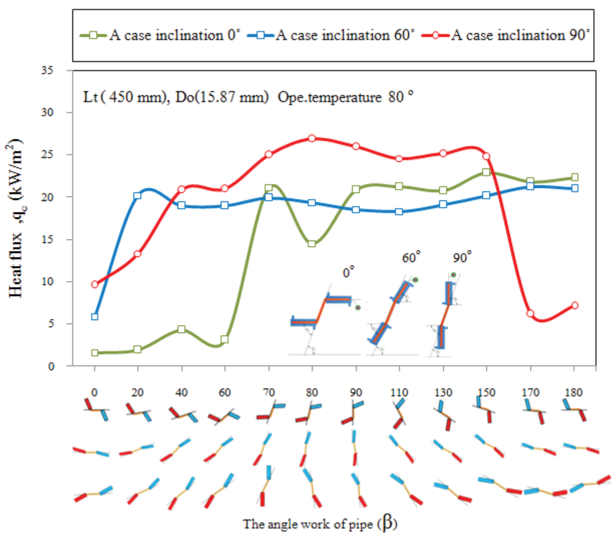

Figure 8. Effect of inclination angle of evaporator and condenser on heat flux at various tested angles (R-134a).

Experiments were set up to examine the heat flux when modifying the evaporator and condenser section orientations to 0, 60 and 90 degrees with respect to the 70 degree inclination of the adiabatic section. From Figure. 8 it can be concluded that the 90 degree orientation was the best due to gravity promoting the enhancement of the heat flux. However, in the case of the 0 degree orientation, the graph shows more fluctuation owing to the tested orientations of 0-60 degrees giving inappropriate positions of the evaporator section, as can be seen in Figure. 8.

3.5 Effect of thermal resistance

When considering the thermal resistance being affected by the modified section, as mentioned in 3.4, it is clear that in the case of the 90 degree orientation, lower thermal resistance values were obtained than at any other tested orientation. The lowest thermal resistance from this experiment was 0.065°C/W

3.5 Effect of tested angle on thermal performance

Figure. 10 displays the effect of the tested orientation on the thermal performance. When increasing the tested angle from 0 to 40 degrees, the thermal performance sharply rises, followed by a slight increase (60 to 110 degrees) and afterward it decreases gradually from 130 to 180 degrees. It can be concluded that the optimal tested orientation angle is in the range of 40 to 110 degrees.

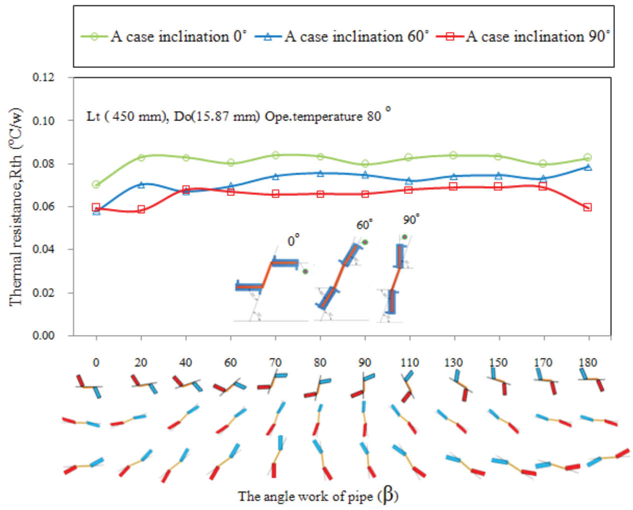

Figure 9. Effect of inclination angle of evaporator and condenser sections on thermal resistance at various tested angles (R-134a).

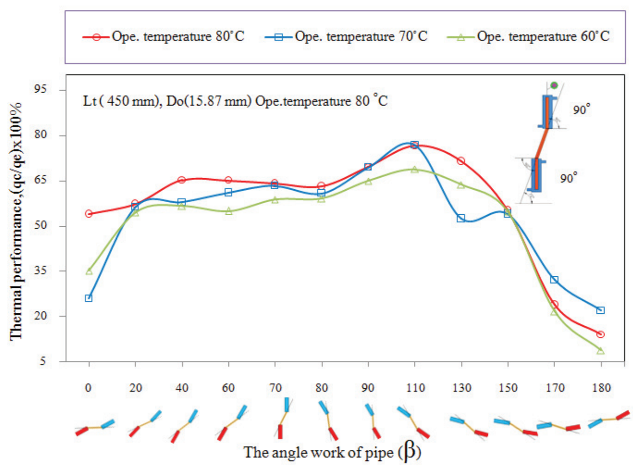

Figure 10. Effect of tested angle on efficiency at various working temperatures (R-134a).

4. Conclusion

The experimental results can be concluded as follows:

4.1 The heat flux depends on the operating temperature.

4.2 The best working fluid that can achieve a high heat flux is R-134a, followed by ethanol and distilled water consequently.

4.3 The heat flux decreased with an increase in the evaporator length, and 100mm was found to be the best.

4.4 In the case of modified evaporator and condenser sections at 0, 60 and 90 degree orientations, the heat flux increased as the orientation angle increased, and 90 degrees was the best (max. 26.85 kW/m^2, min. 0.065 °C/W of thermal resistance). Furthermore, when compared with a conventional thermosyphon, it shows that the conventional thermosyphon achieved a higher heat flux.

4.5 The optimal tested orientation angle was in the range of 40-110 degrees.

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