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Comparison Between A Thermosiphon And A Wick Heat Pipe Performance With Temperature Difference

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Abstract

The heat pipe (HP) is a fundamental heat transfer component frequently utilized for energy recovery in heating, ventilation, and air conditioning (HVAC). However, a heat pipe transmits heat from the hot side (evaporator) to the cold side (condenser), resulting in a temperature difference on both sides. There are numerous methods for measuring heat pipe performance. Using the temperature difference between the evaporator and condenser, the performance characteristics may be evaluated. The objective of this study is to compare the thermal performance of thermosiphon and commercial wick heat pipes (WHP) utilizing water as the working fluid and varying temperatures between the evaporator and condenser. The copper thermosiphon and commercial wick heat pipe had a diameter of 10 mm, a length of 800 mm, and a vacuum pressure of 5000 Pa. The filling ratios range between 30% and 50%, and it was evacuated at a pressure of 5000 Pa; the hot water temperatures at the evaporator were 30, 50, 70, and 90 ºC. Temperature was steadily increased every 30 minutes, and variations were observed at multiple places, including hot water, evaporator, and condenser wall. The average difference in temperature between the WHP and thermosiphon was around 0.6 degrees Celsius. The decreased temperature difference (T) indicates that the heat pipe is performing well. In addition, if the temperature difference is very great, the HP will dry up, therefore the WHP performs better than the thermosiphon.

Keywords:
Heat pipe, Temperature difference, Commercial, Filling ratio, Thermosiphon.

Nomenclature

HP	: Heat Pipe
WHP	: Wick Heat Pipes
HPHE	: Heat Pipe Heat Exchanger
HVAC	: Heating, ventilation, and air conditioning
FR	: Filling Ratio (%)
T_e	: Evaporator Temperature (ºC)
T_c	: Condenser Temperature (ºC)
C	: Celcius (ºC)
ΔT	: Temperature difference (ºC)

1 Introduction

Technological developments are overgrowing; almost all technologies lead to and take advantage of electronic cooling. Cooling technology makes heat pipes a new hope that utilizes the transfer of large amounts of heat without moving parts [1]. There have been inventions and studies involving heat pipes as refrigerants. Jouhara and Althoughmmon shown that employing heat pipe-based free cooling systems in HVAC systems could result in potential energy savings of up to 75% [2, 3]. Kabat, Guzela, and Peciar, get the best heat exchanger performance from the heat pipe at a 50% fill ratio [4].

Applying heat recovery in the HVAC system proves that the heat pipe is a passive heat transfer device that can minimize the HVAC system's energy consumption [5]. Heat pipe technique can cut power consumption and improve energy efficiency, according to Delpech et al [6].

Energy efficiency in heat pipes is widely applied in the field of cooling systems and thermal management, and heat pipes are one of the most promising solutions for today's energy crisis. Ramadhan et al., using condenser exhaust airflow in the HVAC system can reduce energy by up to 60%. Evaluation of the volume of incoming and outgoing energy is beneficial in reducing the energy lost due to the cooling system [7]. Burlacu et al., Heat Pipe Heat Exchanger (HPHE) designed in buildings with flow rates of 6 – 30 (l/min) prove heat exchangers in high heat pipes are categorized as feasible to increase energy and reduce energy consumption [8]. Water serves as the best working fluid at lower temperatures and with higher effective thermal conductivity [9-11].

Researchers in the field of heat pipes is increasingly in demand by researchers in many countries. Research in this area is increasing due to the working fluid filling ratio (FR), capillary axis, and HP material [12, 13]. The number of heat pipe publications in natural science from 2016 to 2021 (6 years) increased by 97%, and 80% of HVAC research was carried out on applications in the field of Heat Pipe. D. Reay, R. McGlen, and P. Kew, the performance of the heat pipe are determined by the working fluid, FR, and the shape of the Heat Pipe [14].

Consideration of a working fluid heat pipe will be beneficial in terms of fluid evaporation, temperature range, and capillary axis and heat pipe tube compatibility. Jouhara and Althoughmmon confirmed that the heat pipe assembly's working fluid is water. Its performance was enhanced by 18% to demonstrate that water is the working fluid at the specified temperature [15]. Rosidi et al. studied heat pipes with FR and heat load variations at hot water temperatures.

The results showed that the axis with the smaller HP did not produce the excellent natural circulation flow expected in natural circulation, and the FR 80% of the water working fluid reached saturation temperature [16]. The greatest efficiency of a two-phase closed-type HP thermosiphon was attained at an operating temperature of 80 °C and a FR of 50%, according to Parametthanuwat et al [17]. Hussain H.Ahmad et al. examined the method for assessing performance. A comparison of two thermosiphon heat pipes with a lighter evaporator variant demonstrates that pipe performance is 70% superior to thermosiphon performance in both phases [18]. There has not been any research on understanding the temperature differences between the evaporator and condenser in two heat pipes that can be the description about the performance using a simple method. This research aims to analyze the Performance of HP thermosiphons (straight heat pipes) and compare it to wick heat pipes.

2 Method

In this study, commercial wick heat pipes and thermosiphons HP are constructed from copper and use water as the working fluid. The heat pipe can be shown in Fig. 1-a. The HP has a length of 800 mm, a condenser of 300 mm, an evaporator of 300 mm, and a diameter of 10 mm. The 10 mm thermosiphon heat pipe was vacuumed prior and filled with water as working fluid, and this activity aims to reduce non-condensable gas inside of the heat pipe. When the filling ratio was reached, the heat pipe was vacuumed again until 5000 Pa (absolute) to reduce non-condensable gas.

The HP thermosiphon, filled with the water as working fluid and vacuumed at the end of the pipe, was closed. In this study, the working fluid was entered in various ways due to the FR of 30% and 50%, and then the HP was vacuumed again. The filling ratio was determined by measuring HP's overall length. The dimensions and shape of a commercial wick heat pipe are same.The heater was installed to heat the hot water regulated by the Proportional Integral and Differential (PID) controller to keep the water temperature constant.

The hot water temperature varied from 30, 50, 70, and 90 ºC. Type K thermocouple was installed at 5 points, that is, at the wall of the evaporator and condenser of each type of heat pipe and the hot water. The temperature data was then gathered and acquired using Agilent 34970A, and the acquisition data was saved to a computer application.

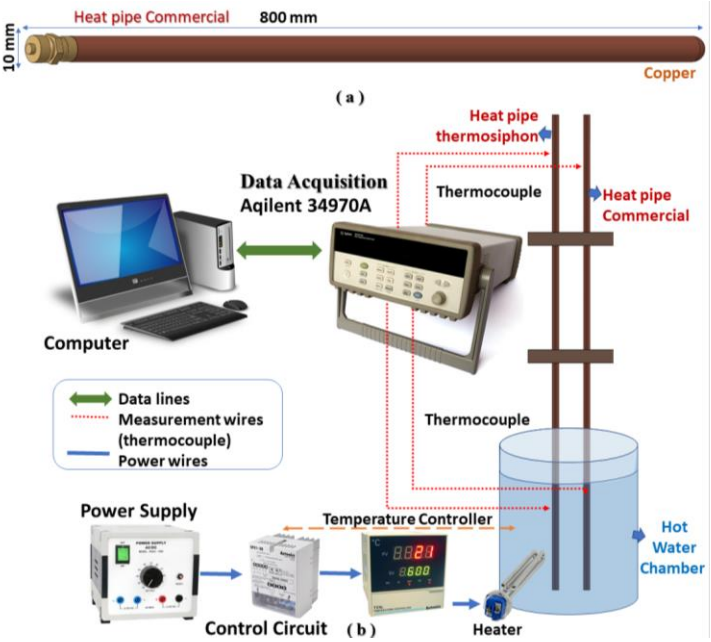


Fig. 1. Straight Heat Pipe Schematic (a) commercial heat pipe (b) experimental measurement arrangement

Every 35 minutes, the temperature of the hot water used for heat transmission is raised by +20 degrees Celsius. Both HP evaporators are heated by hot water, causing the working fluid (water) to evaporate as it absorbs the heat. The water vapor travels along the tube cavity to the side with the lower temperature, condenses into a liquid, and dissipates heat in the condenser. Based on the data, specifically the evaporator temperature (Te) and the condenser temperature (Tc) recorded on the copper pipe's walls. The condenser released its heat into the air at the ambient temperature [19] calculated the thermal performance of the battery module using HP.

This temperature is used to determine the temperature differential (T) between the evaporator temperature (Te) and the condenser temperature (Tc) (Tc). The computation determines the heat-induced mass transfer between liquid and vapor phases during evaporation and condensation eq. (1) [9].

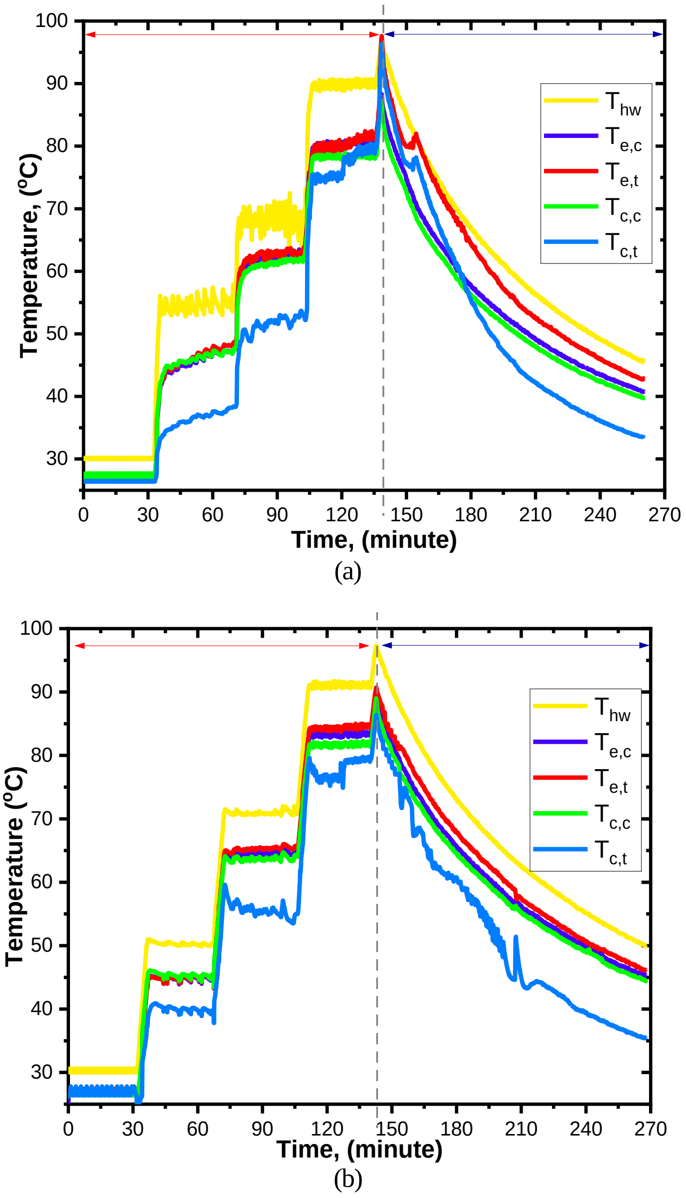
$$\Delta T_{e-c} = \Delta T_e - \Delta T_c \qquad (1)$$

3 Results and discussion

The working fluid on the HP will undergo an evaporation process due to heat transfer to the evaporator wall, and the vapor will flow through the adiabatic section to the condenser section [20, 21]. The vapor will be cooled in the condenser and turned into liquid; this liquid will return to the evaporator due to the force of gravity.

Fig. 2 Demonstrates that the temperature distribution for each temperature increment is nearly uniform. The temperature change in the evaporator at a filling ratio of 30% looks lower than the 50% fill ratio. This is due to the different content of the working fluid in the pipe and the amount of heat needed to increase the temperature [22]. This can be seen at 30% FR. The temperature difference between the two HPs has a maximum range of 9.59 ºC and a minimum of 0.37 ºC, while FR, at 50%, the maximum is 10.98 ºC and a minimum of 1.03 ºC, the uncertainty in this measurement is 0.5%. The temperature difference between the fluid phase and the heat processed between the liquid and vapor phases results in condensation. This phenomenon will continue, indicating that a natural circulating flow has formed. At the high temperature of 90 ºC of hot water, The temperature difference between the thermosiphon and wick heat pipe was almost the same due to the dry-out, and the capacity heat transfer of the wick heat pipe was limited at that point [23]. The condenser temperature of the wick heat pipe is higher than the thermosiphon due to the better heat transfer. The thermosiphon condenser temperature of the FR 50% is higher than the FR 30%, which indicates a total heat transfer of 50% FR more than 30% FR.

Hot water temperature of 30 ºC, the working fluid does not evaporate on the HP thermosiphon because the vacuum does not reach the boiling point, so the HP does not work. At the same time, commercial HP is already running at this point. At the temperature of 50 ºC, the working fluid started evaporation. The evaporator-condenser temperature difference increased at the higher temperature of 70 ºC and decreased when the heating temperature reached 90 ºC due to the maximum heat transfer.



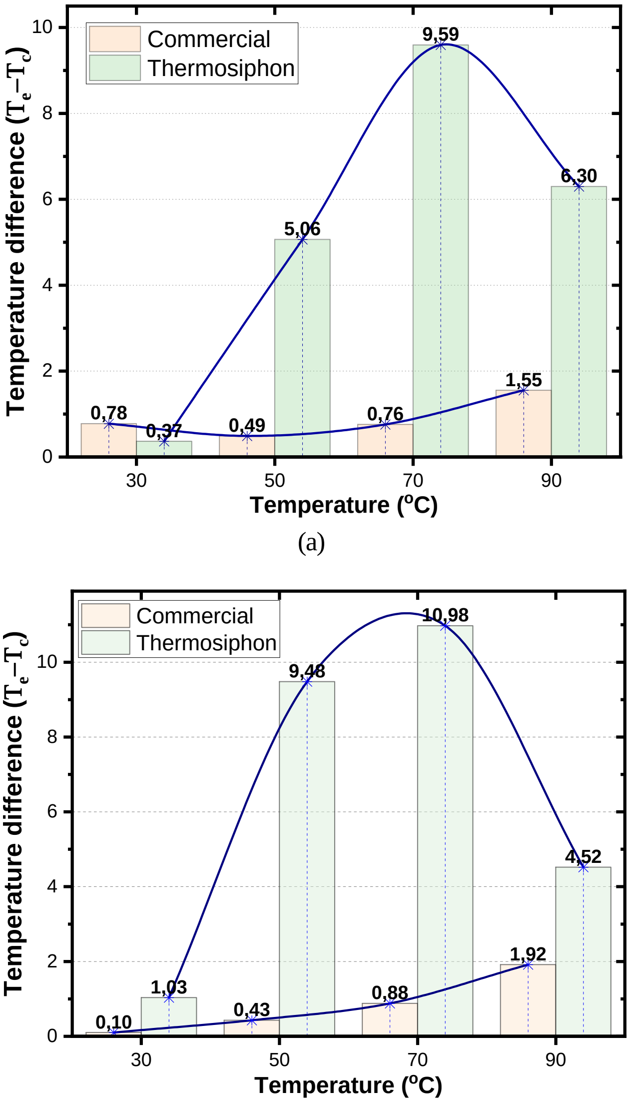
(a)

(b)

Fig. 2. Distribution of temperature on the evaporator-condenser against time, (a) FR 30% and (b) FR 50%.

No heat transfer calculations were performed in this study, but the performance was delivered at different temperatures. Fig. 3. shows the temperature difference based on the experimental setup in Fig. 2. The comparison relationship shows that the greater the percentage filling ratio, the more significant the resulting temperature difference (ΔT).

Fig. 3 depicted difference in temperature between the evaporator and condenser sides indicates the performance of the two HPs. If the ensuing temperature difference is small, HP's performance is fine, and if it is very large, HP is experiencing dryness. The evaporator has dried out when all of the working fluid in the pipe has turned to steam and there is no circulation in the heat pipe. Due to the ability to transmit heat, the Thermosiphon has a different high temperature than the CHP at low temperatures, but the CHP has a higher condenser temperature, allowing it to transfer more heat to its surroundings via natural convection.



(a)

(b)

Fig..3 Temperature difference of heat pipe at FR (a) 30% and (b) 50%.

Meanwhile, the thermosiphon has a lower temperature at the condenser side, and the heat transfer ability to the surrounding through the natural convection is less than CHP. At a high temperature of 90 ºC, the condenser temperature of both HP is almost the same with the lower different temperatures. This different low temperature indicates the Thermosiphon was a better performance at this point. Thermosiphon with 50% FR has a lower differential temperature due to the amount of heat that can be transferred. The higher filing ratio has more working fluid, which can transfer more heat.

Compared with research on heat pipe thermosiphon, Mozumber et al., with the same tilt angle and working fluid, the lowest power is 5 ºC, and the highest is 12 ºC, thus the results obtained are not much different from this study [24]. Several studies with the same variations in temperature differences can be obtained in table 1.

4 Conclusion

Based on experiments using a 10mm diameter HP cylindrical copper material and water as the working fluid, the average temperature difference for commercial HP is 0.6 °C and for HP thermosyphon is 6 °C. Therefore, the lower the yield obtained, the better the performance of the HP Thermosiphon. In this study, the wick heat pipe has superior performance compared to the HP thermosyphon in terms of heat transfer capability.

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Table 1. Comparison of several thermosiphon heat pipes with temperature differences (evaporator-condenser)

Experiment	Mass Fluid	Filling ratio (%)	Inclination angles (º)	Temperature Differense (ΔT)
Hussam Jouhara, and Richard Meskimmon [2]	Ferioksida (Fe_2O_3) nanofluid	50	0, 15, 30, 45, 60, 75, 90	Under to 5 ºC, above 15 ºC
Jianqin Wang, et al. [19]	Water-copper	-	30, 60, 90, 120	Under to 1.8 ºC, above 4.1 ºC
Mozumder, A., et al. [24]	Water, methanol, and acetone	35, 55, 85, 100	90	Under to 5 ºC, above 11 ºC
Engin Gedik [22]	Water, ethanol, and ethylene glycol	35	30, 60, and 90	Under to 6 ºC, above 12 ºC
Baheta, A.T., A.N. Oumer, and S.M. Hailegiorgis [25]	Water-metal nanofluid (Cu-water)	0 to 4	90	Under to 7 ºC, above 13.5 ºC
Ozsoy, A. and V. Corumlu [23]	Silver-water nanofluid	2 - 10	35	Under to 12 ºC, above to 40 ºC

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