# Effect of Working fluids on Thermal Performance of Vertical Closed-loop Pulsating Heat pipe

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## Abstract

This research aims to experimentally investigate the effect of working fluids on thermal performance of vertical closed-loop pulsating heat pipe (VCLPHP) at normal operating conditions. The tested VCLPHP is made from copper capillary tubes with the internal diameter of 2.03 mm. The length of the evaporator, adiabatic and condenser section are equally set as 50 mm. Number of turn are 4 and 12. The evaporator section of the VCLPHPs is heated by a hot bath. The heat is removed from the condenser section by cold bath. The inlet evaporator temperature is controlled at 80 °C. The adiabatic section temperature is controlled at 50 °C. The working fluids used within the VCLPHPs are distilled R141b, Acetone and Ethanol with 50% of the filling ratio. The thermal performance of the VCLPHP is evaluated by calculating the rate of heat transferred to cold bath at condenser section. It is found that, for 4 turn numbers, when working fluid is changed from R141b ($h_{fg}$ = 267 kJ/kg) to Acetone ($h_{fg}$ = 526 kJ/kg) and Ethanol ($h_{fg}$ = 1000 kJ/kg), heat flux continuously increases from 24 to 42 and 54 kW/$m^2$ respectively. This might be because with the higher latent heat, the evaporation rate at evaporator section and condensation rate at condenser section are increased. The heat flux is accordingly increased. For 12 turn numbers, when working fluid changes from R141b (hfg = 267 kJ/kg) to Acetone (hfg = 526 kJ/kg), heat flux continuously increases from 41 to 50 kW/$m^2$. In contrast, when working fluid changes from Acetone (hfg = 526 kJ/kg) to Ethanol (hfg = 1000 kJ/kg), heat flux continuously decreases from 50 to 46 KW/$m^2$. Since there may be other factors besides latent heat involved.

**Keywords:** Vertical closed-loop pulsating heat pipe, Working fluids, Thermal performance

## Introduction

A pulsating heat pipe (PHP) is a heat transfer device that can work without external power. The working fluid inside the pulsating heat pipe is a medium of the heat transfer. The PHPS can provide high thermal performance. Therefore PHP are used in industrial and electronic equipment. The PHP was firstly invented by Akachi, et al.[1]. The PHP is made from capillary tube with meandering bent. The PHP is evacuated and filled with working fluids. The arrangement of the working fluid inside forms into liquid sluge alternating with vapor plugs along the entire length of the tube. The operation of the PHP is Pulsating movement of working fluid and phase change phenomena when heat input at evaporator section and heat remove at condenser section. The PHP can be divided into three types. The first close-end pulsating heat pipe (CEPHP) as showin (Figure 1(a)). The second closed-loop pulsating heat pipe (CLPHP) as shown in (Figure 1(b)).The third closed-loop pulsating heat pipe with check valve as showin (Figure 1(c)). This research will study closed-loop pulsating heat pipe due to heat transfer performance being more than a closed-end pulsating heat pipe, and easier to produce than closed-loop pulsating heat pipe with check valve.

Charoensawan et al.[2], studied experimentally a wide range of pulsating heat pipes thereby providing vital information on the parameter dependency of their thermal performance. The influence characterization has been done for the variation of internal diameter, number of turns, working fluid and inclination angle of the device.

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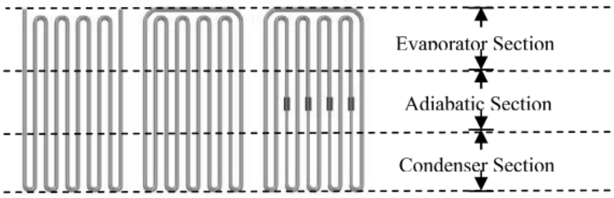
CLPHPs are made from copper tubes of internal diameters 2.0 and 1.0 mm. The number of turns in the evaporator is varied from 5 to 23. The working fluids used within the CLPHPs are distilled water Ethanol and R123. The results indicate a strong influence of gravity and number of turn on the performance. The thermodynamic properties of working fluids affect the performance which also strongly depends on the boundary conditions of PHP operation.

On-ai et al.[4], studied experimentally the effect of working fluid types on thermal performance of closed-loop pulsating heat pipe. CLPHPs are made from copper tubes of internal diameters 1.50, 1.78 and 2.16 mm. The number of turns is 26. The working fluids used within the CLPHPs are distilled R123, R141b, Acetone, Ethanol and Water. It was found that Karman number (Ka), Aspect ratio ($L_e / D_i$) and Prandtl number ($Pr_{lid}$) can reasonably represent the effect of working fluid types on thermal performance of the CLPHPs through a term of kutateladze number (Ku). From relations between these dimensionless numbers and Ku, the correlation was successfully established.

Sriwiset et al.[5], study evaluation of optimum turn numbers for closed-loop pulsating heat pipe. CLPHPs are made from copper tubes of internal diameters 2.03 mm. Number of turns are 5, 10, 16 and 30. It was found that the CLPHP operation depends on many factor's parameters. They have conducted an analysis to evaluate the thermal performance in the form of dimensionless parameters, e.g. are Ku, $Pr_{liq}$, Ja, Ka, N. They analyzed experimental data combined with Charoensawan et al.[2], Khandekar et al.[3] and On-ai et al.[4] as shown in Equation (3). It was found that when dimensionless parameter on horizontal axis, namely $f(ka^{0.47}Ja^{1.43}N^{-0.27})$, is 50000. CLPHP can operation optimum at its highest thermal performance.

Pulsating heat pipe design can provide better thermal performance depending on many variables. In the past study, it was found that there was a lack of information of the effect of working fluids. In this research, therefore, we aimed to experimentally investigate the effect of working fluids on thermal performance of a vertical closed – loop pulsating heat pipe.



(a) CEPHP (b) CLPHP (c) CLPHP/CV

**Figure 1** Three types of Pulsating heat pipe

## Experimental Setup and Procedure

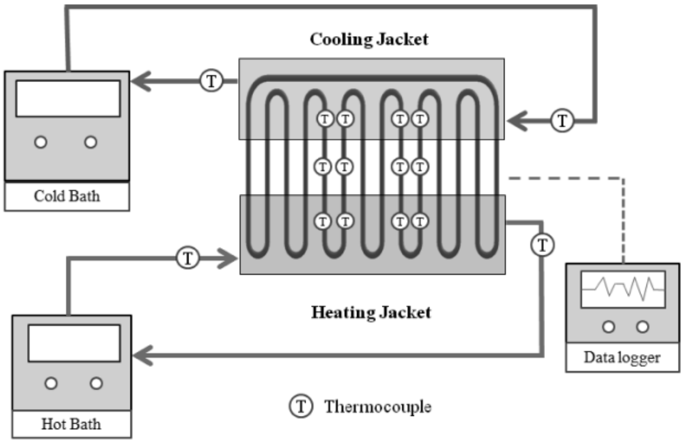


**Figure 2** Experimental Setup

The CLPHPs used in the experimental were made of long capillary tubes with inner diameters 2.03 mm. The length of the evaporator, adiabatic and condenser section were equally set as 50 mm. Number of turns were 4 and 12. The inlet evaporator temperature were maintained at 80 °C (Haake, N6, accuracy ±0.01 °C). The heat was removed from the condenser section by cold bath (Bitzer, D7032, accuracy ±1 °C). The adiabatic section temperature was maintained at 50±5 °C. The working fluids used within the VCLPHPs were distilled R141b, Acetone and Ethanol with 50% to the filling ratio. A schematic diagram of the experimental setup is shown in (Figure 2). Twenty thermocouples (Omega, type k, accuracy ±0.5 °C) are installed on the outer surface of the capillary tube to measure the variation in temperature. The temperature was monitored by a data logger (Brainchild VR18, accuracy ±0.1 °C). Setup thermocouple 4 points on the middle on each tube in the evaporator section, 4 point in the adiabatic section, 4 points in the condenser section. Two points are installed on each inlet and outlet tube of the heating and cooling jacket. By record every 1 second. The thermal performance of the VCLPHP was evaluated by calculating the rate of heat transferred at cooling jacket in the condenser section When the operation into steady state condition. By Calorific Method as equation (1).

$$\dot{q}=\frac{\dot{m}C_p(T_{out}-T_{in})}{A_c} \tag{1}$$

Where $\dot{q}$ is heat flux, $\dot{m}$ is mass flow rate of the cooling, $C_p$ is the specific heat, $(T_{out}-T_{in})$ is the difference in the temperature of the cooling, $A_c$ is the inner surface area of the tube in the condenser section.

Because of these values received from the instruments. It is important to check for errors due to this measure to analyze the results correctly. The error of the heat flux can be calculated by equation (2).

$$d\dot{q}=\sqrt{\left(\frac{\partial \dot{q}}{\partial \dot{m}}d\dot{m}\right)^2+\left(\frac{\partial q}{\partial T_{out}}dT_{out}\right)^2+\left(\frac{\partial q}{\partial T_{in}}dT_{in}\right)^2} \tag{2}$$

Where $d\dot{q}$ is the error of the heat flux, $d\dot{m}$ is the accuracy from measuring the mass flow rate of the cooling, $dT_{out}$ and $dT_{in}$ are the accuracy from measuring the outlet and inlet of water cooling. In this study, the heat flux of which the error calculated from equation (2) was lower than 30% of calculated heat flux from equation (1) which defined the criteria to be analyzed in the next step.

## Results and Discussions

### 1. Effect of Working fluids

In a study on effect of working fluids on heat flux, it is necessary to identify each of the working fluids by quantitative parameters They are the thermodynamic properties of the working fluid such as latent heat of evaporation, specific heat, surface tension, viscosity, thermal conductivity, etc. Since the CLPHP transfers heat by the evaporative and condensation mechanism of the working fluids, the most suitable parameter to identify the difference of the working fluid in this topic is the latent heat of evaporation ($h_{fg}$). R141b, Acetone and Ethanol were chosen to be variable parameters with the latent heat of evaporation of 267, 526 and 1000 kJ/kg respectively.

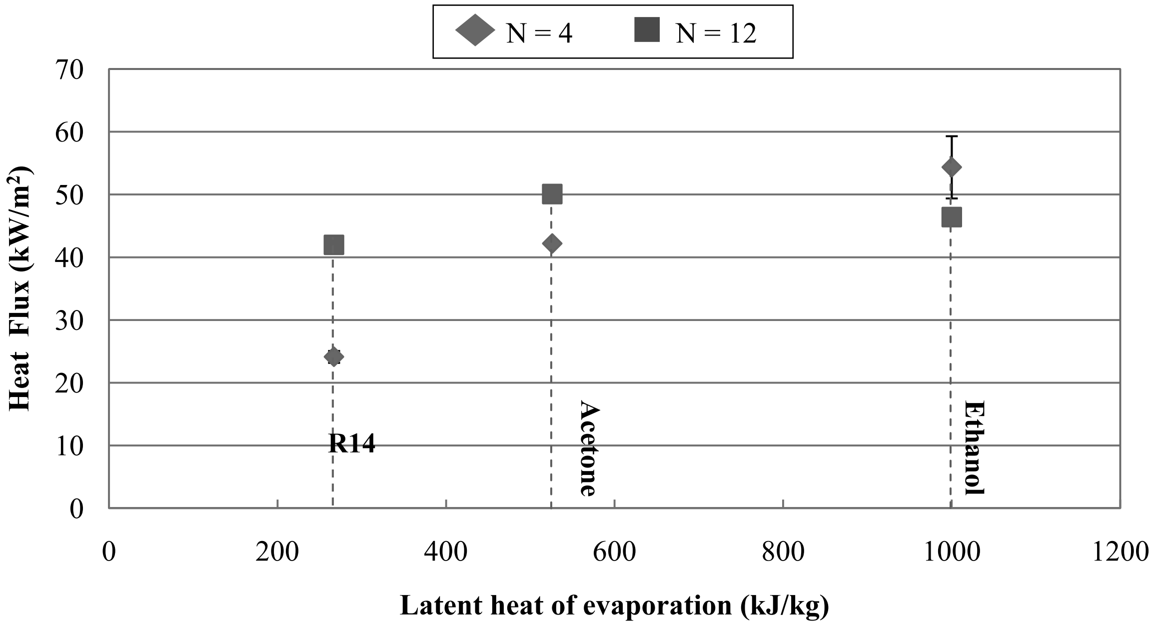


**Figure 3** Effect of latent heat on heat flux (Vertical CLPHP, $D_i$ = 2.03mm, $L_e$ = 50 mm)

(Figure 3) shows effect of latent heat on the heat flux of the CLPHP. It can be seen from the experimental results that, for number of turns is 4 when working fluid changes from R141b ($h_{fg}$ = 267 kJ/kg) to Acetone ($h_{fg}$ = 526 kJ/kg) and Ethanol ($h_{fg}$ = 1000 kJ/kg), heat flux continuously increases from 24 to 42 and 54 kW/m$^2$ respectively.

This might be because when the latent heat increases, the evaporative rate, and also the condensation rate, is increased. The heat flux is accordingly increased.

This trend is quite similar to those obtained by On-ai et al.[4] as they did the experiments with R141b Acetone Ethanol os working fluids and tubes internal diameter of 1.50 mm. They found that, the heat flux increases with the increasing of latent heat.

(Figure 3) shows the effect of latent heat on the heat flux of the CLPHP. It can be seen from the experimental results that, when number of turns is 12 when working fluid changes from R141b ($h_{fg}$ = 267 kJ/kg) to Acetone ($h_{fg}$ = 526 kJ/kg), heat flux continuously increases from 41 to 50 kW/m$^2$. In contrast, when working fluid changes from Acetone ($h_{fg}$ = 526 kJ/kg) to Ethanol ($h_{fg}$ = 1000 kJ/kg), heat flux continuously decreases from 50 to 46 kW/m$^2$.

This might be because there are other factors involved besides latent heat. When the latent heat increases it does not mean that thermal Performance will increase always.

This trend is quite similar to those obtained by On-ai et al.[4] as they did the experiments with R141b Acetone Ethanol as working fluids and tubes with internal diameter of 2.16 mm. They found that, when working fluid changes from R141b to Acetone, heat flux is increased. And when working fluid changes from Acetone to Ethanol, heat flux is decreased.

From the experimental data it is found that, when working fluid changes from R141b ($h_{fg}$ = 267 kJ/Kg) to Acetone ($h_{fg}$ = 526 kJ/Kg), heat flux continuously increases from 41 to 50 kW/m$^2$. In contrast, when working fluid changes from Acetone ($h_{fg}$ = 526 kJ/kg) to Ethanol ($h_{fg}$ = 1000 kJ/kg), heat flux continuously decreases from 50 to 46 kW/m$^2$.

## 2. Correlation to Predict Thermal Performance Verification of the experimental data

The CLPHP depends on many parameters. In past studies, Sriwiset et al.[5] conducted an analysis to evaluate the thermal performance in the form of dimensionless parameters, e.g. are Ku, $Pr_{liq}$, Ja, Ka, N. Sriwiset et al.[5] analyzed experimental data with Charoensawan et al.[2], Khandekar et al.[3] and On-ai et al.[4] as shown in Equation (3). In this work have to analyzie. The verification of recent experimental data with previously existing data is shown in (Figure 4).

$$Ku = f(ka^{0.47} Pr_{liq}^{0.27} Ja^{1.43} N^{-0.27}) \qquad (3)$$

Where Ku is Kutateladze number, Ka is Karman Number, $Pr_{liq}$ Prandtl Number of liquid, Ja is Jacob Number, N is number of turn.

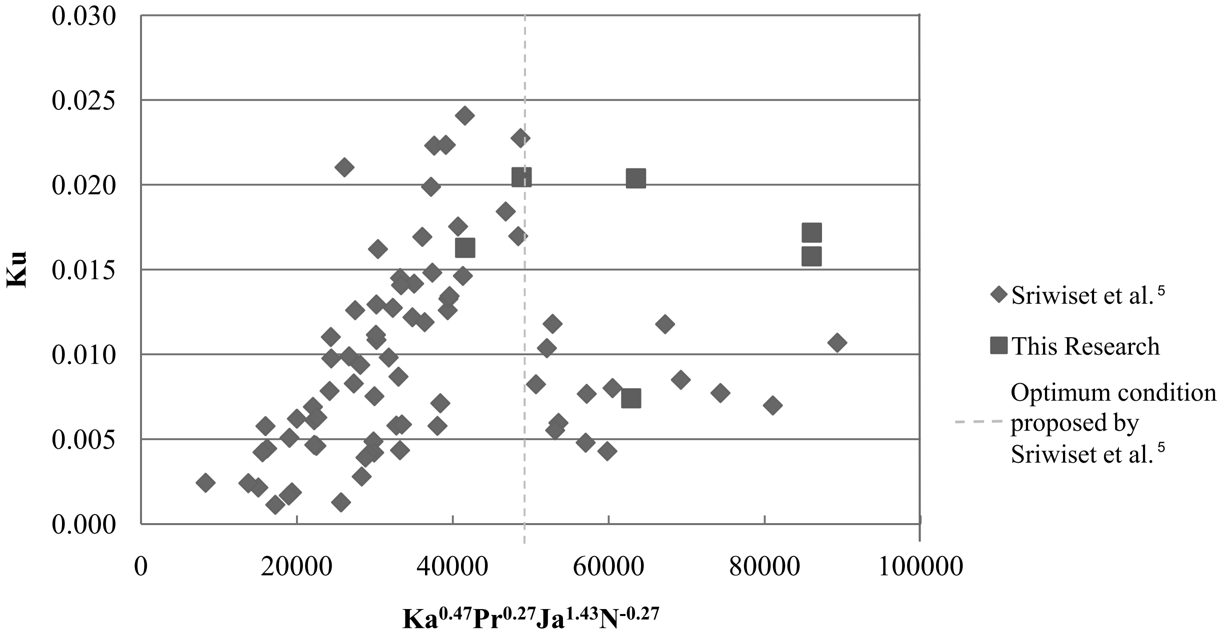


**Figure 4** function of dimensionless in Equation (3) use to evaluation thermal performance

(Figure 4) shows the function of verification of experimental data in dimensionless form suggested in Equation (3). It can be seen that, from the results of past studes and combined with this research, when dimensionless parameter on horizontal axis, namely $f(ka^{0.47}Ja^{1.43}N^{-0.27})$, is 50000 (the optimum condition proposed by Sriwiset et al.,[5]), CLPHP can operate optimum at its highest thermal performance. Since dimensionless parameter $f(ka^{0.47}Ja^{1.43}N^{-0.27})$ is 50000, Ku has a maximum value. This trend is quite similar to those obtained by Sriwiset et al.[5] as they used their equation (3) and they found that, when dimensionless $f(ka^{0.47}Ja^{1.43}N^{-0.27})$ is 50000 the CLPHP can operate at optimum thermal performance. Since Ku has a maximum value.

## Conclusion

1. Effect of working fluids on thermal performance of vertical closed-loop pulsating heat pipe. It was found that for 4 turn numbers when latent heat increases, heat transfer flux increases. This might be because when the latent heat increases, the evaporative rate, and also the condensation rate, is increased. The heat flux is accordingly increased. For 12 turn numbers when latent heat increases, the heat transfer flux increased and then decreased. This might be because other factors involved besides latent heat. When the latent heat increases it does not mean that thermal Performance will always increase.

2. Because the CLPHP depends on many factors. In past studies, Sriwiset et al.[5] have analyzed to evaluate the thermal performance in the form of dimensionless are Ku, $Pr_{liq}$, Ja, Ka, N as shown in Equation (3). It can be seen from the results of the past study and combined with this research, when dimensionless $f(ka^{0.47}Ja^{1.43}N^{-0.27})$ is 50000, CLPHP can operation optimum thermal performance. Since Ku has a maximum value.

## Acknowledgement

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## References

[1] Akachi, H., Polasek, F. and Stulc, P., Pulsating Heat Pipe. Proc. of the 5th International Heat Pipe Symposium. Melbourne Australia, 1995; 208-217.

[2] Chareonsawan, P., Khandekar, S., Groll, M. and Terdtoon, P., Closed-Loop Pulsating Heat Pipe Part A: Parametric Experimental Investigations. Applied Thermal Engineering. 2003; 23: 2009-2020.

[3] Khandekar, S., Chareonsawan, P., Groll, M. and Terdtoon, P., Closed-Loop Pulsating Heat PipePart B: Visualization & semi-empirical modeling. Applied ThermalEngineering. 2003; 23: 2021-2033.

[4] On-ai, K., Kammuang-lue, N., Terdtoon, P., and Sakulchangsatjatai, P., Effect of Working Fluid Types on Thermal Performance of Vertical Closed-Loop Pulsating Heat Pipe. Proc. of the 5th International Conference on Science. Luang Prabang Loa PDR. 2013; 5: 24.

[5] Sriwiset, C., Kammuang-lue, N., Sakulchangsatjatai, P. and Terdtoon, P., Evaluation of Optimum Turn Number for Closed-Loop Pulsating Heat Pipe at Normal Operation. Proc. of the 5th International Conference on Science. Luang Prabang Loa PDR. 2013; 5: 26.