Experimental Investigation of Closed Loop Oscillating Heat Pipe at Startup Condition

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Abstract

The objective of this paper is to investigate startup conditions of a closed loop oscillating heat pipe (CLOHP). The CLOHP are made of a long copper capillary tube with an inner diameter of 2.03 mm. The number of turns was 4, 5 and 7. The ends of the tube are connected to complete the loop. The evaporator, adiabatic and condenser sections are all an equal length of 50 mm. R123, acetone and water were used as the working fluids with a 50% filling ratio. The CLOHP was operated horizontally and the condenser temperature was controlled at 25 °C. A low-voltage high-current heater was used as the heat source and the cooling medium was a solution of water and ethylene-glycol with a 1:1 mixing volume ratio. The number of turns is 7, changing the working fluid between R123, acetone and water, it was found that the heat transfer rate increases from 5.72 W using R123 as working fluid, to 7.35 W and 14.71 W using acetone and water as working fluids, respectively. The frequency of the working fluid decreased from 0.94 cycle/s using R123 as working fluid, to 0.65 cycle/s and 0.19 cycle/s using acetone and water as working fluids, respectively. The amplitude increased from 0.36 °C using R123, to 0.55 °C and 3.62 °C using acetone and water, respectively. In the case of using water as working fluids, changing the number of turn from 4 to 5 and 7 turns, it was found that the heat transfer rate increased from 11.43 W using 4 turns, to 12.25 W and 14.71 W using 5 and 7 turns, respectively. The frequency did not change switching to 5 turns but did change from 0.18 cycle/s to be 0.19 cycle/s when using 7 turns. The amplitude increased from 2.35 °C using 4 turns, to 3.24 °C and 3.62 °C using 5 and 7 turns, respectively.

Keywords: closed-loop oscillating heat pipe, startup condition

Introduction

A Closed Loop Oscillating Heat Pipe (CLOHP) is a type of heat exchanger. It is constructed by bending a capillary tube in an undulating bundle of a tube connecting both ends together to form a closed loop[1]. Heat is transferred by the oscillation of working fluid inside the CLOHP. Nowadays, modern technology usually consists of smaller in size and higher in performing electronic devices. A consequence of this is considerably high heat accumulation in these devices as well as decreasing surface area for heat dissipation. Because of the very high heat generation and limited heat sink area, CLOHP are utilized and installed onto electronic circuits for heat management. However, there are studies showing the oscillating heat pipe cannot start to operate in some cases[2]. This can cause failure in the device, e.g. a decrease in working hours and performance.

CLOHPS were investigated in many previous studies. One main aspect of a quantitative study[3] was concerned with the effect of tube geometry and the type of working fluid on heat transfer rates. But a qualitative study was concerned with the effect of tube geometry, type of working fluid, and filling ratio on internal flow pattern inside CLOHP.

The modeling and theoretical analysis of the startup of an oscillating heat pipe shows the effects of the evaporator surface roughness and superheated temperature necessary to make the CLOHP operate properly at normal conditions. But in some cases, the CLOHP cannot startup, even if the superheated level is

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reached[4,5]. However, a basic concept of startup conditions and a mathematical model to predict operation of the CLOHP was already established[6]. It is found that the point at which a CLOHP can start takes place when replac ement mechanism of the inside working fluid is possible. This mechanism occurs when net condensation rate of vapor plugs is higher than net evaporation rate of vapor plugs. But there are a few studies about the effect of parameters on the approach to steady state of CLOHP. Therefore, this study focuses on quantitative experiments to obtain the startup condition at which the working fluid inside the CLOHP start to operate.

Materials and Methods

The CLOHP was made of a long copper capillary tube with the inner diameter of 2.03 mm and the turns was 4, 5 and 7 turns. The ends were connected to close the loop. The evaporator, adiabatic and condenser section were all an equal length of 50 mm. R123, acetone and water were used as the working fluids with a 50% filling ratio.

1. Experimental setup and procedure

"(Figure. 1)" shows the experimental equipment. The CLOHP were filled with a working fluid by filling machine. Thermocouples were attached to the heat pipe at 10 points on the middle of each tube of the evaporator section (Te_1-Te_10), 4 points on the adiabatic section (Ta_1-Ta_4), and 4 points on the condenser section (Tc_1-Tc_4). The CLOHP was then set up with another experimental instrument. Thermocouples were attached at the inlet and outlet positions of the cooling jacket and then connected to relay information to the data logger for analysis. The AC high current supply was connected, the cold bath was adjusted to a temperature of 25°C, and the flow rate of cooling medium was adjusted, using a ball valve, to about 0.15 kg/min. After this, heat was supplied to the evaporator section continuously, the voltage was adjusted (one step increasing of the Variac can increase temperature of the evaporator section approximately one or two °C), and the temperature data was recorded. During the recording of data from the experiment, the temperatures at the evaporator and condenser sections were observed while the voltage was slightly increased until the CLOHP started up. Then the amplitude and frequency after start up were defined (amplitude ^{3} 0.2°C, frequency ^{3} 0.1 Hz). Before repeating the experiment, all experimental components were paused for 60 minutes or until all measured temperature points were equal to the ambient temperature.

The heat transfer rate of the cooling medium in the condenser section is calculated by substituting an inlet and outlet cooling medium temperature as shown in the following equation.

$$Q = \dot{m}c_p(T_{out} - T_{in}) \quad (1)$$

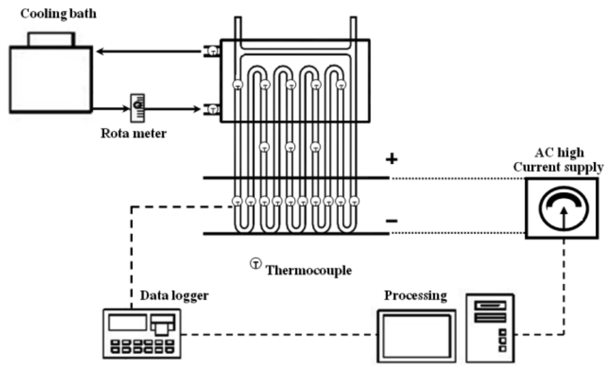
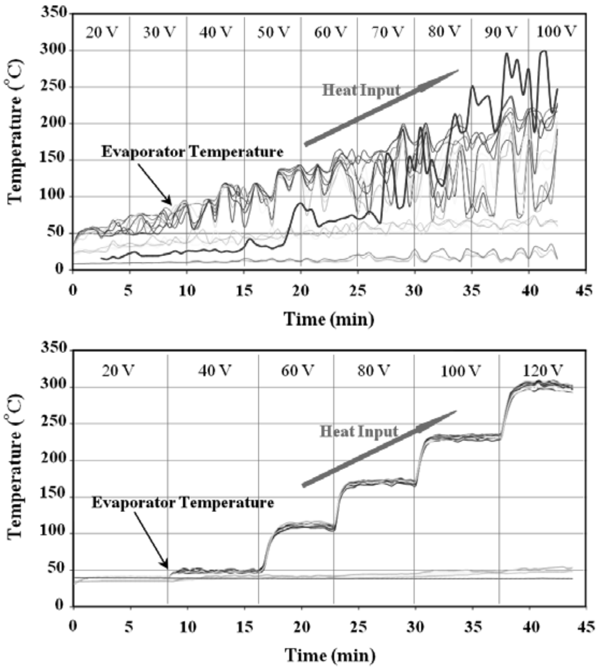


Figure 1 The whole experimental setup

2. Definition of startup condition

Since there is no quantitative definition of operational startup criteria, the definition used in this study considered the fluctuation of working fluid temperature. The CLOHP is defined to start its operation when the fluctuating amplitude of temperature is greater than or equal to 0.2°C and the fluctuating frequency of temperature is greater than or equal to 0.1 Hz. If these conditions are not met, the CLOHP is defined as unable to start transferring heat. The fluctuating amplitude and frequency of working fluid inside CLOHPs are measured using thermocouples, which are attached on the outer surface of the evaporator, adiabatic and condenser sections.

From (Figure 2(a)), it can be seen that the CLOHP starts its operation. When electrical voltage increases to 20 Variac ("Variac" in this study is a scale used in the voltage or current adjustment of the AC high current transformer) or the CLPHP is supplied with a higher input heat, the evaporator section temperature increases during the 1 to 3 minutes but there is no fluctuation of working fluid temperature. Therefore, the CLOHP does not operate during this time. After 3 minutes to find the fluctuation of working fluid temperature within the evaporator section, the amplitude and frequency are in the defined range. Thus, this is defined to be a point at which the CLOHP starts its operation. After the CLOHPs can normally transfer the heat. When electrical voltage increases from 20 Variac up to 100 Variac, will find that the fluctuation of working fluid temperature within the evaporator section to a wider range and the heat transfer is increased as well. In addition, heat transfer rate measured in the startup condition is very low compared with a case of the normal operating state.



(a) The CLOHP starts its operation

(b) The CLOHP cannot operate

Figure 2 Increase of evaporator and condenser section temperature with appropriate startup conditions

(Figure 2(b)) shows the non-working CLOHP. Increasing the heat at the evaporator section, and fluid cannot flow to the evaporator section. Thus the replacement and circulation of working fluid cannot take place because all of the working fluid is evaporated from the increasing activity in the evaporator. This is called dryout. This dryout affects increasing temperature at the evaporator section so that the CLOHP cannot operate, and there is no heat transfer.

Results and Discussions

All results show the relationship between the heat transfer rate, frequency and amplitude, on the effect of closed loop oscillating heat pipes (CLOHP) at startup conditions. For each frequency and amplitude is calculated by the program[7].

1. Effects of working fluids

The investigated CLOHP had an inner diameter of 2.03 mm, evaporator lengths of 50 mm, and was 4, 5 and 7 turns. R123, acetone and water were used as working fluids with latent heat of 161, 501 and 2386 kJ/kg respectively. (Figure 3) shows the effect of working fluids on the startup conditions of CLOHP. (Figure 3(a)) shows effect of heat transfer rate on the working fluids with 7 turns. Changing the working fluid between R123, acetone and water, it is found that the heat transfer rate increases from 5.72 W using R123 as working fluid, to 7.35 W and 14.71 W using acetone and water as working fluids, respectively. (Figure 3(b)) shows the effect of frequency on the working fluids, it is found that the frequency of the working fluid decreases from 0.94 cycle/s using R123 as working fluid, to 0.65 cycle/s and 0.19

cycle/s using acetone and water as working fluids, respectively. (Figure 3(c)) shows effect of amplitude on the working fluids, it is found that the amplitude increases from 0.36 °C using R123, to 0.55 °C and 3.62 °C using acetone and water, respectively.

A working fluid with high latent heat needs more than heat to change phase from liquid to vapor, when compared with the same weight. As a result, heat transfer rate, Amplitude increase and Frequency decrease at startup conditions. It is consistent with the previous study[7,8], when decreasing the working fluid's latent heat causes collapsing ratio of vapor slugs in condenser section increases, the CLOHP's can be easier obtained.

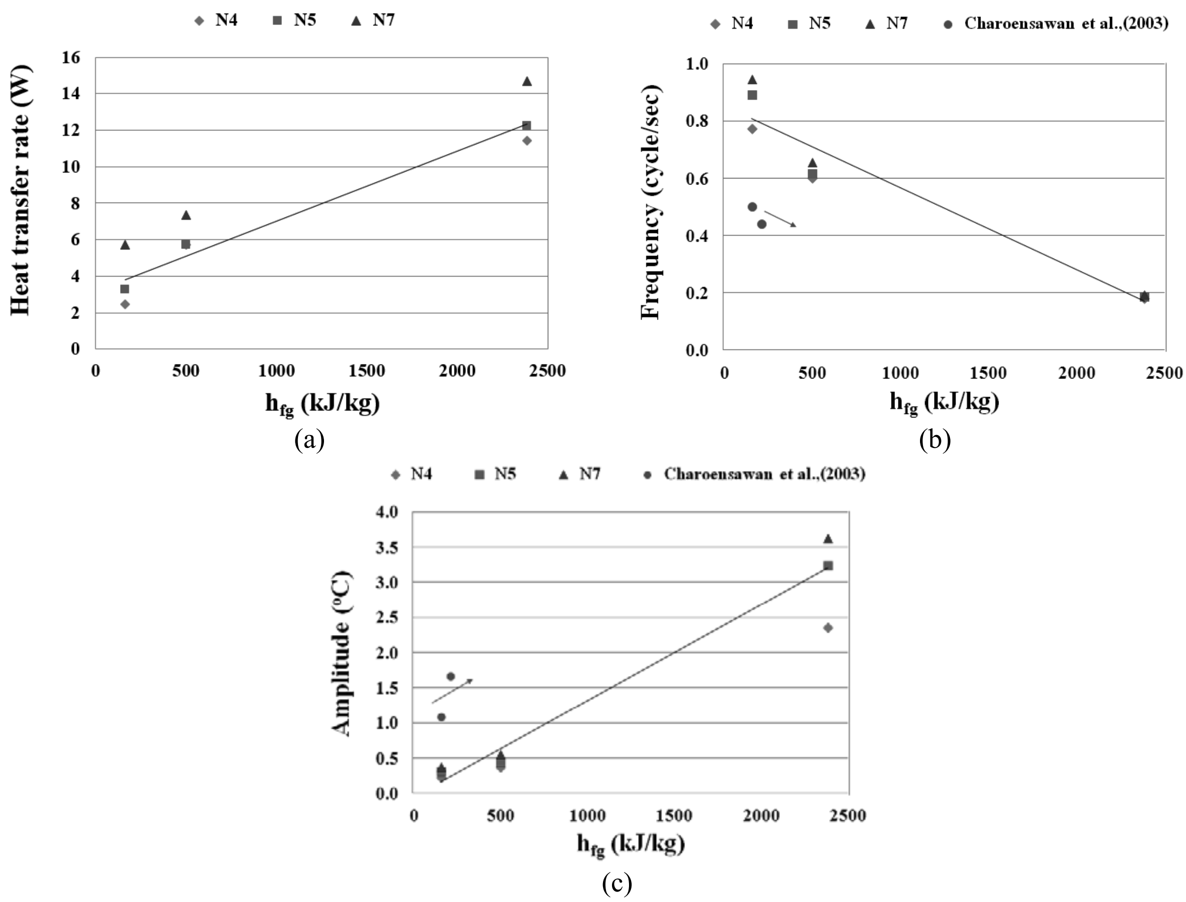


Figure 3 Effect of working fluids on the startup of CLOHP
(a) Heat transfer rate (b) Frequency (c) Amplitude

2. Effects of number of turns

The investigated CLOHP had an inner diameter of 2.03 mm, evaporator lengths of 50 mm, and was 4, 5 and 7 turns. R123, acetone and water were used as working fluids with latent heat of 161, 501 and 2386 kJ/kg respectively. (Figure 4) shows the Effect of number of turns on startup conditions. (Figure 4(a)) shows the effect of heat transfer rate on the number of turns, In case of using water as working fluid, changing the number of turn from 4 to 5 to 7 turns, it was found that the heat transfer rate increases from 11.43 W using 4 turns, to 12.25 W and 14.71 W using 5 and 7 turns, respectively. (Figure 4(b)) shows the effect of Frequency on the number of turns, it is found that the frequency of the number of turns does not change switching to 5 turns but does change from 0.18 cycle/s to 0.19 cycle/s when using 7 turns. (Figure 4(c)) shows the effect of Amplitude on the number of turns, it is found that the amplitude increases from 2.35 °C using 4 turns, to 3.24 °C and 3.62 °C using 5 and 7 turns, respectively.

The increase of number of turns is the same as the increase in the heat transfer area. As a result, the heat transfer rate, Frequency and Amplitude increase at startup conditions. This is consistent with the previous study[8,9].

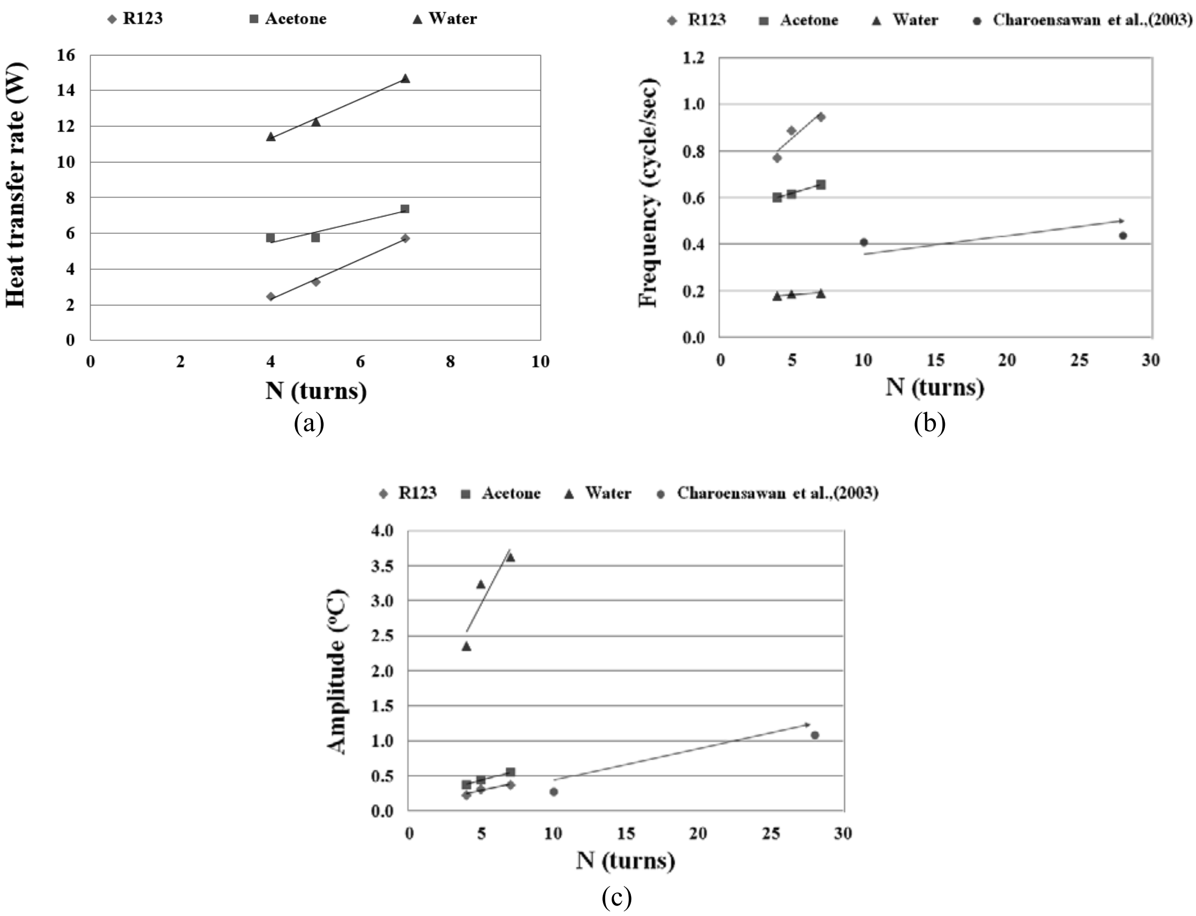


Figure 5 Effect of number of turns on the startup of CLOHP (a) Heat transfer rate (b) Frequency (c) Amplitude

Further work should be extended to study the internal flow patterns on startup condition in CLOHP. This application could be useful for the entire operation.

Conclusion

From this experimental investigation of a closed loop oscillating heat pipe at startup condition, it can be concluded that, when the number of turns is 7 and, chan ging the working fluid between R123, acetone and water:

- The heat transfer rate increases from 5.72 W using R123 as working fluid, to 7.35 W and 14.71 W using acetone and water as working fluids, respectively.
- The frequency of the working fluid decreases from 0.94 cycle/s using R123 as working fluid, to 0.65 cycle/s and 0.19 cycle/s using acetone and water as working fluids, respectively.
- The amplitude increases from 0.36 °C using R123, to 0.55 °C and 3.62 °C using acetone and water, respectively.

In case of using water as working fluid, changing the number of turn was 4 to 5to 7 turns, it was found that.

- The heat transfer rate increases from 11.43 W using 4 turns, to 12.25 W and 14.71 W using 5 and 7 turns, respectively.
- The frequency of the number of turn does not change when switching to 5 turns but does

change from 0.18 cycle/s to be 0.19 cycle/s when using 7 turns.

- The amplitude increases from 2.35 °C using 4 turns, to 3.24 °C and 3.62 °C using 5 and 7 turns, respectively.

It can be noted that working fluid with low latent heat and low number of turns, allows the CLOHP to start easily, which can be observed by the heat transfer rate, frequency and amplitude.

Acknowledgement

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