

Research Article

Internal flow Patterns of the Horizontal Heat Mode Closed-Loop Oscillating Heat Pipe with Check Valves (HHMCLOHP/CV)

S. Rittidech and S. Sangiamsuk

Heat-Pipe and Thermal Tools Design Research Unit (HTDR), Division of Mechanical Engineering, Faculty of Engineering, Maharakham University, 44150, Thailand

Abstract: This research was to study the internal flow patterns on heat transfer rates of the Horizontal Heat Mode Closed Loop Oscillating Heat Pipe with Check Valves (HHMCLOHP/CV). The HHMCLOHP/CV was made from a Pyrex glass capillary tube with a 2.4 mm inside diameter. There were 10 meandering turns with 2 check valves. Ethanol and a silver nano-ethanol mixture were used as working fluid. Experimental results found that if working fluid varies from ethanol to a silver nano-ethanol mixture and the evaporator temperature increases the main flow patterns were Slug flow + Annular flow. The main regime of each flow pattern can be determined from the flow pattern map.

Keywords: Closed loop oscillating heat pipe, flow patterns, horizontal heat mode

INTRODUCTION

The Oscillating/Pulsating Heat Pipe (OHP/PHP), first proposed is one type of heat transfer device (Akachi *et al.*, 1996). The Closed-Loop Oscillating Heat Pipe with Check Valves (CLOHP/CV) is a new type of heat transfer device. It offers high performance heat. Present applications for CLOHP/CV heat pipes include cooling devices, air preheaters etc. In general, the CLOHP/CV has three sections: the evaporator section, adiabatic section and condenser section. The principle is the transfer of the latent heat of the working fluid inside the tubes, which evaporates heat from a heat source at the evaporator section and the heat transfers by condensation to the condenser section. Due to the fact that the latent heat of vaporization of the working fluid is very high, it transfers heat from the evaporator section to the condenser section by a slight temperature difference. It also has the capability to operate in any heat mode such as Horizontal Heat Mode (HHM), Bottom Heat Mode (BHM), of Top Heat Mode (THM). However, the heat pipes operating in horizontal heat mode and bottom heat mode are not always practical for such cooling in electronic devices, humidity control air conditioning system, etc. Therefore, in the present experiment the Horizontal Heat Mode Closed-Loop Oscillating Heat Pipe with Check Valves (HHMCLOHP/CV) as shown in Fig. 1 was evaluated. Bhuwakietkumjohn and Rittidech (2010) studied the internal flow patterns of a CLOHP/CV. The CLOHP/CV used a Pyrex glass tube

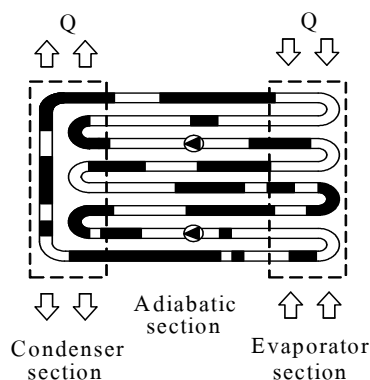


Fig. 1: The HHMCLOHP/CV

with inside diameter of 2.4 mm. The evaporator lengths of 50 and 150 mm. were employed with 10 turns, with R_{cv} of 0.2 and 1. R123 was used as the working fluid with a filling ratio of 50% of the internal volume of tube. It was found that at the high heat source, when the Le decreases, the main flow changes from bubble flow

Corresponding Author: S. Rittidech, Heat-Pipe and Thermal Tools Design Research Unit (HTDR), Division of Mechanical Engineering, Faculty of Engineering, Maharakham University, 44150, Thailand Tel.: +66-43-754316

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with slug flow to dispersed bubble flow. As the R_{cv} decreases, the main flow changes from the dispersed bubble flow with bubble flow to dispersed bubble flow. When the velocity of slug increases, the length of vapor bubbles rapidly decrease and the heat flux rapidly increases. In addition Rittidech *et al.* (2008) investigated the internal flow patterns and heat transfer characteristics of a CLOHP/CV. Ethanol and a silver nano-ethanol mixture were used as working fluids with a filling ratio of 50% by total volume of tube. The CLOHP/CV was made of a glass tube with an inside diameter of 2.4 mm. The evaporator section was 50 mm and 100 mm in length and there were 10 meandering turns. An inclination angle of 90° from horizontal axis was established. Temperature at the evaporator section was controlled at 85, 105 and 125°C . The inlet and outlet temperatures were measured. The silver nano-ethanol mixture gave higher heat flux than ethanol. When the temperature at the evaporator section was increased from 85, 105 and 125°C ., it was found that the flow patterns occurred as annular flow + slug flow, slug flow + bubble flow and dispersed bubble flow + bubble flow, respectively. The above literature review does not investigate the effect of parameters on internal flow patterns of the HHMCLOHP/CV. Therefore, this research will investigate the internal flow patterns of the HHMCLOHP/CV.

METHODOLOGY

Figure 2 shows an experimental setup which consists of a HHMCLOHP/CV. The HHMCLOHP/CV was made from a Pyrex glass capillary tube with 2.4 mm inside diameter and there were 10 meandering turns. The length of the evaporator section of 50 mm. The working fluid used were ethanol and a silver nano-ethanol mixture with the filling ratio of 50% of the total inside volume of tube. The temperatures of evaporator section were 85, 105 and 125°C . The inclination angle of 0° or horizontal axis was established. The heater warmed an aluminum plate, which was attached to the evaporator section while the condenser section was cooled by water from cold bath (EYELA CA-1111, volume of 6.0 l with an operating temperature range of -20 to 30°C with $\pm 2^\circ\text{C}$ accuracy) and then pumped into the cooling jacket. The mass flow rate inside the cooling jacket was measured with a floating rota meter (Platon PTF2ASS-C with a measure flow rate of 0.2-1.5 L/min). The thermocouples (OMEGA type K) with an uncertainty of $\pm 1^\circ\text{C}$ connect to the data logger (Yokogawa DX 200 with $\pm 1^\circ\text{C}$ accuracy, 20 channel input and -200 to 1100°C measurement temperature range) that were measure the inlet and outlet of the

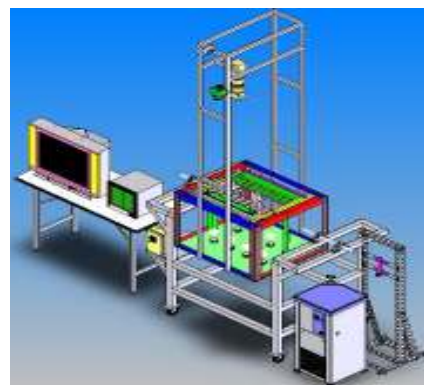


Fig. 2: Experimental test rig

condenser section to determine the heat transfer rate. A video camera (Sony CCD-TR618E) was employed to continuously record the flow patterns at the evaporator section, adiabatic and condenser sections and the total part of HHMCLOHP/CV. A digital camera (Nikon D90) was used to take a photograph of the flow patterns of a HHMCLOHP/CV at specified times. The experiment was conducted as follows. Firstly, a HHMCLOHP/CV was installed with the test rig. The temperature of the heater and cold baths was set at the required value and cold fluids were supplied to the jackets of the condenser section. After reaching the steady state, continuous movies were recorded by video cameras, while photographs were taken at specified times by the digital camera. The temperature and flow rate of the cooling water were recorded.

RESULTS AND DISCUSSION

The internal flow patterns of HHMCLOHP/CV were recorded by video camera and digital camera at specific times. The internal flow patterns show the relationship between effect of working fluids, evaporator lengths and the evaporator temperatures. The results show the internal flow patterns and the flow patterns map.

At working fluid of ethanol, evaporator length of 50 and 100 mm, Fig. 3 and 4 shows the internal flow patterns of HHMCLOHP/CV with the heat source temperature at evaporator section of 85, 105 and 125°C . It was found that, the flow patterns are the same; all were Slug flow + Annular flow. These flow patterns caused the vapor plug to move to the evaporator section. It pushed the liquid slug to the evaporator section and the liquid slug was nucleated boiling at the right and left side to Slug + Annular flow.



Fig. 3: Internal flow patterns of HHMCLOHP/CV using a ethanol at Le of 50 mm

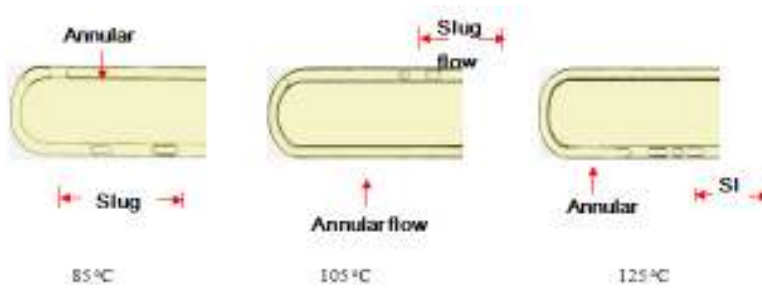


Fig. 4: Internal flow patterns of HHMCLOHP/CV using a ethanol mixture at Le of 100 mm

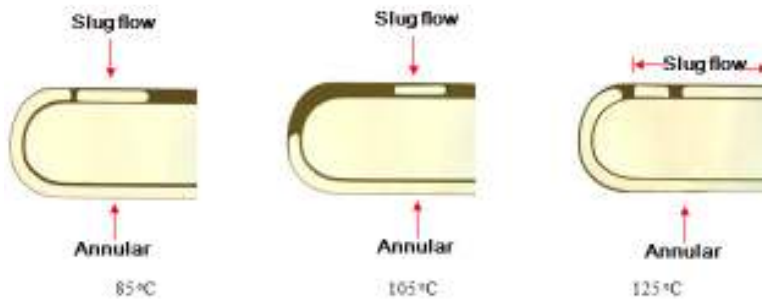


Fig. 5: Internal flow patterns of HHMCLOHP/CV using a silver-nano ethanol mixture at Le of 50 mm

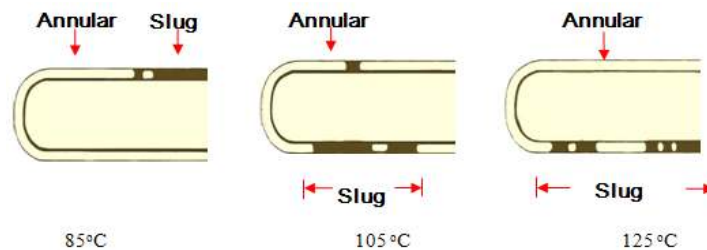


Fig. 6: Internal flow patterns of HHMCLOHP/CV using a silver-nano ethanol mixture at Le of 100 mm

At working fluid of silver nano-ethanol mixture, evaporator length of 50 and 100 mm, Fig. 5 and 6 shows the internal flow patterns of HHMCLOHP/CV with the heat source temperature at evaporator section of 85, 105 and 125°C. It was found that, the flow patterns are the same, all were Slug flow + Annular

flow. Figure 5 these flow patterns caused the vapor plug to move to the evaporator section. It pushed the liquid slug to the evaporator section and the liquid slug was nucleated boiling at the left side to annular flow at the lower part of the evaporator section and the vapor moving at the right side with Slug flow. Figure 6 the

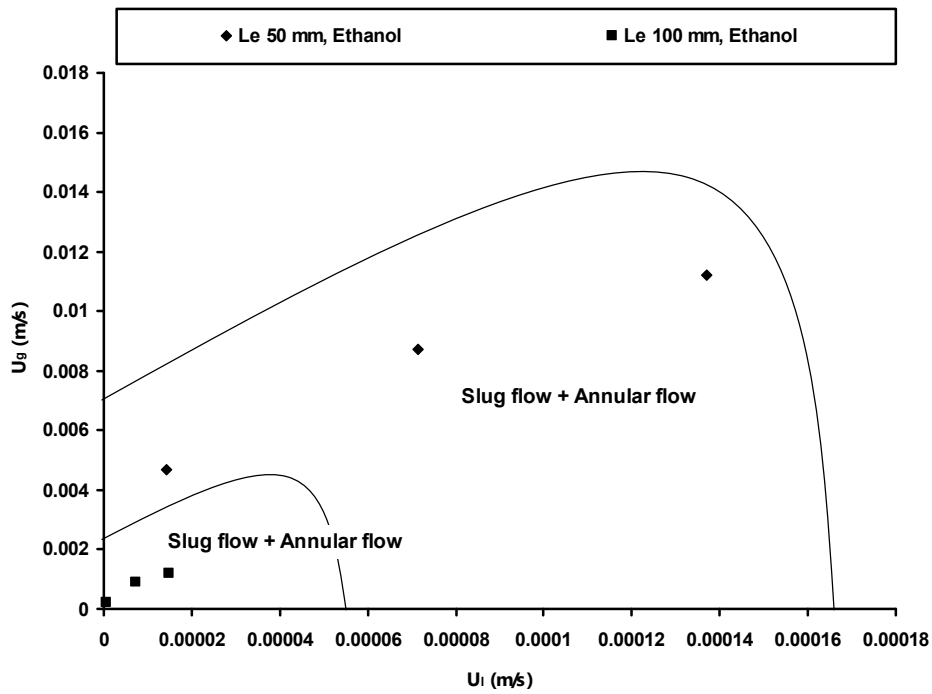


Fig. 7: Flow patterns map obtained using ethanol

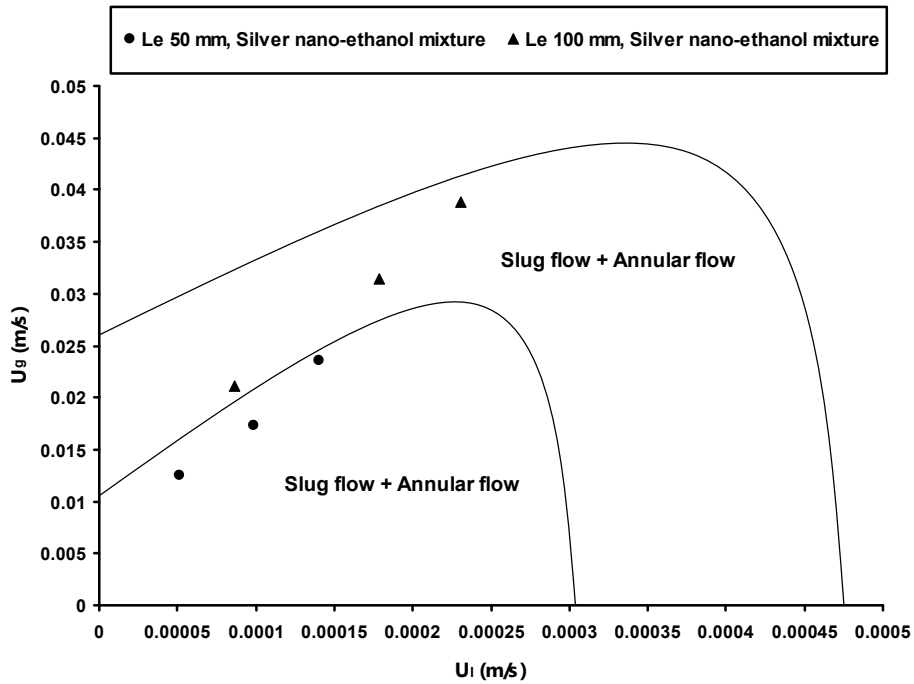


Fig. 8: Flow patterns map obtained using silver nano-ethanol mixture

liquid slug was nucleated boiling at the right side to Annular flow at the lower part of the evaporator section and the vapor moving at the left side with Slug flow.

The data from the experiment were plotted on a map and varied between a velocity of liquid and velocity of slug gas as shown in Fig. 7 to 8 i.e.:

$$U = U_G + U_L = \dot{m} \left[\frac{x}{\rho_G} + \frac{(1-x)}{\rho_L} \right] \quad (1)$$

From the map we can conclude that there are 2 flow patterns: a Slug flow and Annular flow respectively. However, the velocity of slug gas and velocity of liquid with the length of the evaporator does not affect the flow patterns. But it will affect the performance of HHMCLOHP/CV.

CONCLUSION

This section describes the conclusions of the studied result of the internal flow patterns of the Horizontal Heat Mode Closed-Loop Oscillating Heat Pipe with Check Valves (HHMCLOHP/CV) as follow.

For the internal flow patterns of HHMCLOHP/CV at the inclination angle of 0°C with the heat source temperature increased at the evaporator section from 85, 105 and 125°C. It was found that the main flow patterns were Slug flow + Annular flow. The main regime of each flow pattern can be determined from the flow pattern map.

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NOMENCLATURE

- U_G : Velocity of gas (m/s)
- U_L : Velocity of liquid (m/s)
- \dot{m} : Mass flow rate (kg/s)
- ρ_G : Density of slug gas (kg/m³)
- ρ_L : Density of liquid (kg/m³)
- x : The quality (-)

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