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Effect of Evaporator Lengths and Ratio of Check Valves to Number of Turns on Internal Flow Patterns of a Closed–Loop Oscillating Heat-Pipe With Check Valves

S. Rittidech P. Meena and P. Terdtoon
Faculty of Engineering, Mahasarakham University, Thailand, 44150

Abstract: A visualization study of the internal flow patterns of a closed–loop oscillating heat-pipe with check valves (CLOHP/CV) at normal operating condition for several evaporator lengths (Le), and ratio of check valves to number of turns (Rcv) has been conducted. This article describes the effects of varying Le, and Rcv on flow patterns. The CLOHP/CV used a Pyrex glass tube with inside diameter of 2.4 mm. The evaporator length of 50 and 150 mm. (the lengths of evaporator, adiabatic and condenser were equal) were employed with 10 turns, with Rcv of 0.2 and 1. R123 was used as the working fluid with filling ratio of 50% of internal volume of tube. It was found that the internal flow patterns could be classified according to the Le and Rcv as follows: At the high heat source when the Le decreases the main flow changes from the bubble flow with slug flow to disperse bubble flow. The Rcv decreases the main flow changes from the disperse bubble flow with bubble flow to disperse bubble When the velocity of slug increases, the length of vapor bubbles rapidly decreases and the heat flux rapidly increases.

Key words: Flow patterns, Closed-loop oscillating heat-pipe, Check valves

INTRODUCTION

Over the past few years, there has been rapid development of practical engineering solutions to a multitude of heating problems. Heat generated in micro–devices used in manufacturing and electronics require special solutions. Closed-looped oscillating heat-pipe with check valves (CLOHP/CV) in Fig. 1. is a very effective heat transfer device. Heat is transported from the evaporator to the condenser by the oscillation of the working fluid moving in an axial direction inside the tube. In this type of system the inner diameter of the pipe is important. It must be small enough so that under operation conditions liquid slugs and vapor plugs can be formed. If the diameter is too large, the liquid and vapor inside the tube will become stratified and operation cannot be established. In the tradition, closed-looped oscillating heat-pipe with check valves (CLOHP/CV). Akachi et al.[1] has invented a new type of heat made of a capillary tube that has been applied to cool small electronic devices. This new type of heat pipe is called an oscillating heat pipe (OHP), and has the same basic operational principle as that of the oscillating movement of the fluid and phase change phenomena. The first one is a closed-end oscillating heat-pipe (CEOHP). In this type, a capillary tube is bent into many meandering turns and closed at both ends. The second type is a closed-loop oscillating heat-pipe (CLOHP), which is connected at both ends of a tube to form close loop. The third type is a closed-loop oscillating heat-pipe with check valves (CLOHP/CV). This type is a closed loop oscillating heat-pipe connected the both ends of a tube to from a closed loop and has one or more check valves in the loop. Gi et al. [2] conducted experiments with R142b by varying the fill ratios and inclination angles. A CEOHP with an ID of 2 mm and a total length of 80 mm was employed; it has 10 turns and working temperature of 45°. It was observed that the flow was unable circulate thoroughly. The heat transferred by driving force due to the oscillation between heating and cooling section. The internal oscillation occurred at a smaller inclination angle and a smaller fill ratio. Lee et al.[4] conducted a visual study of the flow in a closed–loop oscillation heat pipe (CLOHP) with ethanol by varying in the inclination angles, fill ratios and working temperatures. A CLOHP with 4 turns and total length of 220 mm, and a high-speed camera operating at 400 frame/sec was used to the flow visualization test. The shutter speed was set to 1/2000 sec and a stroboscope was used as light source. The circulation of working fluid could not be clearly identified, and condensate returned to the evaporator section as a simple stratified or rivulet flow along the inner wall of channel. An oscillation of

Corresponding Author: S. Rittidech, Faculty of Engineering, Mahasarakham University, Khamriang Campus, Kantharawichai, Mahasarakham, 44150, Thailand

bubbles was caused by nucleate boiling and vapor oscillation. The most active oscillation was observed at the fill ratio of 40–60% and at inclination angle of 90 degrees. Miyazaki et al. [6] studies the oscillating heat-pipe with check valves. It was found the CHOHP/CV, as a high efficiency heat transfer. Huo et al.[5], investigated the boiling heat transfer in small diameter tubes. It was found that the experimental they categorize six flow patterns. These are dispersed bubble, bubble, Slug, churn, annular, and Mist flow. N. Pipatpaiboon et al.[3]: studies the effect of inclination angle working fluid and number of check vales on the characteristics of heat transfer in a closed-looped oscillating heat-pipe with check valves (CLOHP/CV). It was found the CHOHP/CV is equipped with 2 check valves; there is an increased interest by the heat transfer community into research in the transport phenomena in closed–loop oscillating heat-pipe with check valves (CLOHP/CV). The results of flow pattern were clear and informative; therefore results were recorded in the evaporator section, since there are two main phenomena occurring inside a CLOHP/CV, i.e., liquid slug and vapor slug counter-current flow phenomenon and boiling phenomenon. The inside phenomena of the CLOHP/CV may be predicted by using Le, and Rcv. It is, therefore, the objective of this article to investigate the internal flow patterns of a closed–loope oscillating heat-pipe with check calves at normal operating condition.

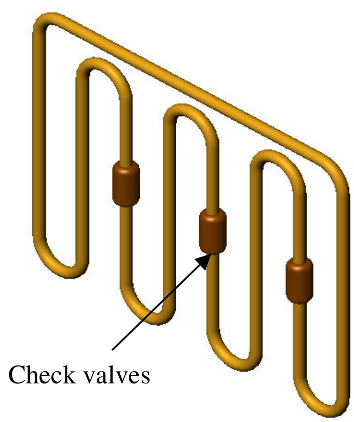


Fig 1: Closed-looped oscillating heat-pipe with check valves (CLOHP/CV)

Experimental setup and procedure: Fig. 2 (a, b). Shows the prototype. The check valve is a floating type valve that consists of a stainless ball and brass tube, in which ball stopper and conical valves seat are provided at the ends, respectively. The ball can move freely between the ball stopper and the valves seat.

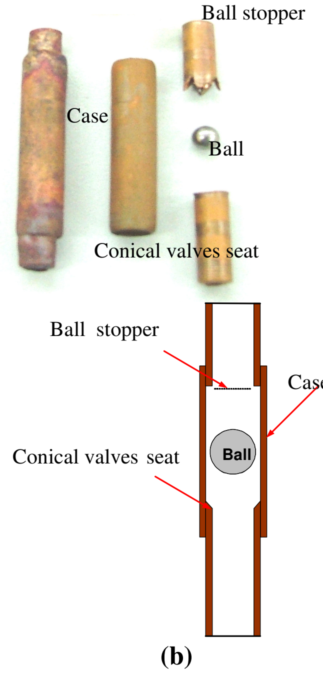


Fig 2: a, b Prototype of check valve

Fig. 3 shows an experimental setup which consists of a CLOHP/CV with the lengths of evaporator, adiabatic (which is equal to condenser sections) were 50 and 150 mm respectively. The selected CLOHP/CVs were made of Pyrex glass tubes with an internal diameter of 2.4 mm. The evaporator glass section was heated by a heater and was cooled by distilled water, which was circulated from a cold bath (EYELA CA-1111, volume of 6.0 l with an operating temperature range of –20 to 30°C with ±2°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 PTF2 ASS-C with a measure flow rate of 0.2 L/min to 1.5 L/min), while 4 points of thermocouples (OMEGA type K) were installed at the inlet and outlet of the condenser section to determine the heat transfer rate. The temperature probes were installed at 4 points on the high temperature aluminum plate of the evaporator and at 1 point for ambient to determine the heat loss. A temperature recorder (Yokogawa DX 200 with ±0.1°C accuracy, 20 channel input and –200°C to 1100°C measurement temperature range) was used with type K thermocouples (Omega with ±1°C accuracy) to monitor all temperatures at specified times. Moreover, 2 points of thermocouples were installed at the middle position.

During the experiment the angle was set at 90 degrees from the horizontal plane. A video camera (Sony CCD-TR618E) was employed to continuously record the flow patterns at the evaporator section, condenser and adiabatic sections, and the total part of CLOHP/CV. A digital camera (DSC-S75) was used to record the flow patterns of the evaporator section at specified times. A scale was attached to the apparatus to measure the length and velocity of vapor bubbles. The controlled parameters were: tube internal diameter of 2.4 mm, and R123 working fluid at a temperature of 50°C. The variable parameters were: L_e of 50 and 150 mm (to observe the effect of L_e), ratios of check valves to number of turns (to observe the effect of Rcv), and the working temperatures of 47.5°C, 50°C and 52.5°C. The experiment was conducted as follows; Firstly, a CLOHP/CV was set into 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 a steady state was reached, continuous movies were recorded by video cameras, while photographs were taken at specified times by a digital camera. In the meantime, temperature and heat transfer rates were monitored. Then the L_e and Rcv were varied according to the required conditions.

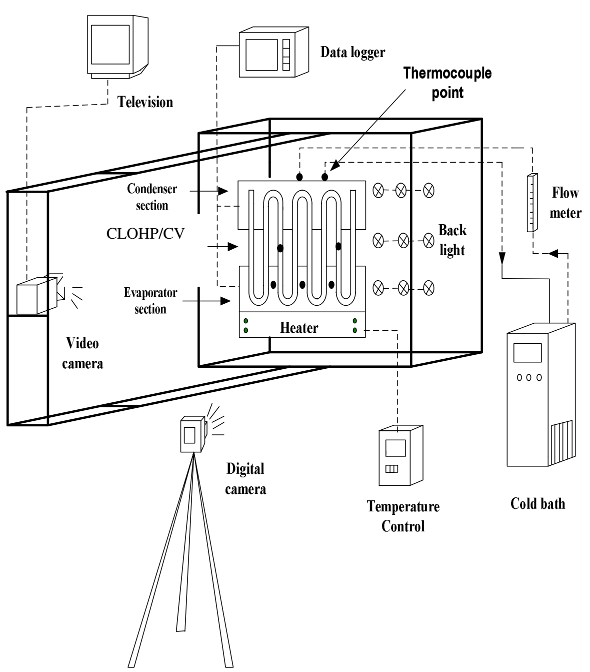


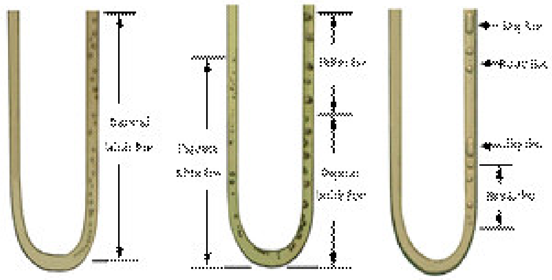
Fig. 3: Experimental setup.

RESULTS AND DISCUSSION

Visualization was focused at the evaporator section since the major phenomena occur in that part. The total flow, which cannot be presented in this paper, could, however, be observed by video movie. The vapor bubble length was measured as the length of the two ends of vapor at a specified time. The internal flow patterns at specific aspect ratios have been presented with respect to first, increasing the heater temperature. Second, a comparison of internal flow patterns at the same heat source temperature for all evaporator section lengths, filling ratios and ratios of check valves. It can be concluded from the experimental results as follows;

Effect of evaporator section lengths: The internal flow patterns are compared using the same number of turns (10) for 2.4 mm inner diameter, a filling ratio of 50% and ratios of check valves to number of turns of 0.2 as the evaporator section lengths increased from 50 mm to 150 mm. (to observe the effect of Le).The temperature oscillations of the working fluid in adjacent tubes of the adiabatic section of the CLOHP/CV with the long and the short evaporator are presented in Fig. 4 and 5, respectively. Circulation of the working fluid in the CLOHP/CV system with all evaporators occurs in one fixed flow direction.

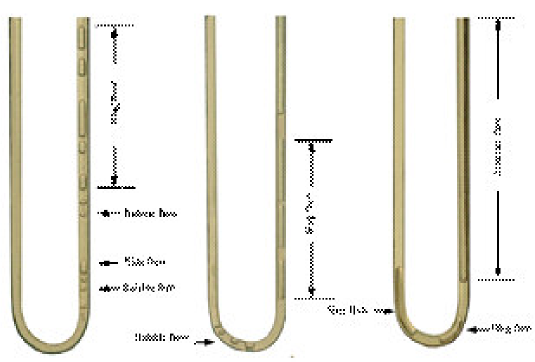
At evaporator section lengths of 50 mm: Figure 4 shows the internal flow patterns of the CLOHP/CV with a Le of 50 mm at the vertical position. It can be observed that, at a relatively low heat source temperature (75-80^{0}C) with a heat flux of 4.08 kW/m^2, dispersed bubble flow with very few nucleation sites appears, and bubble flow with more nucleation sites can be observed in the lower part of the evaporator. These vapor bubbles expend to the middle part of evaporator before moving up to the condenser part. The length of the vapor slug is approximately 0.0215 m. The velocity of vapor slug is 0.290 m/s. At a higher heat source temperature (85^{0}C) with a heat flux of 4.57 kW/m^2, slug flow with very few nucleation sites appears and dispersed bubble flow with more nucleation sites can be observed in the lower part of the evaporator. Bubble flow dominates the middle and upper parts of evaporator. The length of the vapor slug is approximately 0.0096 m. The velocity of the vapor slug is 0.294 m/s. It can be stated that patterns of the dispersed bubble and bubble flows dominate at Le of 50 mm.



85^{0}C 80^{0}C 75^{0}C

Fig. 4: Internal flow patterns of CLOHP/CV at L_e of 50 mm.

At evaporator section lengths of 150 mm: Figure 5 shows the inside flow patterns of the CLOHP/CV with a Le of 150 mm at the vertical position. It can be observed that, at a relatively low heat source temperature (75-80^{0}C) with a heat flux of 1.85 kW/m2, bubble flow with very few nucleation sites appears and slug flow with more nucleation sites can be observed in the lower part of the evaporator. Slug and annular flows dominate the middle and upper parts of the evaporator. These vapor slugs expend to the middle part of evaporator before moving up to the condenser part. The length of the vapor slug is approximately 0.0194 m. The velocity of vapor slug is 0.281 m/s. At a higher heat source temperature (85^{0}C) with a heat flux of 2.13 kW/m^2, bubble flow with more nucleation sites can be observed in the lower part of the evaporator. Bubble and slug flows dominate the middle and upper parts of the evaporator, annular flow slightly occurs. The length of the vapor slug is approximately 0.0154 m. The velocity of vapor slug is 0.404 m/s. It can be stated that patterns of the bubble and slug flows dominate at L_e of 150 mm.



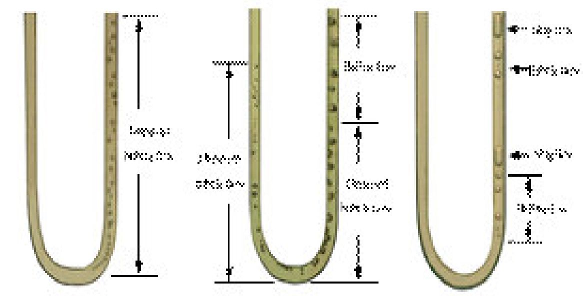
85^{0}C 80^{0}C 75^{0}C

Fig. 5: Internal flow patterns of CLOHP/CV at L_e of 150 mm.

Effect of ratios of check valves to number of turns: The internal flow patterns are compared for the same number of turns (10) at 2.4 mm inner diameter, filling ratios of 50% and evaporator section lengths of 50 mm as the ratios of check valves to number of turns of 0.2 increased from 0.2 to 1 (to observe the effect of Rcv).

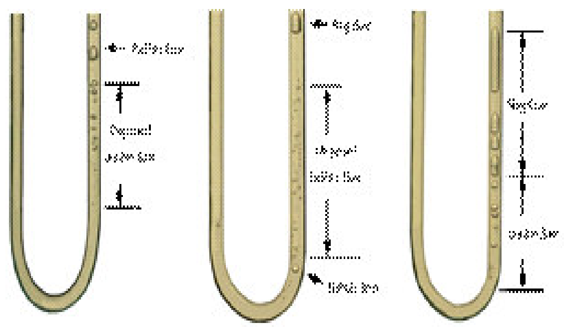
At ratios of check valves to number of turns 0.2: Figure 6 shows the internal flow patterns of the CLOHP/CV with the Rcv of 0.2 at the vertical position. It can be observed that, at a relatively low heat source temperature with a heat flux of 4.08 kW/m^2, dispersed bubble flow with very few nucleation sites appears and bubble flow with more sites can be observed in the lower part of the evaporator. These vapor bubbles expend to the middle part of evaporator before moving up to the condenser part. The length of the vapor slug is approximately 0.0215 m. The velocity of vapor slug is 0.290 m/s. At a higher heat source temperature with a heat flux of 4.57 kW/m^2 , slug flow with very few nucleation sites appears, and dispersed bubble flow with more nucleation sites can be observed in the lower part of the evaporator. Bubble flows dominate the middle and upper parts of evaporator. The length of slug and annular flows is approximately 0.0096 m. The velocity of the vapor slug is 0.294 m/s. It can be stated that patterns of the dispersed bubble and bubble flows dominate at Rcv of 0.2.

At ratio of check valve to number of turns of 1: Figure 7 shows the inside flow patterns of the CLOHP/CV with the Rcv of 1 at the vertical position. It can be observed that at a relatively low heat source temperature, with a heat flux of 2.47 kW/m^2, slug flow with more nucleation sites appears in the lower part of the evaporator. While slug and annular flows dominate the middle and upper parts of the evaporator, slight bubble flow occurs. The length of the vapor slug is approximately 0.0125 m. The velocity of vapor slug is 0.214 m/s. At a higher heat source temperature with a heat flux of 2.76 kW/m^2, bubble flow with more nucleation sites can be observed in the lower part of evaporator. The length of the vapor slug is approximately 0.0161 m. The velocity of vapor slug is 0.112 m/s. It can be stated that patterns of the bubble and slug flow dominate at Rcv of 1.



85^{0}C 80^{0}C 75^{0}C

Fig. 6: Internal flow patterns of CLOHP/CV at Rcv of 0.2



85^{0}C 80^{0}C 75^{0}C

Fig. 7: Internal flow patterns of CLOHP/CV at Rcv of 1

CONCLUSIONS

In this experimental for internal flow patterns of a closed-loop oscillating heat pipe with check valves under normal operating conditions, it can be concluded as follows:

The evaporator section length decreases from 150 mm to 50 mm. The main flow changes from a bubble flow with slug flow to a dispersed bubble flow for the high heat source. When the velocity of slug increases, the length of vapor slug rapidly decreases and the heat flux rapidly increases.

The ratio of check valves to number of turns decreases from 1 to 0.2. The main flow changes from the dispersed bubble flow with bubble flow to disperse bubble flow for the high heat source. When the velocity of slug increases, the length of vapor bubbles rapidly decreases and the heat flux rapidly increases.

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