filling ratio of 50%. The number of check valves were 2 5, 8 and 10. It was found, from experiment, that the values of the maximum heat-transfer rate (Q_{max}) of the CLOHP/CV for R123, ethanol and water were 872, 635 and 585 W, respectively. The angle at which Q_{max} occurs was 90°, 80° and 0°, respectively. It can be seen that the check valves affected the heat-transfer characteristics of the CLOHP/CV such that with two check valves for R123 and ethanol, the values of Q_{max}/Q_0 were 1.54 and 1.8, respectively. However, the five check valve system gave Q_{max}/Q_0 as unity.

The heat-transfer characteristics of the CLOHP/CV are usually shown by its capability of transferring heat at 90° (i.e. in the vertical plane, when the condenser sections are over the evaporator section). However, there has been little previous experimental research undertaken on the heat-flux for the vertical position. It is, therefore, the objective of this research to investigate experimentally the following aspects of a CLOHP/CVs behaviour:

- To study the effects of the ratio of check valves, inner diameter of the tube, aspect ratios and the dimensionless parameters on the heat-transfer characteristics of a CLOHP/CV in the vertical position.
- Establish a correlation to predict the heat-transfer characteristics of a CLOHP/CV used in the vertical position.

2. Experimental set-up and procedure

2.1. Check valves

The check valve (see Fig. 2) is a floating type valve that consists of a stainless steel ball and copper tube, in which a ball stopper and conical valve seat are provided at the ends of the check-valves case:a conical valves seat is provided at the bottom of the case and ball stopper provided at the top of the case, respectively. The ball can move freely between the ball stopper and conical valve-seat. A conical valve seat contacts the stainless-steel ball in order to prevent a reversal of the flow of the working fluid. The ball stopper allows the working fluid to travel to the condenser section for transferring heat.

2.2. Experimental set-up

Figs. 3 and 4 show the experimental rig, which consists of a CLOHP/CV with a heating bath for the evaporator section and a cooling bath for the condenser section. The CLOHP/CV was made of copper tubes. The temperatures of the evaporator and condenser section were controlled at 80 °C and 20 °C, respectively. The data logger (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) attached to the inlet and outlet of the cooling jacket, to monitor the temperatures. In order to calculate the heat-transfer characteristics using the calorific method, eight sets of thermocouple were attached to the outside surface wall of the CLOHP/CV and data were recorded. These were for three points on the evaporator, four points on the condenser and three points on the adiabatic section. A hot bath (TECHNE TE-10D with an operating range of −40 °C to 120 °C and ±0.01 °C accuracy) was used to pump hot water into the heating jacket at the temperatures of 80 °C. While the cold bath

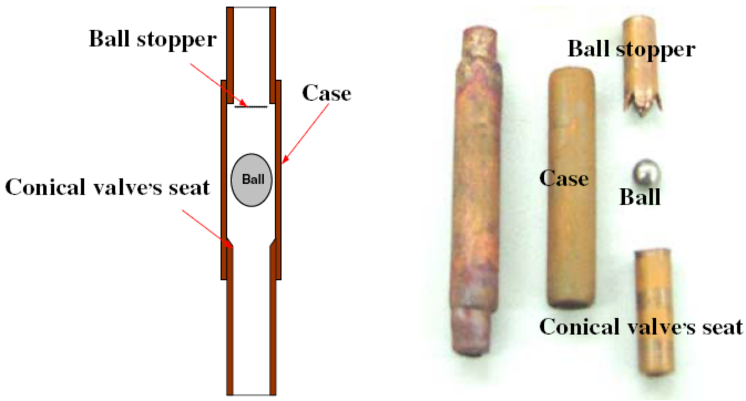

Fig. 2. Check valve.

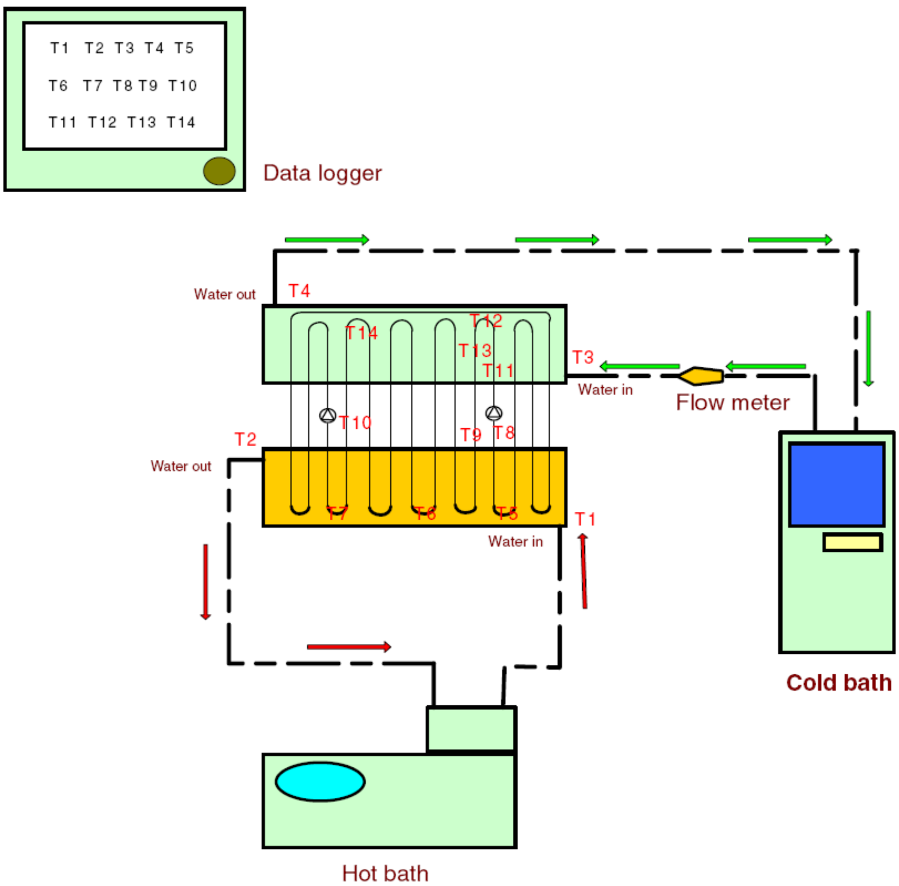

Fig. 3. Experimental set-up.

(EYELA CA-1111, volume 6.0 litres with an operating temperature range of −20 to 30 °C and ±2 °C accuracy) system was used to pump the cooling water into the cooling jacket. The inlet temperature of the cooling water was maintained at 20°C and the floating

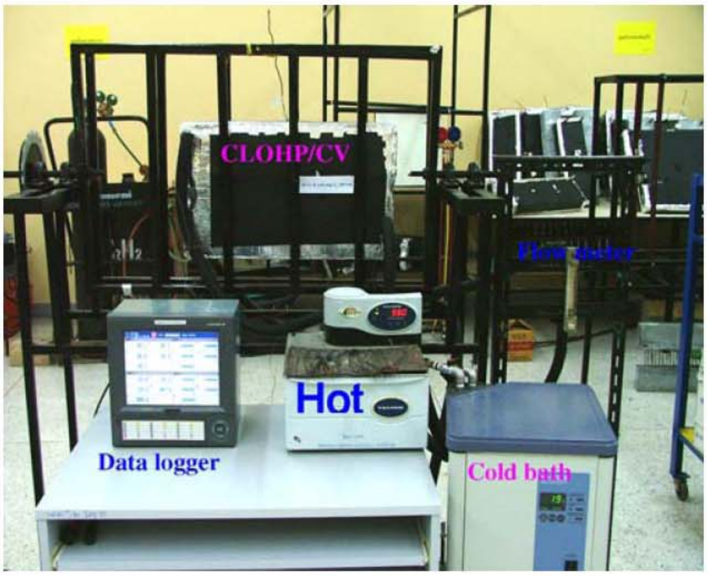

Fig. 4. The test rig.

rotameter (Platon PTF2 ASS-C for a flow rate of 0.2 litre/min – 1.5 litre/min) was used to measure the flow rate of the cooling medium. During the experiment, the mass-flow rate was set at 1.3 litres/min with the inclination at 90°. When a steady state was achieved, the temperature and flow rate of the cooling water were recorded. The following equations were used to calculate the heat-transfer rate of the test CLOHP/CV:

$$Q = \dot{m}C_{\mathrm{p}}(T_{\mathrm{out}} - T_{\mathrm{in}}) \tag{1}$$

The controlled parameters were:

- working temperature = 50 °C.
- filling ratio = 50% (by total volume).
- number of turns = 40.
- 90 inclination to the horizontal.

The variable parameters were:

- working fluid = R123, ethanol or water.
- Ratio of check valves = 4, 5, 8, and 20 (i.e. number of turns divided by the number of check valves).
- tube inner diameter = 1.77 or 2.03 mm.
- aspect ratio ($L_{\mathrm{e}}/d_{\mathrm{i}}$) = 24, 28, 49, 56, 74 or 84.

3. Results and discussion

The rate of heat-transfer (Q) of the CLOHP/CV in the vertical position (see Figs. 5–15) was varied. Also

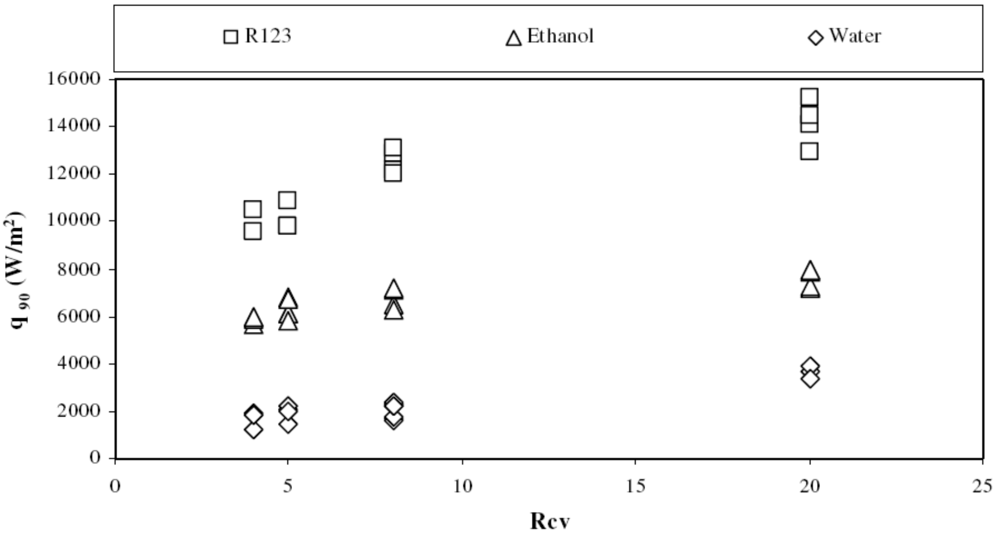

Fig. 5. Relationship of the ratio of check valves to heat flux of the CLOHP/CV.

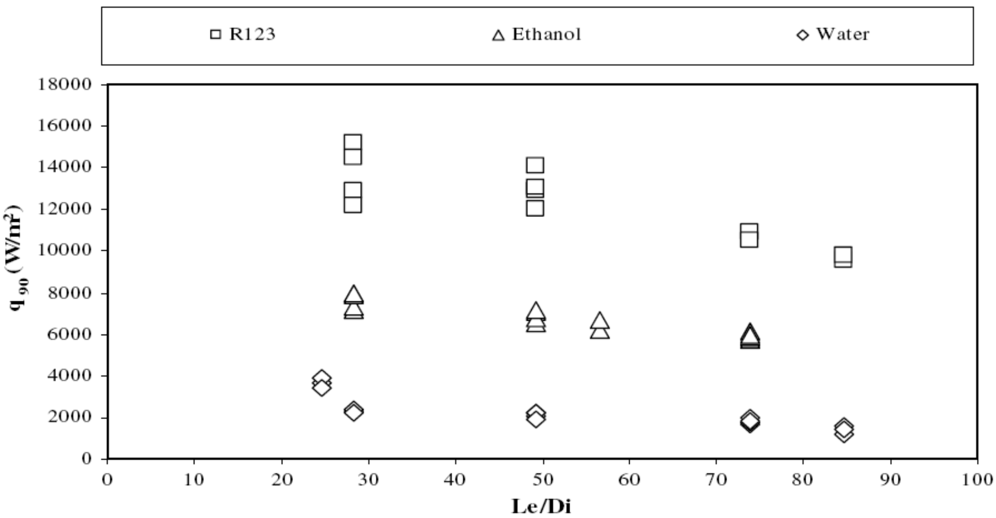

Fig. 6. Relationship of aspect ratio to heat flux of the CLOHP/CV.

$$q_{90} = \frac{Q_{90}}{A_o} \tag{2}$$

3.1. Effect of the ratio of check valves

In this experiment, the effect of ratio (R_{cv}) of the check valve on the heat-flux of a CLOHP/CV in a vertical position was considered. (see Fig. 5). The ratio of check valves is the number of turns divided by the number of check valves. This figure shows the relationship between R_{cv} and the heat-flux of a CLOHP/CV with 40 meandering

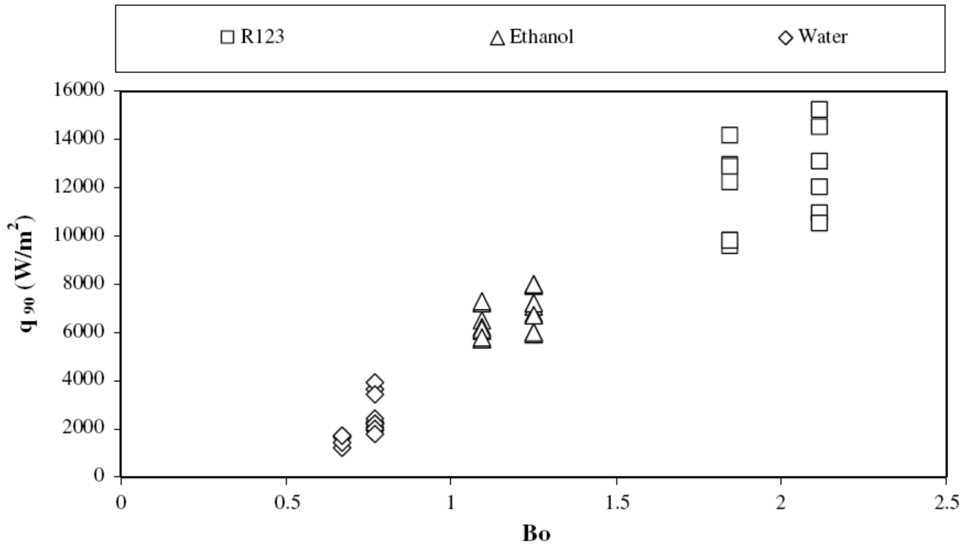

Fig. 7. Relationship of Bond number to heat flux of the CLOHP/CV.

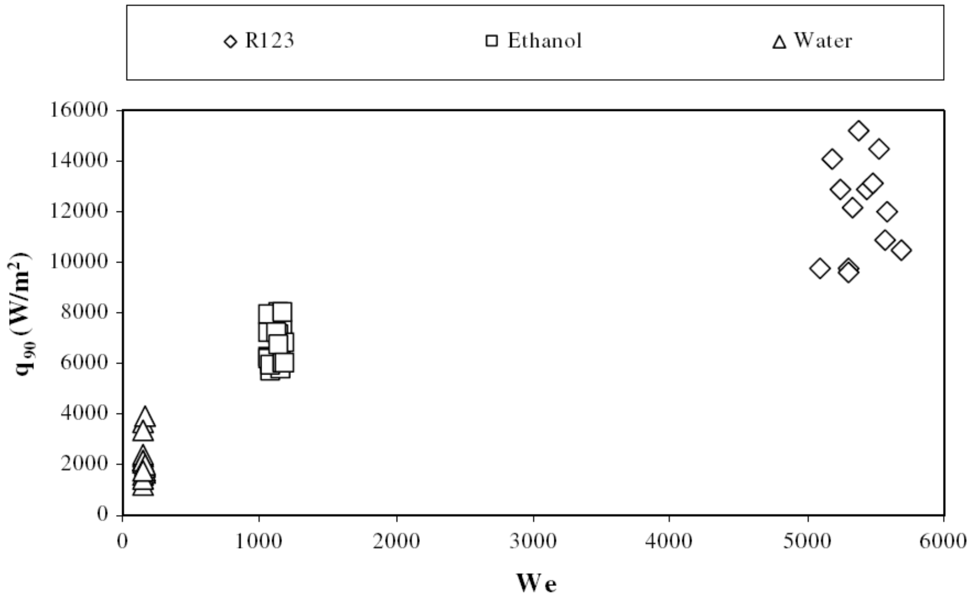

Fig. 8. Relationship of Weber number to heat flux of the CLOHP/CV.

turns: the number of check valves were 2, 5, 8 or 20, respectively.Various working fluids were used. The greater the ratio of check valves, the higher the heat-flux. The maximum heat-flux of each working fluid was obtained at the maximum ratio of check valves. This may be because, in this experiment, when the ratio of check valves increases (i.e. the number of check valves decreases), the effect of gravity on the ball of the check valves decreased.

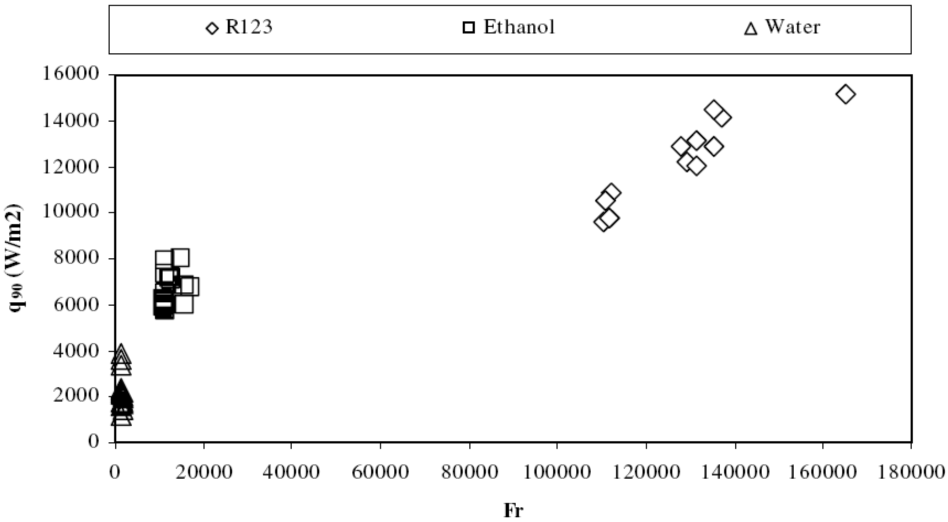

Fig. 9. Relationship of the Froude number to heat flux of the CLOHP/CV.

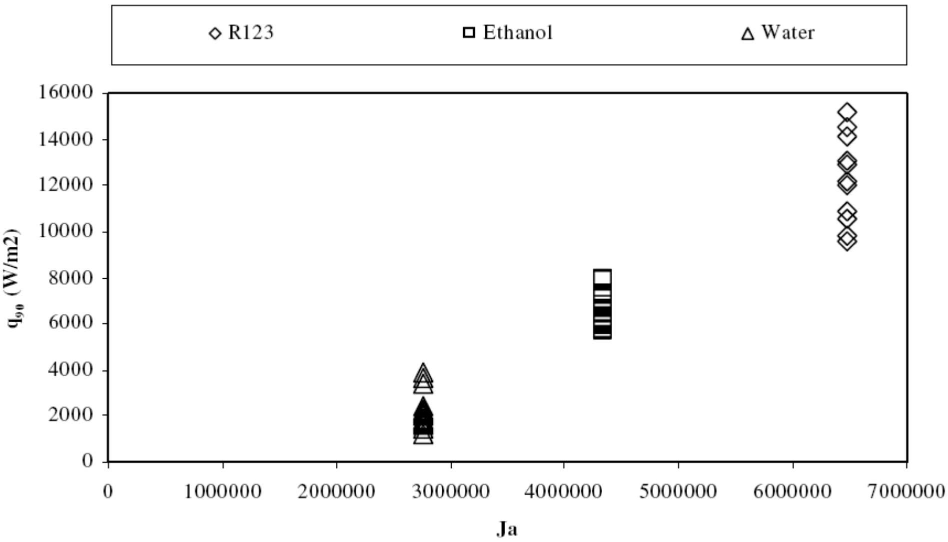

Fig. 10. Relationship of the Jacob number to heat flux of the CLOHP/CV.

3.2. Effect of aspect ratio

In this experiment, the evaporator, adiabatic and condenser sections were of equal length. This paper will concentrate on study the effect of aspect ratio (L_e/d_i) on heat-flux of a CLOHP/CV. Fig. 6, shows the relationship of the aspect ratio to the heat-flux of CLOHP/CV with an inner diameter of 1.77 or 2.03 mm, with 40 meandering turns; R123, ethanol or water was used as the working fluid, with a filling ratio of the 50% of the internal volume of the tube. It was seen that, the maximum heat-flux for each inner diameter was obtained at an aspect ratio L_e/d_i of 28. As the L_e/d_i increased from 24 to

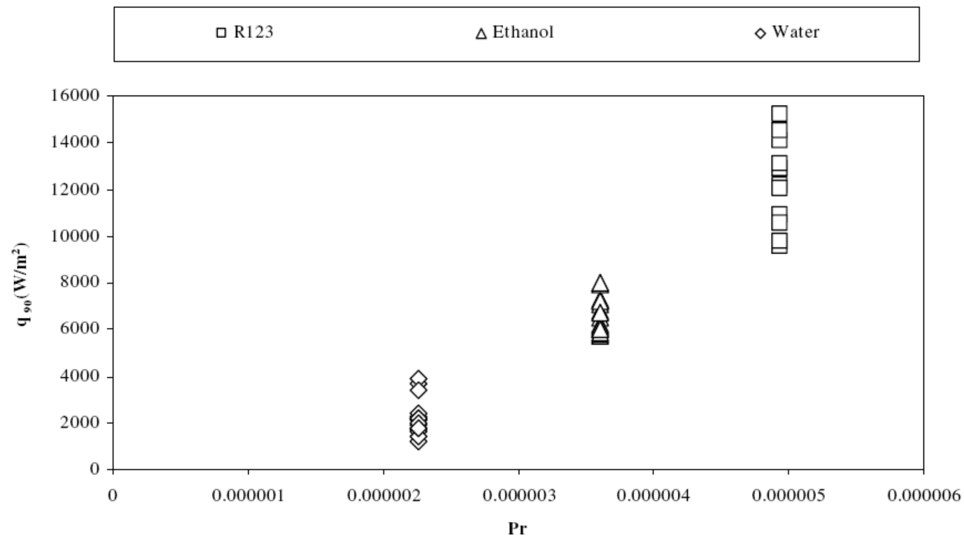

Fig. 11. Relationship of the Prandtl number to heat flux of the CLOHP/CV.

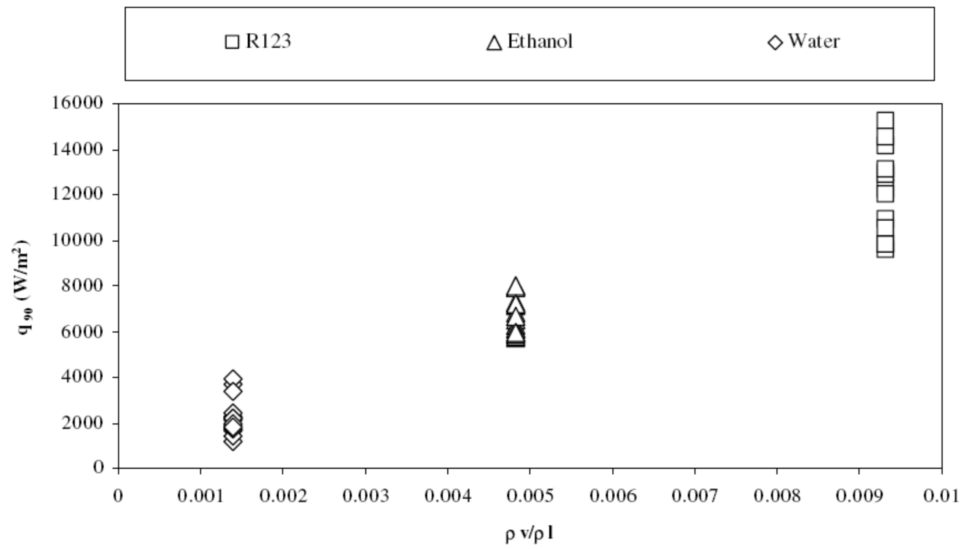

Fig. 12. Relationship of $[\frac{\rho_v}{\rho_l}]$ to the heat flux of the CLOHP/CV.

84, the heat-flux slightly decreased. At a high L_e/d_i, boiling ensued inside a confined channel and a low heat-flux occurs.

3.3. Effect of inner diameter

The Bond number is the ratio of buoyancy force to surface tension force. In this experiment, the effect of the Bond number (*Bo*) on the heat-flux of a vertical CLOHP/CV was considered. The experimental results indicate the effect of the Bond numbers on the heat-flux in Fig. 7: the inner diameter was either 2.03 or 1.77 and R123, ethanol or water was

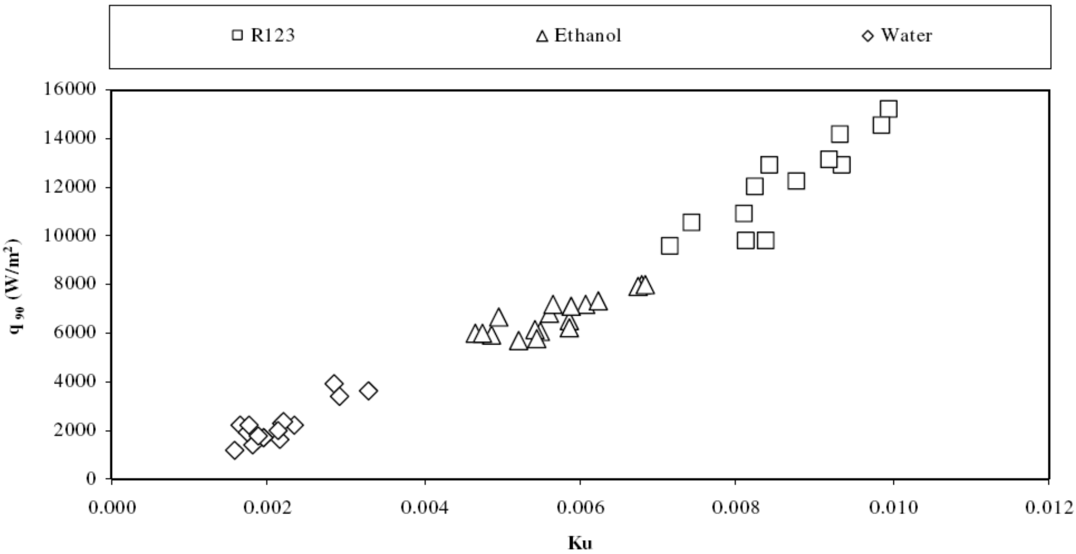

Fig. 13. Relationship of Ku to the heat flux of the CLOHP/CV.

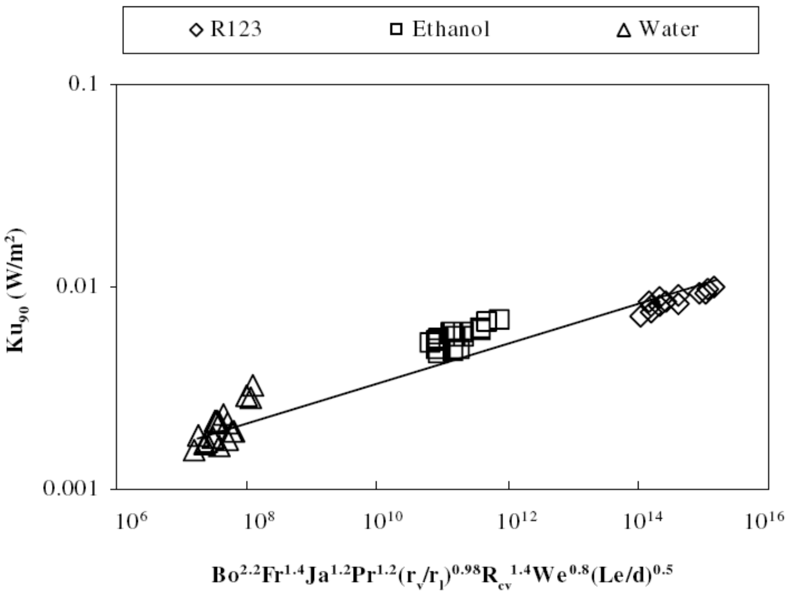

Fig. 14. Solid line represents the correlation: $Ku_{90}=0.0004[(Bo)^{2.2}(Fr)^{1.42}(Ja)^{1.2}(P_r)^{1.02}(\rho_v/\rho_l)^{0.98}(R_{cv})^{1.4}(We)^{0.8}(L_e/d_i)^{0.5}]^{0.107}$.

used as the working fluid. When the Bond number increased, the maximum heat-flux slightly increased.

3.4. Effects of dimensionless parameters

The dimensionless parameters, which may have an effect on the heat flux of the CLOHP/CV in the vertical mode include the ratio of the check valve (R_{cv}), aspect ratio

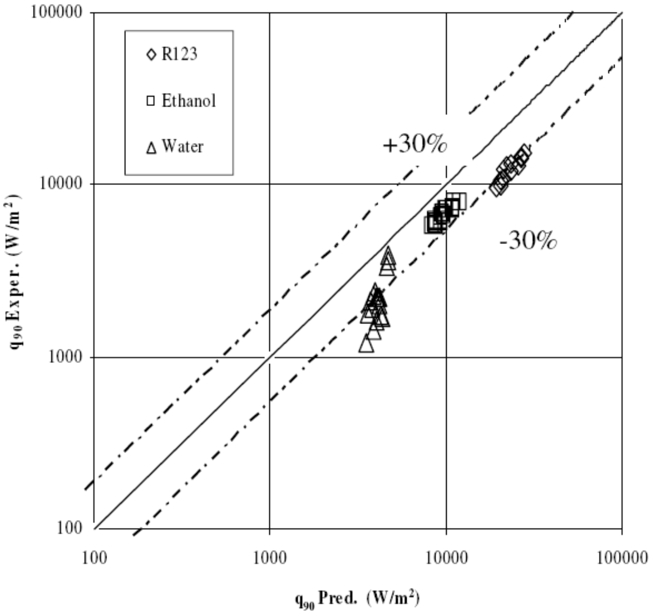

Fig. 15. Comparison of heat-flux measurements versus predictions.

(L_e/d_i), Bond number (Bo), Weber number (We), Froude number (Fr), Jacob number (Ja), Prandtl number (P_r), (ρ_v/ρ_l) and Kutateladze number (Ku). R_{cv} is the ratio of number of turns to number of check valves. L_e/d_i is the ratio of the evaporator length to the inner diameter of tube and is a characteristic of the geometry of a CLOHP/CV. *Bo* is the ratio of buoyancy force and surface tension force. *We* is the ratio of dynamic force to surface tension force *Fr* is the ratio of dynamic viscosity to weight. We and Fr are important dimensionless parameters in a two-phase flow, which occurs in both the evaporator and the condenser sections of the CLOHP/CV. Counter-current interaction between the liquid and vapour flows inside a CLOHP/CV can be understood by means of these two parameters. P_r is the ratio of momentum diffusivity to the thermal diffusivity of the vapour. It represents convection heat-transfer in the tube and this may occur when the vapour bubble moves from the evaporator to the condenser. *Ja* is the ratio of sensible heat to latent heat of the working fluid. ρ_v/ρ_l is the ratio of vapour density to liquid density of the working fluid. *Ku* is the ratio of heat flux of a CLOHP/CV to the critical heat-flux of the working fluid. It represents the pool boiling of the working fluid in the evaporator sections of a CLOHP/CV, for the ratio of check valves, aspect ratio and inner diameter: it was found that the heat-transfer experimental results were scattered. However, *We*, *Fr* and *Ku* each had a linear relationship with the heat flux see Figs. 8, 9 and 13. The *Bo* versus heat flux pattern for all data is shown in Fig. 7. Furthermore, R_{cv}, L_e/d_i, *Ja*, P_r, and ρ_v/ρ_l had relationships to the heat flux of the CLOHP/CV as shown in Figs. 5, 6, 10, 11 and 12, respectively. Thus *We*, *Fr*, *Ku*, R_{cv}, L_e/d_i, *Bo*, *Ja*, P_{rv} and ρ_v/ρ_l can be used to formulate a correlation for the heat flux of a CLOHP/CV in its vertical position. The important dimensionless parameters which have an effect on the heat flux of a CLOHP/CV in its vertical position are *We*, *Fr*, *Ku*, R_{cv}, L_e/d_i, *Bo*, *Ja*, P_{rv} and ρ_v/ρ_l.

3.5. Correlation for the heat flux of the CLOHP/CV in its vertical position

The correlation of dimensionless parameters is shown in Fig. 14, i.e.

$$Ku_{90} = 0.0004[Bo^{2.2}Fr^{1.42}Ja^{1.2}P_{\mathrm{r}}^{1.02}(\rho_{\mathrm{v}}/\rho_{\mathrm{l}})^{0.98}R_{\mathrm{cv}}^{1.4}We^{0.8}(L_{\mathrm{e}}/d_{\mathrm{i}})^{0.5}]^{0.107} \quad (3)$$

With a coefficient of determination of 0.91, Fig. 15 shows a comparison of heat flux from the experiment to heat-flux predictions from Eq. (3). The standard deviation (STD) of experimental heat-fluxes from the predictions of Eq. (3) is ±30%. Thus Eq. (3) can be used to predict the heat flux of a CLOHP/CV in its vertical position.

4. Conclusion

From the result obtained, it can be concluded that:

- As the ratio of check valves increased, the heat-flux increased.
- As the aspect ratio increased, the heat-flux decreased.
- As the inner diameter increased, the heat-flux increased.
- $Ku_{90} = 0.0004\ [Bo^{2.2}\ Fr^{1.42}\ Ja^{1.2}\ P_{\mathrm{rv}}^{1.02}\ (\rho_{\mathrm{v}}/\rho_{\mathrm{l}})^{0.98}\ R_{\mathrm{cv}}^{1.4}\ \mathrm{We}^{0.8}\ (L_{\mathrm{e}}/d_{\mathrm{i}})^{0.5}]^{0.107}$ was derived as a correlation for predicting heat-fluxes for the vertical heat-pipe.

Acknowledgement

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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

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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

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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.

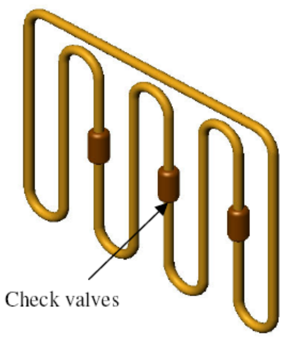


Fig 1: Closed-looped oscillating heat-pipe with check valves (CLOHP/CV)

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.

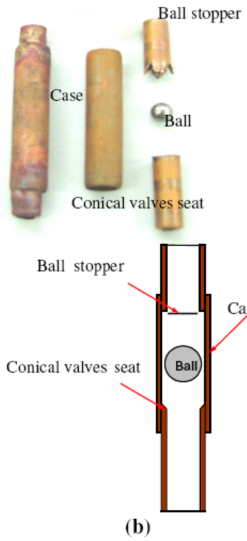


Fig 2: a, b Prototype of check valve

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.

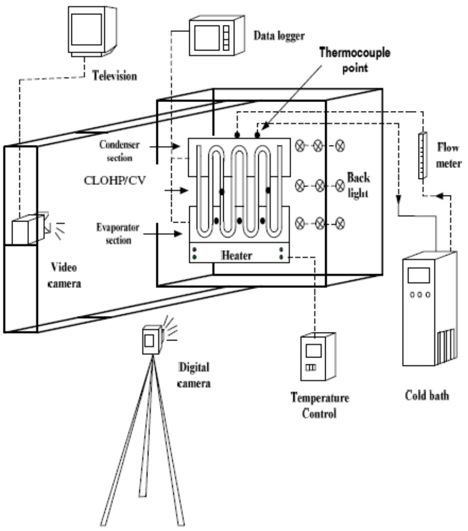


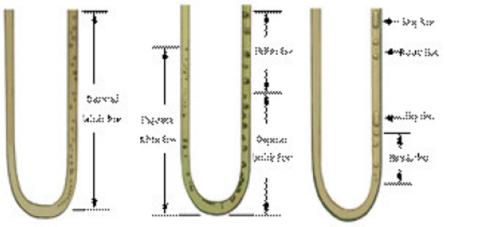
Fig. 3: Experimental setup.

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.

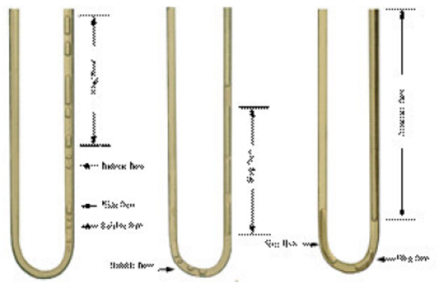
At evaporator section lengths of 50 mm: Figure 4 shows the internal flow patterns of the CLOHP/CV with a Le of 50 mm at the vertical position. It can be observed that, at a relatively low heat source temperature (75-80^{0}C) with a heat flux of 4.08 kW/m^2, dispersed bubble flow with very few nucleation 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°C 80°C 75°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°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°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°C 80°C 75°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.

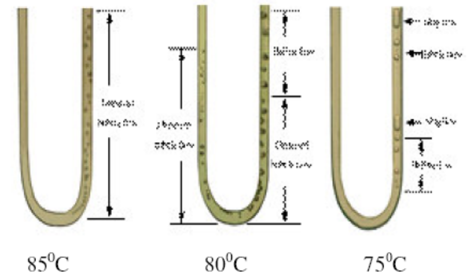


Fig. 6: Internal flow patterns of CLOHP/CV at Rcv of 0.2

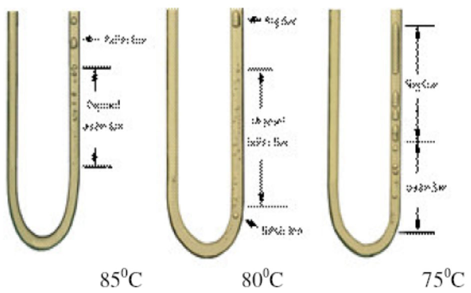


Fig. 7: Internal flow patterns of CLOHP/CV at Rcv of 1

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.

ACKNOWLEDGEMENTS

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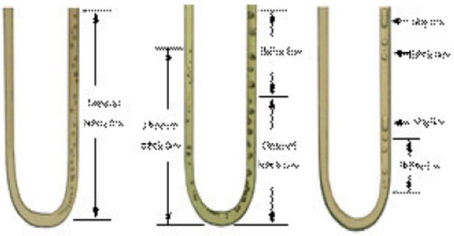
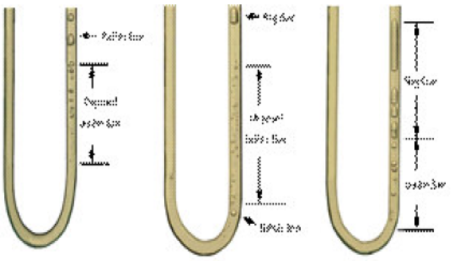


85^{0}C 80^{0}C 75^{0}C

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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