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Experiments of Condensation Heat Transfer in Micro Channel Heat Exchanger

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ABSTRACT

In this paper, a two-phase HFC134a condensing flow has been investigated in a heat exchanger with micro channels. The experimental range is in low Reynolds number of condensing flow. Experimental data are close to the Koyama correlation. The friction coefficient was compared with previous correlations, and the result was close to the correlation by H.L.Mo and Wu&Little

1. INTRODUCTION

The application of micro scale devices is very active, micro-scale flow and heat transfer is the basis for the heat disspation with micro channel heat exhanger. There is growing demand to research the principle through the basic theory and experiment technology, however the discussion about condensing flow in micro channel is not sufficient by now.

The micro channel flow condensation process has been met the micro heat pipe or the wick of the heat pipe for electronic cooling in aerospace and laser diode cooling system, micro heat exchangers in vapor compression refrigeration system, compact micro fuel cell, and some chemical engineering utilizations.

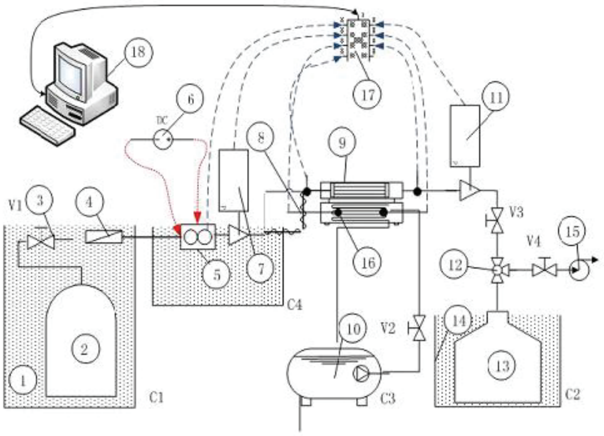
There were a lot of works on experiments about micro channel flow in recent years, such as, the micro channel flow of water had been tesed in silicon wafer[M.M. Rahman, etc.], the simular test about heat transfer performance had been done with the hydrolic diameter 62—169 μm[W. Qu, etc.], it was thought that the heat transfer coeficient was increased with the R134a mass flow rate in micro channel[S.S. Bertsch, etc.], and the pressure drop was unsteady with a certain R134a flow rate in the tube of 0.691 mm diameter[Jeong Seob Shin, etc.].

About condense flow in microchannel, in reference[J.R. Baird, etc.], the local heat transfer coefficients for flow condensation of HCFC-123 and of R11 have been measured in tubes with internal diameters of 0.92—1.95mm. The heat transfer coefficient was senstive to mass flux and local quality. The measurement of the local condensation heat transfer coefficient inside circular 0.96mm diameter minichannels with R134a and R32, the data are almost agree with macroscale tubes[Marko Matkovic, etc.] .

In this paper, a two-phase condensing flow has been researched through experiment to evaluate the theat transfer performance and observe the phenomena in the process. A heat exchanger with micro channel had been designed, which had been assembled and set up in the lab, the test with HFC134a was done, the experimental data were collected experimental.

2. EXPERIMENTAL APPARATUS

Fig. 1 shows the experimental scheme, it includes two cycles, refrigerant cycle, and water cycle. In the refrigerant cycle, there are refrigerant supplying tank, refrigerant collector, filter, flow controlling meter, pressure sensor, temperature sensor, temperature controller, valves, and the microchannel condenser; in the water cycle, there are water bath, regulator, volume cup, time meter. The temperature of water flowing into the test rig is controlled by the water bath. All the signals of temperature, mass flux, pressure are collected by the Datalog Keithley 2700, and connect to the computer.



1 thermoset C1, 2 tank for refrigerant, 3 valve V1, 4 filter, 5 mass flowmeter, 6 electrical regulator, 7 and 11 pressure sensor, 8 controller for heater, 9 test chip with micro channels, 10 thermoset C3, 12 switch valve, 13 receiver for refrigerant, 14 thermoset C2 C4, 15 vacuum pump, 16 thermocouple, 17 datalog Keithly, 18 computer

Figure 1. Experiment setup for micro-channel condenser

In experiment, the refrigerant R134a exchange heat with the water from a water bath, the heat flux is measured by the mass flux and the temperature difference of the water flowing through the chip with micro channels. The pressure of saturated R134a is controlled by the water bath C1, and the temperature on the test chip is kept by the water bath C4.

The test chip is made with 40 parallel channels, each channel is 0.15 mm deepth, 0.5 mm width, and 80mm length, for enhancing heat transfer, each channel is separated into several branches, and the branch length is 3.5mm, the test chip is made of PEEK, its overall size is 100X100X1.5 mm^3. Its assemble is shown in figure 2.

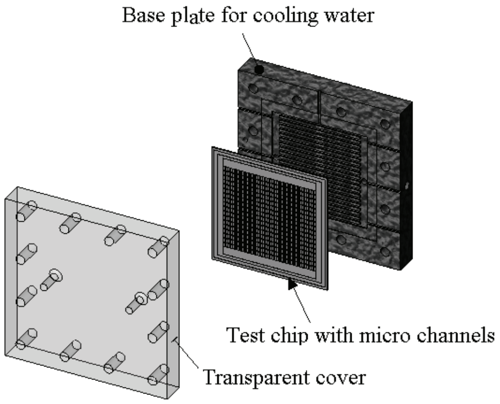


Figure 2. Assembly of heat exchanger

The temperatures were tested by T—type thermal couples, their unaccurcies are checked about 0.1℃ in the experimental range. And the pressure sensors employ 0.1% FS accuracy, and 2 kPa. The accuracy of the mass flowmeter is 0.1% FS, and 3ml/min. The total error could be less than 13%.

In order to prevent the refrigerant and water from leaking heat to environment, the test rig is merged in the water controlled by thermoset C3. In checking test, the deviation between the exchanged heats from the refrigerant and the water was about 2.5%, besides, the heat dissipation from the transparent cover is evaluated as about 2.3%.

3. EXPERIMENT AND DISCUSSION

3.1 Analysis of Heat Transfer Performance

In the test data, the pressure drop was less than 20 kPa in the experiment, so the temperature difference by pressure drop is about 0.2 K. In experiment, the refrigerant is superheated at the entrance of the test chip, and slightly supercooled at the exit.

In figure 3, the averaged coefficients of condensed heat transfer were obtained in saturated pressures 650 kPa, 750 kPa, 850 kPa. In low mass flux, the heat transfer coefficients are low due to low Re values. With the mass flow rate rising, the velocity increases, and the heat transfer coefficient increases as well. Moreover, the differences on the three saturated pressures are more apparent in high flow rate than in low flow rate. The latent heat related to the saturated pressure is one of the reasons, the behavior of bubbles is affected by surface tension and some properties, such as saturated pressure. The bubbles in low pressure are easy to generate and move, this disturbation by bubble is helpful to heat transfer.

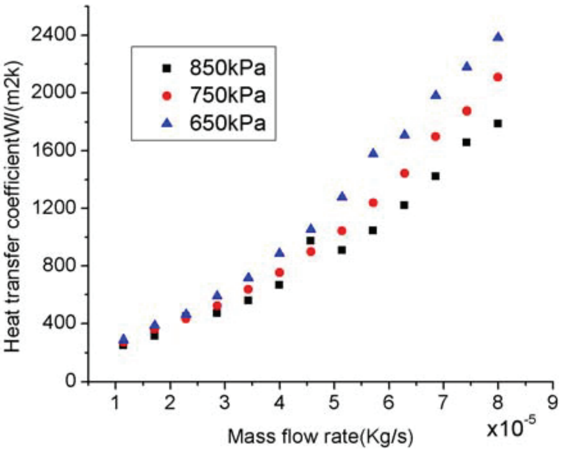


Figure 3. Heat transfer coefficient versus mass flow rate

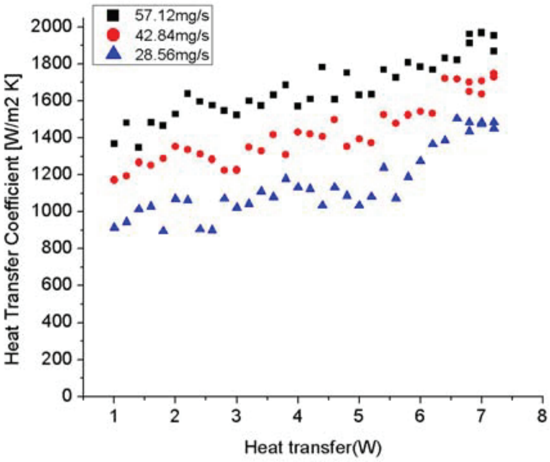


Figure 4. Heat transfer coefficient versus heat flux

Figure 4 shows the thermal performance in condensing process with various mass flow rate, 28.56, 42.84 and 57.12mg/s. The heat transfer coefficient in high mass flow rate is higher than the value in low mass flow rate. The heat transfer coefficients have a certain rise when the heat flux increases as well in the experiment range.

In this experiment, the average Re is among 50—500, there are not rich related data in present references. In literatures [Shigeru Koyama, 2003(1&2)], R134a condensing experiments were done on multi-port channel with the diameters 0.8mm and 1.1mm, which is similar as the conditions in the paper.

Figure 5 shows the comparison between the experimental results and the values from the Koyama relation. In low Re, the experimental data agrees well with the Koyama, while Re is greater than 150, their deviations are about 30%. The deviation comes from the differnce of channel material, size, and roughness. In this paper, the diameter is 0.23 mm, the channel was made of PEEK, and machined with the high speed milling, the roughness is about less than 2% of the channel diameter.

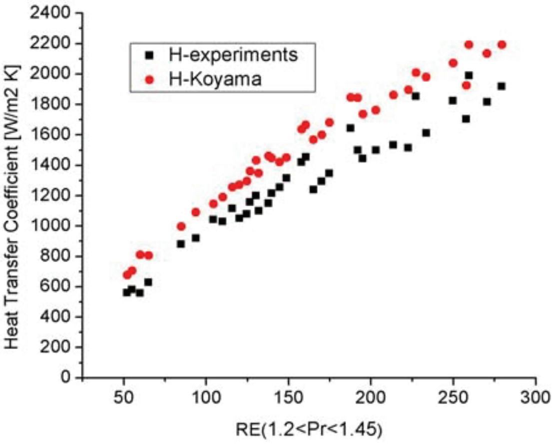


Figure 5. Comparison of Measurement results with Koyama correlation.

3.2 Pressure Drop of Condensing Flow in Micro Channels

The experimental data about friction coefficients are shown in figure 6, which are compared with the correlations by Wu and Little and H.L.Mo. Their deviations with the two correlation are in ±18.42%, and the tested data present a similar trend with the correlations in literatures.

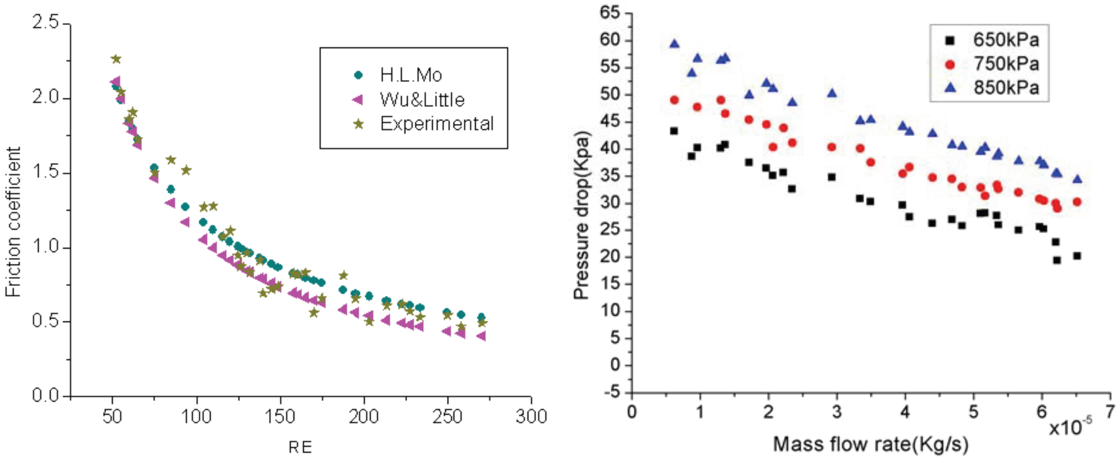


Figure 6. Comparison of friction factors between experimental values and correlations

Figure 7. Pressure drop versus mass flow rate

In figure 7, the pressure drops were obtained with the saturated vapour at the entrance, and the condensed liquid R134a at the exit, and the averaged temperature at water side is about 15℃. With the mass flow rate increasing, the pressure drop is decreased, this is due to the variation of the length filled with condensed liquid. Moreover, since the averaged density of the condensing flow is increased in high pressures, its pressure drop is increased as well.

3.3 Flowing Type in Micro Channels

There is a transparent cover on the channels, therefore, the phenomena about the condensing process could be observed directly. From the entrance to the exit of the chip of heat exchanger, the flow decelerated gradually. While the mass flow rate was 28.56mg/s, there was annular flow in the 1/4 channel length near the entrance, from the 1/4 to 2/3 channel length, there was slug flow, then the bubble flow appeared. The more the heat flux, the longer the length of the annular flow and the slug flow, and the shorter the bubble flow. The variation of flow types was not sensitive to pressure, but the more the pressure, the less bubbles in bubble flows.

In experiments, there was a kind of periodic pulse slug flow in the channels, its periods were about 15~70 micro seconds, and decreased with the heat flux rising. According to the video record, in the flow pulsing, the steady envolvement of flowing types variation was destroyed and rebuilt.

Moreover, there are several cross channels in the chip, which separated each long flowing channel into several short channels. The cross channel is helpful to re-distribute the flow in each channels, and the short channel is easy to prevent boundary layer from developing. in experimental result, the temperature field is even. Due to the disturbing flow from the cross channel, there was not a steady two phase flow, such as, frequent alternation among bubble flow, slug flow and annular flow in same short channels.

4. SUMMARY

According to above experiment about R134a condensing flow in micro channels, some performance are analyzed, the phenoma of condense process are observed.

The heat transfer coefficient is affected by the mass flow rate, the size of channel, the heat flux, etc. The the heat transfer coefficient is increased with R134a mass flow rate rising. The experimental data about low Re condensing flow are close to the correlation by Koyama.

In term of the analysis on the pressure drop about condensing flow experiment, the testes friction coefficients are close to the literatures' correlations from H.L. Mo, and Wu & Little.

From direct observation, there are annular flow, slug flow and bubble flow in the condensing process, the flowing type and its variation is not sensitive to pressure. The cross channel leads the flows to distribute evenly in each channels, and the short channel is enhance the disturbation on flow.

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