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Convective heat transfer characteristics of single phase liquid in multiport minichannel tube: Experiment and CFD simulation

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Abstract

This study demonstrated the single phase boiling heat transfer of water in horizontal multiport minichannels. The experimental data were observed in aluminum tube of 7.9 x 2.5 mm (width x high) with 7 rectangular channels and the length of 500 mm, the Reynolds number of 1400 – 4200, and heat fluxes of 3 – 6 kWm^{-2}. The effects of mass fluxes and heat fluxes on heat transfer coefficient were analyzed. The transition of flow regime was observed at the Reynolds number of 3000. Finally, the CFD simulation was also set up and compared with the experimental data. The results showed that the CFD simulation was in well agreement with the experimental ones.

Key word: Multiport minichannel; Convective heat transfer; CFD simulation; Single phase fluid

1. Introduction

The flat-tube heat exchangers with multiport mini channel are widely used in the automotive applications nowadays. This tube type has many advantages compared to conventional tube such as the more compactness, low refrigerant charge and lower air side pressure drop. From the last decades, multiport minichannels have been taken great attention from the researchers. There are various studies about the heat transfer characteristics and pressure drop of multiport minichannels published in the open library.

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Xiulan Huai et al. (2004) performed the flow boiling heat transfer of carbon dioxide in multiport mini channel. The experimental data was measured for following condition: the pressure ranging from 3.99 to 5.38 MPa, inlet temperature of CO2 from 3.08 to 16.96 ºC, heat fluxes from 10.1 to 20.1 kW/m^2, mass flux from 131.4 to 399 kg/m^{2}s, and vapor quality from 0 to 1. The results indicate that pressure drop along the test section is very small and two-phase CO2 flow exhibits a higher heat transfer coefficient than that of the single-phase liquid or vapor flow. Cavallini et al. (2005) demonstrated the two phase frictional pressure gradient of R236ea, R134a and R410A inside multi-port mini-channels. The results presented cover a wide range of the reduced pressure, from 0.1 up to 0.5. The results show that R410A has significantly lower pressure drop in comparison with R134a and R236ea at the same operating conditions because of its physical properties. The low pressure of fluid R236ea shows the highest pressure gradient among the three fluids. Caroline et al. (2011) evaluated the liquid phase heat transfer in multiport minichannels with different cross-section geometry. The experimental data was performed with four different secondary refrigerant liquids: water, propylene glycol, Hycool 20 and Temper-20. This study focused on the laminar flow regime and the results showed that the Gnienlinski model predicted well the experimental data despite the shape of geometry. Jatuporn et al. (2011) presented the flow boiling heat transfer of R134a in the multiport minichannels heat exchangers. The heat exchanger was designed as the counter flow tube-in-tube heat exchanger with refrigerant flowing in the inner tube that made from multiport aluminum tube and hot water in the gap between the outer and inner tubes. The experiments were performed at the heat fluxes between 15 and 65 kW/m^2 and mass flux between 300 and 800 kg/m^{2}s and saturation pressure ranging from 4 to 6 Bar. The effect of heat flux but mass flux was found in this study. However, there are limited studies about the single phase heat transfer characteristics of multiport minichannel published in open library.

Hence, in this study, we focused on the convective heat transfer characteristics of single phase liquid in multiport minichannels. The working fluid is water. Furthermore, the experimental data was compared with the CFD simulation. These results can be used to optimize the heat exchanger designing process with using the multiport aluminum tube.

2. Experimental model and CFD simulation set up

2.1 Experimental Apparatus

Fig. 1 (a) shows a schematic diagram of the experimental apparatus. The facility consist of three water loops and the data acquisition system. The inner water loop includes a magnetic gear pump, a mass flow meter, test section, heating unit, cooling unit and a receiver. The water is delivered to the test section by the gear pump. The mass flow rate of refrigerant is measured by a Coriolis mass flow meter and controlled by adjusting the pump speed.

The test sections were made from aluminum flat tube with 7 mini-channels and the effective length of 500mm. The detail setup of test section is shown in figure 1(b). There are 5 attached positions of T type thermocouple along the test section included 2 top and two bottom each. Two absolute pressure transmitters were set up at the inlet and outlet of test section to measure the local pressure and to calculate the pressure drop.

The test data were collected using a recorder and analyzed in real time with a PC running the data reduction program. All the information about test conditions and test data during the test, were displayed on the monitor and test conditions were changed based on this information. Table 1 presented a summary of the estimated uncertainty associated with all the parameters at a 95% confidence interval.
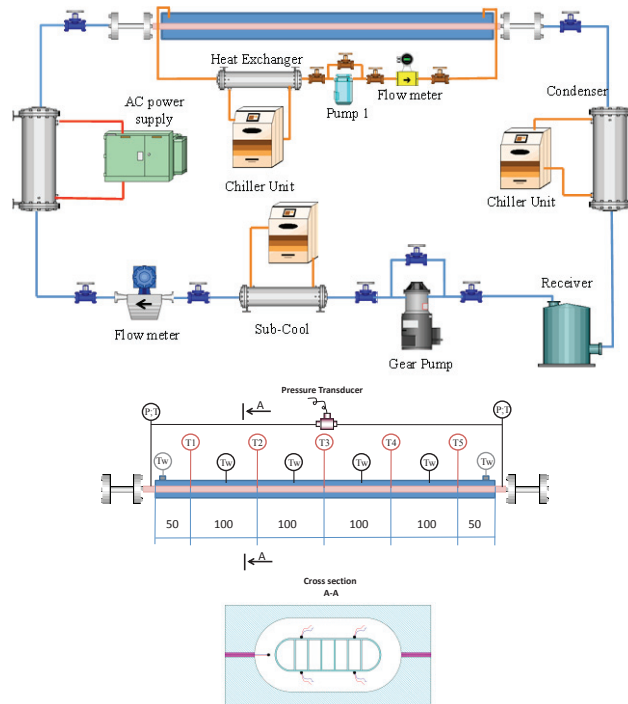
2.2 Data reduction

Figure 1 (a) Experimental Apparatus; (b) Test section

Table 1. Estimated uncertainty

Parameter	Uncertainty
Temperature	±0.35 (ºC)
Absolute pressure	±0.2 %
Mass flow rate of water	±0.2 %
Heat flux (%)	± 3 %
Heat transfer coefficient (%)	± 10 %

As shown above table 1, the working fluid was heated by outside hot water using double tube heat exchanger with counter flow. Hence the Wilson plot technical was used to calculate the heat transfer coefficient of the minichannels. The overall heat transfer rate was defined as following:

$$Q = UA.\Delta T_{LMTD} \tag{1}$$

Where, U is the overall heat transfer coefficient, A is the surface area of aluminum tube and ΔT_{LMTD} is the log mean temperature and can be determined as:

$$\Delta T_{LMTD} = \frac{(T_{w,in} - T_{ref,out}) - (T_{w,out} - T_{ref,in})}{\ln\left(\dfrac{T_{w,in} - T_{ref,out}}{T_{w,out} - T_{ref,in}}\right)} \tag{2}$$

The total thermal resistance of multiport was defined as:

$$\frac{1}{UA} = \frac{1}{h_o A_o} + \frac{\delta_t}{k_t A_m} + \frac{1}{h_i A_i} \tag{3}$$

Where, h_o is the heat transfer coefficient of outside hot water and can be expressed by the following equation:

$$h_o = \frac{Q}{A_o (T_b - T_{wall})} \tag{4}$$

Where, A_o is the outside surface area, T_b is the bulk mean temperature of water and T_{wall} is the outside wall temperature of tube. Both values were calculated by the average values of inlet and outlet water temperature and measurement values of thermocouple, respectively.

The frictional factor can be calculated by the following equation:

$$f = \Delta p \frac{D_h}{L} \frac{2\rho}{G^2} \tag{5}$$

2.3 Simulation setup

In this study, the Fluent code was used to simulate the flow boiling characteristics. A 3D model of test section was built in Catia and then meshing in Ansys Meshing. The grid model includes 271386 elements and 1656690 nodes with tetrahedron and hexahedron shapes. The skewness number was stable about 0.8.

Since the variation of Re number from 1400 to 4200, both the laminar and turbulent were applied with the transition value from laminar to turbulent regime of 2300. For the turbulent regime, the SST k-ω was used to simulate the flow. The discretization such as momentum, energy and dissipation rate were selected in second order upwind while the pressure drop was chosen as standard.
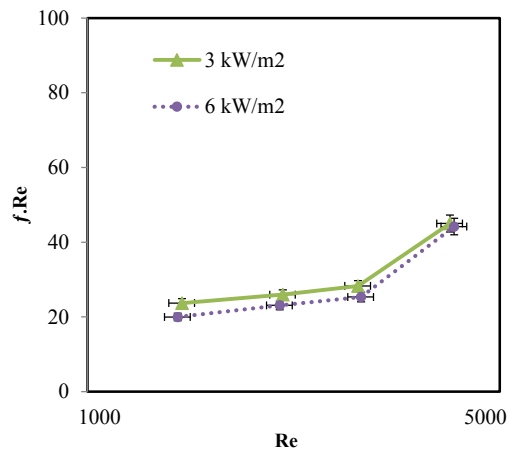
3. Result and discussion

Figure 2 Frictional Factor

Figure 2 illustrates the frictional factor with the variation of heat flux and Reynolds number. The results show that the frictional factor is slightly higher with lower heat flux. On the other hand, the trend

also depicts that when the Reynolds was about 3000, the tendency of frictional factor changed that a significant increase was observed.

The contours of temperature and pressure distribution of water inside test section are shown in figure 3. The contours were record in the mid plane of test section. The mass flow rate was set at 150kg/h and 100 kg/h with the heat fluxes of 3 and 6 kW/m^2 for each cases. It can be seen that the temperature and pressure were different in single channel. The temperature also increase slower at the center compared to the outer side.

Figure 4 depicts the mean Nusselt number with non-dimensional axial length x*. The Nusselt number is high when x* < 0.06 and decrease and keep constantly as theory. The trend also shows that the Nusselt increase with the increasing of heat flux. In addition, the comparisons of Nusselt number between the experimental results, the CFD simulation and 2 existing correlations proposed by Glielinski (1989) and Mills (1999) are also performed. The CFD simulation results show a good agreement with the experimental value for all the cases but two correlations over predict.
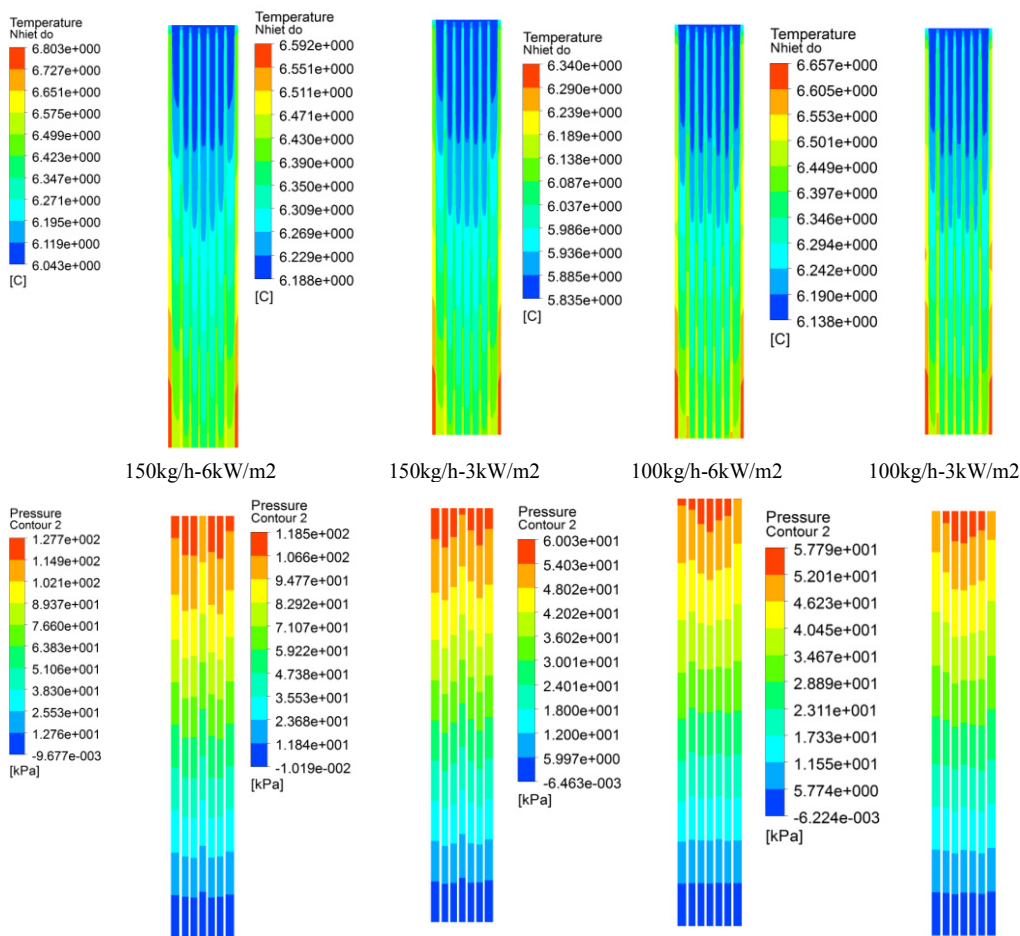

150kg/h-6kW/m2　　　　　150kg/h-3kW/m2　　　　　100kg/h-6kW/m2　　　　　100kg/h-3kW/m2

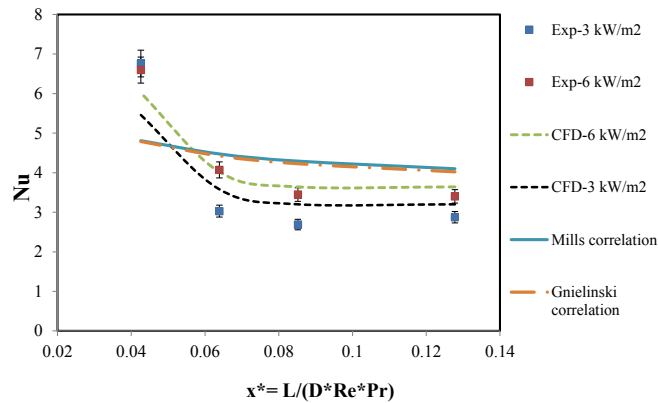Figure 3 The distribution of temperature and pressure inside the test section

Figure 4 Variation of Nusselt number

4. Conclusions

The experimental boiling heat transfer and pressure drop of single phase liquid in multiport minichannel were performed in this study. The results show that the frictional factor is slightly higher for lower heat flux while the Nusselt number is higher with higher heat flux. Moreover, the transition of fractional factor was observer when the Re > 3000. The experimental data were compared with the existing correlations in literature. A CFD simulation was also setup and the simulation results were in well agreement with the experimental ones.

References

[1] A.F. Mills, Heat Transfer, Second Edition, Prentice-Hall, New Jersey, 1999.

[2] Cavallini, a., Del Col, D., Doretti, L., Matkovic, M., Rossetto, L., & Zilio, C. (2005). Two-phase frictional pressure gradient of R236ea, R134a and R410A inside multi-port mini-channels. Experimental Thermal and Fluid Science, 29(7), 861–870.

[3] Dai, B., Li, M., Dang, C., Ma, Y., & Chen, Q. (2014). Investigation on convective heat transfer characteristics of singe phase liquid flow in multi-port micro-channel tubes. International Journal of Heat and Mass Transfer, 70, 114–118.

[4] Dehghandokht, M., Khan, M. G., Fartaj, A., & Sanaye, S. (2011). Flow and heat transfer characteristics of water and ethylene glycol–water in a multi-port serpentine meso-channel heat exchanger. International Journal of Thermal Sciences, 50(8), 1615–1627.

[5] Gnielinski, V., Zur W¨arme¨ubertragung Bei Laminarer Rohrstr¨omung Und Konstanter Wandtemperatur (in German), Chemieingenieurtechnik, vol. 61, no. 2, pp. 160–161, 1989.

[6] Huai, X., Koyama, S., Zhao, T. S., Shinmura, E., Hidehiko, K., & Masaki, M. (2004). An experimental study of flow boiling characteristics of carbon dioxide in multiport mini channels. Applied Thermal Engineering, 24(10), 1443–1463.

[7] Kaew-On, J., Sakamatapan, K., & Wongwises, S. (2011). Flow boiling heat transfer of R134a in the multiport minichannel heat exchangers. Experimental Thermal and Fluid Science, 35(2), 364–374.

[8] Stignor, C. H., Sundén, B., & Fahlén, P. (2009). An Experimental Study of Liquid-Phase Heat Transfer in Multiport Minichannel Tubes. Heat Transfer Engineering, 30(12), 941–951.

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Biography
Jong-Taek Oh is currently a Professor at the Department of Refrigeration and Air Conditioning Engineering, Chonnam National University at Yeosu, South Korea.

Research fields: boiling and condensation heat transfer experiment and simulation of a natural and alternative refrigerants in small tubes and conventional tubes, heat pump system, refrigeration storage and transportation..