International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 908

TWO-PHASE FLOW BOILING HEAT TRANSFER COEFFICIENT AND PRESSURE DROP OF R-717 AND R-290 INSIDE MINICHANNEL MULTIPORT TUBE

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ABSTRACT

Natural refrigerants such as carbon dioxide (R744), ammonia (R717) or propane (R290) have been considered as promising candidates for the next generation in order to make the friendly environment refrigeration systems. This study investigates the two-phase flow heat transfer coefficient and pressure drop of ammonia and propane during the evaporation inside a minichannel multiport tubes. The tube has a hydraulic diameter of 0.83 mm. The length of test section is 200 mm. The experimental data were conducted at saturation temperatures of 6 °C, the heat flux from 3 to 12 kW/m2, the mass flux varied from 50 to 150 kg/m2s and the quality up to a unit. The effects of mass flux, heat flux and vapor quality on heat transfer coefficient and pressure drop are analyzed. Also, the heat transfer coefficient data were compared with various correlations in the literature.

Keywords: R-717, R-290, Heat Transfer Coefficient, Pressure drop, Multiport Tube, Natural Refrigerant

NONMENCLATURE

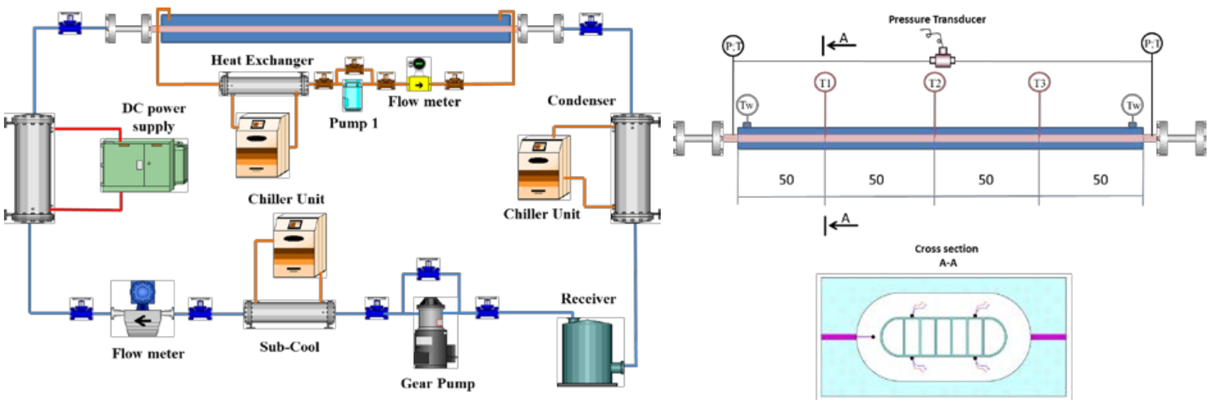
Abbreviations	
sat	Saturation
wi	Wall inner
f	Fluid
g	Gas
Symbols	
A	Area (m^2)
Cp	Specific heat (J/kgK)
G	Mass flux (kg/m^2s)
h	Heat transfer coefficient (W/m^2K)
$\dot{m}$	Mass flow rate (kg/s)
x	Vapor quality (-)
T	Temperature (^oC)
p	Pressure (Pa)
α	Void fraction (-)
ϑ	Specific Volume (m^3/kg)

1. INTRODUCTION

In few pass decades, multiport minichannel heat exchangers (MMHX) have been increasingly used in various refrigeration applications due to its effectiveness and compactness. Therefore, researching on the heat transfer and pressure drop characteristics of refrigerants during the evaporation and condensation in multiport minichannel is necessary to improve the design. On the other hand, since most of existing heat transfer coefficient correlations in literature were developed based on the empirical or semi-empirical methods, the experimental data of two-phase flow boiling in small channel are still needed to improve the prediction.

Moreover, the natural refrigerants are considering as the promising candidate for next refrigerant generation because they are friendly with environment. Despite that, reports on two-phase flow boiling heat transfer coefficient of natural refrigerants in minichannel multiport tube are still limited.

Therefore, the aim of this study is to investigate the experimental two-phase flow boiling heat transfer



(a) Experimental apparatus (b) Test section

Fig. 1 Schematic of testing system

coefficient and pressure drop of two natural refrigerants included R-717 and R290, in a minichannel multiport tube. The effects mass flux and heat flux are analyzed. The present experimental data were compared with some well-known heat transfer coefficient correlations

2. MODEL SET-UP

2.1 Experimental apparatus

The experimental apparatus used in our study is shown in Fig. 1. The detail of the model was described in the previous study [1].

The test sections made of aluminum tube with the hydraulic diameters of 0.83 mm.

2.2 Data reduction

In this work, the experimental data were collected by a data acquisition system. The thermodynamics properties of R-717 and R-290 are obtained from REFPROP [2].

The heat rate applied on the test section is determined by the mass flow rate and temperature change of water jacket as following:

$$Q = \dot{m}.C_p(T_{in} - T_{out}) - Q_{loss} \tag{1}$$

The heat balance procedure was also established, and the deviation was not larger than three percent. The local then can be calculated as following:

$$h = \frac{Q}{A.(T_{wi} - T_{sat})} \tag{2}$$

In present study, the temperature of inner wall was determined based on the steady-state one dimensional radial conduction heat transfer through the wall without the internal heat generation.

The vapor quality at the inlet of test section was determined as the state of refrigerant at the outlet of preheater and was calculated as following:

$$x = \frac{\Delta i + i_{\mathrm{f,in}} - i_{\mathrm{f}}}{i_{\mathrm{fg}}} \tag{3}$$

The pressure drops of two-phase flow in horizontal tube is the sum of momentum and frictional pressure drop. In this study, the momentum pressure was calculated as follows:

$$-\left(\frac{dp}{dz}a\right) = G^2 \upsilon_f \left\{ \begin{array}{l} \left[\frac{x^2}{\alpha}\left(\frac{\upsilon_g}{\upsilon_f}\right) + \frac{(1-x)^2}{1-\alpha}\right]_{out} \\ -\left[\frac{x^2}{\alpha}\left(\frac{\upsilon_g}{\upsilon_f}\right) + \frac{(1-x)^2}{1-\alpha}\right]_{in} \end{array} \right\} \tag{4}$$

The void fraction was calculated using the correlation proposed by Steiner [3]. The uncertainty of heat flux, vapor quality and the heat transfer coefficient are approximately 3%, 5% and 8.9%, respectively. All the uncertainties were reported with the confident level of 95%.

3. RESULTS AND DICUSSIONS

3.1 Pressure drops

The effect of mass fluxes on the frictional pressure drop of R-717 and R-290 is shown in Fig. 2. The heat flux was kept at 3 kW/m2 while the mass flux was adjusted from 50 kg/m2s to 500 kg/m2s. The results show that the mass flux strongly affected to the frictional pressure drop. The pressure drop increases with the increasing of mass flux. Also, pressure drop increases with the increasing of vapor quality prior to value of about 0.8. The dry-out occurred at this point is the reason for this phenomenon.

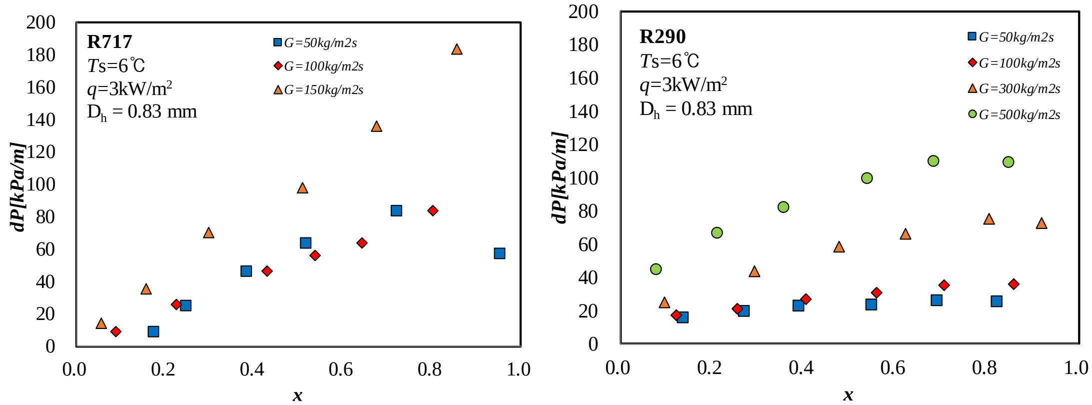


Fig. 2 Effect of mass fluxes on frictional pressure drop

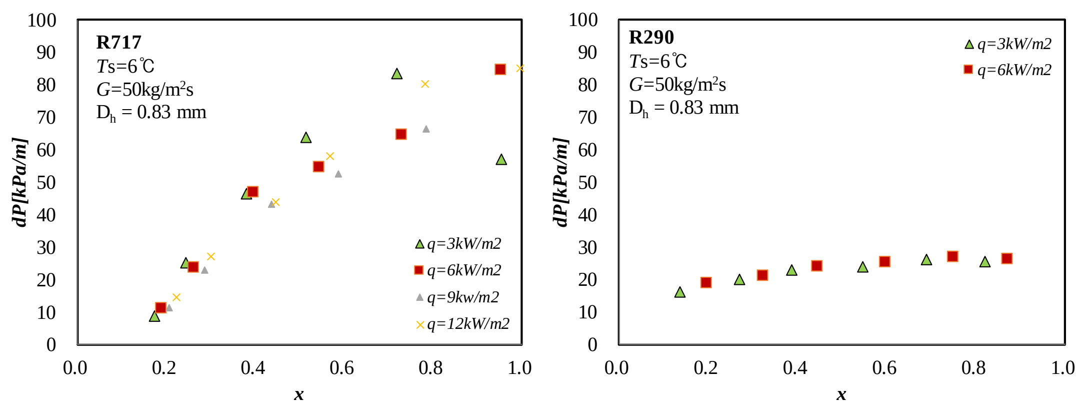


Fig. 3 Effect of heat fluxes on frictional pressure drop

The effect of heat fluxes on the frictional pressure drop is illustrated on Fig. 3. The mass flux was fixed at 50 kg/m2s and the heat flux was ranged 3 kW/m2 to 12 kW/m2. However, no significant effect of heat flux was observed on the frictional pressure drop on pre dry-out regime.

3.2 Heat transfer coefficients

Fig. 4 shows the effect of heat flux on the heat transfer coefficient of R-717 and R-290. The results show that, for both refrigerants, the heat transfer coefficient correlation increases when the applied heat flux increase. The heat transfer coefficient is also dropped at the vapor quality of about 0.8. It means the refrigerant starting dry-out at this regime.

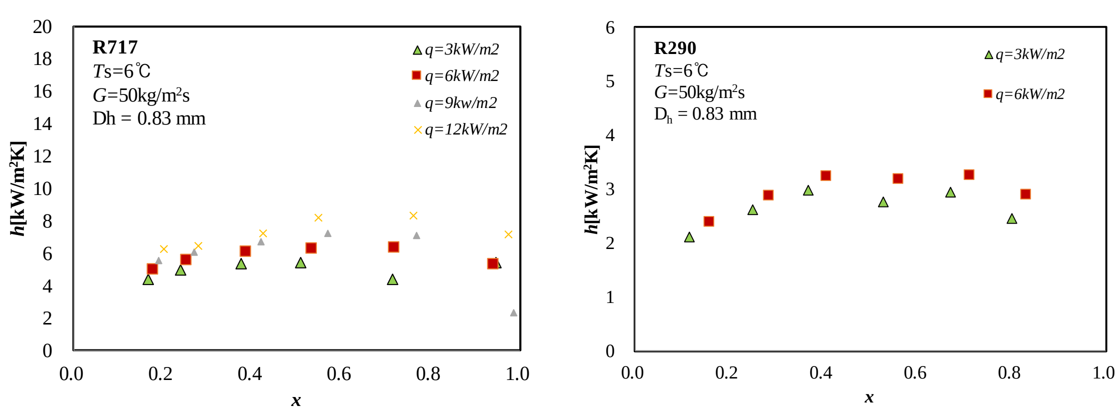


Fig. 4 Effect of heat fluxes on heat transfer coeffcient

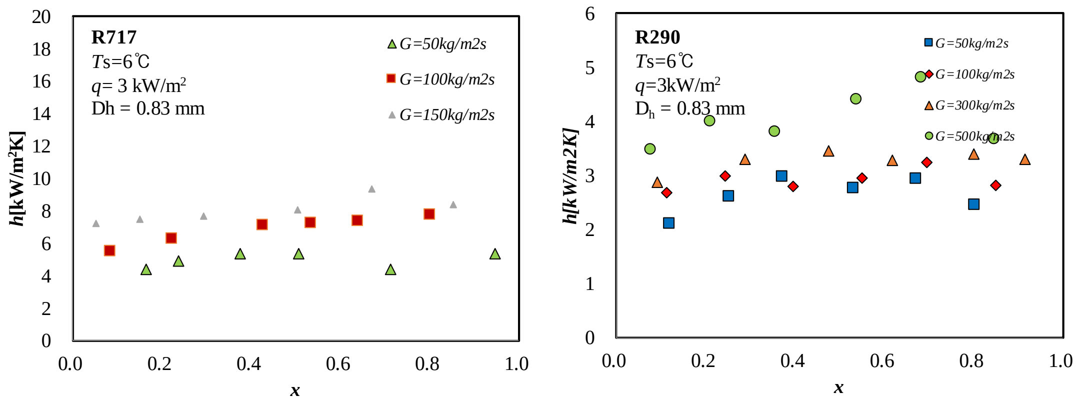


Fig. 5 Effect of mass fluxes on heat transfer coeffcient

The effect of mass flux on the heat transfer coefficient of R-717 and R290 is described in Fig. 5. The higher mass fluxes raise the higher heat transfer coefficients. This phenomenon means that both the contribution of nucleate boiling and forced-convective boiling should be considered in developing the heat transfer coefficient correlation. Also, since the effect of heat flux was not suppressed at high quality regime, the suppression factor should be re-evaluated.

The experimental data in present study are also compared with various existing heat transfer coefficient correlations [4]–[8] in the literature and the correlation proposed by Liu and Winterton archived the best prediction with mean deviation of 35%.

4. CONCLUSION

The experimental two-phase flow heat transfer coefficient and frictional pressure drop of the natural refrigerants R-717 and R-290 during evaporation inside horizontal minichannel multiport tube were demonstrated in this study. Both the mass flux and heat flux have the positive effect on the heat transfer coefficient and pressure drop. Therefore, the contribution of nucleate boiling and forced-convective boiling mechanisms should be considered. The experimental heat transfer coefficient data were compared with several correlations and the one proposed by Liu and Winterton[6] showed the best prediction with the mean deviation of about 35%.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by Ministry of Education, Science, and Technology (NRF-2016R1D1A1A09919697).

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