IOP Conf. Series: Materials Science and Engineering **316** (2018) 012058 doi:10.1088/1757-899X/316/1/012058

Two-phase Frictional Pressure Drop of Propane with Prediction Methods of Viscosity and Density in 500 μm Diameter Tube

S Novianto[1,2], A S Pamitran[1], R Koestoer[1], K Saito[3]

[1] Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
[2] Department of Research, Sekolah Tinggi Teknologi Texmaco, Pabuaran-Subang, Indonesia
[3] Department of Applied Mechanics and Aerospace Engineering, Waseda University,1-104, Totsuka-machi, Shinjuku-ku, Tokyo 169-8050, Japan

E-mail: pamitran@eng.ui.ac.id

Abstract. The experimental study of frictional pressure drop of two-phase flow with propane on the microchannel has been done. The aim of the present research is to characterize pressure drop of evaporative propane in microchannel with 500 μm diameter and 0.5 m length. The experimental apparatus used heating process in the test section with closed loop process system. Variable of research are mass flux of 360 to 915 kg/m^{2}s and vapor quality of 0 to unity. The homogeneous and separated model used to determine the two-phase flow frictional pressure drop. Some existing correlations of two-phase flow viscosity and density used to predict frictional pressure drop, including parameter C that used non-dimensional parameter of two-phase viscosity number $N_{\mu tp}$ which developed as a function of two-phase viscosity and density. The comparison of prediction frictional pressure drop showed that the Hibiki, Xuejiao and Pamitran correlation from separated model.

1. Introduction

The natural refrigerant is became popular and more intensively discussed since the issue of environment. Propane is one of friendly refrigerant with zero ODP and its GWP is less than four [1]. Moreover, the natural refrigerant (R-290) has indicated to replace R-22 in terms of its hydrodynamic performance [2].

Two-phase flow in microchannels application at industries have more popular recently. Microchannel technology appears to be a very good opportunity to minimize the charge without performance loss. [3] research the performance of a refrigeration system with a cooling capacity between 1 kW and 2 kW provided with air-to-propane minichannel heat exchanger. [4] reported the experimental performance heat pump with the power 100 kW using propane as working fluids. The experimental apparatus used shell and tube heat exchanger using minichannels.

Pressure drop on heat exchanger are mainly importance topic in saving energy issue. Therefore, research on pressure drop in microchannels is very important and more conducted. Homogeneous pressure drop models is the first model which assumed the equal vapor and liquid velocities. The attainment of thermodynamic equilibrium between the phase and the use of a suitably defined single phase friction factor for two-phase. Separated pressure drop models assumed constant but not necessarily equal velocity for the vapor and liquid phases. The use of empirical correlations or simplified

IOP Conf. Series: Materials Science and Engineering **316** (2018) 012058 doi:10.1088/1757-899X/316/1/012058

concepts to relate the two-phase friction multiplier ($\emptyset^2$) and the void fraction (α) to the independent variables of the flow.

[5] have showed flow regime, void fraction, rising velocity slug bubble and drop friction. The accumulation data on flow characteristics to produce newly C as function of inner diameter. The value of C parameter decrease with decreasing inner diameter. [6] used R-134a, R-410A, R-290 and CO_2 as working fluids with tube diameter 1,5 and 0,5 mm. Pamitran et al. develop *C* parameter as function Reynolds number and Weber number and used viscosity two phase from [7] equation. [8] develop C parameter with non-dimensional parameter. The analysis indicates that the two-phase Reynolds number, Re_{tp}, the gas quality, x , and the two-phase viscosity number, $N_{\mu_{tp}}$, to be the key parameters for all flow conditions: liquid turbulence-vapor turbulence, liquid turbulence-vapor laminar, liquid laminar-vapor turbulence and liquid laminar-vapor laminar.

The aim of this experiment is prediction of frictional pressure drop two-phase flow with some viscosity and density parameter in horizontal diameter 0.5 mm tube.

2. Methodhology

2.1. Experiment set up

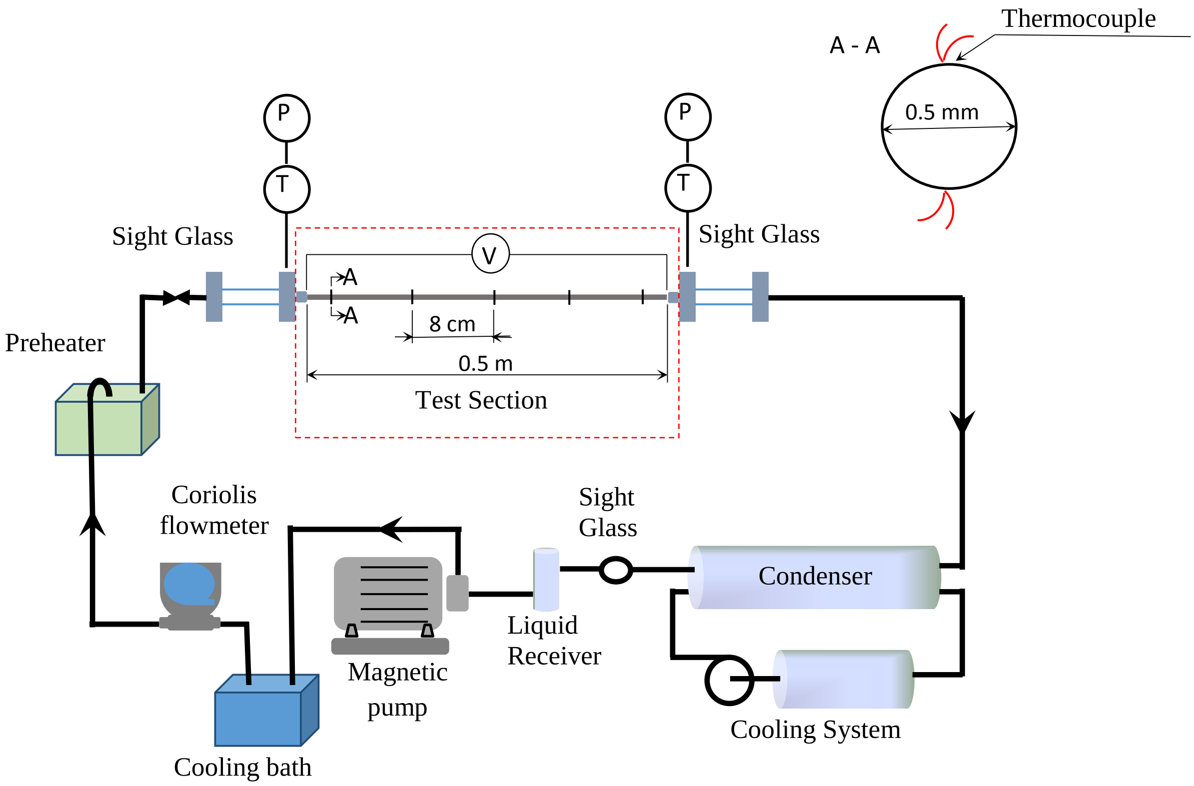

Figure 1. Experimental apparatus

Figure 1 describes the experimental apparatus. The main observation is on the test section heated by electrical heater. The test section is a horizontal tube with diameter of 500 μm and length of 0.5 m. Surface temperature in the test section were measured by attaching K-type thermocouples at the top and bottom of the test section. There are five temperature measurement locations on the test section. Moreover, inserted thermocouple and pressure transmitter are installed at the inlet and outlet of the test

IOP Conf. Series: Materials Science and Engineering **316** (2018) 012058 doi:10.1088/1757-899X/316/1/012058

section. A condensing unit is used to condense the vapor of working fluids. After the condensation process, the liquid of working fluids is pumped by a magnetic pump. A cooling bath is placed after the magnetic pump to maintain the working fluids in liquid phase condition. A Coriolis flow meter is used for measuring flow rate of the working fluids. Before the working fluid enters the test section, it is flowed in a preheater to adjust the inlet temperature of working fluids. There are sight glasses at the inlet and outlet of the test section for observation the phase of working fluids.

2.2. Data reduction

[9] introduced confinement number (Co) as a ratio of capillary length and hydraulic diameter.

$$Co = \frac{\left[\frac{\sigma}{g(\rho_l - \rho_v)}\right]^{1/2}}{d_h} \quad (1)$$

Where $\sigma, g, \rho_l, \rho_v$ and d_h represent surface tension, acceleration due to gravity, liquid density, vapor density, and hydraulic diameter, respectively. Kew and Cornwell defined that the microchannel flow occurred when Co > 0.5. The average calculated Co for the present experimental data is 2.38. Based on the classification proposed by Kew and Cornwell, it can be classified as a microchannel flow.

The measured temperature and pressure is recorded by a Data Acquisition. Vapor quality is calculated using the following equation.

$$x_o = \frac{\Delta i + i_{fi} - i_f}{i_{fg}} \quad (2)$$

Where $x_o, \Delta i$, i_{fi}, i_f, and i_{fg} represent outlet quality, increasing enthalpy, fluid inlet enthalpy, enthalpy of saturated liquid, and latent heat of vaporization, respectively.

Pressure drop friction from homogeneous equation is given as:

$$\left(\frac{dP}{dz}F\right) = \frac{2 f_{tp} G^2}{D\bar{\rho}} \quad (3)$$

Where$\left(\frac{dP}{dz}F\right)$,f_{tp}, G and $\bar{\rho}$ represent pressure drop friction, two-phase friction factor, mass flux and mean density, respectively.

Assuming that the friction factor (f_{tp}) may be expressed in terms of the Reynolds number by Blasius equation:

$$f_{tp} = 0.079\left[GD/\mu_{tp}\right]^{-0,25} \quad (4)$$

The equation of mean density used Adams and Cicchiti. The equation is given as:

$$\bar{\rho} = \left[\frac{x}{\rho_v} + \frac{(1-x)}{\rho_l}\right]^{-1} \quad (5)$$

$$\bar{\rho} = x\rho_v + (1-x)\rho_l \quad (6)$$

Where ρ_v and ρ_l represent vapor density and liquid density, respectively.

Pressure drop from separated models. These models calculate the frictional pressure gradient by the frictional pressure gradient of a single-phase flow. Depending on the chosen approach, this flow can be either for the liquid (or vapor) phase considered as total flow in the channel, or for the liquid (or vapor) considered to flow alone in the channel, both corrected by the corresponding two-phase friction multiplier parameter [10]. The letter is given by the following this equation:

$$\left(\frac{dp}{dz}F\right) = \left(\frac{dp}{dz}F\right)_f \emptyset_f^2 \quad (7)$$

IOP Conf. Series: Materials Science and Engineering **316** (2018) 012058 doi:10.1088/1757-899X/316/1/012058

Pressure drop is correlated as a function of Reynolds number. Reynolds number of two phase flow is a function of viscosity, mass flux, and hydraulic diameter. This present study uses some two phase viscosity correlations, viz. [11], [12], [13], and [7] as shown in the following equations.

$$\mu_{tp} = \left[\frac{x}{\mu_v} + \frac{(1-x)}{\mu_l}\right]^{-1} \tag{8}$$

$$\mu_{tp} = x\mu_v + (1-x)\mu_l \tag{9}$$

$$\mu_{tp} = \bar{\rho}[x v_v \mu_v + (1-x) v_l \mu_l] \tag{10}$$

$$\mu_{tp} = \mu_l(1-\alpha)(1+2.5\alpha) + \mu_v \alpha \tag{11}$$

Where $\mu_{tp}, \mu_v, \mu_l, v_l, v_v, \alpha,$ and x represent two-phase viscosity, vapor viscosity, liquid viscosity, liquid specific volume, vapor specific volume, void fraction and quality, respectively.

3. Result and discussion

Experiment two-phase flow boiling on microchannel have done successfully. The data result showed mass flux between 360 to 915 kg/m^{2}s. Heat flux between 30 to 43 kW/m^2. Saturation temperature between 38.3 to 48.7^{o}C. Flow regime experiment on micro channel found as liquid turbulence-vapor turbulence.

[8] develop new C parameter based on the data experiment. The parameter has correlation with viscosity number. The equation viscosity number is given as:

$$N_{\mu_{tp}} = \frac{\mu_{tp}}{\left(\rho_{tp}\sigma\sqrt{\frac{\sigma}{g\Delta\rho}}\right)^{0,5}} \tag{12}$$

The common logarithm of the two-phase viscosity number data experiment have bigger range number. Xuejiao experiment reported the common logarithm of the two-phase viscosity number between – 3 to – 2 at the same regime flow, liquid turbulence and vapor turbulence.

Table 1. Data experiment with parameter measurement quality, logarithm viscosity number, C parameter and regime flow regime.

x_o	$\log(N_{\mu_{tp}})$	C Parameter			Flow Regime
		Xuejiao	Pamitran	Hibiki	
0,35 – 0,97	(- 3.40) – (- 2,65)	6,67 – 19,2	10,27 – 58,3	3.09	Turbulence – Turbulence

Table 1. Describing data experiment with parameter measurement i.e. quality, logarithm viscosity number, C parameter and regime flow regime. Frictional pressure drop from separated models is effected by C parameter. [5] develop C parameter as function of hydraulic diameter. For the tube with 0.5 mm, The C parameter has constant 3.09 value. [8] develop C parameter for flow regime turbulence-turbulence as function of viscosity number, Reynolds two-phase and quality. The equation from Li and Hibiki is given as:

$$C = 6.28 N_{\mu_{tp}}^{0.78} Re_{tp}^{0.67} x^{0.32} \tag{13}$$

Data experiment showed the C parameter from Xuejiao on flow regime turbulence-turbulence lower than C from Chisholm. [6] develop C parameter as function of Weber number and Reynolds number. The equation is given as:

$$C = 3\ 10^{-3} We_{tp}^{-0.433} Re_{tp}^{1.23} \tag{14}$$

Data experiment showed the C parameter from Pamitran 10.27 to 58.3 value. Some of data experiment over than 20 for turbulence-turbulence.

Characteristic of pressure drop from separated models more predominated by C parameter. Flow regime is effected to two-phase frictional multi player. This data experiment showed on turbulence-turbulence condition.

Figure 2. Describing pressure drop prediction on the all data experiment with various parameter i.e. mass flux, heat flux and saturation temperature. For round type is frictional pressure drop from homogeneous models. Calculating frictional pressure drop used varying mean density from Adams and Cicchiti. Calculating two-phase friction factor used varying two-phase viscosity from Adams, Cicchiti and Dukler.

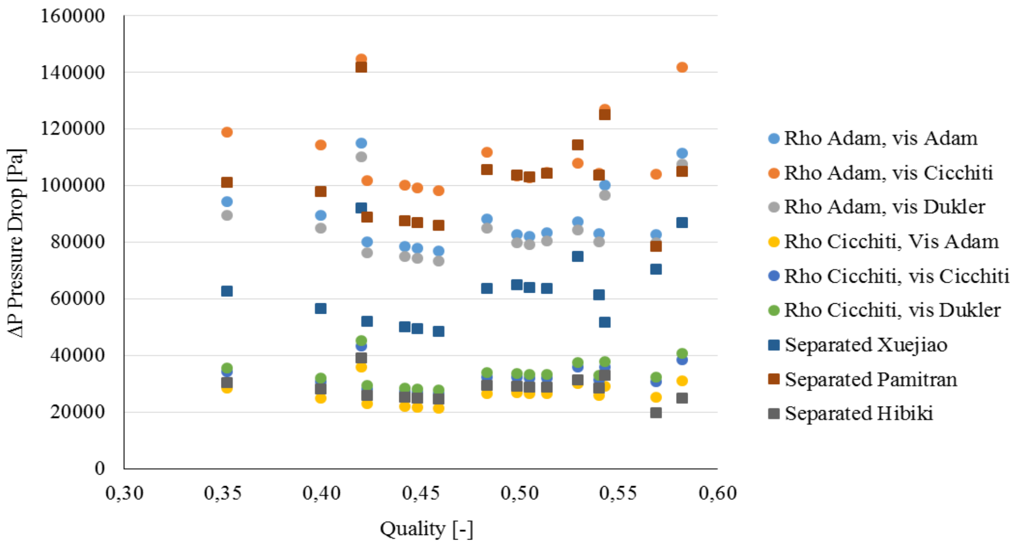

Figure 2. Homogenous and separated frictional pressure drop calculation. Round type is homogeneous models, square type is separated models.

The figure showed frictional pressure drop with density from Adams and two-phase viscosity from Cicchiti has higher pressure drop. Vice versa frictional pressure drop with density from Cicchiti and two-phase viscosity from Adams has lower pressure drop.

For square type is frictional pressure drop from separated models. There are three correlation pressure drop i.e. Xuejiao, Pamitran and Hibiki. The figure showed frictional pressure drop from Pamitran correlation has higher pressure drop. The lower frictional pressure drop occur on Hibiki correlation.

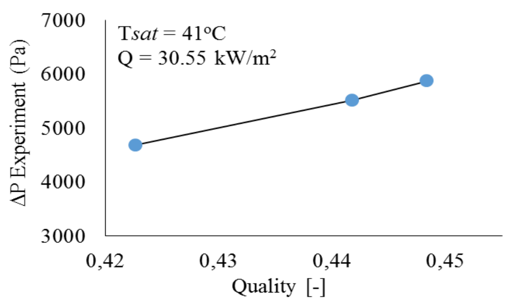

Figure 3. Effect of quality on pressure drop

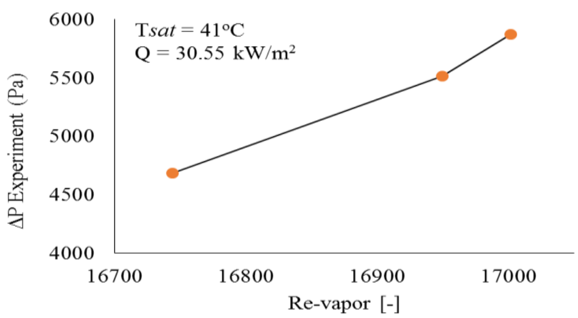

Figure 4. Effect of Reynolds vapor on pressure drop

Figure 3 showed the increasing quality will effect on increasing pressure drop. Then figure 4 showed the increasing Reynolds vapor will effect on increasing pressure drop. The condition experiment on $41^{O}C$ saturation temperature and 30.55 kW/m^2 heat flux.

On quality 0.42 showed the pressure drop 4682 Pa, and quality 0.45 showed the pressure drop 5873 Pa. Both of figure have inter connecting. The vapor Reynolds number increase if quality increase. The figure showed increasing quality or vapor Reynolds number will increase frictional pressure drop. Differences of quality occur due to mass flux experiment is different.

4. Conclusion
Experimental frictional pressure drop on the microchannel has done successfully. Frictional pressure drop from homogeneous models showed the frictional pressure drop with density from Adams and two-phase viscosity from Cicchiti has higher pressure drop. Vice versa frictional pressure drop with density from Cicchiti and two-phase viscosity from Adams has lower pressure drop.

Quality and vapor Reynolds number predominant to effect on frictional pressure drop in microchannel. Heat transfer on microchannel have big effect to contribute evaporating fluid to be vapor.

5. Acknowledgement
This study is funded by Hibah Ristekdikti PUPT 2017.

6. References

[1] K.-I. Choi, A. Pamitran, J.-T. Oh, and K. Saito, "Pressure drop and heat transfer during two-phase flow vaporization of propane in horizontal smooth minichannels," *International Journal of Refrigeration,* vol. 32, pp. 837-845, 2009.
[2] N. Ghazali, Q. A. Yousif, A. S. Pamitran, S. Novianto, and R. Ahmad, "OPTIMIZATION OF THE FRICTION FACTOR AND FRICTIONAL PRESSURE DROP OF R22 AND R290," *INTERNATIONAL JOURNAL OF TECHNOLOGY,* vol. 7, pp. 227-234, 2016.
[3] M. R. Hoehne and P. Hrnjak, "Charge minimization in systems and components using hydrocarbons as a refrigerant," *Urbana,* vol. 51, p. 61801, 2004.
[4] A. Cavallini, E. Da Riva, and D. Del Col, "Performance of a large capacity propane heat pump with low charge heat exchangers," *International Journal of Refrigeration,* vol. 33, pp. 242-250, 2010.
[5] K. Mishima and T. Hibiki, "Some characteristics of air-water two-phase flow in small diameter vertical tubes," *International journal of multiphase flow,* vol. 22, pp. 703-712, 1996.
[6] A. Pamitran, K.-I. Choi, J.-T. Oh, and P. Hrnjak, "Characteristics of two-phase flow pattern transitions and pressure drop of five refrigerants in horizontal circular small tubes," *International Journal of Refrigeration,* vol. 33, pp. 578-588, 2010.
[7] D. Beattie and P. Whalley, "A simple two-phase frictional pressure drop calculation method," *International Journal of Multiphase Flow,* vol. 8, pp. 83-87, 1982.
[8] X. Li and T. Hibiki, "Frictional Pressure Drop Correlation for Two-Phase Flows in Mini and Micro Single-Channels," *International Journal of Multiphase Flow,* 2016.
[9] P. A. Kew and K. Cornwell, "Correlations for the prediction of boiling heat transfer in small-diameter channels," *Applied Thermal Engineering,* vol. 17, pp. 705-715, 1997.
[10] J. G. Collier and J. R. Thome, *Convective boiling and condensation*: Clarendon Press, 1994.
[11] W. McAdams, W. Woods, and L. Heroman, "Vaporization inside horizontal tubes-II-benzene-oil mixtures," *Trans. ASME,* vol. 64, pp. 193-200, 1942.
[12] A. Cicchitti, C. Lombardi, M. Silvestri, G. Soldaini, and R. Zavattarelli, "Two-phase cooling experiments: pressure drop, heat transfer and burnout measurements," Centro Informazioni Studi Esperienze, Milan1959.
[13] A. Dukler, M. Wicks, and R. Cleveland, "Frictional pressure drop in two-phase flow: A. A comparison of existing correlations for pressure loss and holdup," *AIChE Journal,* vol. 10, pp. 38-43, 1964.