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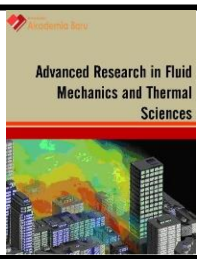

Analysis of Temperature and Heat Measurement on Two-phase Flow Nucleate Boiling with R-290 in Microchannel

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ABSTRACT

Research of two-phase flow boiling in microchannel has been done intensively. Microchannel has been increasingly applied in industrial equipment, especially for cooling system. Measurement of temperature and heat on the test section of microchannel became the main concern on this research. The aims of this research is to study a characteristic of temperature measurement and heat on two-phase flow boiling with R-290 in microchannels. The research method that is used including evaporative process at the test section with electrical heating. There are 10 type K thermocouple placed on the surface of test section and an immersed thermocouple to measure inlet and outlet temperature difference. In order to determine heat received and error, the statistical and mathematical approach were conducted. The average uncertainty of heat received on two-phase flow boiling was 0.05 Watt. Heat transfer coefficient of two-phase flow has been determined based on temperature measurement.

Keywords:
Temperature, Heat, Measurement, Two-phase, Nucleate Boiling, R-290, Microchannel

1. Introduction

One of the challenges in a research is the measurement method in a microchannel instrument. Measuring of temperature and heat on research of two-phase flow boiling in microchannel has done intensively. Recently, microchannels are widely used to design heat exchanger. Microchannels have heat transfer more effective than macrochannels [1,2]. Industrial equipment also use more microchannels application for cooling system.

Measurement of tube surface temperatures is necessary for many areas of two-phase flow research. The thermocouple is a sensor that is used commonly to measure surface temperature. There were many method or configuration to place thermocouple on measuring surface temperature. But there is no explanation about the optimal or the best suit on applications.

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A type K thermocouple has low thermal conductivity and needs 60% contact length than thermocouple with higher conductivity [3].

Alwaaly studied the effects of thermocouple wire with electrical insulation on the temperature measurement. Type K thermocouple with diameter 80 µm and 200 µm were used to measure various surface temperatures from 4°C to 35°C [4]. Other researcher, Li and Well used type K thermocouple to measure surface temperature with different method [5]. The thermocouple was pushed through a hole opposite to the surface. The research has examined the effect of the hole used to insert the thermocouple into the sample.

Coefficient of heat transfer two-phase flow has been proposed by [6,7] and It called as super position model. The model represent of sum of single phase heat transfer and nucleate heat transfer. New model correlation of heat transfer coefficient has been built as function of Reynolds number, Boiling number and Weber number [8-11]. Increasing of heat transfer coefficient is caused by increasing of Reynolds number [12,13].

Heat transfer coefficient of two-phase flow is generated from heat received and difference of surface temperature and fluids saturation temperature. Besides the surface temperature, measuring of fluids temperature in the inlet and outlet can be conducted with immersed thermocouple. It is known that measurement of temperature and heat have contributed on determining of heat transfer. The aims of this research is to study a characteristic of temperature measurement and heat on two-phase flow boiling in microchannels.

2. Methodology

The experiment in a laboratory was conducted for research of flow boiling heat transfer on microchannel. The focus is on the test section. Figure 1 showed experiment apparatus. The test section used stainless steel 0.5 mm diameter and 0.5 meter length. Heating process were given to test section by electrical equipment. Working fluid flowed to the test section with evaporative process.

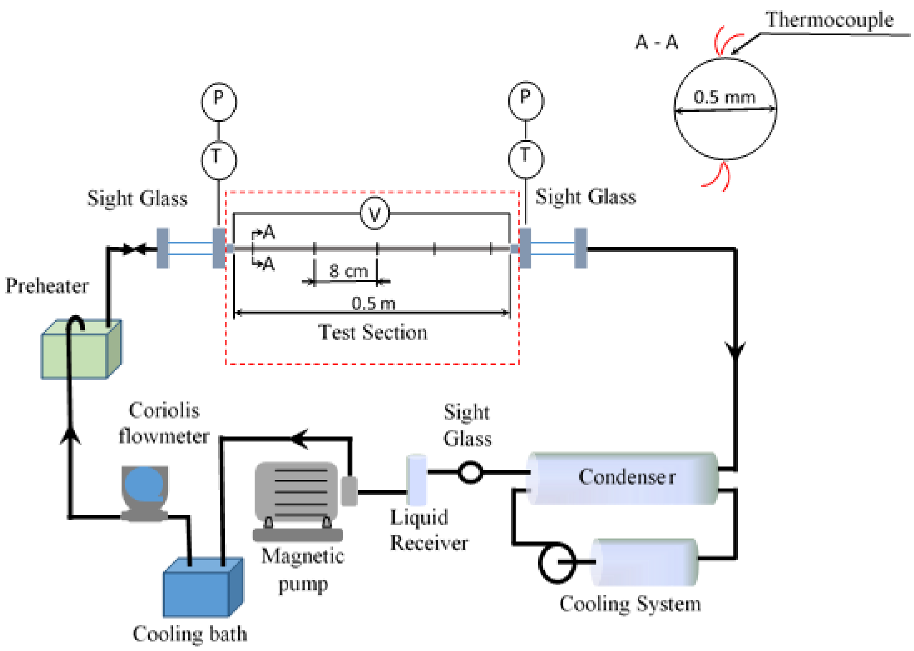

Fig. 1. Experiment apparatus

Working fluid (R-290) as liquid phase flowed to the test section and out from test section as two-phase flow. The thermocouples are located at surface test section. Length of each thermocouple is 8 cm. There are two thermocouple at the top and bottom on five location of surface test section. An immersed thermocouples are placed at inlet and outlet to measure temperature different. Beside that pressure transmitters are placed at inlet and out let to measure working fluid pressure. After working fluid out from test section, working fluid will condense in condenser from cooling system. Working fluid as liquid is moved and circulated by magnetic pump. Cooling bath is placed after magnetic pump to maintain liquid temperature lower.

Flow rate of working fluid is measured by Coriolis meter. Working fluid will enter the preheater to adjust fluid temperature before enter to inlet of the test section. Two sight glass are placed at inlet and outlet of the test section as visualization of working fluid phase.

Local heat transfer experimental of two-phase flow boiling in microchannel uses the equation as follow [14].

$$h = \frac{\ddot{q}}{T_{wall} - T_{sat}} \quad (1)$$

3. Results

3.1 Temperature Distribution

The initial test of the twelve thermocouple were conducted to measure ambient temperature for 15 minute in room chamber without/slightly air flow condition. Figure 2 shows wave of twelve thermocouple. All thermocouple have trend similar wave.

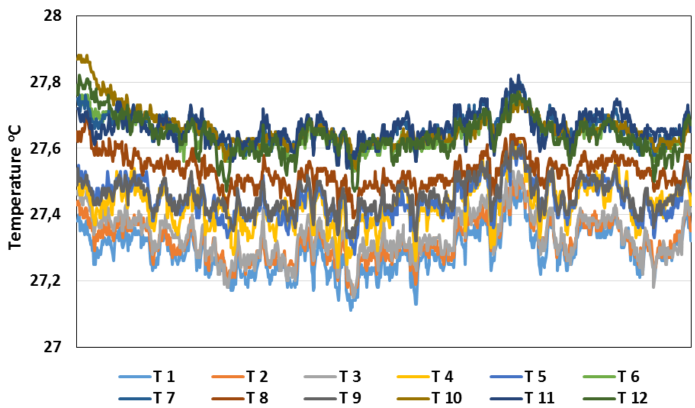

Fig. 2. Initial test of type K thermocouple

Uncertainty of the twelve thermocouple were calculated by mean deviation. Table 1 shows result of uncertainty all thermocouple.

Table 1
Uncertainty of type K thermocouple

Type K Thermocouple	Uncertainty	Type K Thermocouple	Uncertainty
1st Thermocouple	± 0,05	7th Thermocouple	± 0,04
2nd Thermocouple	± 0,03	8th Thermocouple	± 0,04
3rd Thermocouple	± 0,05	9th Thermocouple	± 0,04
4th Thermocouple	± 0,05	10th Thermocouple	± 0,04
5th Thermocouple	± 0,05	11th Thermocouple	± 0,03
6th Thermocouple	± 0,04	12th Thermocouple	± 0,04

Calibration thermocouple were conducted to ensure the temperature measuring exactly right on real temperature condition. In this study, there were 3 temperature point for calibration, 15°C, 20°C and 25°C. The equation of each thermocouple has been developed and inserted to block diagram of National Instrument device for data acquisition.

Measurement result of surface temperature and immersed temperature is shown on figure 3. Figure 3 (a-e) show temperature on each point as function of time. The figure shows increasing of surface temperature from 1st until 5th point location. Heat received at along test section influence to surface temperature. At the same time, fluids temperature also increase. This condition can be explained with inlet and outlet temperature differential. Figure 3 (f) shows distribution of upper wall temperature, bottom wall temperature and fluids temperature on the same time.

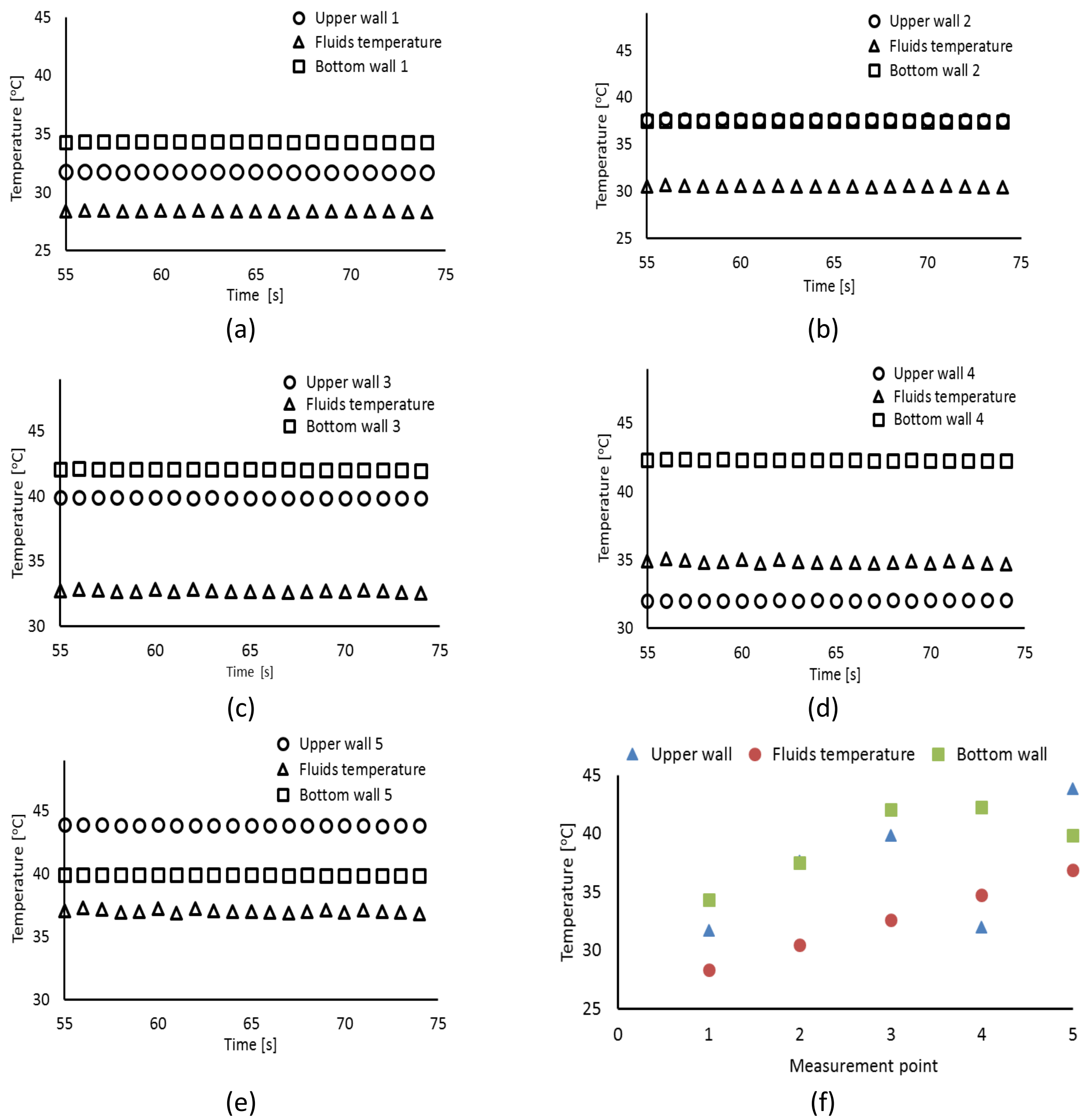

Fig. 3. Temperature measurement as function of time on each point location

3.2 Local Heat Transfer Two-phase Flow

Two-phase flow boiling experiment was done with evaporative process on the test section. Parameter analysis of two-phase flow boiling used heat flux, saturation temperature, mass flux and two-phase Reynolds number. Result of experiment parameter and measurement on two-phase flow boiling nucleate were written on table 2 as follow.

Table 2
Experimental parameter and some result measurement

Parameter	Range	Result measurement	Range
Heat flux (kW/m^2)	5.28 – 7.66	Mass quality	0.09 – 0.15
Saturation temperature (°C)	31.96 – 33.14	Void fraction	0.66 – 0.77
Mass flux (kg/m^2.s)	681 – 776	$Z_{subcooled}$ (m)	0.16 – 0.19
Two-phase Reynolds	4603 – 5466	Z_{ONB} (m)	0.006 – 0.105

Heat uncertainty of heat received and heat transfer coefficient used partial differential model with equation as follow:

$$V = V(a, b) \tag{2}$$

$$\delta V = \frac{\partial V}{\partial a}\delta a + \frac{\partial V}{\partial b}\delta b \tag{3}$$

The equation of heat received as follow:

$$q = \dot{m}\, Cp\, \Delta T \tag{4}$$

$$\delta q = \frac{\partial q}{\partial \dot{m}}\delta \dot{m} + \frac{\partial q}{\partial Cp}\delta Cp + \frac{\partial q}{\partial \Delta T}\delta \Delta T \tag{5}$$

$$\delta q = Cp\, \Delta T\, \delta \dot{m} + \dot{m}\, \Delta T\, \delta Cp + \dot{m}\, Cp\, \delta \Delta T \tag{6}$$

From the above equation, on table 3 shows calculating result of heat received uncertainty.

Table 3
Uncertainty of heat received

	ΔT (°C)	δT (°C)	Cp (J/kg.°C)	δCp (J/kg.°C)	m kg/s	δm kg/s	δQ Watt
No 1	12,82	0,14	2796,26	0,50	0,000138	6,92214E-08	0,06
No 2	12,20	0,15	2785,74	0,41	0,000139	6,95749E-08	0,06
No 3	16,06	0,06	2799,36	0,29	0,000152	7,61825E-08	0,03
No 4	14,93	0,08	2794,94	0,29	0,000139	6,9266E-08	0,03
No 5	12,03	0,27	2799,48	1,04	0,000146	7,28768E-08	0,11
No 6	14,92	0,10	2795,72	0,43	0,000134	6,68926E-08	0,04
No 7	14,70	0,06	2791,28	0,21	0,000143	7,15201E-08	0,03
No 8	15,28	0,11	2795,77	0,46	0,000144	7,21369E-08	0,05
Average	14,12	0,12	2794,82	0,45	0,000142	7,09589E-08	0,05

From experimental data on table 3 above the average uncertainty of heat received ± 0.05 Watt. The equation of heat received is calculated as follow.

$$q_{receive} = \dot{m} C_p \Delta T \tag{7}$$

The heat transfer coefficient of two-phase flow is calculated as follow [15]:

$$h = \frac{\ddot{q}}{T_W - T_{sat}} \tag{8}$$

$$\delta h = \frac{\partial h}{\partial \ddot{q}} \delta \ddot{q} + \frac{\partial h}{\partial T_W} \delta T_W + \frac{\partial h}{\partial T_{sat}} \delta T_{sat} \tag{9}$$

$$\delta h = \frac{1}{T_W - T_{sat}} \delta \ddot{q} - \frac{\ddot{q}}{(T_W - T_{sat})^2} \delta T_W + \frac{\ddot{q}}{(T_W - T_{sat})^2} \delta T_{sat} \tag{10}$$

Uncertainty calculation of heat transfer coefficient on 5 point location resulted as follow: 1st point ± 11.85, 2nd point ± 0.23, 3rd point ± 0.01, 4th point ± 1.77, and 5th point ± 1.31.

Figure 4 shows heat transfer two-phase nucleate boiling on measurement of surface temperature location. Heat transfer single phase occurred on point 1 and nearly point 2. Where mass quality less than 0 on location 1 and 2.

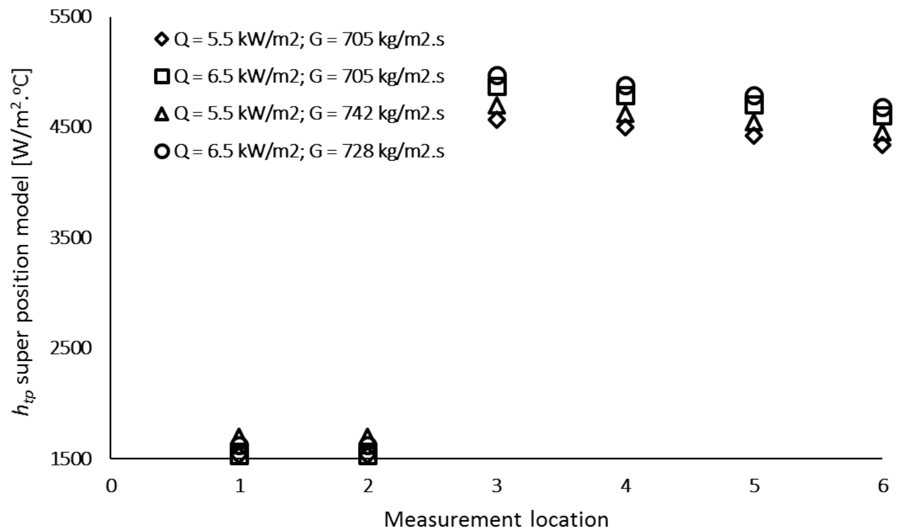

Fig. 4. Heat transfer two-phase nucleate boiling on measurement of surface temperature location

Heat transfer two-phase nucleate boiling were occurred near 2nd measurement location, where heat transfer nucleate boiling has contributed on total heat transfer two-phase flow. From the figure 4 shows clearly that heat flux very effect to heat transfer two-phase flow became higher.

3.3 Result Comparison

Comparison of heat transfer two-phase flow with superposition models has been determined in table 4. Heat transfer two-phase flow as sum of heat transfer single phase and heat transfer nucleate boiling. Correlation of heat transfer nucleate boiling used correlation from [16]. Some heat transfer two-phase flow correlation used non dimensional number as Boiling number, Bond number and Reynolds number. Correlation comparison evaluated used mean absolute deviation.

Research comparison with [9] showed higher mean absolute deviation. Where [9] has heat transfer two-phase higher than experiment result. [9] was studied research literature data from many experiment. The literature data has vary working fluids, tube diameter and operational condition. Result of [11] showed higher mean absolute deviation. It is occurred because experiment tube has vertical orientation and developing of heat transfer model by [11] were conducted on nucleate boiling and film boiling regime. Result of [8] showed higher mean absolute deviation. Operational condition of experiment used working fluid R-113, where surface tension of working fluid of R-113 lower than R-290. Heat transfer from [8] higher than heat transfer experiment. Result of [10] has moderate mean absolute deviation. [10] used working fluid R-12 with pipe diameter 2.46 mm. Fluids properties R-12 has surface tension lower than R-290. [10] correlation better than [8] correlation. It is caused the diameter [10] experiment more little. Heat transfer from [10] higher than heat transfer experiment.

Table 4
Comparison of heat transfer coefficient two-phase flow experiment with existing correlation

Author	Correlation	MAD
[9]	$h_{tp} = 334Bl^{0.3}(BoRe_l^{0.36})^{0.4}\left(\frac{k_l}{D_h}\right)$	79%
[11]	$h_{tp} = 30Re_{lo}^{0.857}Bo^{0.714}\frac{k_l}{D}(1-x)^{-0.143}$	75%
[8]	$h_{tp} = 30Re^{0.857}Bo^{0.714}\frac{k_l}{D}$	75%
[10]	$h_{tp} = (8.4\, x\, 10^{-3})(Bo^2We_l)^{0.3}\left(\frac{\rho_l}{\rho_g}\right)^{-0.4}$	48%
[17]	$h_{tp} = sh_{nb} + Fh_c$ $S = \frac{1}{1+2.53\times10^{-6}Re_l^{1.17}}$ $F = Max\left[0.64\left(1+\frac{C}{X_{tt}}+\frac{1}{X_{tt}^2}\right)^{0.5}, 1\right]$	83%
[18]	$S = 9.4625(\emptyset^2)^{-0.2747}Bo^{0.1285}$ $F = 0.062\emptyset^2 + 0.938$	87%

Heat transfer from [17] and [18] used super position model, where two-phase heat transfer total is sum of convective heat transfer and nucleate heat transfer. [17] showed higher mean absolute deviation. Zhang collected experimental data from many study of two-phase flow. [17] proposed saturation boiling flow model with liquid turbulence and gas turbulence. This condition caused [17] correlation higher than heat transfer experiment. Research comparison with [18] showed higher mean absolute deviation. [18] used mixture refrigerant R-32 and R-125, which calls R-410A. Operational condition of experiment from [18] also effected on differences of result, like low inlet temperature, heat flux more than 10 kW/m^2 and pipe diameter 1.5 mm. Heat transfer [18] correlation higher than heat transfer experiment.

4. Conclusions

The experimental study of temperature and heat measurement on two-phase flow nucleate boiling in microchannels has been conducted. The conclusion can be written as follow.

- Temperature measurement to calculated heat transfer of two-phase flow can be conducted on surface test section. Surface temperature of test section increase along with the test section.
- Measuring of inlet and outlet temperature difference with immersed thermocouple resulted in the average uncertainty of heat received lower.
- Heat transfer of two-phase flow nucleate boiling in microchannel is effected by heat transfer nucleate boiling and slightly effected by convective heat transfer.
- Heat flux effected more significant to heat transfer of two-phase flow nucleate boiling in microchannels, where higher heat flux cause increasing of heat transfer of two-phase flow nucleate boiling in microchannels.

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