# Heat transfer coefficient of near boiling single phase flow with propane in horizontal circular micro channel

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**Abstract.** Experimental study of heat transfer coefficient of single phase has conducted successfully. Technology to reduce energy consumption is important to be investigated, moreover with implementation of renewable energy. The study used natural refrigerant of propane as working fluid with heating process. The aim of the present research is to study near boiling single phase heat transfer coefficient on the micro channel of 500 µm diameter and 0.5 meter length. Variable of research are heat flux of 1 to 15 kW/m$^2$, mass flux of 297 to 1102 kg/m$^2$.s, and test section inlet temperature of 21 to 26ºC. The experimental results showed single phase laminar-turbulence flow with Reynolds number less than 10000. Heat transfer coefficient of near boiling single phase flow is significantly affected by Reynolds number and Prantl number. Using the present experimental data, new correlation of Nusselt number is developed as a function of Reynolds number and Prantl number.

## 1. Introduction

Technology to reduce energy consumption is important to be investigated, moreover with implementation of renewable energy. Many of renewable energy system use heat exchanger as cooling or evaporating units. Discussion about environmental issue is more intensively, mainly to reduce the using of refrigerant as working fluid in cooling system. Propane is one alternative refrigerant to replace conventional refrigerants. Propane has zero ODP (Ozone Depletion Potential) and less than four GWP (Global Warming Potential) [1]. [2] proposed single phase heat transfer with conventional channel. The correlation has range limited for smooth channel with ratio D/L higher than 60, turbulence flow, and Pr between $0.7 \leq$ Pr $\leq 160$. [3] proposed a modified Petukhov correlation. The correlation has developed as function of Reynolds, Prantl, friction factor with laminar flow. [4] found heat transfer coefficient in microchannel was higher than that in conventional channel for both laminar and turbulence flow. [5] found heat transfer coefficient in microchannel is higher for laminar flow. A new correlation has proposed for laminar correlation.

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[6] studied the single-phase forced-flow convection of water or methanol flowing through micro-channels. A modified correlation of heat transfer coefficient has been proposed with a factor of 0.023 to 0.00805. [7]  explained a wide range empirical Nusselt-type correlation for channel flow; these were generally obtained using hydraulic diameters of 2 cm or more. Some author has studied heat transfer i.e. [8] reviewed on the convective heat transfer on micro-channels. In many cases the experimental data of the Nusselt number in micro-channels disagree with the conventional theory but they also appear to be inconsistent with one other. [9] have investigated fully developed liquid and vapor flow with hydraulic diameters varying from 69.5 to 304.7 µm. R 134a liquid and vapor were used as testing fluids. During the experiments, the Reynolds numbers were varied between 112 and 9180. The goal of the present research is to study single phase heat transfer coefficient on the microchannel 500 µm diameter and length 0.5 meter. The new correlation can be used to determine heat transfer coefficient on design of heat exchanger with microchannel.

## 2. Methodology

### 2.1. Experiment set up
The main observation is on the test section heated by electrical heater. Figure 1 describes the experimental apparatus. The test section is a horizontal tube with diameter of 500µm and length of 0.5 m.
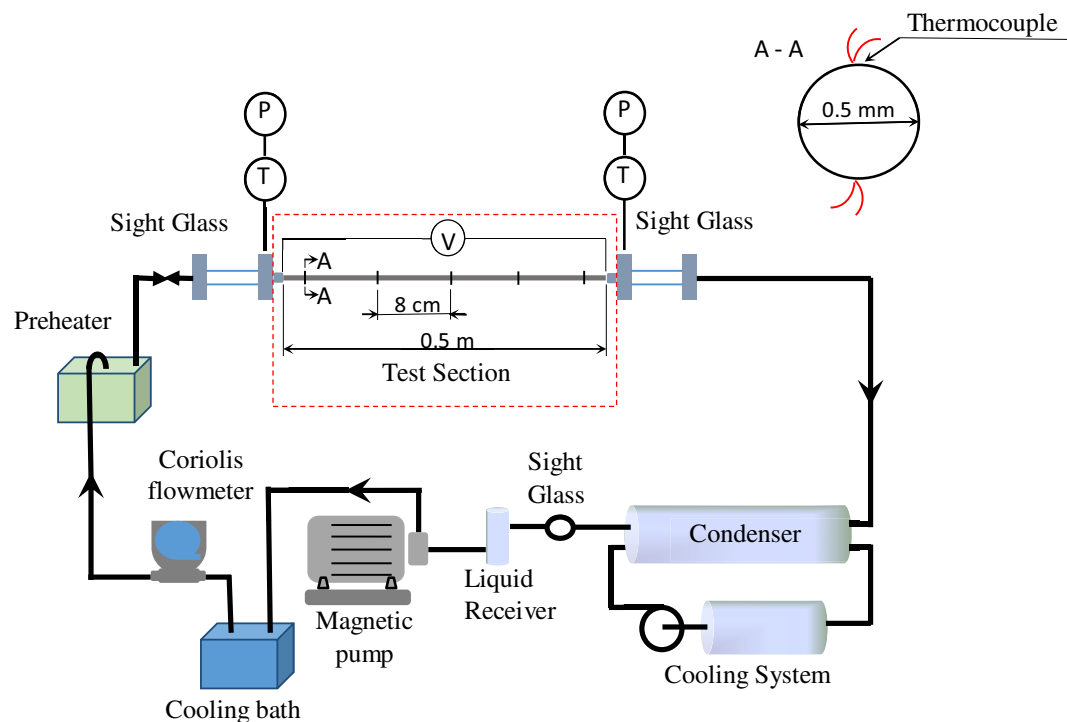


**Figure 1.** Experimental apparatus

Temperature of refrigerant flowed in the test section were measured by attached K-type thermocouples at the top and bottom of the test section, as shown in figure 1. 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 section. A condensing unit is used to condense the evaporated refrigerant.  After

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

*2.2. Data Reduction*

[10] introduced confinement number (Co) as a ratio of capillary length and hydraulic diameter. Kew and Cornwell defined that the micro channel 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 micro channel flow. The experimental uncertainty is shown in table 1.

**Table 1.** Experimental uncertainties

| Variable | Uncertainty |
|---|---|
| Average Temperature (°C) | 0.46 |
| Mass flow (%) | 0.05 |
| Heat (%) | 1 |

The heat from electrical heater is given to the test section can be calculated as

$$q_{given} = V.I \qquad (1)$$

Where V, and I represent voltage and current, respectively.

The equation for calculating heat received to the fluid working is given as

$$q_{received} = \acute{m}C_p(T_{out} - T_{in}) \qquad (2)$$

where $\acute{m}, C_p, T_{out}$ and $T_{in}$ represent flow rate, specific heat, outlet temperature and inlet temperature, respectively. Heat flux is given as

$$\ddot{q} = \frac{q_{received}}{A_{surface}} \quad , \text{with} \quad A_{surface} = \pi DL \qquad (3)$$

where D, and L represent inner diameter and length test section, respectively.

**Table 2.** Existing single phase heat transfer coefficient correlation

| Author | Heat transfer | Range |
|---|---|---|
| (Dittus and Boelter, 1930) | $Nu = 0.023Re^{0.8}Pr^n$ | $Re > 10000$ |
| (Gnielinski, 1975) | $Nu = \dfrac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$ | $3 \times 10^3 < Re < 5 \times 10^6$ |
| (Wu and Little, 1984) | $Nu = 0.00222Pr^{0.4}Re^{1.08}$ | $Re > 3000$ |
| (Choi et al., 1991) | $Nu = 0.000972Re^{1.17}Pr^{1/3}$ | $Re < 2000$ |
| (Wang and Peng, 1994) | $Nu = 0.00805Re^{0.8}Pr^{1/3}$ | $Re > 1500$ |

## 3. Result and discussion

The importance parameter used in the data reduction and analyze are Reynolds number (Re), and Nusselt number (Nu). During the present experiment, Reynolds number was varied between 1522 and 5549. Liquid phase were flowing on the inlet and outlet of the test section. Figure 2 showed the effect of Reynolds number on Nusselt number. The red trend line shows increasing Reynolds number results in increasing of Nusselt number.
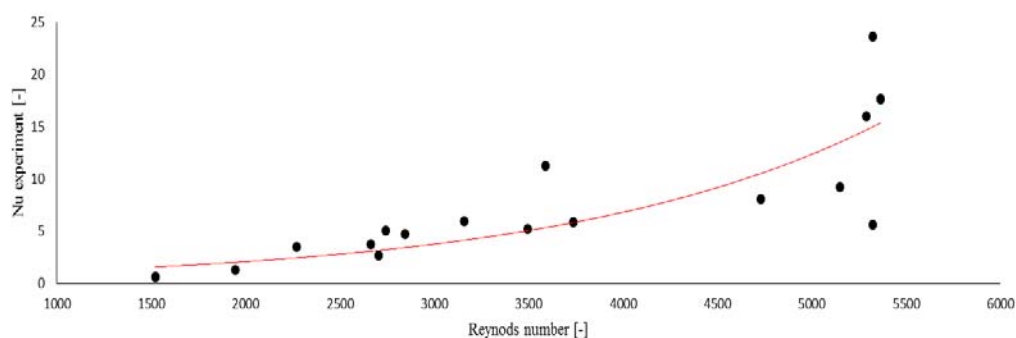


**Figure 2.** Effect of Reynolds number on Nusselt number

Reynolds number on the microchannel is predominately affected by diameter. The experimental Reynolds number experiment was less than 5600. Laminar, transition, and turbulence flow is observed on the experiment.

Liquid temperature on regime of convective flow was less than wall temperature. The increasing of heat flux caused increasing of liquid temperature and wall temperature. But more increasing heat flux, made the different of liquid temperature and wall temperature is lower, therefore the heat transfer coefficient is higher.
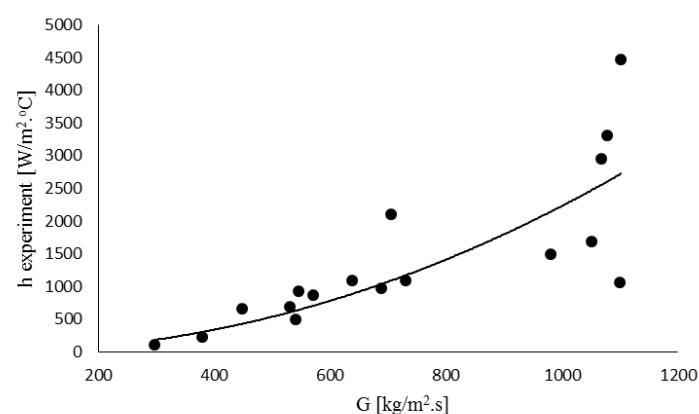


**Figure 3.** Effect of mass flux on experimental heat transfer coefficient.

Figure 3 showed effect of mass flux on experimental heat transfer coefficient. Increasing mass flux results in increasing heat transfer coefficient. The same results were found by [11].

The predicted Nusselt number were calculated with [2] equation. The equation is given as

$$Nu = 0.023Re^{0.8}Pr^{0.4} \tag{4}$$

Where $Nu,$ and $Pr$ represent Nusselt number, and Prantl number, respectively.

### 3.1. Development of a new Nusselt number with microchannel

Generally, the Nusselt number can be expressed as a function of Reynolds number and Prantl number.

$$Nu = C.Re^{m}Pr^{n} \tag{5}$$

Dittus-Boetler used m = 0.8 and n = 0.4 for heating process. With present experimental data, a new correlation is proposed with C of 0.00789. The news proposed Nusselt number is given as
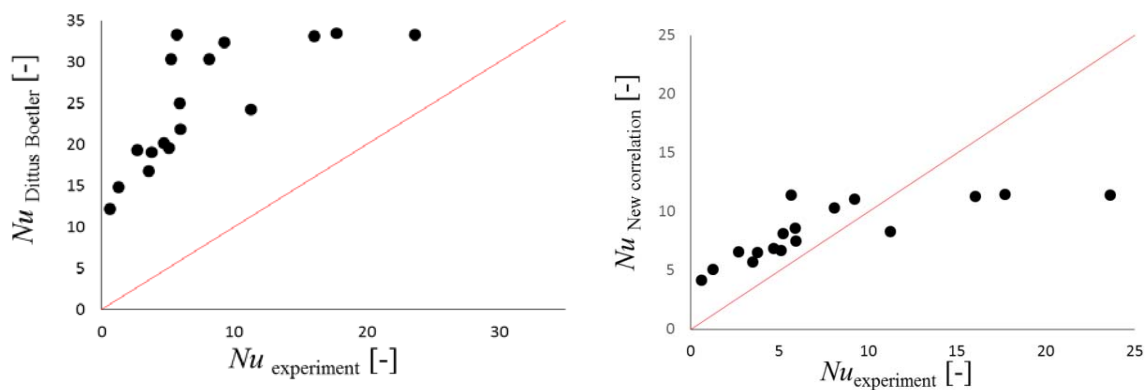
$$Nu = 0.00789Re^{0.8}Pr^{0.4} \tag{6}$$



**Figure 4.** Comparison of experimental Nusselt number and calculated Nusselt number with Dittus-Boetler and comparison of experimental Nusselt number and calculated Nusselt number with New Correlation

Figure 4 showed comparison of experimental Nusselt number and calculated Nusselt number with Dittus-Boetler. The predicted Nusselt number with Dittus-Boetler was higher than the experimental Nusselt number. The mean deviation and absolute deviation of the Nusselt Dittus Boetler are both 245%. Figure 4 also showed comparison of experimental Nusselt number and calculated Nusselt number with a new correlation. The mean deviation and absolute deviation of the new correlation are 18% and 42%, respectively.

### 3.2. Comparison heat transfer coefficient with some existing correlation

Predicted heat transfer coefficient with [3] shows high mean deviation 195%. Gnielinski correlation is function of friction factor, Prantl number and Reynolds number, with range of Reynolds number of $3 \times 10^3$ < Re < $5 \times 10^6$. Predicted heat transfer coefficient with [4] shows high mean deviation 240%. Wu and Little correlation is function of Prantl number and Reynolds number, with Reynolds number higher than 3000. Predicted heat transfer coefficient with [5] shows high mean deviation 297%. Choi correlation is function of Prantl number and Reynolds number, with Reynolds number lower than 2000. Predicted heat

transfer coefficient with [6] shows high mean deviation 13%. Wang and Peng is function of Prantl number and Reynolds number, with Reynolds number higher than 1500.

## 4. Conclusion

Experimental study of heat transfer coefficient of single phase flow near boiling has conducted successfully. Characteristic of heat transfer is affected by Reynolds number and Prantl number. Increasing Reynolds number results increasing heat transfer coefficient. Heat flux is predominately affected heat transfer coefficient of single phase in microchannel. Increasing of heat flux caused the different of liquid temperature and wall temperature become lower. Heat transfer coefficient will be higher when the different of liquid temperature and wall temperature become lower. New correlation of heat transfer coefficient in micro channel has been developed based on Dittus-Boetler correlation. The new correlation can be used to determine heat transfer coefficient on design of heat exchanger with microchannel.

## 5. Acknowledgement

## 6. References

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