Experimental investigation of forced convective heat transfer in cylindrical pipe flow

Yoshinori Hattori
Shibaura Institute of Technology, Mechanical Engineering
Tokyo, Japan
md18060@shibaura-it.ac.jp

I. Introduction

Forced convective heat transfer in cylindrical pipe flow plays an important role in many technical cooling systems. These coolant technology is used wide varaety of coolant applications such as electric devices, automotive, and plant factory. Considering heat transfer issues, heat transfer coefficients are one of the most important numbers.

Much remains to be studied for providing experimental data for high Pramdlt number and laminar-to-turbulent transitional regime. In this study, I focus on forced convective heat transfer in cylindrical pipe flow in particular high Pramdlt number and transitional regime. Shell Heat Transfer Oil was used as a operating liquid.

II. state-of-art

Figure. 1 shows dimensionless heat transfer coeffcients from literature. Gunielinski [1] showed correlations for each flow regime, laminar and turbulent, respectively. Morover, he presented transitional flow regime as a liner interpolation between laminar and turbulent flow.

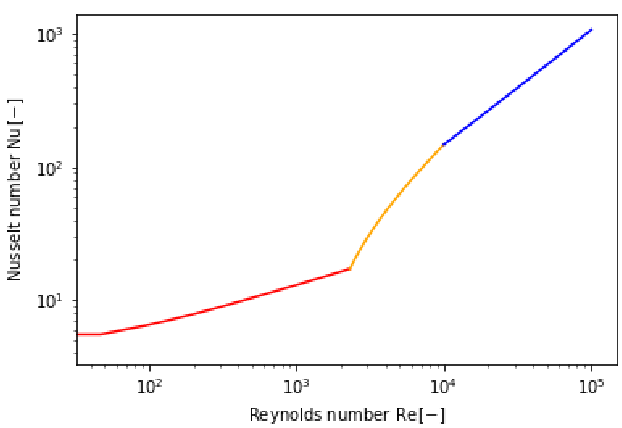

Fig. 1. Dimensionless heat transfer coefficients compared to literature data for Pr = 26. The red, yellow and blue lines are Gnielinski correlations for laminar, transitional and turbulent, respectively.

Here, reliable prediction and experimental data are needed to predict heat transfer coefficients. **Considering reliable prediction, uncertainty in Nusselt number is extremely important.**

III. Uncertainty in Nusslet number

It is nessesary to estimate the maximum possible error in the parameters evaluated from the measuring data.

Nusselt number is calcuretad from Equation 1.

$$Nu = \frac{\dot{m}c_p(T_1 - T_0)}{\lambda(T_w - T_1)d\pi L} \tag{1}$$

The uncertainty in Nusselt number is calcurated from Equation 2.

$$Nu = \sqrt{\sum \left(\frac{\partial Nu}{\partial X_i}\Delta X_i\right)^2} \tag{2}$$

Each parameter, X effects each parameters of Equation.1 Then, the mesurement uncertainty in Nusselt number leads to Equation 3.

$$\frac{\Delta Nu}{Nu} = \frac{1}{Nu}\sqrt{\left(\frac{\Delta\dot{m}}{\dot{m}}\right)^2 + \left(\frac{\Delta c_p}{c_p}\right)^2 + \left(\frac{\Delta\lambda}{\lambda}\right)^2 + \left(\frac{\Delta T}{T_0 - T_1}\right)^2 + \left(\frac{\Delta T(T_0 - T_w)}{(T_0 - T_1)(T_1 - T_w)}\right)^2 + \left(\frac{\Delta T}{T_1 - T_w}\right)^2} \tag{3}$$

I estimated mesurement error of mass flow and temperature sensors are 0.20E-3$\dot{m}$, 0.2K. Specific heat capacity and heat conductivity are calcurated from fluid properties, temperature dependance. Specific heat capacity and heat conductivity are function of temperature as shown in Equation 4 and 5.

$$C_p = 818 + 3664T \times 10^{-3} \tag{4}$$

$$\lambda = 0.157 - 7.328T \times 10^{-5} \tag{5}$$

Therefore, mesurement error of specific heat capacity Cp and heat conductivity λ are 0.73 and 1.56E-5, respectively.

Here, I picked up two experimental data. Shell Heat Transfer Oil was used as a operating liquid. TableI shows experimental results for Re=4275, Pr=26 and Re=6172, Pr=27, respectively.

TABLE I
Esperimental results for Re=4275, Pr=26 and Re=6172, Pr=27.

	Re	Pr	T0	T1	Tw	Massflow	Nu
CASE A	4275	26	438.25	446.85	472.45	0.054	56.0
CASE B	6172	25	452.87	452.87	478.97	0.073	81.6

The resulting uncertainty in nusselt numbers were analyzed for each of 2 data points. TableII summrizes uncertainty in Nusselt number of each data points.

TABLE II
UNCERTAINTY IN NUSSELT NUMBER.

Uncertainty in Nusselt number		
CASE	Flow regime, Pr	Nusselt number
CASE A	Re = 4275, Pr = 26	4%
CASE B	Re = 6172, Pr = 25	3%

Figure. 2 shows heat transfer coefficients compared to literature data for transitional regime, Pr = 26. Two data shows good agreement with calcuration method for transitional regime proposed by Gunielinski [1].

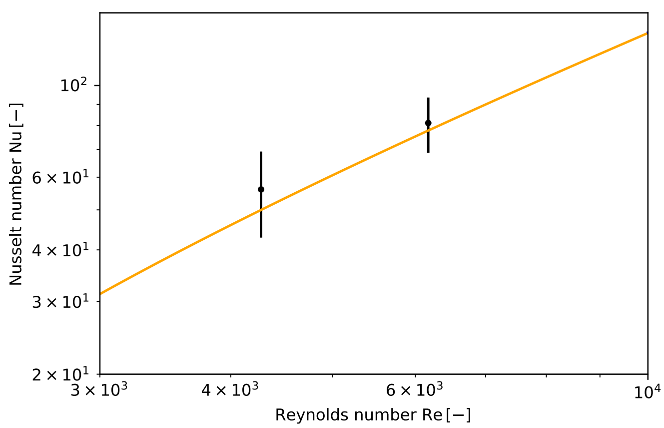

Fig. 2. Dimensionless heat transfer coefficients compared to literature data for Pr = 26.

IV. Purpose of the Solution

Table III shows the orders of each terms in Equation 3. From this comprehensive result, temperature term is several orders of magnitude larger than others. Therefore, temperature mesurement is strongly inflected to mesurement uncertainty. According to this analisis, careful selections of temperature sensors are needed.

TABLE III
ODERS OF EACH TERMS IN EQUATION 3.

	Mass flow	Specific heat capacity	Lambda	Temperature
Order	O (-8)	O (-8)	O(-8)	O(-4)

References

[1] V. Gnienlinski, “Heat Transfer in Laminar Flow,” VDI Heat Atlas, second ed., Springer Verlag, 2010 (Chapter Ga 1-7), Section 3.
[2] Dirk Bertsche, Paul Knipper, Thomas Wetzel, “Experimental investigation on heat transfer in laminar, transitional and turbulent circular pipe flow,” International Journal of Heat Transfer, 95 (2016) 1008-1018.
[3] Christphan, “Title of paper if known,” unpublished, 2018.