Experimental investigation of forced convective heat transfer in cylindrical pipe flows

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***Abstract*—Forced convective heat transfer in cylindrical pipe flow plays an important role in many technical cooling system. Heat transfer coefficients are vary with flow regime. Much remains to be study for providing experimental data for transitional regime. Reliable prediction of heat transfer coefficients for transitional flow is still challenging tasks. In this study, I focused on forced convective heat transfer in cylindrical pipe flow for transitional regime in particular high Prandtl number. Moreover, the measurement of wall friction coefficients were also performed in this study. The engineeres is frequently interested in pressure drop which is related to determine pump or fan power equipments.**

***Index Terms*—Forced convection, Nusselt number, Wall friction, transitional, Cylindrical pipe flow**

現在完了形に

I. Introduction

In recent years, forced convective heat transfer in cylindrical pipe flow plays an important role in many technical cooling systems. Nusselt number (Nu) is a dimensionless number which represents the ratio of convective (h) and conductive heat transfer (k), as expressed in Equation (1).

$$Nu = \frac{h \cdot L}{k} \tag{1}$$

数られる単語

In/For a ~~From~~ general dimensional analysis, Nusselt number represents function of Reynolds number (Re) ~~times~~ multiplied by Prandtl number (Pr) as Equation (2).

$$Nu = \alpha \cdot Re^{\pi_\beta} \cdot Pr^{\pi_\gamma} \tag{2}$$

Number check!

according to

Here, factors α, β and γ are constant values that depend on flow regime and are calculated from an experimental result. Nusselt number is one of the most important numbers for forced convective heat transfer and are (is) calculated from Equation (1) and (2).

Many studies have pointed out that a heat transfer coefficient varies depending on the type of flow: laminar, transition and turbulent. Gnienlinski [2] showed a calculation method for the laminar heat transfer coefficient of (under) two kinds of boundary conditions: (I) Constant wall temperature (UWT) and (II) Constant heat flux (UHF). Petukhvov and Kirillov [3] showed a calculation method for turbulent flows. There has been very scarce experimental data of laminar-to-turbulent transitional region. Bertsche et al. [4] focused on reliable prediction of heat transfer coefficient for transitional flows. In their study, Bertsche et al. showed experimental heat transfer coefficients for Reynolds number $500 < Re < 23000$ and Prandtl number $7 < Pr < 41$.

? More studies should be conducted to obtain experimental data for ~.

Much remains to be studied for providing experimental data for (1a) except water and glycole as operation fluids. In this study, I (the author(s)) focused on forced convective heat transfer in flow of water and glycole in a cylindrical pipe. A 50/50vol% mixture of water and glycole, which is a typical liquid coolant in automotive applications, was used as a (an) operating fluid. The experiment was carried out by considering a board range of Reynolds numbers spanning from a laminar to fully turbulent flow. Moreover, the measurements of wall friction coefficients were also performed in this study. The experimental data were compared with other sources as well as computational results obtained from already existing numerical simulations (CFD) by Christphan [5].

II. Experimental setup of this study

Figure. 1 shows a diagram of the experimental loop. The experimental loop consists of a heat exchanger, a pump, a coriolis mass flow rate, a welder, a reservoir, and the test section basically. Heat exchenger keeps the thermal stationary condition in flow pipe. Mass flow rate is controlled by the pump and baypass valve C, which is located in parallel. The pipe is thermally isolated, surrounded with glass wool.

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別の表現にする

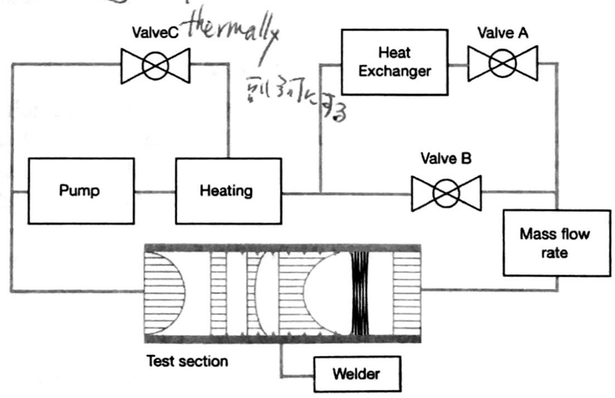

Fig. 1. Process flow diagram of the test facilities including test section.

a available の方が実践っぽい

The pipe is insulated by using glass wool.
断熱材

C = a * b 数式の読み方
C equals a times b
The value of C is a multiplied by b.

In this study, the author tried to keep ~ constant, but ~ varied

that in the layers of (1a) the the and their

Figure. 2 shows velocity and thermal boundary layer development vary with horizontal axis in a test section. Velocity and thermal profile are shown blue and red color, respectively. The test section is made of stainless steel (1.4301) with an inner diameter ~~di=~~12mm and outer diameter ~~do=~~ 15mm. Highly accurate resistance thermall probes (PT-100) are used to find out the inlet and outlet bulk temperature (Tib , Tob) and wall temperature(Tw). Moreover, thermocouple (Type-K) are used to take temperature gradient in flow direction.

measure

The test section consist of entrance, heated and thermal equalized parts.

1) Entrance part
   The first part of test section is 1.2 [m] length entrance part which is sufficiently long to ensure ~~dynamically~~ developed flow condition at the exist. The bulk temperature (Tb0) at this section were measured by PT-100.
2) Heated part
   The second part of test section is 2 [m] length heated part which is sufficiently long to ensure thermaly fully developed flow condition at the exist. The tube wall were heated electrically by welder which provide high current and low voltage to keep the uniform heat flux condition in a inner pipe flow. Convective heat transfer is independent with horizontal axis in fully developed flow constant heat flux conditions. The wall temperature (Tw) at the exist of this section were measured by PT-100.

上を参考に書きなおす

the end

3) Thermal equalized part
   includes
   The third part of test section is thermall equalized part which ~~is including~~ static mixture. Static mixture forms turbulent and vortex. Then, the thermal profile of heated ~~exist~~ mix together. ~~At the end,~~ the bulk temperature(Tb1) ~~are~~ measured.

were region

After the thermal gradients of fluids become

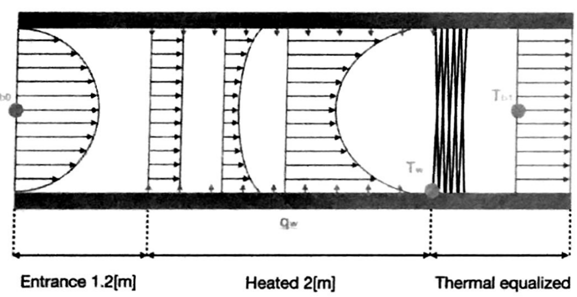

Fig. 2. Velocity (blue) and thermal (red) boundary layer development vary with horizontal axis in a test section.

III. Calucuration Flow

since all can be expressed by

~~All~~ Material properties ~~are all~~ temperature-dependent functions. At first, material properties varies with temperature were taken. Next, ~~I move to experimental facilities and~~ measured temperature differences, pressure differences and mass flow rates. Finaly, Nusselt, Prandtl, Reynolds numbers and friction coefficients were calcurated by post-proccesing LabView and MATLAB.

no

the auther meaured the material properties of (12) that depend on temperature.

with using

IV. Results and Discussion

The Density rho, heat conductivity(k) specific heat transfer Cp, kinetic viscosity nu, dynamic viscosity mu, Pradtl number (Pr) ~~are~~ all varies with temperature. It is difficult to keep high Pramdlt number and transitional Reynolds number. For example, as ~~enhance cooling,~~ temperature decrease, statics viscosity increase. As a result, Pr increase and Re decrease. An Experimental data and correlations were compared. In correlations, the Prandtl number was assumed to be constant. However, the experimental Prandtl number is not constant because the fluid properties vary with temperature. The aim is to set Prandlt number level and vary the Reynolds number. The avaraged Prandlt numbers were taken to plot Nusselt and Reynolds number.

between (A) and (B)

Figure. 3 shows heat transfer coefficients for $500 < Re < 4000$ for $Pr = 26$, which shows good agreement with calcuration method showed by Gnienski of each flow regime, laminar, transitional and turbulent. [#]

results by using Gnienski's method

200 experimental results ($500 < Re < 4000$ and $10 < Pr < 30$) ~~has been~~ compared with calcurations ~~method~~ for predictiong the laminar, transitional and turbulent heat transfer coefficiets.

Two hundred

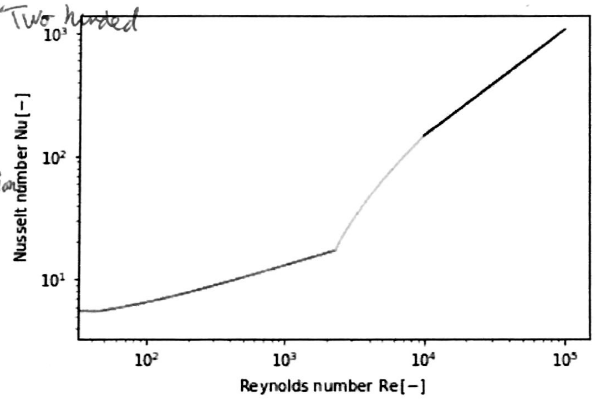

Fig. 3. Dimensionless heat transfer coefficients compared to literature data for Pr = 26. The red, yellow and blue lines are Gnielinski correlations for laminar, transitional and turbulent, respectively.

V. Conclusion

much has been

Forced convective heat transfer in cylindrical pipe flow has been investigated experimentally. Not so ~~many~~ data ~~were~~ available for transitional regime and high Prandtl number. Therefore, in this study, 200 experimental results ($500 < Re < 4000$, $10 < Pr < 30$) ~~has been~~ checked with calcuration method showed by Gnielinski [2] ~~and it~~ showed good agreement.

results

The comparison between them

VI. Acknowledgement

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