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Preliminary Evaluation of Turbulent Pressure Drop Correlations' Applicability on Narrow Rectangular Channel Flow

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1. Introduction

In thermal-hydraulic design of research reactor core, accurate prediction of core pressure drop is important considering that significant portion of reactor structure assembly (RSA) pressure drop occurs in the core. In addition, huge number of research reactor core is fueled by plate-type fuels which forms narrow rectangular cooling channels. It is therefore worthwhile to check the applicability of the existing pressure drop correlations on rectangular channel flow. The prediction accuracy or applicability of the correlations can be evaluated by comparing predicted values with analytic solutions or experiment data. In this study, single-phase flow experimental results from available literatures are predicted by selected turbulent correlations, and their applicabilities are evaluated.

2. Methods and Results

In this section, some of existing single-phase water flow experiments on the narrow rectangular channel geometry are introduced and their results are predicted using well-known pressure drop correlations.

2.1 Narrow Rectangular Channel Flow Experiments

In 1969, series of isothermal and heat transfer tests were carried out by Centre d'Etudes Nucléaires (CEA) on narrow rectangular channel[1]. Its test section was made of stainless steel with channel aspect ratio (α=thickness/width) of 0.09. According to the literature, the test was carried out for upward flow with velocities up to 12 m/s, and measured pressure drop values are presented in terms of friction factor with corresponding Reynolds numbers. In 1993, as a part of multicomponent (air/water) flow experiments done by Kyoto university, single-phase pressure drop data were obtained for narrow rectangular channel[2]. Its test section was made of transparent acrylic resin for visualization purpose. In the literature, the measured pressure drop values are presented in terms of friction factor for 3 different channel thicknesses (1.07, 2.45, and 5.00 mm). In 2014, tests were carried out by Massachusetts Institute of Technology (MIT) on narrow rectangular channel for studying flow and heat transfer characteristics of narrow rectangular channel of MIT research reactor core[3]. Its test section surface was made of stainless steel with channel aspect ratio of 0.04. In the literature, the test facility was reported to be operated with maximum coolant flow velocity of 7 m/s. However, isothermal flow test results were presented for Reynolds numbers less than 27,000, which corresponds to velocities less than 2 m/s. In 2016, experimental results of thermal-hydraulic experiments on narrow rectangular channels in SULTAN-JHR facility at CEA-Grenoble were compiled and published[4]. The test section was made of Inconel-600 with aspect ratio of 0.03~0.04. During the test, the coolant flow velocity reached up to 18 m/s, which is the highest value among experiments mentioned in this paper. The test results were presented in terms of friction factor. Table I summarizes list of experiments reviewed in this paper with test section geometric specifications and hydraulic conditions. Some of the data are uncertain due to limited resources. These regions (values with underlines) are deduced based upon engineering judgements.

Table I: Summary of Experiment Conditions

Item	Costa, 1969	Mishima et al., 1993	Forrest, 2014	Ghione et al, 2016
D [mm]	6.4	2.1~8.9	3.8	2.9~4.2
α [-]	0.09	0.03 ~0.13	0.04	0.03 ~0.04
L [mm]	600	200	482.6	599.8, 599.7
Max. Re [-]	210,920	<u>38,300</u>	<u>26,400</u>	<u>435,600</u>

2.2 Applicability of Selected Pressure Drop Correlations

In this study, following 4 friction factor ('*f*') correlations are selected and their prediction performances are evaluated. Blasius (1912) correlation is developed by obtaining correlation form from law of similarity on friction processes and finding coefficients which best describes available experimental data on smooth pipes[5]. Correlation developed by Zigrang and Sylvester (1985) is a numerically derived explicit approximation of well-known Colebrook-White (1939) formula which is implicit in terms of Reynolds number[6,7]. Kakaç et al. (1987) correlation is obtained by comparing friction factor values calculated by Techo et al. (1965) correlation with experimental data for rectangular channel flows[8,9]. Filonenko (1954) correlation is modified and proposed by Siman-Tov et al. (1991) to be used for thermal-hydraulic design and analysis of Advanced Neutron Source Reactor core[10,11].

Blasius (1912):

$$f = \frac{0.3164}{Re^{0.25}} \tag{1}$$

Zigrang and Sylvester (1985):

$$\frac{1}{\sqrt{f}} = -2\, log_{10}\left\{\begin{matrix}\frac{\varepsilon}{3.7D} + \\ \frac{2.51}{Re}\left[\begin{matrix}1.114 \\ +2\, log_{10}\left(\frac{\varepsilon}{D} + \frac{21.25}{Re^{0.9}}\right)\end{matrix}\right]\end{matrix}\right\} \tag{2}$$

Kakac et al. (1987):

$$\frac{1}{\sqrt{f_{Techo}}} = 1.7372 \ln \frac{Re}{1.964 \ln Re - 3.8215} \tag{3}$$

$$f = (1.0875 - 0.1125\alpha) f_{Techo} \tag{4}$$

Modified Filonenko (1991):

$$f = \frac{1.0875 - 0.1125\alpha}{(1.82\, log_{10} Re - 1.64)^2} \tag{5}$$

where, f, Re, ε, D, and α correspond to friction factor [-], Reynolds number [-], wall roughness [m], equivalent hydraulic diameter [m], and channel thickness-to-width ratio [-], respectively.

Figure 1 summarizes the assessment results of the selected correlations. For comparison purpose, box and whisker plot of relative prediction error as described in Eq. (6) is depicted. The comparison is done on the fully turbulent flow condition data (Re>10,000) to minimize the unpredictable transition region effects[12]. The analysis shows that classic Blasius (1913) correlation underestimates the experimental data (-7.5% on average), which seems natural considering that it was developed based on data from experiments with smooth walls. In addition, it seems that other 3 correlations gives reasonable prediction results in terms of mean values (1.9, 0.1, 0.3%, respectively). Lastly, Kakac et al. (1987) and modified Filonenko (1991) correlations exhibit improved prediction performance considering that the data variances are relatively smaller than that of Zigrang-Sylvester (1985).

$$Error_{rel}[\%] = \frac{Measured - Predicted}{Measured} \times 100 \tag{6}$$

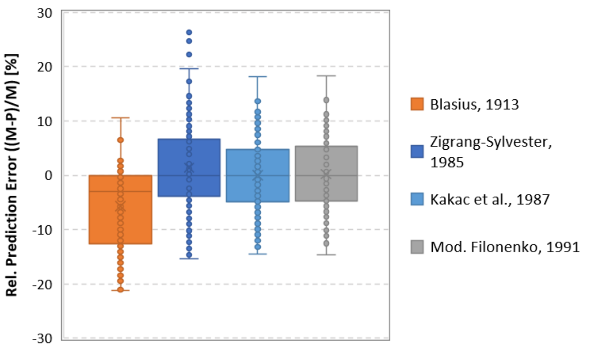

Fig. 1. Assessment Results.

3. Conclusions

In this study, applicability of the existing pressure drop correlations on narrow rectangular channel flow is briefly checked by utilizing experimental data available in the literature. In this preliminary assessment, underestimating behavior is seen in Blasius (1913) predictions. In addition, a general type correlation developed by Zigrang and Sylvester (1985) gave reasonable predictions similar to other correlations tailored for the rectangular channel flow. In order to stastically evaluate the predictive performance of the correlations in detail, the uncertainty quantification of the experimental data must be preceded, which will be carried out as future works.

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