Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Experimental Investigation of the Entrance Effect on the Convective Heat Transfer in Narrow-Vertical Rectangular Channel for Upward and Downward Flow

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1. Introduction

Developing flow convective heat transfer characteristics has been experimentally investigated via Nu number behavior in a narrow vertical rectangular channel for upward and downward flows. The results showed that there were no distinct flow characteristics between the upward and downward flows. The experimental data were compared with the existing correlations for evaluating the Nu number in laminar and turbulent regimes. The comparison showed that many correlations can be applied, and clearly evaluates the entrance effect on the heat transfer characteristics for a laminar flow. However, the existing correlations for a turbulent flow can be utilized for a fully developed flow without any consideration of the entrance effect on the Nu number such as in Dittus-Boelter (1930) and Battista-Perkins (1970). In the present work, a new correlation was developed to evaluate the Nu number for a turbulent flow in a narrow rectangular channel in consideration of the entrance effect.

2. Experiment Set

The experiment was conducted on a 1200 mm long narrow rectangular channel (640 mm the heated section and 280 mm at each end). Between upper and lower plenums, the channel thickness and width are 2.35 mm and 54 mm, respectively, as shown in Fig.1. The heater width is 50 mm. Ten thermocouples (TC) were installed at the back of each heater to measure the centerline temperature in the axial direction; the distance between each TC is different, as most of them are installed near the ends to detect the temperature changes at the inlet and outlet. The experiment facility is located at KAERI (Korean Atomic Energy Research Institute). It is obvious that the flow (water) had a wide range of Reynolds number and heat flux as shown in Table 1 for both flow directions. A uniform heat flux was applied on the heated section as a boundary condition by considering linear increases in the bulk temperature [2].

Table 1. Test conditions

	Upward flow	Downward flow
Mass flux [kg/m^2/s]	100~6,000	222~ 6,000
Heat flux [kW/m^2]	7 ~ 750	1.5 ~750
Re	466~45,000	1,190~40,000
Pr	2.8~7	3.5 ~ 6.15

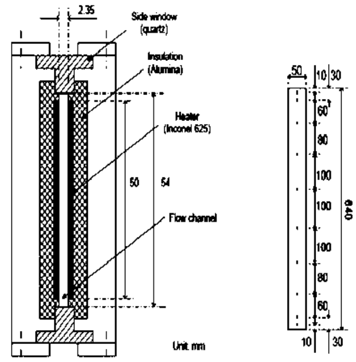

Figure 1. Cross sectional view of the test section

3. Results

Fig. 2 shows there is no difference in the heat transfer characteristics between upward and downward flows for different Reynolds numbers. However, the effect of buoyancy force can be negligible for a flow with (Re>1,000).

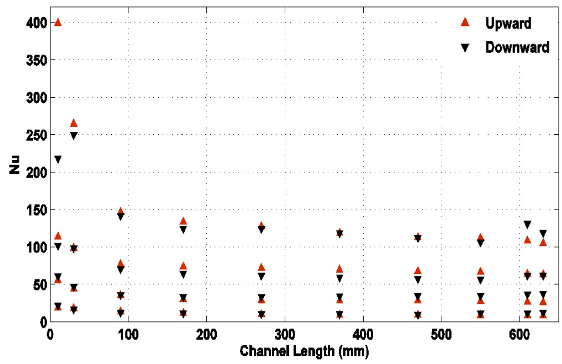

Figure 2. Nu number for upward and downward

The results in this analysis were compared with existing correlations, as shown in Fig.3. For a laminar flow, Sudo, Churchill, Shah, and Leveque correlations were used. Sudo et al. [3] generated a correlation for each flow direction in the laminar regime:

For a downward flow:
$Nu = 0.915\ Gz^{0.4}$ Gz>40
$Nu = 4.0$ 40> Gz> 16

For an upward flow:
$Nu = 2.0\ Gz^{0.3}$ Gz > 40
$Nu = 6.0$ 40> Gz> 16

where $Gz=RePrD_h/z$

The Shah correlation [4] is

$$Nu_{x}=\begin{cases}1.302\, z^{*^{-\frac{1}{3}}}-1\ , & z^{*}<0.00005\\ 1.302\, z^{*^{-\frac{1}{3}}}-0.5\ , & 0.00005<z^{*}<0.0015\\ 4.364+8.68(10^{3}\, z^{*})^{-0.506}\ \exp\left(-41z^{*}\right), & z^{*}>0.001\end{cases}$$

The Leveque solution [5] is

$$Nu=0.652(15.7)^{1/3}(2z^{*})^{-1/3}$$

Churchill [6] is

$$Nu=\left[(0.587(z^{*})^{-1/2})^{3}+8.235^{3}\right]^{1/3}$$

In a turbulent forced convection heat transfer, the results were compared with the correlations proposed by Dittus-Boelter [3] and Battista-Perkins [5] for Re > 10,000. Dittus-Boelter is still applicable for turbulent flow in fully developed flow. Batista-Perkins used as follows

$$Nu_{BP}=0.021Re^{0.8}Pr^{0.4}\left(\frac{T_w}{T_b}\right)^{-0.7}\times\left[1+\left(\frac{z}{D_h}\right)^{-0.7}\left(\frac{T_w}{T_b}\right)^{0.7}\right]$$

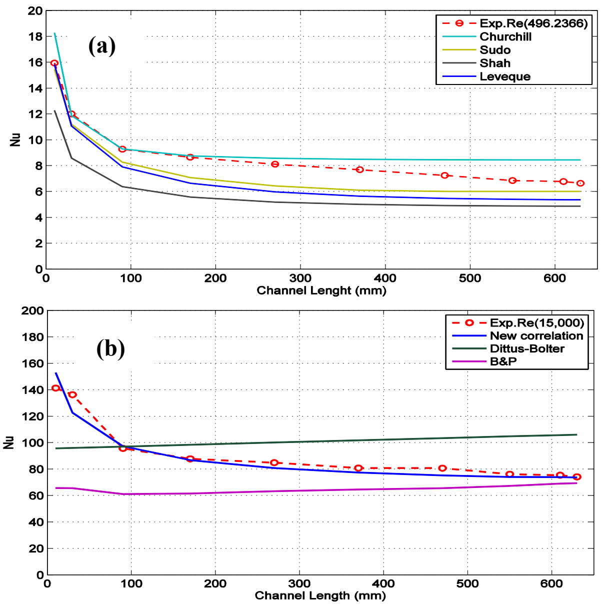

Figure 3. Comparison between experimental data with some correlations: (a) Laminar, (b) Turbulent

4. New proposed correlation

A new correlation for a turbulent flow is proposed, and it can be applicable for a wide range of Reynolds number for the local Nu number, and the entrance one to obtain more accuracy in the system design process, especially for thermal-hydraulic and safety design in plate type fuel research reactors.

$$Nu_{o}=0.01715\left[Re^{0.6904}\,Pr^{0.22}\right]z^{*^{-0.2097}}\times\left[\left(\frac{T_b}{T_w}\right)^{0.1957}\left(\frac{D_h}{z}\right)^{-0.007}\right]$$

where $z^{*}=z/(D_hRePr)$. T_b and T_w are bulk and wall temperature, respectively.

As shown in Fig. 4, the new correlation has very good agreement with the experimental results. However, the new correlation has +19.3% and -19.95% errors to meet the 95% confidence level.

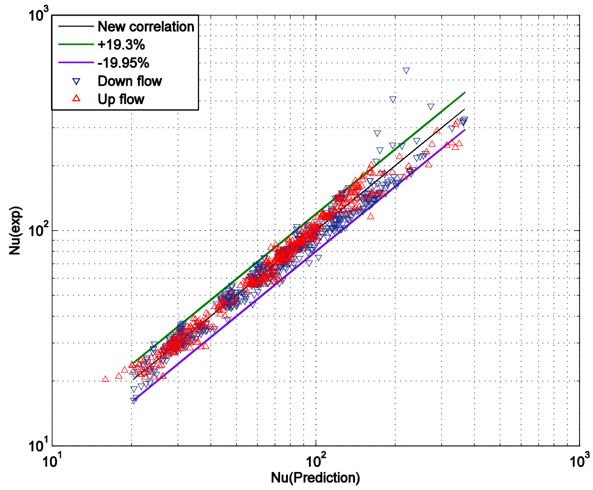

Figure 4. New proposed correlation with experimental data

Acknowledgement

This work has been carried out under the auspices of the Jordan Research and Training Reactor Project being operated by Korea Atomic Energy Research Institute

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