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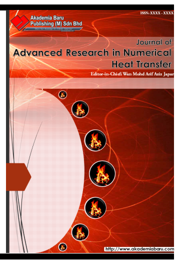

Validity of Performance Factors used in Recent Studies on Heat Transfer Enhancement by Surface Modification or Insert Devices: Constant Heat Flux Case

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ABSTRACT

Heat transfer enhancement had been widely applied in developing a more compact heat exchanger which can save a lot of energies, materials and costs. Based on our literature review, the performance factors that proposed previously had been widely used in various papers to evaluate the heat transfer enhancement. However, no validation had been conducted before to validate the performance factors. Recently, the performance factors had been studied for the heat transfer enhancement of a circular duct with periodic annular baffle plates which is heated by constant wall temperature, and the result shown that the performance factors are not valid for evaluating the heat transfer. Whereas this study is examined the validity of the performance factors by comparing the heat transfer rate in a fully periodic developed region of a circular duct to a modifies duct with periodic annular baffle plates, which are heated by constant heat flux. The heat transfer rates are obtained numerically. Validity of the performance factors is examined by comparing the average temperature difference between wall temperature and bulk temperature. It was found that the performance factors used in previous papers except for equation (2) defined below are not valid to evaluate the heat transfer enhancement.

Keywords:
Heat transfer enhancement, validity, performance factor, baffle plate, constant heat flux

1. Introduction

Heat exchanger is a device that used to transfer heat or thermal energy from one medium to another medium and it is widely used in various industries. In past decades, much effort has been implemented to develop more compact heat exchangers. A high-performance heat exchanger with great heat transfer efficient can save many energies, materials and costs. Hence, heat transfer enhancement become a very important topic in designing a heat exchanger. There are different techniques to enhance heat transfer [1]. The performance of heat transfer enhancement can be evaluated by the performance factor which defined as the ratio of the relative effect of change in heat transfer rate to change in friction factor. Various types of performance factors had been developed by different researchers to evaluate heat transfer enhancement of enhanced surface. The

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performance factors are developed based on Performance Evaluation Criterion (PEC) [2,3,4,5,6]. Following are the performance factors proposed by different researchers:

$$\eta = \frac{Q}{Q_s} = \frac{h_m A\Delta t}{[h_m A\Delta t]_s} \quad \text{............ (1)}$$

$$\eta \approx \frac{Nu_m}{Nu_{m,s}} = \frac{\frac{St}{St_s}}{\left(\frac{f}{f_s}\right)^{\frac{1}{3}}} \quad \text{............ (2)}$$

$$\eta = \frac{\frac{Nu_m}{Nu_{m,s}}}{\left(\frac{f}{f_s}\right)^{\frac{1}{3}}} \quad \text{............ (3)}$$

$$\eta = \frac{\frac{Nu_m}{Nu_{m,s}{}^*}}{\left(\frac{f}{f_s{}^*}\right)^{\frac{1}{3}}} \quad \text{............ (4)}$$

where $Nu_{m,s}{}^*$ and $f_s{}^*$ are cycle average Nusselt number and friction factor of smooth duct at $Re_s = Re$.

2. Methodology

This numerical validation is conducted in a fully periodic developed region of a circular duct with periodic annular baffle plates, and the duct will be heated with constant heat flux as shown in figure 1. Where, the flow is characterized by a velocity field as described by S. V. Patankar [7].

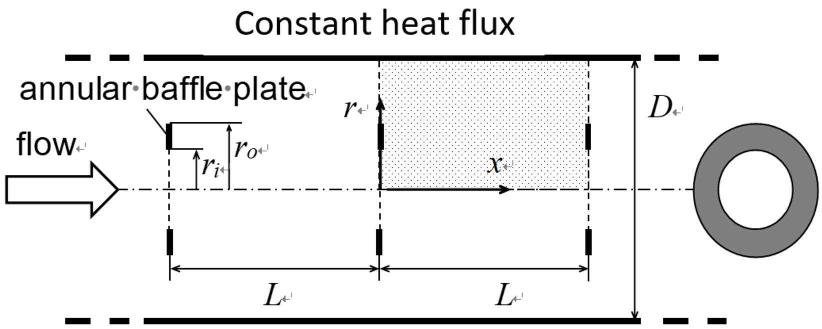

Fig. 1. Schematic diagram of the circular duct annular baffle plates which heated by constant heat flux

By using the dimensionless variables below

$$U = \frac{uD}{\nu}, X = \frac{x}{D}, R = \frac{r}{D}, V = \frac{vD}{\nu}, P = \frac{p'}{\rho(\frac{\nu}{D})^2}, B = \frac{\beta D^3}{\rho \nu^2}, Pr = \frac{\nu}{k/(\rho C_p)}, Re = \frac{\bar{u}D}{\nu} \quad \text{............ (5)}$$

The governing equations are expressed as below.
Continuity & Momentum Equations:

$$\frac{\partial U}{\partial X} + \frac{1}{R}\cdot\frac{\partial RV}{\partial R} = 0 \quad \text{.................. (6)}$$

$$\frac{\partial UU}{\partial X} + \frac{1}{R}\cdot\frac{\partial RVU}{\partial R} = -\frac{\partial P}{\partial X} + \left\{\frac{\partial^2 U}{\partial X^2} + \frac{1}{R}\cdot\frac{\partial}{\partial R}\left(R\cdot\frac{\partial U}{\partial R}\right)\right\} + B \quad \text{.................. (7)}$$

$$\frac{\partial UV}{\partial X} + \frac{1}{R}\cdot\frac{\partial RVV}{\partial R} = -\frac{\partial P}{\partial R} + \left\{\frac{\partial^2 V}{\partial X^2} + \frac{1}{R}\cdot\frac{\partial}{\partial R}\left(R\cdot\frac{\partial V}{\partial R}\right)\right\} - \frac{V}{R^2} \quad \text{.................. (8)}$$

Energy equation:

.... (9)

$$:\frac{\partial UT}{\partial X}+\frac{1}{R}\cdot\frac{\partial RVT}{\partial R}=\frac{1}{Pr}\left\{\frac{\partial^2 T}{\partial X^2}+\frac{1}{R}\cdot\frac{\partial}{\partial R}\left(R\cdot\frac{\partial T}{\partial R}\right)\right\}-\frac{4U}{Re\cdot Pr}$$

All the governing equations are derived by the discretization procedure based on power law scheme of Patankar [8]. The discretization equations that contain the relevant variables at chosen control volume are derived by integrating the governing equation over the control volume with structural grid points defined by power-law spacing fashion [9].

In this paper, the grid size effect has also been studied. The numerical computation is carried out using a window prompt as simulation application and Fortran is the programming language. The validation is conducted for 3 cases which are identical pumping power, identical pressure drops and identical mass flow.

3. Results

As a result of the numerical computation, the heat transfer shows enhancement with decrease of the difference between wall and bulk temperature. Hence, the evaluation index is defined as the ratio of temperature difference for the case of constant heat flux.

$$\eta=\frac{(t_w-t_b)_s}{(t_w-t_b)_b}=\frac{\overline{(t'_w-t'_b)_s}}{\overline{(t'_w-t'_b)_b}}=\frac{\overline{(T'_w-T'_b)_s}}{\overline{(T'_w-T'_b)_b}}=\frac{(Nu_m)_b}{(Nu_m)_s}\quad\text{.................... (10)}$$

The result of the performance factors calculated from equations (2), (3), (4) and (10) under identical pumping power are plotted in figure 2. Based on the figure 2, we can see there are discrepancies between the performance factors calculated from equations (2), (3), (4) and (10). The performance factors obtained from the equations (2) and (10) results higher value and they show more significant of increase of performance factor as the pumping power increased. Hence, the performance factors calculated from equations (3) and (4) are not appropriate for the evaluation of the heat transfer enhancement under the identical pumping power.

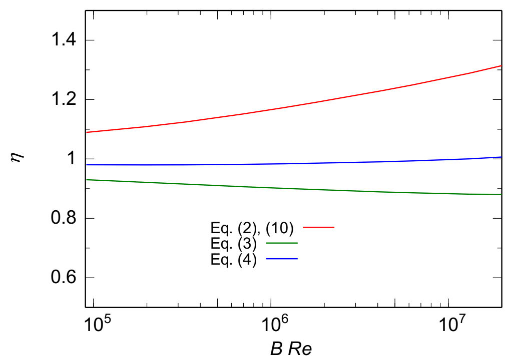

Fig. 2. Relationship of η and *BRe*

The plotted graph shown in figure 3 is the result of performance factors which are calculate from equations (2), (3), (4) and (10) under identical pressure drops. From the graph in figure 3, it can be seen that the equations (2), (3), (4) and (10) show different results. Hence, it can be clearly seen that there are also discrepancies between the performance factors calculated from equations (2), (3) & (4) and the performance factor calculated from equation (10) for the case of identical pressure drops. In the case of identical mass flow, the equations (2), (3), and (4) obtained same result as shown by the red line in figure 4. It is obvious that there are discrepancies between the performance factors calculated from equations (2), (3), (4) and equation (10).

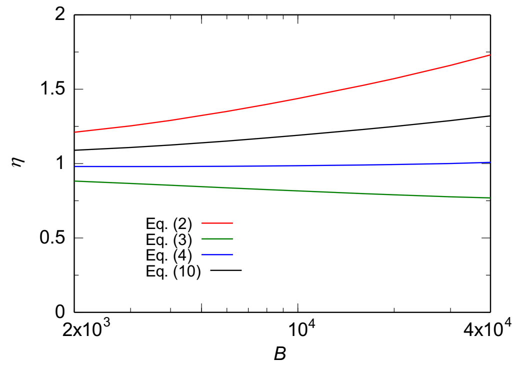

Fig. 3. Relationship of η and B

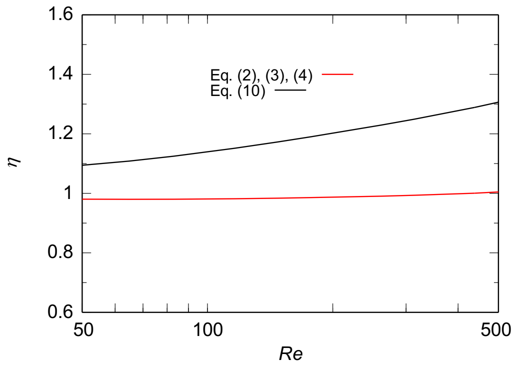

Fig. 4. Relationship of η and *Re*

4. Conclusions

The validity of the performance factors for heat transfer enhancement in circular duct with periodic annular baffle plates under constant heat flux which expressed by equations (2), (3), and (4) that published previously were examined. The validity is investigated by comparing result obtained by the performance factors under the three different flow constraints such as identical pumping power, identical pressure drops and identical mass flow. From the result, it is obvious that there are significant discrepancies between the performance factors calculated from the equations (2), (3), (4) and (10). It can be concluded that the performance factors expressed in equations (3) and (4) used in previous studies are not valid to evaluate the heat transfer enhancement by baffle plates insert. However, the equation (2) is valid under the flow constraint of identical pumping power.

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