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Numerical analysis of the effect of baffle on heat transfer enhancement nanofluid flow over a backward facing step: A correlation for the average Nusselt number

H. Moayedi

Thermo-Fluids Department, Faculty of Mechanical Engineering, University of Guilan, Rasht, Iran

ABSTRACT: In this paper, the effect of baffle on the flow field and heat transfer enhancement of forced convection of Cu-water nanofluid flow in the laminar regime over a backward facing step is numerically investigated. Finite volume method is used to solve governing equations of flow and temperature. In this study, the influence of baffle geometrical parameters as height, width and number of baffles, as well as the Reynolds number and the volume fraction of nanoparticles on the flow filed and heat transfer are evaluated. Also, to evaluate the simultaneous of the heat transfer enhancement and pressure drop, the performance evaluation index is calculated. It is obvious that by increasing the Reynolds number and decreasing the volume fraction of nanoparticles, the performance evaluation index is increased. The average Nusselt number and the performance evaluation index for the width of baffle 2 are higher than other cases about 7.6% and 15% respectively. The results show that using 2 baffles must be more beneficial than other number of baffles. Finally, a correlation for the average Nusselt number as a function of Reynolds number, volume fraction of nanoparticles, number of baffles, baffle height and baffle width is presented with an average error of 2.88%.

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1. INTRODUCTION

The fluid flow separation phenomenon and its subsequent reattachment due to a sudden expansion occurs in many practical engineering applications in various fields. Armaly et al. [1] investigated the relationship between the reattachment length and the Reynolds number via experimental and numerical analysis of laminar, transitional, and turbulent airflow. They revealed that in the laminar regime, the recirculation length increases by increasing the Reynolds number. Moreover, Togun et al. [2] numerically studied the heat transfer of laminar and turbulent Cu/water nanofluid flow over a BFS. They showed that the heat transfer is augmented when the volume fraction and Reynolds number are increased. Furthermore, it was indicated that the pressure drop increases by increasing the Reynolds number and decreasing the nanofluid volume fraction. Nath and Krishnan [3] carried out a numerical simulation of the mixed convective heat and mass transfer of Cu-water nanofluid in a BFS. They demonstrated that the average Nusselt number and the reattachment length at the downstream of the step increase with increasing the nanoparticle volume fraction, whereas the average Sherwood number decreases. The goal of the current study is to examine the new advanced method on the heat transfer augmentation nanofluid flow over a BFS by utilizing baffles. In this regard, the case studies are conducted for a 2D BFS with varying substantial parameters; Reynolds number, number of baffles, arrangement of baffle, and volume fraction of the nanofluid.

*Corresponding author's email: hesam_moayedi@phd.guilan.ac.ir

2. GEOMETRY

Fig. 1 represents a schematic view of the computational domain used for the present study.

3. GOVERNING EQUATIONS

The governing equations of the nanofluid flow, thermal, and species fields including continuity, momentum energy equations are as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial P}{\partial x}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial P}{\partial y}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{K_{nf}}{\left(\rho c_P\right)_{nf}}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

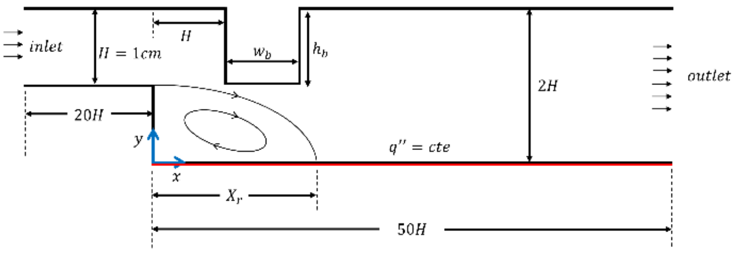

Fig. 1. Schematic view of the computational domain.

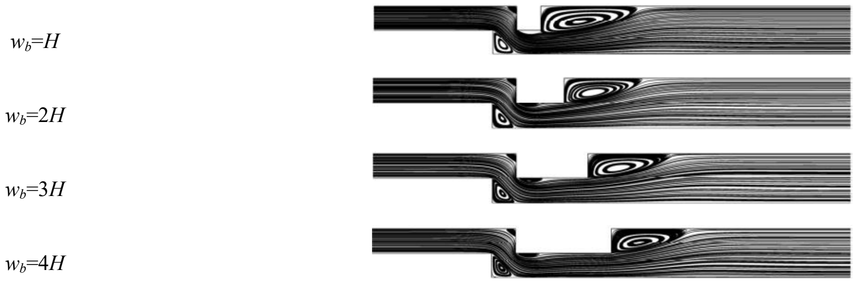

Fig. 2. Streamlines (φ=0.03, *Re*=100, h_b=*H*).

The thermo-physical properties of nanofluid are expressed as follows [4]:

$$\rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_p \tag{5}$$

$$(\rho c_P)_{nf}=(1-\varphi)(\rho c_P)_f+\varphi(\rho c_P)_p \tag{6}$$

$$\mu_{nf}=\frac{\mu_f}{(1-\varphi)^{2.5}} \tag{7}$$

$$K_{nf}=K_f\left[\frac{(K_p+2K_f)-2\varphi(K_f-K_P)}{(K_p+2K_f)+\varphi(K_f-K_P)}\right] \tag{8}$$

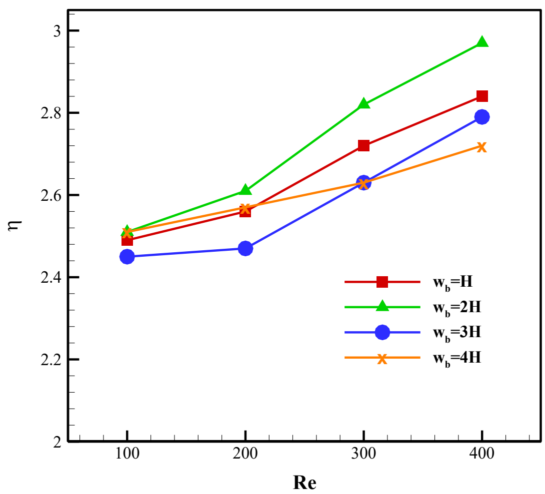

Fig. 3. Performance evaluation index based on the width of baffle (h_b=*H*, φ=0.02).

4. RESULTS AND DISCUSSION

To express the effect of the width of baffle on the flow field and heat transfer enhancement, the streamlines for different width of baffle are shown in Figs. 2. It is clear that the presence of baffle causes considerable changes in the flow pattern. According to this Figure, it is found that the baffle remarkably influences the size and the position of the stream vortices through the backward-facing step.

Moreover, the Performance Evaluation Index (PEI) based on the width of baffle is shown in Fig. 3. It is clear that the PEI for the width of baffle 2 are higher than other cases.

To explain the influence of the number of baffles on the flow filed and heat transfer, the PEI for different number of baffles is depicted in Fig. 4. According to this Figure, it can be argued that by increasing the Reynolds number, the PEI is increased. Also, The results show that using 2 baffles must be more beneficial than other number of baffles.

To help engineering calculations, the correlation of the average Nusselt number as a function of Reynolds number, volume fraction of nanoparticles, number of baffles, baffle height and baffle width is developed as follows:

$$\frac{Nu_m}{Nu_{m0}}=1.15\,\mathrm{Re}^{0.2}\,\varphi^{0.02}N^{0.19}\left(\frac{h_b}{H}\right)^{0.93}\left(\frac{w_b}{H}\right)^{0.03} \tag{9}$$

5. CONCLUSIONS

In this study, the forced convection of nanofluid flow in the presence of the baffle over a 2D backward-facing step in a hydraulically laminar regime was numerically investigated. The effects of effectiveness parameters as: Reynolds number, height and width of baffle, number of baffle, and volume

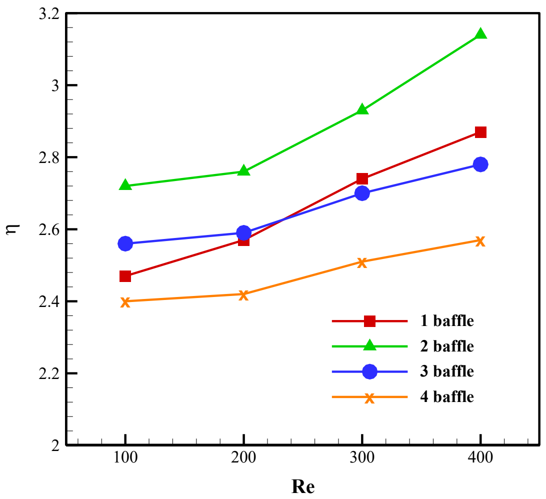

Fig. 4. Performance evaluation index based on the number of baffle for varios the nanoparticles volume fraction (h_b=H, w_b=H, φ=0.01).

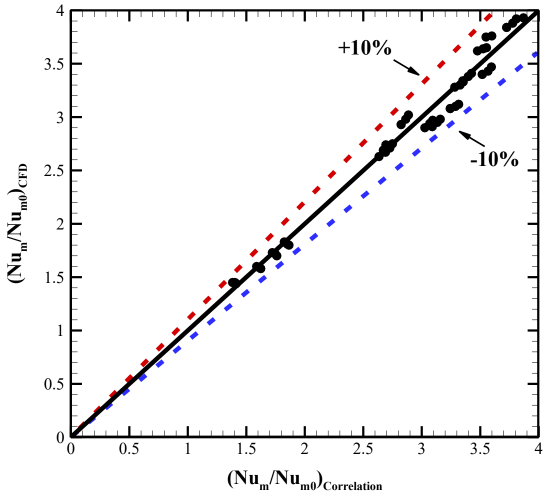

Fig. 5. The ratio of average Nusselt number from the correlation and numerical simulation of the present study within the tolerance range of 10%.

fraction of the nanofluid were studied for evaluation the heat transfer enhancemet. The results indicated that the average Nusselt number and the Performance Evaluation Index for the width of baffle 2 are higher than other cases about 7.6% and 15% respectively. Finally, a correlation for the average Nusselt number is presented with an average error of 2.88%.

6. REFERENCES

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