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Eulerian-Eulerian Description of Water Flow in a Backward-Facing Step with Nanofluid Blowing

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ABSTRACT

This paper deals with water flow in a backward-facing step with blowing of different nanofluids. The objective is to evaluate the effect of nanofluid blowing on the heat transfer rate. For this purpose, the Eulerian-Eulerian two-phase model is employed. The accuracy of the current simulations is demonstrated by comparing the obtained results with those of open literature. The results show that increasing the nanofluid blowing as well as nanoparticles fraction therein improves heat exchange from different surfaces of the channel. Comparing the results of different nanofluids leads one to conclude that the bottom wall heat transfer attains its maximum value when the blowed nanofluid contains nanoparticles with the highest thermal conductivity. However, it is found that maximum heat transfer in the top wall is achieved during blowing of a nanofluid with the highest nanoparticle penetration into the channel flow. Moreover, it is observed that discrepancies appearing between the results of different nanofluids become more remarkable as one increases the nanofluid blowing or nanoparticles fraction therein. Finally, the Eulerian-Eulerian model demonstrates that among the interphase forces, the effects of the virtual mass force and the particle-particle interaction force are negligible in such a way that they can be ignored.

KEYWORDS:

Nanofluid, Two-phase flow, Eulerian-Eulerian model, Backward-facing step, Blowing.

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1- INTRODUCTION

Flow separation with subsequent reattachment that appears in backward-facing steps produces prominent consequences on heat transfer performance in various applications such as combustion chambers, turbine blades, and heat exchangers.

In this study, attention is focused to control convection heat transfer of a water flow in a backward-facing step with blowing of different nanofluids into the separation zone. For this purpose, the Eulerian-Eulerian two-phase model is used.

By applying the Eulerian-Eulerian two-phase model to nanofluid flows, the base fluid and the nanoparticles are considered as two distinct phases. Furthermore, all of the interphase forces and the phase interactions are calculated. In spite of that, this method has rarely been used in previous studies of nanofluid flows. Kalteh et al. [1] employed the Eulerian-Eulerian model for the analysis of Cu-water nanofluid flow in a microchannel.

2- Mathematical Modeling

The considered problem is a water flow in a microchannel with a backward-facing step and nanofluid blowing (Figure 1). Three different types of nanoparticles including Al_2O_3, CuO, and TiO_2 with water as the base fluid are used for blowing. The fluid flow is laminar, steady and two-dimensional. At the channel inlet, velocity and temperature of the water flow are constant at 2cm/s and 293 K, respectively. Also, temperature of the blowed nanofluid is 293 K and its velocity ranges from 5% to 20% of the inlet water velocity. It is assumed that temperature of the walls is constant at 313 K.

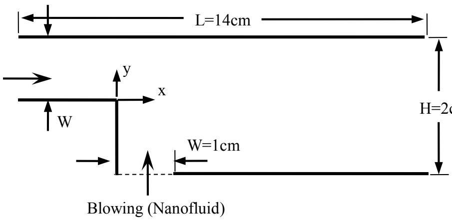


Figure 1. Schematic of the present problem

The governing equations in the Eulerian-Eulerian two-phase model are as follows [2]:

Continuity equations:

$$\frac{\partial}{\partial t}\left(\rho_{\mathrm{f}}\phi_{\mathrm{f}}\right)+\nabla\cdot\left(\rho_{\mathrm{f}}\phi_{\mathrm{f}}V_{\mathrm{f}}\right)=0 \tag{1}$$

$$\frac{\partial}{\partial t}\left(\rho_{\mathrm{p}}\phi_{\mathrm{p}}\right)+\nabla\cdot\left(\rho_{\mathrm{p}}\phi_{\mathrm{p}}V_{\mathrm{p}}\right)=0 \tag{2}$$

Momentum equations:

$$\frac{\partial}{\partial t}\left(\rho_f\phi_fV_f\right)+\nabla\cdot\left(\rho_f\phi_fV_fV_f\right)=-\phi_f\nabla P+\nabla\cdot\left[\phi_f\mu_f\left(\nabla V_f+\nabla V_f^{\,T}\right)\right]+F_d+F_{vm} \tag{3}$$

$$\frac{\partial}{\partial t}\left(\rho_p\phi_pV_p\right)+\nabla\cdot\left(\rho_p\phi_pV_pV_p\right)=-\phi_p\nabla P+\nabla\cdot\left[\phi_p\mu_p\left(\nabla V_p+\nabla V_p^{\,T}\right)\right]-F_d-F_{vm}+F_{col} \tag{4}$$

Energy equations:

$$\frac{\partial}{\partial t}\left(\rho_f\phi_fC_{pf}T_f\right)+\nabla\cdot\left(\rho_f\phi_fC_{pf}T_fV_f\right)=\nabla\cdot\left(\phi_fk_{eff,f}\nabla T_f\right)-h_v\left(T_f-T_p\right) \tag{5}$$

$$\frac{\partial}{\partial t}\left(\rho_p\phi_pC_{pp}T_p\right)+\nabla\cdot\left(\rho_p\phi_pC_{pp}T_pV_p\right)=\nabla\cdot\left(\phi_pk_{eff,p}\nabla T_p\right)+h_v\left(T_f-T_p\right) \tag{6}$$

In the momentum equations, F_d, F_{vm}, and F_{col} are the drag force, the virtual mass force and the particle-particle interaction force, respectively.

In order to numerically solve the governing equations, the finite volume method in conjunction with the PCSIMPLE algorithm is used. The following relation is used for the computation of the averaged Nusselt number:

$$Nu_{ave}=\frac{h_{ave}\left(2W\right)}{k_f}=\frac{2W}{L\,k_f}\int_{\frac{-2L}{7}}^{\frac{5L}{7}}h_x\,dx \tag{7}$$

3- Results and Discussion

To ensure the validity of the current numerical solution, SiO_2-water nanofluid flow in a 3D microchannel having a backward-facing step with the volume fraction of 1% is simulated. The corresponding results are compared with the experimental results of Kherbeet et al. [3] in Figure 2 that indicates good agreement.

Variations of the nanoparticles volume fraction at the section of y =0 are depicted in Figure 3 for V_{bl}/V_{in} of 0.05 and 0.2. As can be seen, the CuO nanoparticles have the most penetration into the water flow. It is also clear that penetration of the TiO_2 nanoparticles is higher than the Al_2O_3 ones. This discrepancy is attributed to density difference between the current nanoparticles. In fact, more dense nanoparticles lead to more penetration into the water flow.

Figure 4 discloses that maximum and minimum heat transfer in the bottom wall are achieved in the blowing of Al_2O_3- and TiO_2-water nanofluids, respectively.

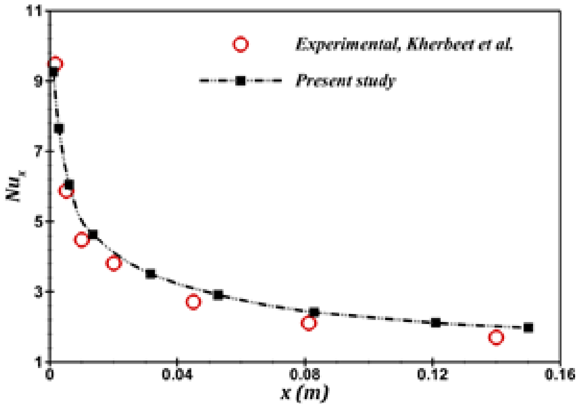


Figure 2. Validation of the Eulerian-Eulerian model

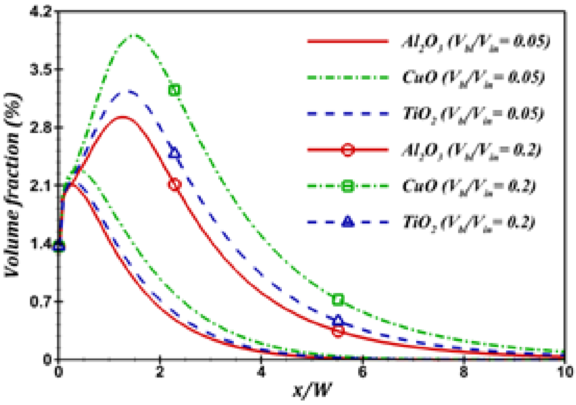
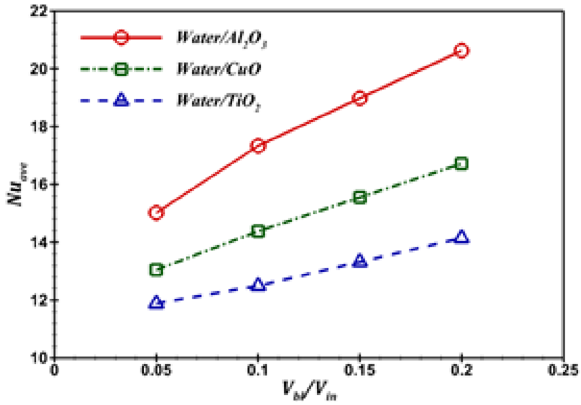


Figure 3. Variations of the nanoparticles volume fraction at the section of y=0 for ϕ_p=5%

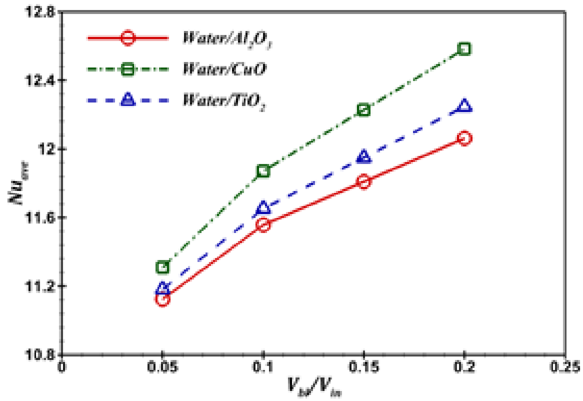
This pattern is predictable and goes back to the thermal conductivities of the nanoparticles. The corresponding results on the top wall are, however, quite different. Obviously, heat transfer in this wall attains its maximum value in the blowing of CuO-water nanofluid and declines to its minimum value in the blowing of Al_2O_3-water nanofluid. This is not surprising since heat exchange from the top wall is strongly influenced by the nanoparticles penetration and therefore, nanofluids with higher permeabilities into the water flow provide higher heat transfer rates.

4- Conclusions

Based on the presented results, it was found that increasing the nanofluid blowing leads to higher heat exchange from both walls of the microchannel. Also, it was observed that in addition to the thermal conductivity of the nanoparticles, their penetration into the water flow may affect heat transfer in the channel walls.



a) Bottom wall



b) Top wall

Figure 4. Variations of the averaged Nusselt number with blowing velocity for ϕ_p=5%

5- References

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