Comparison between Single-Phase, Two-Phase Mixture and Eulerian-Eulerian Models for the Simulation of Jet Impingement of Nanofluids

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1- Introduction

Increasing heat exchange in industries has always been of interest to designers and engineers. One of the procedures for heat exchange enhancement of conventional thermal fluids goes back to distributing metal or metal oxide particles with high thermal conductivities in the base fluid. Improvement of convective heat transfer as a result of nanoparticle addition has motivated many researchers to concentrate on studying the use of nanoparticles in a wide range of engineering problems.

In a transport process, boundary layer resistance has a significant impact on the transport rate such that any reduction in the boundary layer thickness leads to substantial improvement in the momentum, heat and mass transfer rates. One way to achieve this goal is to use impinging jets. Despite the extensive analysis conducted on impinging jets, less attention has been paid to nanofluids jet impingement.

To analyze nanofluid flows, the single-phase model and two-phase models can be used. Two-phase approaches used in this paper are the mixture model and the Eulerian-Eulerian model. The Eulerian-Eulerian model has been used less in previous studies of nanofluid flows, owing to the complexity of the relations and computations.

2- The governing equations

The single-phase model

In this formulation, all of the governing equations used for pure fluid flow are employed for the nanofluids. But, the effective properties of nanofluid must be used in the aforementioned equations.

The two-phase mixture model

In the two-phase mixture simulation, in addition to solving the continuity, momentum, and energy equations for the mixture, the equation governing the nanoparticles volume fraction has also been solved.

The Eulerian-Eulerian two-phase model

By applying the Eulerian-Eulerian model to nanofluid flows, the base fluid and the nanoparticles are considered as two distinct phases and the continuity, momentum and energy equations are solved separately for each of the constituents. Moreover, phase interactions are computed. Thus, in this approach, the base fluid and the nanoparticles can have different velocities and temperatures in the flow field.

3- Numerical solution

The schematic of the problem is given in Fig. 1. As can be observed, the considered geometry is a two-dimensional confined slot jet. All computations in this study have been performed for Al_2O_3-water nanofluid with nanoparticle diameters of 30 nm.

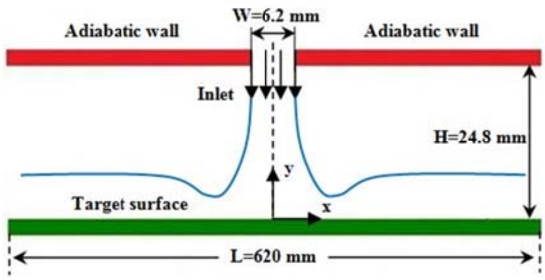

Fig. 1. Schematic of the jet impingement problem

At the inlet section of the jet, local thermodynamic equilibrium has been assumed between the nanoparticles and the base fluid and uniform profiles of velocity and temperature are applied.

In order to numerically solve the governing equations in all of the three models, the finite volume method is used. The averaged Nusselt number is obtained from the following equation:

$$Nu_{ave} = \frac{1}{L}\int_0^L \frac{h_x W}{k_f}\, dx \qquad (1)$$

4- Simulation results

Variations of velocity and temperature with distance from the target surface (y) are presented in Fig. 2. Since the temperatures of the nanoparticles and the base fluid are identical, only one temperature curve is plotted here for the Eulerian-Eulerian model.

It is obvious that among the current models, maximum and minimum velocities are predicted by the single-phase model and the Eulerian-Eulerian model, respectively. Furthermore, it can be seen that the fastest temperature rise in the incoming nanofluid is predicted by the Eulerian-Eulerian model while the slowest one belongs to the single-phase model.

Figure 3 shows the variations of the averaged Nusselt number at the target surface with the nanoparticles volume fraction. The curves gradually diverge from each other by the addition of the nanoparticles. It can be

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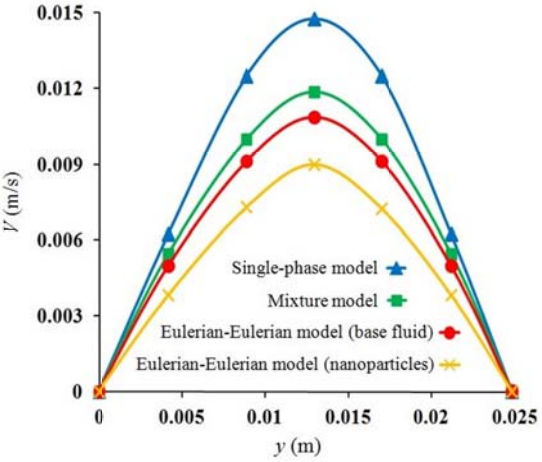
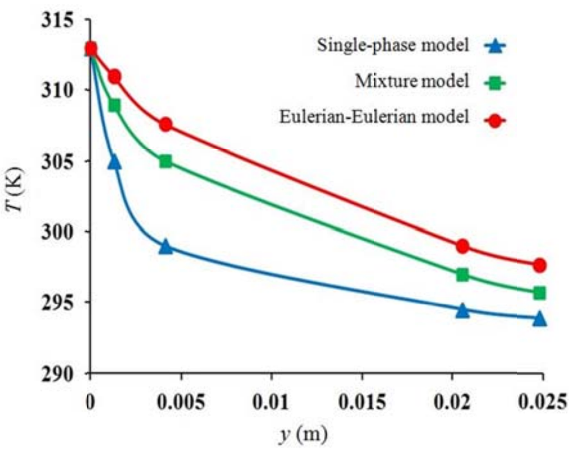
observed that the two-phase models predict higher heat exchange than the single-phase model while this trend is more severe in the Eulerian-Eulerian model in comparison with the mixture model. It is evident that in all cases, increasing the Reynolds number leads to heat exchange enhancement. Moreover, by increasing the Reynolds number, slopes of the mixture model curves increase more than the other curves and become closer to the Eulerian-Eulerian results.



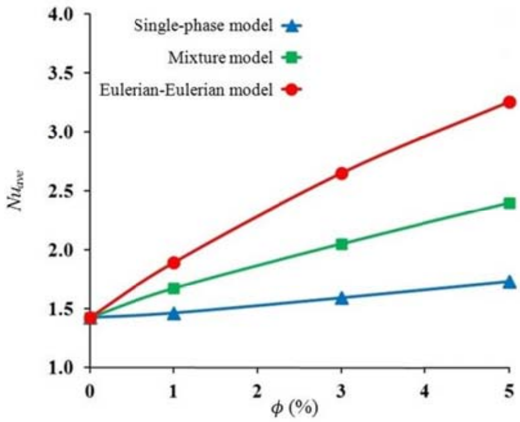
a) Velocity variations



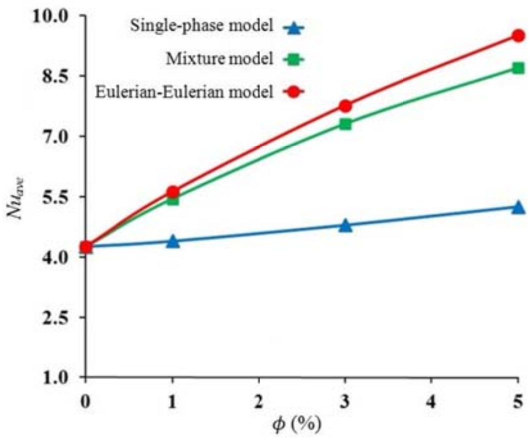
b) Temperature variations
Fig. 2. Variations of velocity and temperature at the section of x=0.15m for $\phi_p = 5\%$

5- Conclusion

Based on the presented results, nanofluid velocity in the single-phase model is higher than the two-phase approaches. Moreover, the mixture model predicts higher velocities than the Eulerian-Eulerian model. Additionally, it was found that the two-phase models predict faster temperature rise in the incoming nanofluid, with a more pronounced trend in the Eulerian-Eulerian model. Furthermore, it was observed that the Eulerian-Eulerian two-phase model provides the possibility of studying the appearance of local thermodynamic non-equilibrium between the nanoparticles and the base fluid. Hence, it can be used as an effective method for the numerical simulation of nanofluid flows.



a) Re = 100



b) Re = 500
Fig. 3. Comparing the results of the current models in terms of the averaged Nusselt number