Benchmark Model: Natural Convection of Water-Aluminum Oxide Nanofluids in a Square Cavity

M. Z. Saghir[1], A. Ahadi[1] , A. A. Mohamad[2]

1. Ryerson University, Department of Mechanical Engineering, Toronto, ON, Canada

2. University of Calgary, Department of Mechanical Engineering, Calgary, AB, Canada

Introduction: Nanofluids is a new class of fluid consisting of particles in a liquid. Different base liquids have been proposed and the most common one is water. The concentration of these particles can range from 0.1%vol to 5%vol or greater. we have solved the problem using the finite element technique (COMSOL) as well as the lattice Boltzmann approach and the finite volume method. With these three approaches we have solved the problem for a range of particle concentration from 1%vol to 3%vol. This benchmark should serve as a guidance for researchers embarking in numerical modelling of nanofluids.

Computational Methods: The set of differential equations are;

$$\left(\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}\right)=0;$$

$$Re\left(U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}\right)=\frac{\partial P}{\partial X}+\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right);$$

$$Re\left(U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}\right)=\frac{\partial P}{\partial Y}+\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ra_{nf}(\theta)$$

Where $Ra_{nf}=\frac{g\rho_{nf}^2 Cp_{nf}\beta_{nf}(T_h-T_c)L^3}{k_{nf}\mu_{nf}}$ and $Pr_{nf}=\frac{Cp_{nf}\mu_{nf}}{k_{nf}}$

The physical properties are;

$$\frac{\mu_{nf}}{\mu_{bf}}=1+4.93c_v+222.4\,c_v^2;\ \rho_{nf}=c_v\rho_p+(1-c_v)\rho_{bf}$$

$$\rho_{nf}\beta_{nf}=(1-c_v)\rho_{bf}\beta_{bf}+c_v\rho_p\beta_p$$

$$\frac{k_{nf}}{k_{bf}}=1+2.944c_v+19.672c_v^2$$

$$Cp_{nf}=c_v\rho_p Cp_p+(1-c_v)\rho_{bf}Cp_{bf}$$

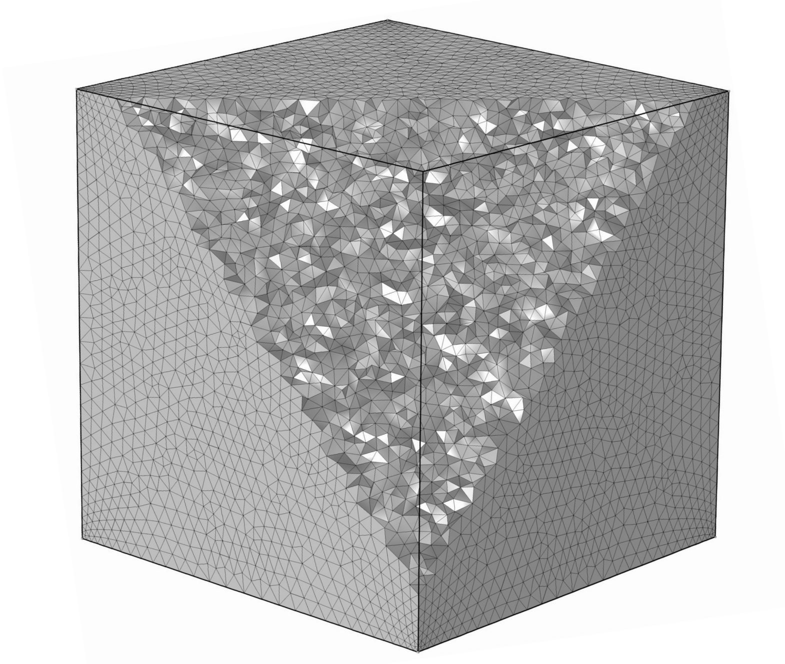


Figure 1. Finite Element Model

Results:

Table 1. Comparison with Experimental data

Case	1%, Ra= 7.74547e7, Pr=7.0659	2%, Ra= 6.6751180e7, Pr=7.3593	3%, Ra= 5.6020687e7, Pr=7.8353	Average Variation from Experiment	Average Absolute Variation from Experiment
$\overline{Nu}_{Exp}$[1]	32.2037	31.0905	29.0769	___	___
$\overline{Nu}_{FEM-2D}$	31.8633	31.6085	28.216	-2.0%	2.0%
$\overline{Nu}_{FEM-3D}$	32.7829	32.1833	31.3692	+3.0%	3.0%
$\overline{Nu}_{FDM-2D}$	30.657	30.503	30.205	-1.1%	3.7%
$\overline{Nu}_{LBM-2D}$	30.001	29.837	29.618	-3.2%	4.3%

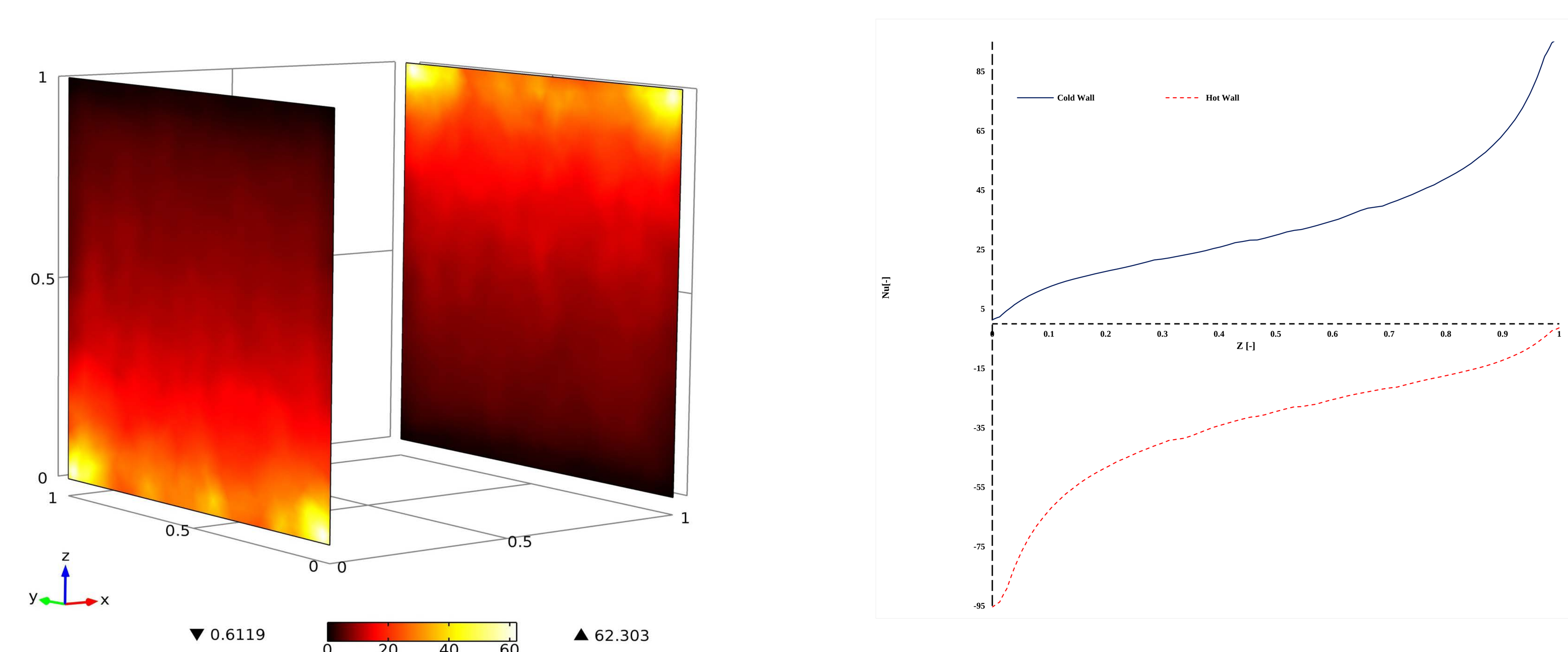
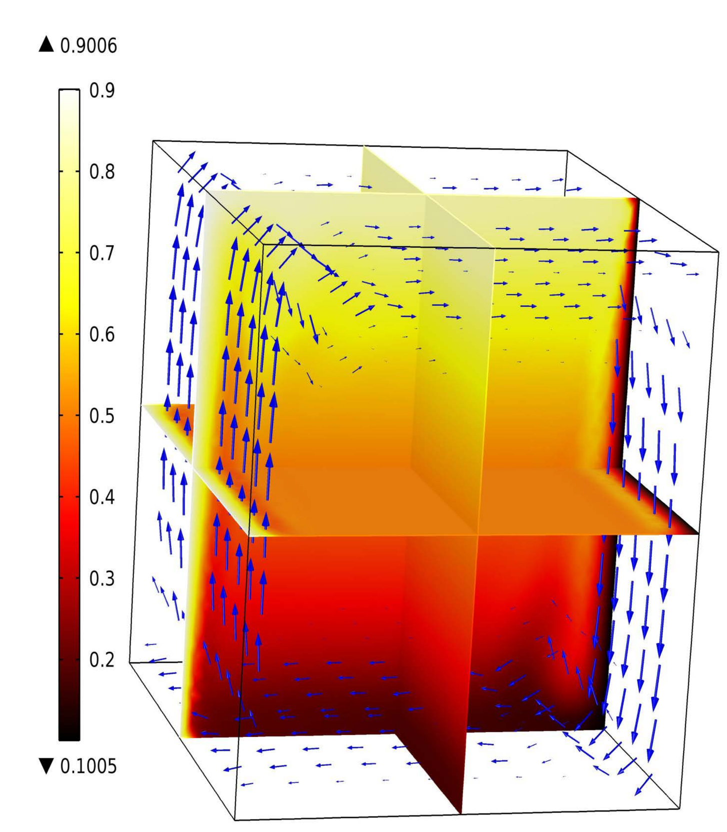


Figure 2 Local Nusselt Number



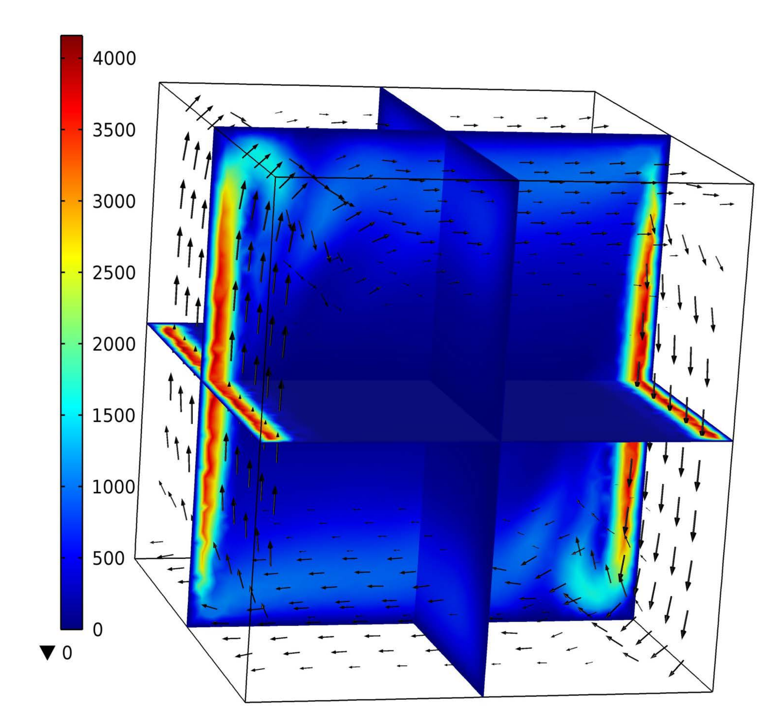


Figure 3. Temperature Contours **Figure 4**. Velocity Contours

Conclusions: A lot of efforts are allocated to understand the behavior of the nanofluids for heat enhancement; while, some randomness and confusion can be observed in the numerical results published by different groups. . While all CFD approaches showed an acceptable results in comparison with experimental data, finite element models (using COMSOL) provide data closer to the experimental results.

References:

1. C.J. Ho, W.K. Liu, Y.S. Chang, C.C. Lin, Natural convection heat transfer of alumina-water nanofluid in vertical square enclosures: An experimental study, Int. J. Therm. Sci. 49 (2010) 1345–1353.
2. M.Z. Saghir, A. Ahadi, T. Yousefi and B. Farahbakhsh,, Two-Phase and Single Phase Models of flow of Nanofluid in a Square Cavity: Comparison with Experimental Results, Int. J. Therm. Sci. (under review).

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