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Convective Heat Transfer of Al_2O_3 /Water Nanofluids Flow inside a Porous Channel

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ABSTRACT

This work aims to simulate convective heat transfer of Al_2O_3 water based nanofluids in three different volume concentrations of 0.5%, 1% and 2%, in a porous zone channel under a constant heat flux as boundary condition. ANSYS FLUENT 2016 was considered as the simulation software and the applied nanofluids thermo-physical properties were modeled via the available formulations in the literature. Results show that the convective heat transfer coefficient enhances up to 27% in the highest volume fraction of 2%. In addition, it was detected an increase in friction factor of 8% by applying the high volume fraction of applied nanofluids.

Keywords: Al_2O_3/ Water Nanofluid, Convection Heat Transfer, Simulation, Porous Media

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INTRODUCTION

From the last two decades, so many investigations have been done on the thermal characteristics of these types of fluids. Almost all of the researchers in this field have detected a significant enhancement in convective heat transfer of nanofluids [1-6]. So many studies on nanofluids have been done experimentally, but in some cases, when the experimental instrumentations are not financially accepted, or the test sections cannot be properly manufactured, simulation softwares come to scene to solve and analyze the problem. For example, an enhancement of 14% in Nusselt number has been observed by Abbasian et al [7] they experimented Ag/ oil nanofluids in annular tube. Jafarimoghaddam et al [8] showed not only increasing of 26% in Nusselt number using Cu/ Ethylene Glycol, But also, in their other researches they showed that Cu/ oil nanofluid can enhance the convective heat transfer coefficient by around 29% [9].

Based on some of those experiments, correlations have been proposed to predict Nusselt number [9-11]. In overall, analytical formulations for predicting rheological properties of nanofluids are very rare. These formulations ignore the different sorts of nanoparticles and the only related engaged parameter is the fraction of suspended nanoparticles into the base fluid. Besides, a comparison between these theoretical formulations and experimental results for specific nanofluids has shown their failure in predicting the rheological parameters in an appropriate manner [12-15]. So, experiments have remained valuable for predicting thermal characteristics of nanofluids.

In this study, a porous zone channel has been set to be as the test section, and Al_2O_3/ water nanofluids have been applied as working fluid. The range of Reynolds number was from 50 to 700 and the boundary condition has been set to be the constant heat flux of 10000 W/m^2. ANSYS FLUENT 2016 was used to simulate the problem. This work stands as an extension to the previous works on nanofluids in which in this research we have targeted Al_2O_3/ water as the working fluid in different volume fractions and Reynolds numbers in the particular test case of porous media.

SCHEMATIC OF THE PROBLEM

A channel with 9 porous zones was simulated by Fluent 2016, while the inlet flow was set to be pure water and Al_2O_3/ water in three different volume fractions with a uniform velocity profile. A constant heat flux of 10000 W/m^2 was applied as the boundary condition on the walls. The channel has 20 cm length and 3.5 cm height. Moreover, the porous zones are symmetrically set in the middle of the channel. The schematic of the applied boundary conditions is drawn in Fig. 1. Using GAMBIT as meshing tool, the channel with the porous zones was meshed precisely with 25000 grids. The generated mesh is shown in Fig. 2. Before continuing simulation with this numbers of grids, mesh independency was checked. Validation for this numbers of grids is provided in Table 1.

Table -1 Mesh Independency

Number of Applied Grids	Pressure Gradient between Inlet and Outlet of the Channel (Pa)
10000	12
13500	10.1
17000	9.57
19500	9.48
22000	9.47
25000	9.47

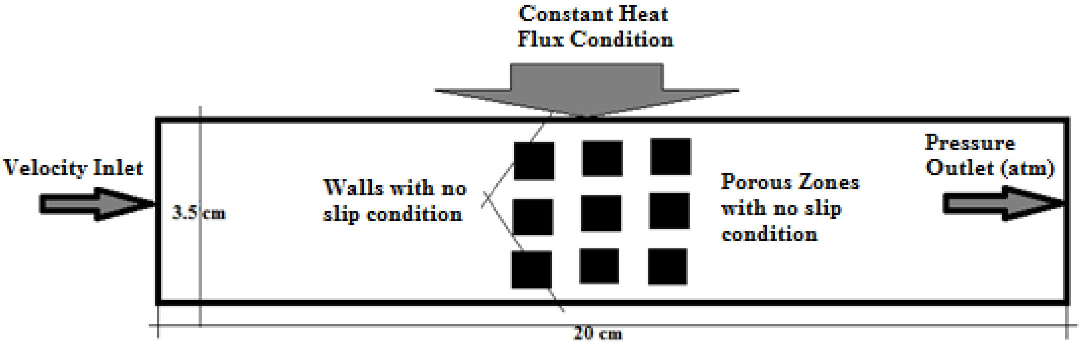

Fig. 1 Schematic of the Problem

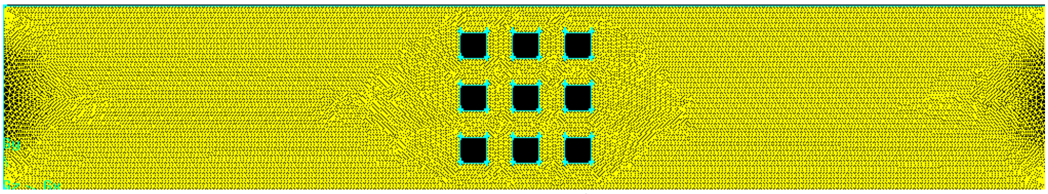

Fig. 2 Meshed Geometry of the Problem

GOVERNING EQUATIONS

Momentum and energy equations were solved with SIMPLE algorithm in this work. Thermo-physical properties such as density, thermal conductivity, viscosity and specific heat capacity of applied nanofluids were modified. These modified rheological parameters are as:

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_{bf} \tag{1}$$

$$\frac{k_{eff}}{k_{bf}} = 1 + \frac{3(\alpha-1)\varphi}{(\alpha+2)-(\alpha-1)\varphi} \tag{2}$$

$$\alpha = \frac{k_{np}}{k_{nf}}$$

$$\mu_{nf} = \mu_{bf}\,(1+2.5\varphi) \tag{3}$$

$$C_{p,nf} = \varphi C_{p,np} + (1-\varphi)C_{p,bf} \tag{4}$$

While *np* and *bf* are referred to nanoparticles and nanofluid, respectively [13].

RESULTS AND DISCUSSION

In the first step, pure water was simulated in porous channel with the constant heat flux rate boundary condition. By this simulation, as it can be seen from Fig. 3 to 5, temperature ranging decreases with the increase of Reynolds number. However, increasing in the Reynolds number is one of the primary ways of enhancing heat transfer.

Figs. 6 to 11 indicate the velocity and pressure distributions of water flowing in porous channel. These contours mainly show the effect of increasing in Reynolds number on the fluid characteristics.

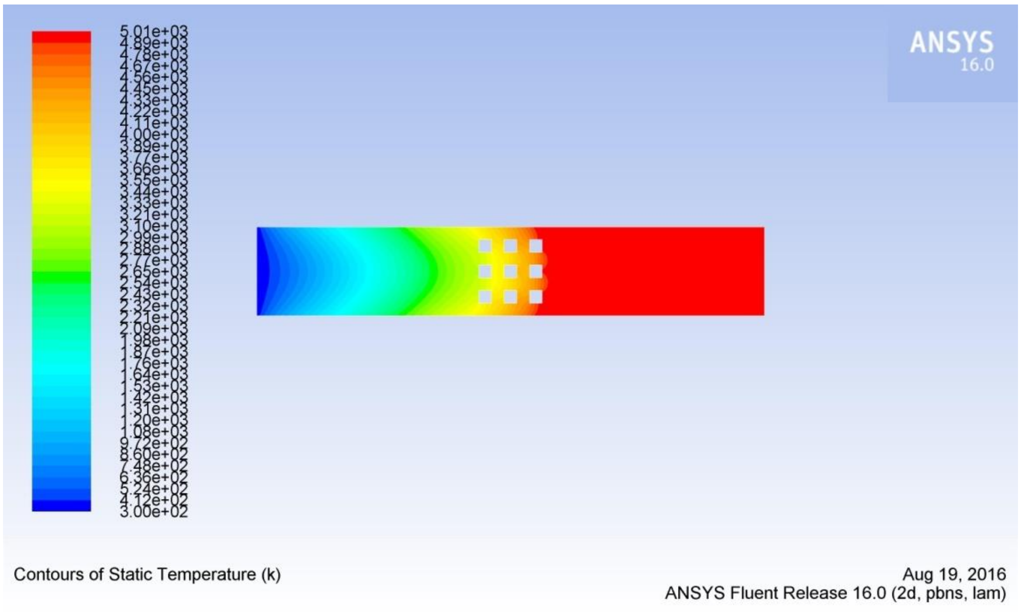

Fig. 3 Temperature contour in Re=50

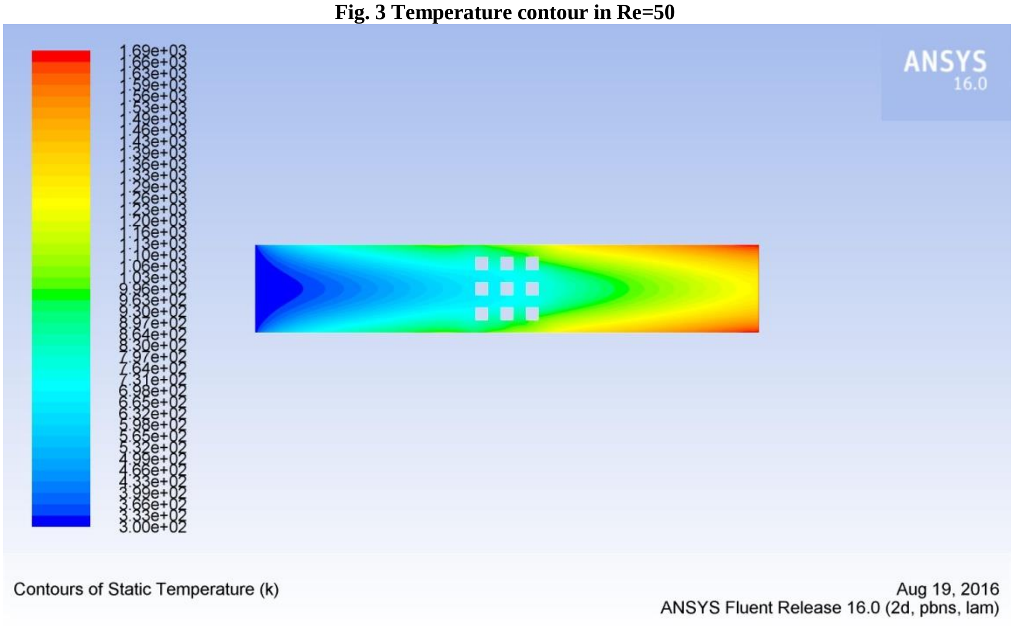

Fig. 4 Temperature contour in Re=300

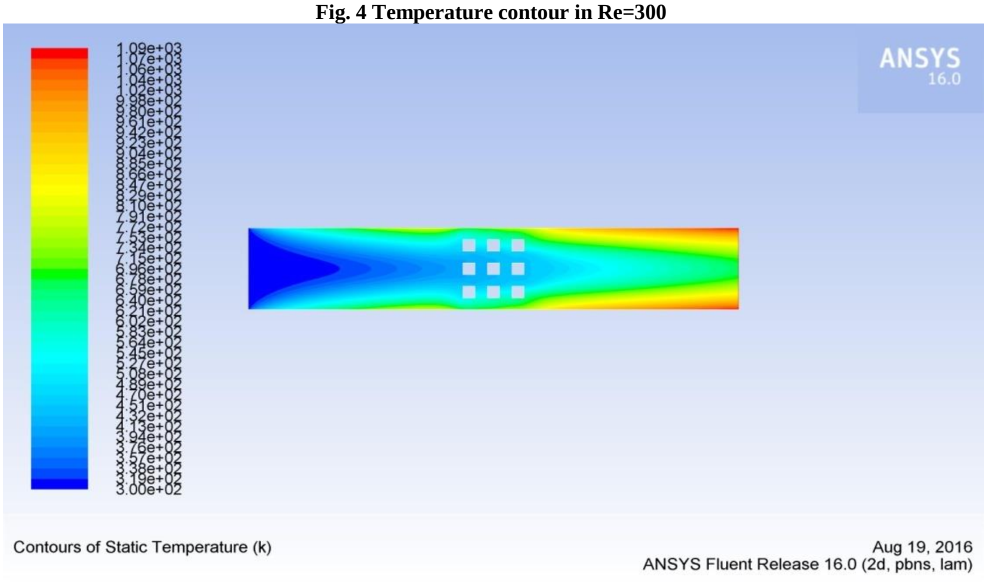

Fig. 5 Temperature contour in Re=700

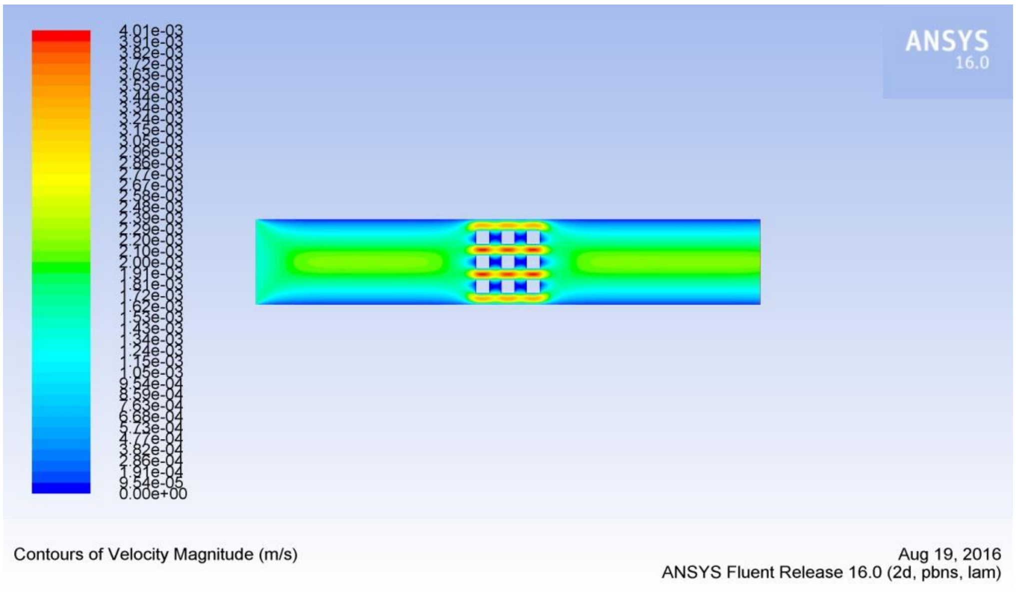

Fig. 6 Velocity contour in Re=50

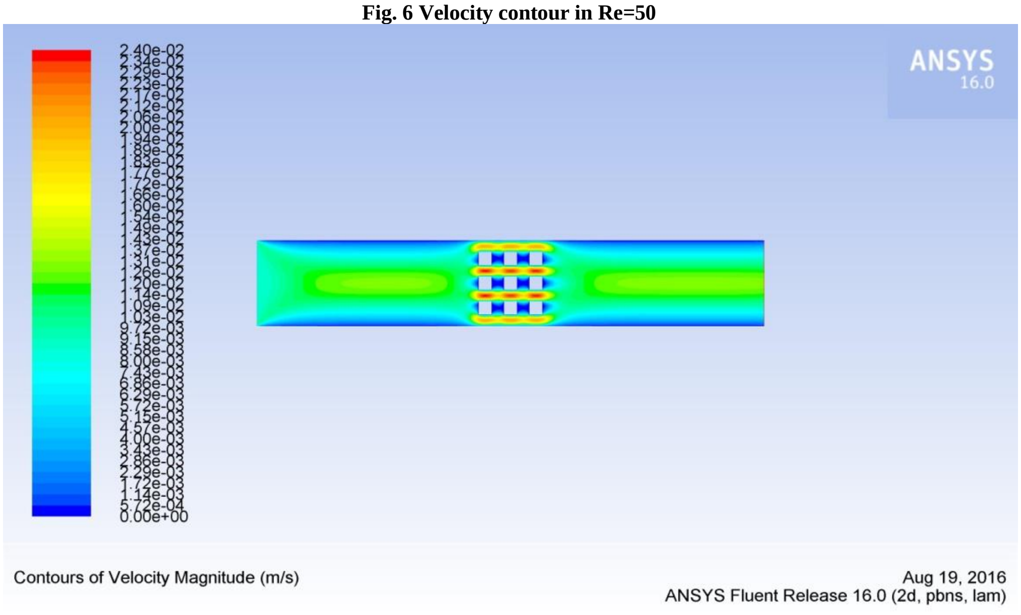

Fig. 7 Velocity contour in Re=300

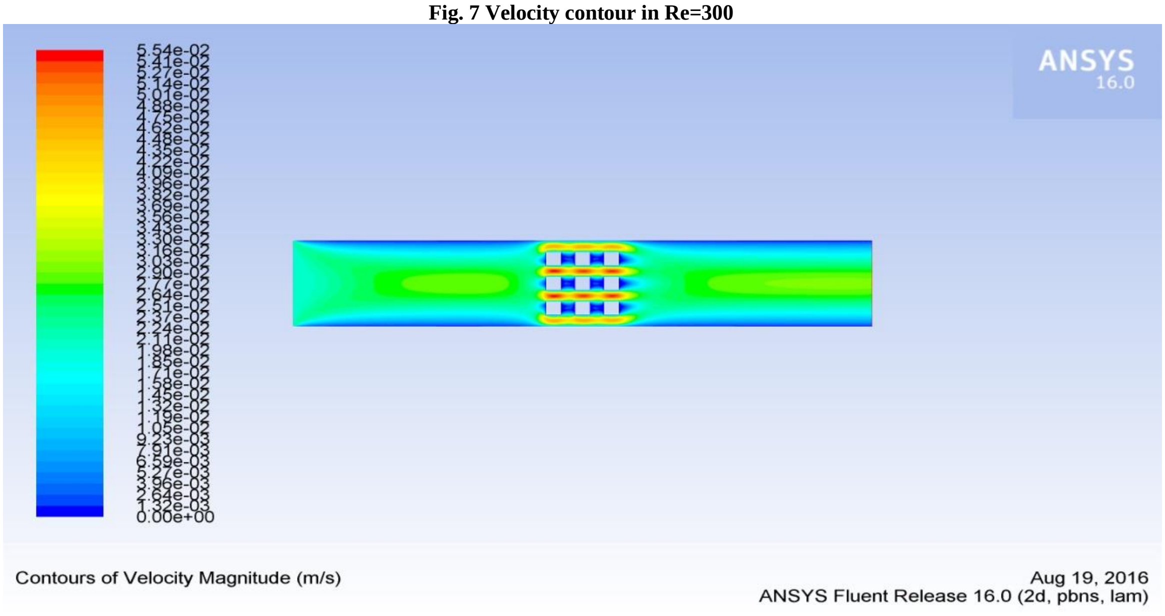

Fig. 8 Velocity contour in Re=700

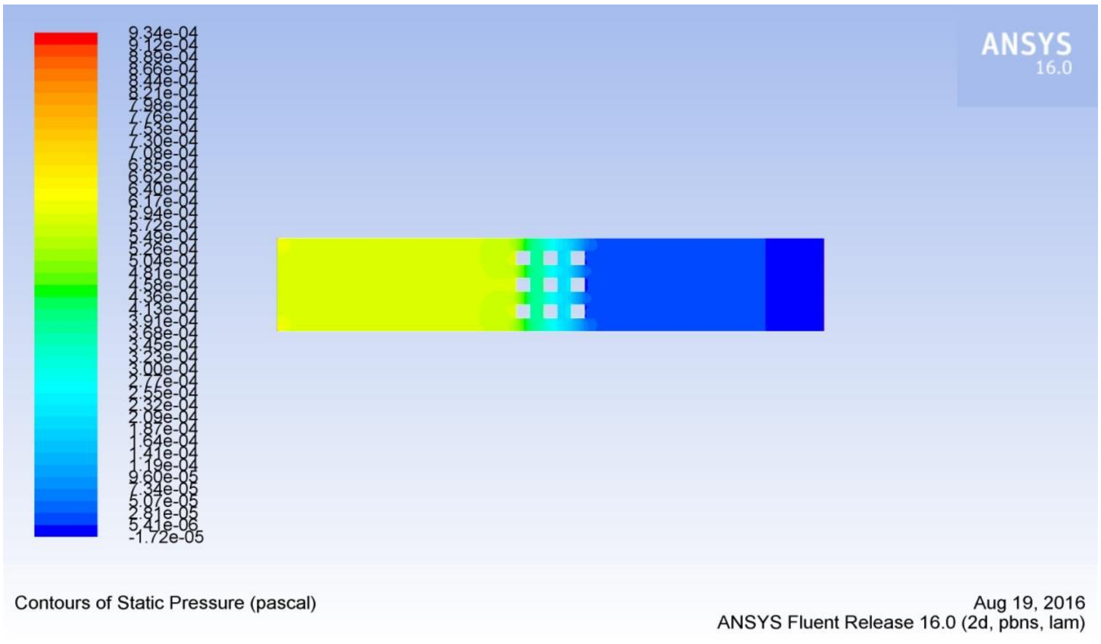

Fig. 9 Pressure contour in Re=50

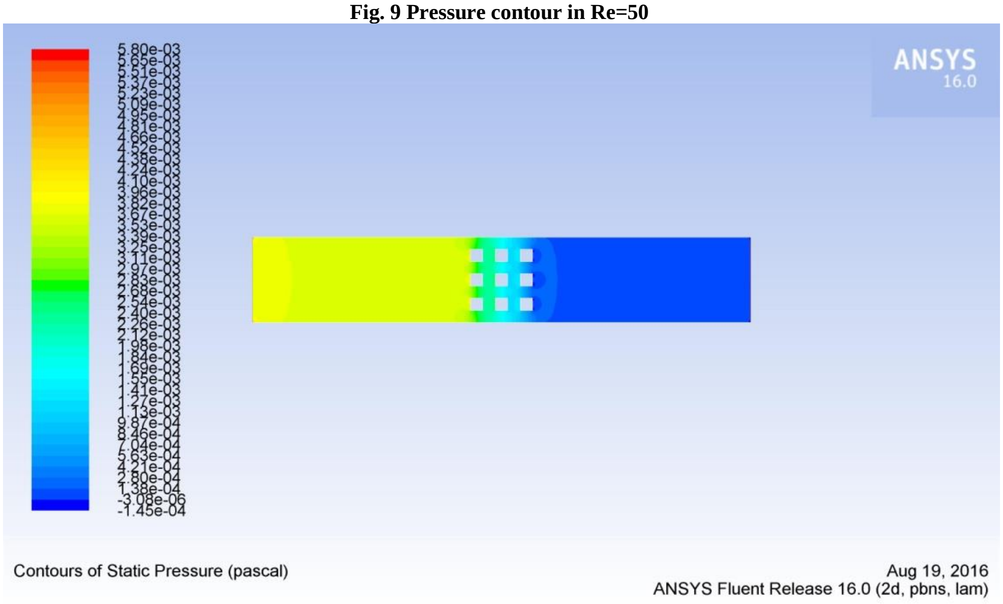

Fig. 10 Pressure contour in Re=300

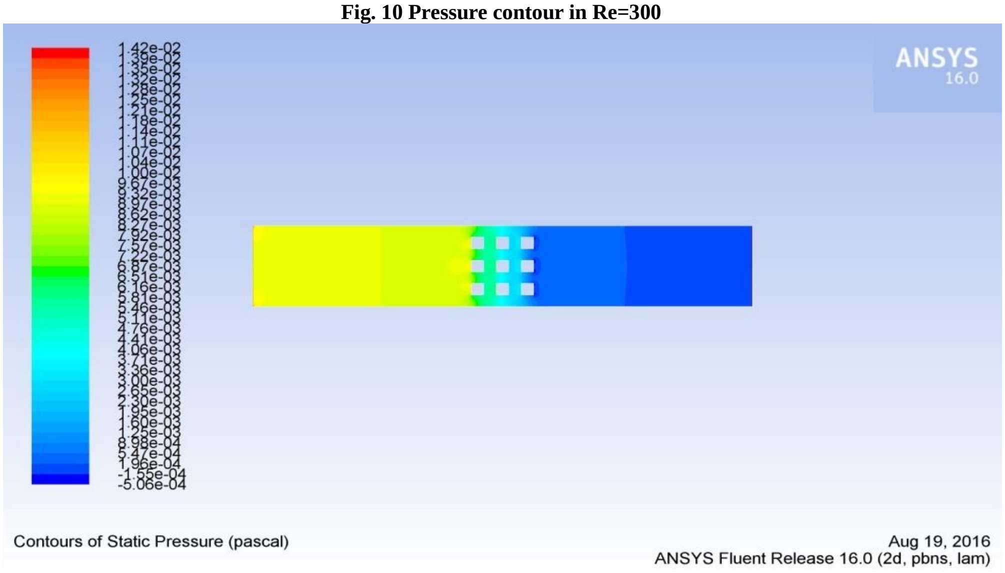

Fig. 11 Pressure contour in Re=700

Applying nanofluids instead of water in three different volume concentrations of 0.5%, 1% and 2% with modified thermo-physical properties can enhance the convective heat transfer. But, a pressure drop is anticipated because of the presence of nanoparticles and also in the presence of porous zones in the channel. Brownian motion of nanoparticles is behind the enhancing in heat transfer, that this motion can increase thermal conductivity of nanofluids. Fig. 12 and 13 show the convective heat transfer coefficient and fiction factor of working fluids in the present porous channel. As it can be observed, the maximum enhancement of convective heat transfer coefficient is for 2% Vol. of nanofluid which is around 27%. It also clears that friction factor will be increased around 10% by using the maximum volume fraction of the applied nanofluid. The basic knowledge behind these manipulations in friction factor and convective heat transfer coefficient are comprehensively discussed by the previous works by authors in [12, 13]. Moreover, the contours presented in this work were the same in topological shape for the applied nanofluids as well. The only difference was the ranging of characteristics; so for shortening the context, these contours were not shown in this work and only the main outcome results (convective heat transfer coefficient and friction factor) are evaluated.

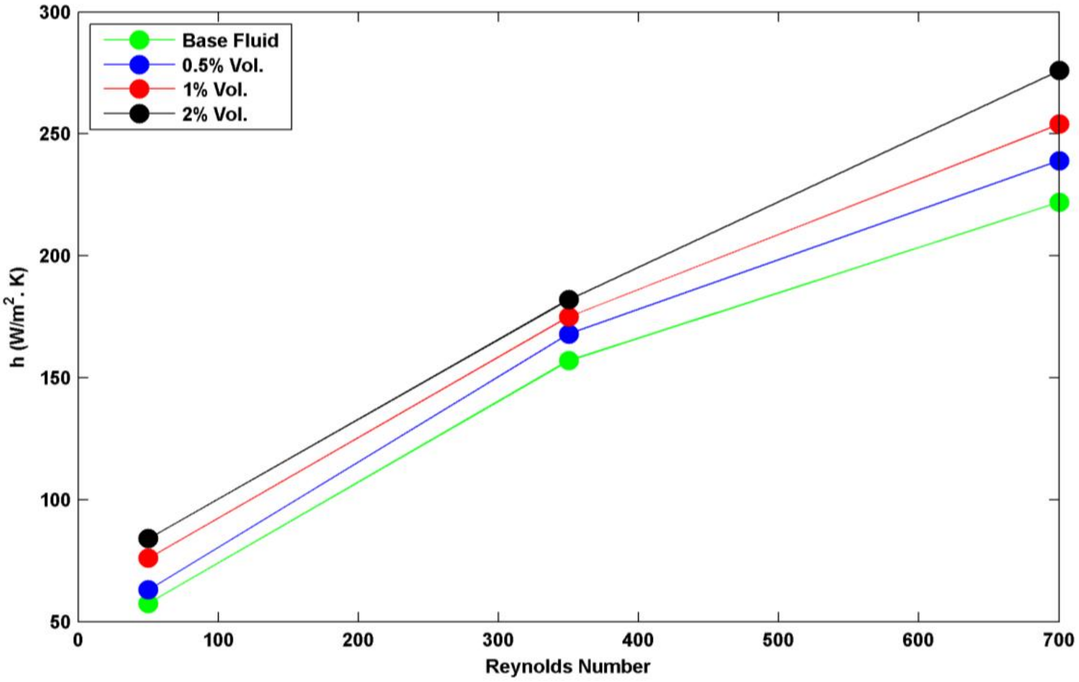

Fig. 12 Convective heat transfer coefficient of working fluids in different Reynolds numbers

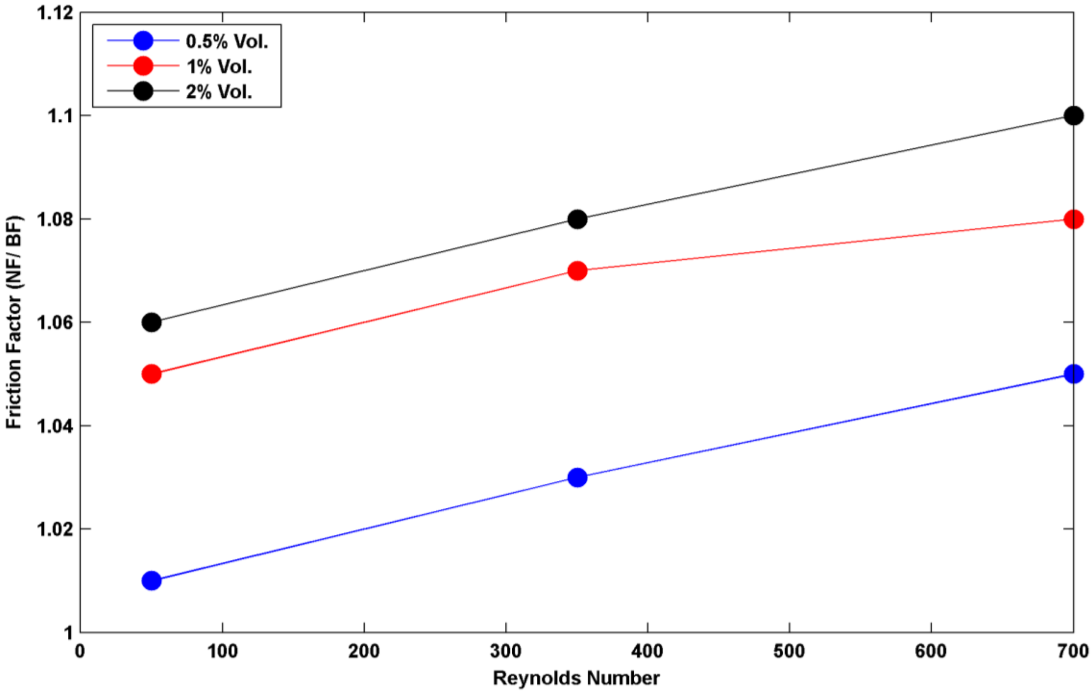

Fig. 13 Friction factor of working fluids in different Reynolds numbers

CONCLUSION

A porous channel has been simulated by ANSYS FLUENT 2016 under constant heat flux. Al2O3/ water nanofluid of three volume fractions of 0.5%, 1% and 2% have been applied in order to evaluate the convective heat transfer and pressure drop behavior of this type of nanofluids. Based on the outcome results, it has been observed that convective heat transfer and friction factor increased by around 29% and 10% respectively for the highest volume fraction of 2%.

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