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Numerical investigation of the effect of thermophysical properties of nanofluid on fluid flow and heat transfer in a tube in presence of magnetic field

Y. Malmir-Chegini[1], N. Amanifard[2*]

[1] Faculty of Mechanical Engineering, University Campus 2, University of Guilan, Rasht, Iran
[2] Thermo-Fluids Department, Faculty of Mechanical Engineering, University of Guilan, Iran

ABSTRACT: In this paper, flow characteristics and heat transfer in a smooth horizontal pipe subjected to forced heat convection with constant wall heat flux in the presence of magnetohydrodynamic have been computationally analyzed. The effects of temperature-dependent density, specific heat capacity, thermal conductivity, and viscosity on heat transfer and frictional flow characteristics of transformer oil and local and average heat transfer coefficient have been numerically investigated. Firstly, to validate, the present numerical result has been compared with the analytical and experimental results through a smooth pipe, which shows a good agreement. A significant deviation between constant and variable properties has been achieved. Changes in fluid velocity profiles have led to changes in fluid characteristics including coefficient of friction and heat transfer coefficient. By considering the changes in the parameters, it was observed that the viscosity of the base fluid and the nanofluid have the maximum effect with approximately 30 and 25% increase in heat transfer coefficient and apparent friction coefficient relative to the fixed properties, respectively. Despite the dependence of the thermal properties of the nanofluid on temperature-dependent viscosity, the change in thermal conductivity leads to 35% increase in the heat transfer coefficient in the presence of a magnetic field.

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1. INTRODUCTION

Generally, the theoretical relationships proposed for heat transfer in the fluid flow in tubes do not take into account the effects of the temperature gradient on the axial and radial velocity components. Harms et al. [1] analyzed the fully developed laminar flows in a semicircular duct with temperature-dependent viscosity variations. Both the constant temperature and constant heat flux boundary conditions were considered. Numerical solutions for the flow velocity and the temperature fields have been obtained by the finite difference technique. They revealed that the friction factor and Nusselt number results display a strong dependence on the viscosity ratio.

Liu et al. [2-3] numerically investigated the effects of variable properties on flow and temperature fields on microchannel. They showed that flow and temperature fields are affected by the effect of temperature on viscosity and thermal conductivity. Herwig and Mahulikar [4] investigated the effects of variable properties on single-phase and incompressible flow. They reported that the error in the Nusselt number in terms of variable properties compared to the state of constant properties is due to the dependence of viscosity and thermal conductivity on temperature. Besides, many studies have been performed on micro scales that indicate the effect of changing the properties by gradient temperature on the heat transfer coefficient [5-6]. In the present study, the effect of temperature in the base fluid, nanofluid, and nanofluid under a non-uniform magnetic field on the coefficient of friction and average heat transfer coefficient has been investigated.

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

2. GEOMETRY

The present geometry consists of a semi-insulated horizontal tube under a constant heat flux with a diameter of 10 cm and a length of 4 m (Fig. 1).

In this study, transformer oil was selected as the working fluid. It is worth noting that solar collectors generally use mineral oils due to their high heat absorption.

3. GOVERNING EQUATION

In this section, the equations of continuity, momentum, energy with the assumption of laminar flow, incompressible Newtonian flow by applying a magnetic field are presented. The continuity equation is obtained as follows:

$$\nabla.(\rho \vec{V}) = 0 \tag{1}$$

By considering Kelvin and Lorentz forces, the momentum conservation equation is obtained as follows:

$$\rho \frac{D\vec{V}}{Dt} = -\nabla p + \mu \nabla^2 \vec{V} + \rho \vec{g} + \mu_0 \left(\vec{M}.\nabla\right)\vec{H} + \sigma\left(\vec{V} \times \vec{B}\right) \times \vec{B} \tag{2}$$

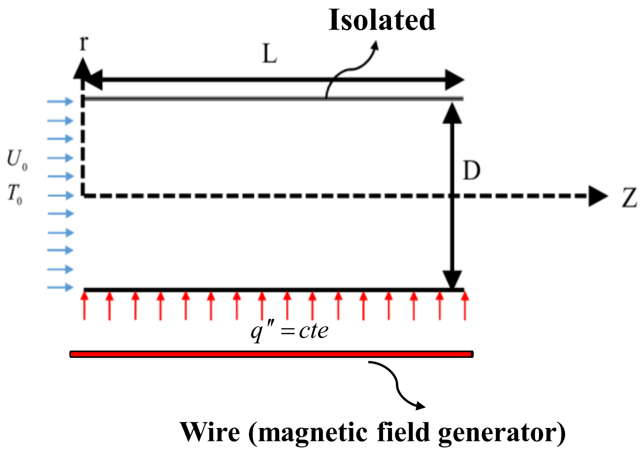

Fig. 1. Schematic view of the computational domain.

By considering the Joule heating effect and magnetocaloric terms, the energy equation is given as follows:

$$\rho Cp\frac{DT}{Dt}-\mu_0\vec{H}.\left(\frac{\partial\vec{M}}{\partial T}\right)_H\frac{DT}{Dt}+\mu_0 T\left(\frac{\partial\vec{M}}{\partial T}\right)_H.\frac{D\vec{H}}{Dt}=\nabla.\left(k\nabla T\right)+\sigma\left|\vec{V}\times\vec{B}\right|^2 \tag{3}$$

4. RESULTS AND DISCUSSION

Figs. 2 and 3 show the variations of the average heat transfer coefficient of the variable properties (relative to the constant properties) for different heat fluxes on the base fluid. According to the results, it can be deduced that the variations of the average heat transfer coefficient of the variable viscosity properties are closer to the results of all the variable properties. In other words, viscosity is a more effective impact than other properties. Most deviations are related to the variable viscosity, all variable properties, variable coefficient of thermal conductivity, variable density, and variable specific heat capacity, respectively. Also, these deviations increase with rising heat flux.

As shown in Fig. 3, the effect of the temperature-dependent viscosity in comparison with the temperature-dependent density on the apparent friction coefficient is significant. Therefore, it can be highlighted that finding the trend of variations in viscosity as a function of temperature can provide a correct approximation of pressure changes.

By adding nanoparticles to the base fluid, changing the properties of the base fluid, all variable properties, variable viscosity, variable thermal conductivity, variable specific heat capacity, and variable density have a remarkable effect on the results, respectively. Also, by increasing heat flux, deviations in heat transfer coefficient have increased due to more impact of fluid properties on temperature. Moreover, only the viscosity determines the hydrodynamic behavior of the fluid for the nanofluid.

By comparing the deviations of the average heat transfer coefficient, it is observed that all variable properties, the variable thermal conductivity, the variable viscosity, variable specific heat capacity, and the variable density of the nanofluid under the magnetic field have the more impact on the results, respectively. Variable density and variable viscosity properties are the factors that change the hydrodynamic behaviors, as the magnetic field increases, the uniformity of heat transfer throughout the tube increases, and the effects of temperature on viscosity and density decrease.

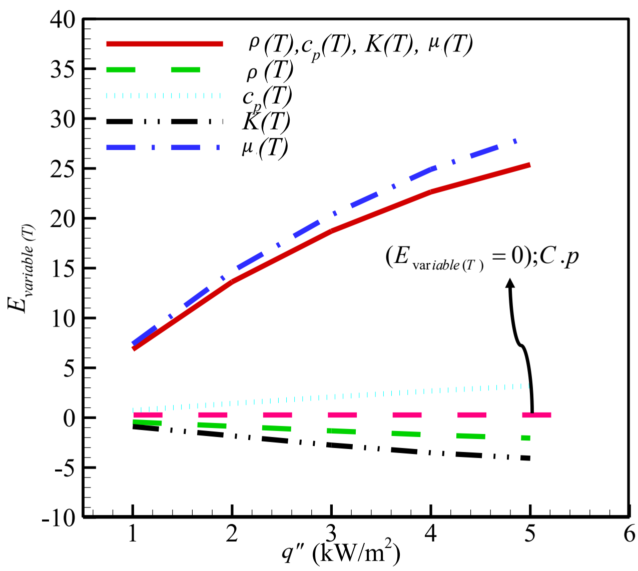

Fig. 2. Variations of the average heat transfer coefficient of the base fluid for variable properties to constant properties at different heat fluxes for *Re*=1000.

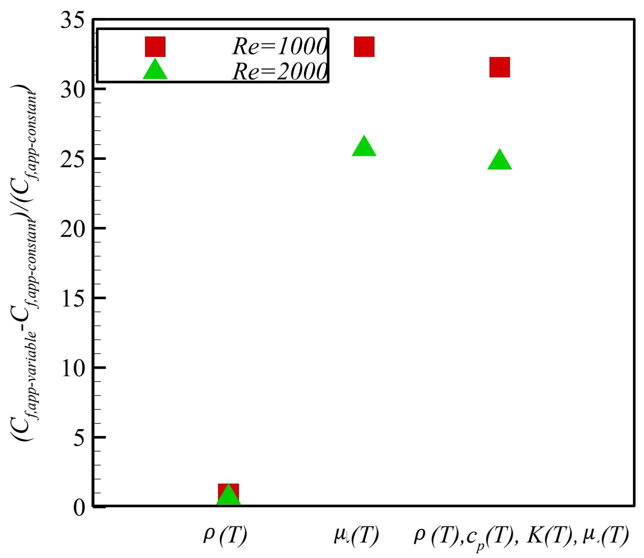

Fig. 3. Variation of the apparent friction coefficient of the properties of the base fluid at $q''=$۵ kW/m^2

5. CONCLUSIONS

In the present study, the effect of variable properties of fluid due to temperature change has been investigated numerically and the following items have been gained.

· In the base fluid, in terms of the deviation of heat transfer coefficient, the variable viscosity, and all variable properties have the same impact. In other words, viscosity is more effective than other properties ($E_{\mu(T)} > E_{\mu(T),K(T),\rho(T)\&C_p(T)} > E_{K(T)} > E_{\rho(T)} > E_{C_p(T)}$). Besides, by increasing heat flux the deviation rises.

· In nanofluid without a magnetic field, all variable properties, variable viscosity, variable thermal conductivity, variable specific heat capacity and variable density have the maximum effect on deviations of heat transfer coefficient, respectively($E_{\mu(T),K(T),\rho(T)\&C_p(T)} > E_{\mu(T)} > E_{K(T)} > E_{\rho(T)} > E_{C_p(T)}$)

· In a nanofluid under a magnetic field, the deviation of the average heat transfer coefficient decrease as the magnetic field increases. Also, all variable properties, variable thermal conductivity, variable viscosity, variable specific heat capacity, and variable density have more influence on deviations of heat transfer coefficient, respectively.
($E_{\mu(T),K(T),\rho(T)\&C_p(T)} > E_{K(T)} > E_{\mu(T)} > E_{C_p(T)} > E_{\rho(T)}$).

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