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Fluid Flow and MHD Forced Convection Heat Transfer Investigation of Ostwald De Waele Fluid Through Porous Microchannel in the Presence of the Lorentz Force

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ABSTRACT

The present study devotes a special consideration to perceiving the effects of the slip flow, heater length, Darcy number, medium porosity, flow behaviour index, Hartmann numbers, and magnetic field inclination angle on the momentum and heat transfer characteristics via offering and discussing the different statistical quantities such as the local and average Nusselt numbers, velocity profiles, temperature profiles carefully. The present study concerns a steady-state laminar magnetohydrodynamic (MHD) flow forced convection heat transfer inside a fully and partially filled microchannel. The parametric study indicates that the momentum characteristics and heat transfer mechanism strongly depend on the Knudsen number, heat source length, media porosity, flow behaviour index, and Hartmann number. The increased Knudsen number induces a pronounced increase in the axial velocity and a reduction in the shear rate at the wall, resulting in a noticeable decrease of the velocity in the microchannel centre and a marked increase of the axial velocity at the microchannel wall.

Keywords: Microchannel, MHD, Forced convection, LTE, Nusselt number.

1. Introduction

Energy has been assumed as the factor for the advancement of the industry for a long time ago, and following to improvement of the industry, employing heat transfer techniques with high thermal efficiency and potential for transfer of a high quantity of energy along with small dimensions are deemed as one of the essential needs in many modern industries and equipment. This issue is crucially important in various industrial tools and processes such as cooling and heating of thermal sources, production processes and industries, e.g. transportation, pharmacology, electronics, automotive and microelectromechanical and nanoelectromechanical systems.

Microchannels are used in several industries and equipment, such as the cooling of electronic packages, microchannel heat sinks, microchannel heat exchangers, microchannel fabrication, and different device cooling and heating. In recent years, research on characteristics of flow and heat transfer behaviour in microchannels has gotten great attention Akbari et al. [1] (2016). Magnetohydrodynamic MHD is the mutual interaction between the magnetic fields and electrically conducting fluids flow used for pumping, controlling and mixing fluids, as well as incorporating switches and valves into lab-on-a-chip devices. At present, a rich amount of literature is available on flow characteristics of non-Newtonian fluids in microchannels Javidi Sarafan et al. [2] (2020). The primary purpose of the present investigation is to look for the best heat transfer efficiency configuration of the heat sink microchannel.

This research also seeks to determine and reveal the effects of heater length, Knudsen number, Darcy number, medium porosity, flow behaviour index, Hartmann numbers, and magnetic field inclination angle on the momentum and heat transfer characteristics via offering and discussing the different statistical quantities such as the local and average Nusselt numbers, velocity profiles, and temperature profiles carefully.

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2. Problem Description

The present investigation was devoted to a numerical analysis of a two-dimensional steady laminar flow (MHD) forced convection heat transfer within a fully and partially porous medium heat sink rectangular microchannel subjected to a uniform transverse magnetic field (B_0) inclined by an angle (α). Cu-Al_2O_3/hybrid water nanofluid, pseudoplastic and dilatant fluids occupied the pores with a nanofluid concentration of ϕ = 1% and flow behaviour index from 0.2 to 1.8. The porous medium is modelled by employing the Brinkman-Darcy model with a local thermal equilibrium (LTE) approach between the working fluid and the porous matrix for energy transfer.

The present investigation consisted of a set of simulations for wide ranges of heat source length ($5 \leq B \leq 30$), Knudsen numbers ($0.001 \leq Kn \leq 0.1$), Darcy numbers ($10^{-5} \leq Da \leq 10^{-2}$), medium porosities ($0.1 \leq \varepsilon \leq 0.9$), Hartmann numbers ($0 \leq Ha \leq 160$), and magnetic field inclination angles ($0° \leq a \leq 90°$) for the following fixed parameters: Reynolds number (Re=50); porous thermal conductivity ratio (K_s=0.613).

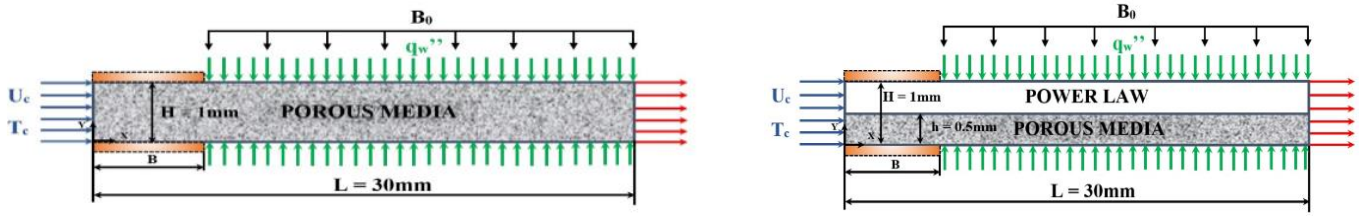
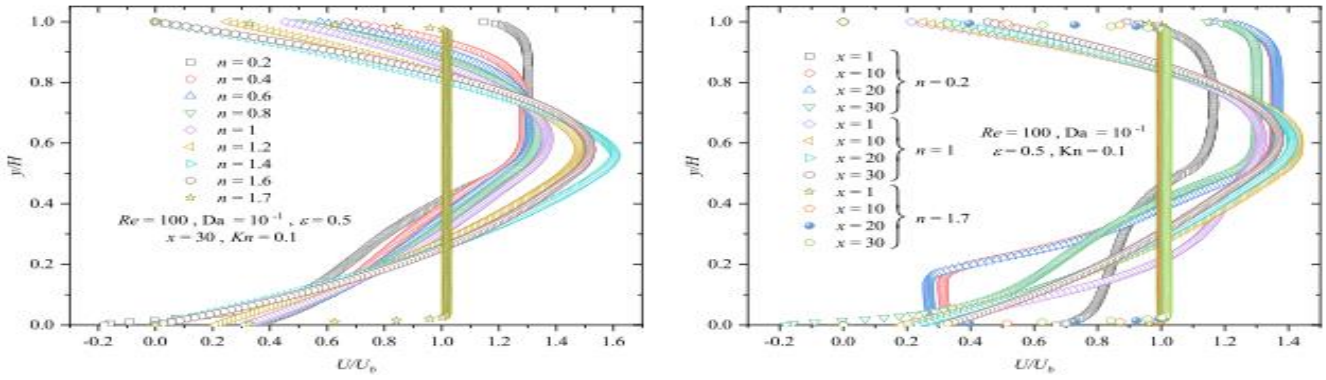


Figure 1: The schematic of the studied microchannel.

3. Results and Discussion

The momentum characteristics seem more dependent on the flow behaviour index in all considered cases; the axial velocity profiles of the Ostwald de Waele fluid inside the microchannel exhibit a significant deviation with varying flow behaviour index in all axial positions. As shown in **Fig.2**, the axial velocity profile marked a pronounced deviation in the lower microchannel half with varying flow behaviour index due to the apparent viscosity of the Ostwald de Waele fluid and porous medium. The axial velocity profile increases gradually further away from the microchannel pipe towards the centreline, where the axial velocity profile is characterised by the parabolic shape for a flow behaviour index of l. It can be seen from **Fig.2** that the velocity profiles of the dilatant fluid with flow behaviour index of l.2, l.4, and l.6 are higher than on the Newtonian fluid (n = l) along the microchannel high for all axial positions. It should be noted the increased flow behaviour index results in the apparent deviation in the shear rate distribution of the dilatant fluid along the radial coordinates, resulting in a marked variation in the apparent fluid viscosity, which leads to an increase in the axial velocity distributions along the microchannel high. The decreased flow behaviour index of the pseudoplastic also leads to moving the axial velocity's maximum value (peak value) toward the upper microchannel wall.



(a) **(b)**

Figure 2: Velocity profile of U/U_b for different values of flow behaviour index at Darcy number $Da = 10^{-1}$, for fixed Knudsen number Kn=0.1, Re=100, ε = 0.5.

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4. Conclusions

The major conclusions of this research will be summarised:
-The magnetic field and inclination angle considerably affected the momentum and thermal characteristics with varying Hartmann numbers and magnetic field inclination angles for all considered configurations.
- The increased flow behaviour index resulted in the apparent deviation in the shear rate distribution of the dilatant fluid along the radial coordinates, resulting in a marked variation in the apparent fluid viscosity, which leads to an increase in the axial velocity distributions along the microchannel high.

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