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Non-Newtonian fluid flow in plane channels: Heat transfer enhancement using porous blocks

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ABSTRACT

A numerical investigation is performed for heat transfer enhancement in a parallel-plate channel. Porous blocks are inserted to partially fill the channel, which is crossed by a power-law fluid. The modified Brinkman–Forchheimer extended Darcy model for power-law fluids is used in the porous layer while the Navier–Stokes equation are employed in the clear region of the channel. Results are reported for two cases: (1) a channel with a single porous block and (2) a channel with two porous blocks mounted alternatively at the bottom and top walls of the channel. The combined effects of both the porous blocks and the non-Newtonian fluid properties on the hydrodynamic and thermal characteristics of the flow are analyzed. To this end, computations are performed to highlight the effect of parameters such as the Darcy number, the Reynolds number, and the power-law index. For the case of the single porous block, the heat transfer is enhanced and maximized at low permeability. In the second configuration as well, heat transfer improvement can also be obtained, even if the thermal conductivity ratio is equal to 1. This enhancement is maximized for particular values of the Darcy number that depend on the flow pattern and the power-law index. Concerning the rheological aspect, it is found that pseudo plastic fluids exhibit the highest Nusselt number and the lowest pressure loss. The presence of the porous inserts causes a significant increase in pressure drop, which is found to be more important with dilatant fluids.

1. Introduction

During the last few years, there has been an increasing interest in fundamental studies of forced convection in ducts of various shapes fully or partially filled with a porous material. This interest is due to the presence of porous media in numerous engineering applications and natural processes such as ceramic processing, filtration, geothermal systems, groundwater flow, enhanced oil recovery, compact heat exchangers, packed bed chemical reactors and many others. The use of porous/fluid composite systems is an innovative method able to provide valuable solutions for improving energy the efficiency of thermal systems. This can have a positive impact in areas ranging from preservation of energy resources to limiting global warming. Hadim [1] conducted a numerical analysis on laminar forced convection in fully and partially porous parallel-plate channels with discrete heat sources. The obtained results showed that the partially porous channel can get almost the same improvement of heat transfer as that obtained with the fully porous channel while the pressure drop is drastically reduced. Hamdan and Al-Nimr [2] numerically explored heat transfer enhancement by using a succession of high-thermal conductivity porous fins in isothermal parallel-plate channel. It was found that the heat transfer can be enhanced by using high thermal conductivity fins with low permeability and by increasing the microscopic inertial coefficient. Using a vorticity stream function formulation, Huang and Vafai [3] showed that a significant heat transfer increase can be obtained by adding porous blocks on the bottom wall of an isothermal parallel-plate channel. Sung et al. [4] reported some results on the effect of both height and permeability of a single porous block on the flow and heat transfer characteristics of forced convection in a channel. They considered two types of location for the porous block. The situation where the porous medium is inserted between the channel walls has been analyzed by Tong et al. [5]. It was shown that heat transfer enhancement can be obtained. Moreover, either the partially or the completely porous channel according to the choice of the physical conditions specific to each configuration, allows obtaining a maximum heat transfer. Chikh et al. [6] focused their attention on an annular cylindrical duct with a porous substrate mounted on the inner cylinder. The velocity field was obtained analytically for a fully developed flow. The results showed that there exists a critical thickness of the porous layer at which heat transfer is minimal. Nield and Kuznetsov

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