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Effect of heat generation/absorption on natural convective boundary-layer flow from a vertical cone embedded in a porous medium filled with a non-Newtonian nanofluid ☆

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ABSTRACT

This work is focused on the study of the natural convection boundary-layer flow over a downward-pointing vertical cone in a porous medium saturated with a non-Newtonian nanofluid in the presence of heat generation or absorption. The transformed boundary layer governing equations are solved numerically. The influences of pertinent parameters such as the heat generation or absorption, the solid volume fraction of nanoparticles and the type of nanofluid on the flow and heat transfer rate in terms of Nusselt number are discussed. Comparisons with previously published work on special cases of the problem are performed and found to be in excellent agreement. The generalized governing equations derived in this work can be applied to different cases of non-Newtonian fluids with different values of the power-law viscosity index. The results of this parametric study are shown graphically and the physical aspects of the problem are highlighted and discussed.

1. Introduction

Nanotechnology is considered by many researchers to be one of the significant forces that drive the next major industrial revolution of this century. A significant research effort has been committed to exploring the thermal transport properties of colloidal suspensions of nanosized solid particles (nanofluids). The presence of the nanoparticles in the fluids increased appreciably the effective thermal conductivity of the fluid and consequently enhanced the heat transfer characteristics. Enhancement of heat transfer performance in these systems is an essential topic from an energy saving perspective. The low thermal conductivity of conventional heat transfer fluids such as water and oils is a primary limitation in enhancing the performance and the compactness of such systems. Solid typically has a higher thermal conductivity than liquids. For example, copper (Cu) has a thermal conductivity 700 time greater than water and 3000 greater than engine oil. An innovative and new technique to enhance heat transfer is by using solid particles in the base fluid (i.e. nanofluids) in the range of sizes 10–50 nm [1]. Due to small sizes and very large specific surface areas of the nanoparticles, nanofluids have superior properties like high thermal conductivity, minimal clogging in flow passages, long term stability, and homogeneity. Thus, nanofluids have a wide range of potential applications in electronics, automotive, and nuclear applications where improved heat transfer or efficient heat dissipation is required.

The conventional heat transfer fluids including oil, water and ethylene glycol, etc. are poor heat transfer fluids, since the thermal conductivity of these fluids plays an important role on the heat transfer coefficient between the heat transfer medium and the heat transfer surface. An innovative technique for improving heat transfer by using ultra fine solid particles in the fluids has been used extensively during the last several years. Choi [1] introduced the term nanofluid which refers to these kinds of fluids by suspending nanoparticles in the base fluid. Khanafer et al. [2] investigated the heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. The convective boundary-layer flow over vertical plate, stretching sheet and moving surface is studied by numerous studies and in the review papers Buongiorno [3], Daungthongsuk and Wongwises [4]; Oztop and Abu-Nada [5]; Nield and Kuznetsov [6,7]; Ahmad and Pop [8]; Khan and Pop [9]; Kuznetsov and Nield [10,11] and Bachok et al. [12].

The natural convection flow over a surface embedded in saturated porous media is encountered in many engineering problems such as the design of pebble-bed nuclear reactors, ceramic processing, crude oil drilling, geothermal energy conversion, use of fibrous material in the thermal insulation of buildings, catalytic reactors and compact heat exchangers, heat transfer from storage of agricultural products which generate heat as a result of metabolism, petroleum reservoirs, storage of nuclear wastes, etc. The derivation of the empirical equations which govern the flow and heat transfer in a porous medium has been discussed in Nield and Bejan [13]; Vafai [14]; Pop and Ingham [15]; Ingham and Pop [16]; Cheng and Minkowycz [17]; Chamkha et al. [18]; Mahdy and Hady [19]; Ibrahim et al. [20]; Abdel-Gaied and Eid [21]; Yih [22–25] and Cheng [26–30].

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