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Non-Darcy free convection flow over a horizontal cylinder in a saturated porous medium with variable viscosity, thermal conductivity and mass diffusivity

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ABSTRACT

In this paper, the effects of variable viscosity and thermal conductivity on coupled heat and mass transfer by free convection about a permeable horizontal cylinder embedded in porous media using Ergun mode are studied. The fluid viscosity and thermal conductivity and are assumed to vary as a linear function of temperature while the mass diffusion is assumed to vary as linear function of concentration. The surface of the horizontal cylinder is maintained at a uniform wall temperature and a uniform wall concentration. The transformed governing equations are obtained and solved by using the implicit finite difference method. Numerical results for dimensionless temperature and concentration profiles as well as Nusselt and Sherwood numbers are presented for various values of parameters namely, Ergun number, transpiration parameter, Rayleigh and Lewis numbers and buoyancy ratio parameter.

1. Introduction

Convective heat and mass transfer (or double-diffusion) from a curved surface has attracted a great deal of attention owing frequent applications of curved heat conducting surfaces. For examples the flow over a horizontal cylinder is of considerable significance due to the relevance of the cylindrical geometry to heat rejection systems, nuclear reactors, heating elements, temperature control of a catalytic bed, pipes conveying hot fluid in every generation system etc. Further the spreading of chemical contaminants through-saturated soil and extraction of geothermal energy.

The study of free convection from a horizontal cylinder embedded in a porous medium was studied by Merkin [1], Nakayama and Koyama [2] and Pop et al. [3]. Yih [4] has extended the work of Merkin and Pop et al. [3], to investigate numerically heat and mass transfer by free convection over a horizontal cylinder. Bejan and Khair [5] reported on the natural convection boundary layer flow in a saturated porous medium with combined heat and mass transfer. Coupled heat and mass transfer about a vertical cylinder in porous media was analyzed by Yucel [6]. The effects suction and blowing on free convection coupled heat and mass transfer flow over a vertical plate in saturated porous medium was studied by Raptis et al. [7]. Lai and Kulacki [8] have investigated coupled heat and mass transfer by natural convection from a sphere embedded in porous media. Yih [9] used the Keller box method to investigate the coupled heat and mass transfer by free convection over a truncated cone in a saturated porous medium. Also Yih [10,11] has studied the heat and mass transfer characteristics in mixed

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Nomenclature

a	radius of the cylinder
C	dimensionless concentration
D	mass diffusivity
f	dimensionless stream function
f_w	transpiration parameter
g	gravitational acceleration
h	mass diffusivity parameter
k	thermal conductivity
k_1	inertia coefficient
K	permeability of the porous medium
N	buoyancy ratio
Er	Ergun number
Nu	Nusselt number
Le	Lewis number
Ra	Rayleigh number for porous medium
Sh	Sherwood number
r	viscosity parameter
T	fluid temperature
u	dimensionless velocity in the x-direction
v	dimensionless velocity in the y-direction
V_w	uniform transpiration velocity
x, y	coordinates along of the cylinder and normal to it, respectively

Greek symbols

α	thermal diffusivity of porous medium
β_T	coefficient of thermal expansion
β_c	coefficient of concentration expansion
θ	dimensionless fluid temperature
ψ	stream function
η	pseudo similarity variable
ε	thermal conductivity parameter
ξ	dimensionless coordinate
μ	dynamic viscosity of the fluid
ν	kinematic viscosity of the fluid
Ω	angle of the y axis with respect to the vertical, x/a
ρ	density

Superscript

w	condition at the wall
∞	condition at infinity

convection about a wedge and inclined surfaces with VHF/VMF and uniform transpiration effects on the flow through porous media: the entire regime, respectively. All these studies confined to Darcy flow only.

The inertial effects due to the solid obstruction at moderate and height flow velocity are accounted by considering the Forchheimer flow model in porous structure. Vafai and Tien [12,13] indicate the important of the inertial effects on heat and mass transfer in porous media. Combined heat and mass transfer by natural convection from a vertical wall in a non-Darcy porous medium has been investigated by Wang et al. [14]. Bansod et al. [15] studied the heat and mass transfer from a horizontal surface in non-Darcy porous media.

All the above investigations were carried out for fluids having uniform viscosity, thermal conductivity and mass diffusivity, throughout the flow regime. However, it is known that the physical properties may change with temperature [16]. The effects of variable viscosity, thermal conductivity and mass diffusivity, on the flow and heat transfer through porous media have become more important in engineering applications such as geothermal systems, crude oil extraction and ground water pollution etc. The aim of the present work is to study the non-Darcy free convection heat and mass transfer about a horizontal cylinder embedded in porous media under the effects of variable viscosity, thermal conductivity and mass diffusion as wall as the transpiration velocity. The governing partial differential equations have been solved numerically using the finite difference method [17]. The results have been compared with those of Merkin [1], Pop et al. [3], Yih [4] Bejan and Khair [5], Kumari and Jayanthi [12] and Hossain et al. [13] for the cases of Darcy model ($Er = 0$ or $\xi = 0$) and constant fluid properties ($r = \varepsilon = h = 0$).