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Double diffusive mixed convection flow from a vertical exponentially stretching surface in presence of the viscous dissipation

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ABSTRACT

This paper is devoted to obtain non-similar solutions for the effect of viscous dissipation on the steady double diffusive mixed convection flow over a vertical exponentially permeable stretching surface. The non-linear partial differential equations governing the flow, thermal and species concentration fields are written in the non-dimensional form by using suitable group of transformations. The final non-dimensional set of coupled partial differential equations is solved using the implicit finite difference method in combination with the Newton's linearization technique. The effects of various non-dimensional physical parameters on velocity, temperature and species concentration fields are discussed. The presence of the suction/injection at the surface expedites the mass transfer phenomena. The numerical results in terms of the skin friction coefficient, the rate of heat transfer in terms of local Nusselt number and mass transfer rate in terms of Sherwood number shown graphically for various physical parameter involved in the problem. The present results are compared with previously published work, and these comparisons are found to be in excellent agreement.

1. Introduction

Double-diffusive mixed convection, which is driven by a combination of temperature and solute concentration gradients, have been the subject of intensive study. In recent times, work was stimulated by the oceanographic applications and the situations in which both the concentration gradient and the temperature gradients are in the vertical direction [1]. The convective heat and mass transfer process takes place due to the buoyancy effects owing to the differences of temperature and concentration, respectively. It plays a vital role in dealing with the transport phenomena, the thermal and the mass diffusions occurring by the simultaneous action of buoyancy forces are of considerable interest in practice. Mixed convection flows, or combined forced and free convection flows, arise in many transport processes in engineering devices and in nature. These flows are characterized by the buoyancy parameter which depends on the flow configuration and the surface heating conditions. This plays vital role in the solidification process in a binary system and oceanography. In recent studies, Kefayati [2] examined the mesoscopic simulation of double diffusive mixed convection of pseudoplastic fluids in an enclosure with sinusoidal boundary conditions. FDLBM simulation of double diffusive mixed convection of shear thinning fluids between two-square concentric duct annuli was examined by Kefayati [3]. Also, Kefayati [4] investigated double-diffusive mixed convection of Pseudoplastic fluids in a two sided lid-driven cavity using FDLBM. Mesoscopic simulation of magnetic field effect on double diffusive mixed convection of shear thinning fluids in a two sided lid-driven cavity is examined by Kefayati [5].

The heat and mass transfer on an exponentially stretching surface under boundary layer approximations is studied by Magyari and Keller [6]. The steady mixed convection flow of Maxwell fluid over an exponentially stretching vertical surface with magnetic and viscous dissipation is discussed by Kumari and Nath [7]. Bidin and Nazar [8] discussed the numerical solutions of the boundary layer flow over an exponentially stretching sheet with thermal radiation. An effect of suction on the heat transfer phenomena over an exponentially stretching continuous surface was discussed by Elbashbeshy [9]. Dulal Pal [10] examined the mixed convection heat transfer in the boundary layers on an exponentially stretching sheet with magnetic field. The boundary layer stagnation point flow of third grade fluid over an exponentially stretching sheet

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Nomenclature

A	suction parameter
C	species concentration
C_f	local skin friction coefficient
C_p	specific heat at constant pressure
C_w	concentration at the wall
C_{w0}	reference concentration
C_∞	ambient species concentration
f	dimensionless stream function
f_η	dimensionless velocity
g	acceleration due to gravity
G	dimensionless temperature
Gr, Gr^*	Grashof numbers due to temperature and species concentration, respectively
H	dimensionless species concentration
L	characteristic length
N	ratio of buoyancy forces
Nu	Nusselt number
Pr	Prandtl number (ν/α)
Q, Q_o	heat generation coefficient
Re_L	Reynolds number
Ri	Richardson number
Sc	Schmidt number (ν/D)
Sh	Sherwood number
T	temperature
T_w	temperature at the wall
T_{w0}	reference temperature
T_∞	ambient temperature of the fluid
u	velocity component in the x direction
v	velocity component in the y direction
x, y	Cartesian coordinates

Greek symbols

β, β^*	volumetric coefficients of the thermal and concentration expansions, respectively
ε	velocity ratio parameter
ξ, η	transformed variables
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density
ψ	stream function
Γ	heat generation/absorption parameter

Subscripts

e	free stream condition
w	conditions at the wall
ξ, η	denote the partial derivatives with respect to these variables, respectively.

was studied by Rehman et al. [11]. The effects of three dimensional flows for MHD, viscoelastic and Eyring-Powel fluids over exponentially stretching sheet is discussed by Hayat et al. [12–14].

Suction/injection of a fluid through a stretching surface like, in mass transfer cooling, may also change the flow field significantly, and as a consequence, surface suction or blowing will affect the heat and mass transfer rates. In general, suction and injection tends to be opposite, suction increases the skin friction, heat transfer and mass transfer coefficients, where as injection has the opposite tendency [15]. In practical problems involving boundary layer control applications such as film cooling, polymer fibre coating and coating of wires injection or blowing of fluid through permeable bounding heated or cooled surface is of general interest [16]. Mukhopadhyay [17] discussed the slip effects on MHD boundary layer flow over an exponentially stretching sheet with suction/blowing and thermal radiation which concludes that the effect of suction parameter on viscous incompressible fluid is to suppress the velocity field which in turn causes the enhancement of skin friction coefficient. Vajravelu and Hadjinicolaou [18] has been analyzed the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a linearly stretching surface with variable wall temperature subject to suction or blowing (injection). Ali and Al-Yousef [19] have been analyzed with surface suction/injection with the form of general power function for stretching velocity of the wall.

The effects of viscous dissipation in natural convection process have been studied by Gebhart [20], Gebhart and Mollendorf [21]. It is observed that the effect of viscous dissipation is more predominant in vigorous natural convection and mixed convection processes. Also they have shown the existence of similarity solution for the external flow over an infinite flat vertical surface having an exponential variation of surface temperature. Magyari and Keller [6] have been analyzed the steady free convection flow and heat transfer from an exponentially stretching vertical surface with an exponential temperature distribution both analytically and numerically. They neglected the effect of viscous dissipation in the medium and also the body force which is more significant in the vertical wall configuration. K. Govardhan et al. [22] studied the effect of viscous dissipation and radiation on MHD gas flow and heat and mass transfer over a stretching surface with a uniform free stream.

Naramgari and Solochana [23] discussed the dual solutions of radiative MHD nanofluid flow over an exponentially stretching sheet with heat generation/absorption. They have concluded that exponential parameter improves the heat and mass transfer rate and depreciates the velocity profiles. Patil et al. [24] discussed the mixed convection flow from a moving vertical slender cylinder in presence of viscous dissipation effects. The study of heat generation/absorption effects in moving fluids plays a vital role in view of various physical problems, such as fluids undergoing exothermic or endothermic reactions.

In this article, the authors aim at presenting non-similar solutions of double diffusive mixed convection flows over a vertical exponentially stretching surface in presence of the suction/injection, viscous dissipation and heat generation/absorption. In this analysis, effects of radiation have been neglected and effect of chemical reaction is not considered in the present study. The analysis showed that the viscous dissipation and non-similarity have significant influence on the flow, heat and mass transfer coefficients.

2. Formulation of the problem

Consider a steady two-dimensional laminar mixed convection boundary layer flow along a semi-infinite vertical permeable exponentially stretching surface with velocity $U_w(x)$ moving in an exponentially free stream with velocity $U_e(x)$ under the influence of surface mass transfer moving in the positive x-direction of an incompressible Newtonian fluid of temperature T_∞ and concentration C_∞. The x-axis is taken along the plate in the vertically upward direction and the y-axis is taken normal to it. The suction/injection is considered at the plate. A schematic representation of the phys-