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Radiation, inclined magnetic field and cross-diffusion effects on flow over a stretching surface

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Abstract

The steady two-dimensional flow over a vertical stretching surface in presence of aligned magnetic field, cross-diffusion and radiation effects are considered. The governing partial differential equations are transformed to nonlinear ordinary differential equation by using similarity transformation and then solved numerically by using bvp4c with MATLAB package. The effects of various non-dimensional governing parameters on velocity, temperature, concentration profiles along friction factor, Nusselt and Sherwood numbers are discussed and presented through graphs and tables'.We observed that increase in aligned angle strengthen the magnetic field and decreases the velocity profile of the flow and enhances the heat transfer rate. Comparisons with existed results are presented.

Keywords: Stretching sheet; Aligned magnetic field; Cross diffusion; Radiation; Convection

1. Introduction

In recent years convective heat and mass transfer over a stretching sheet plays major role because of it tremendous applications in engineering and sciences. For this reason now a day's large amount of work is focused in this area. Prasad et al. [1] have given detailed description about the effects of different physical properties of fluids on MHD flow. A steady two dimensional MHD flow analysis in presence of radiation by using homotopy analysis method was discussed by Rashidi et al. [2]. Boundary layer flow through exponentially stretching sheet in the presence of stratified medium by using Shooting technique was discussed by Swathy Mukhopadhyay [3]. Pavithra and Gireesha [4] used Runge–Kutta method and analysed radiation effect on dusty fluid over exponentially stretching sheet. Zaimi et al. [5] analyzed steady two dimensional flow of a nanofluid over a stretching/shrinking sheet. Wang and Mujumdar [6] given good literature on heat transfer characteristics of nanofluids.

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Rana and Bhargava [7] used finite element and finite difference methods for nonlinear stretching sheet problem. Zaimi et al. [8] extended the work of Rana and Bhargava and studied heat transfer and boundary layer flow of a nano fluid over a stretching/shrinking sheet. Radiation effect on MHD viscous fluid over exponentially stretching sheet in porous medium was analyzed by Ahmad et al. [9]. Hady et al. [10] studied heat transfer characteristics of nonlinear stretching sheet in the presence of thermal radiation. The boundary layer flow of a stagnation point over a stretching sheet was analysed by Bhattacharya [11]. He found that the rate of heat transfer enhances due to its unsteadiness and he compared the unique solution to dual solution. Free convection heat transfer through a horizontal plate with soret and dufour effect was discussed by Lakshminarayana and Murthy [12]. Ece [13] proposed the similarity analysis for the laminar free convection boundary layer flow in the presence of a transverse magnetic field. Hamad and Ferdows [14]. The thermal conductivity of solid particles is several times more than that of the base or convectional fluids was discussed by Das et al. [15] in the book nanofluids science and technology. In this book they clearly explained the thermal properties and behavior of the particles at different temperatures. Boungiorno [16] presented different theories on enhanced heat transfer characteristics of nanofluids and he concluded that thermal dispersion phenomenon cannot explain fully about the high heat transfer coefficients in nanofluids. A clear investigation on nanofluid thermal properties was done by Phillip et al. [17]. Radiation effects on unsteady MHD flow over moving vertical plate was studied by Mohan Krishna et al. [18]. The researchers [19–21] have been given their valuable contribution to analyze the heat transfer characteristics in convective flows. All the above studies focused on transverse magneticfield with radition. Khidir and Sibanda [22] considered cross-diffusion effects for a steady flow over an exponentially stretching surface. Makinde and Ogulu [23] analyzed thermal radiation and transverse magneticfield effects on a flow over a vertical porous plate. Makinde [24] discussed mixed convection flow over a vertical porous plate by considering radiation and chemical reaction effects. The researchers Seini and Makinde [25] studied MHD boundary layer flow towards exponentially stretching surface. Shateyi and Makinde [26] presented MHD stagnation point flow over a radially heated stretched disk.

To the author's knowledge no studies have been reported on effects of aligned magnetic field, cross-diffusion and radiation on steady two-dimensional flow over a vertical stretching surface. The governing partial differential equations are transformed to nonlinear ordinary differential equation by using similarity transformation and then solved by numerically by using bvp4c with MATLAB package. The effects of various non-dimensional parameters on velocity, temperature, concentration profiles are discussed and presented through graphs. Also the effect of physical parameters on friction factor, Nusselt and Sherwood numbers are analyzed and presented through tables.

2. Flow analysis

Consider a steady, two dimensional, laminar, incompressible and electrically conducting boundary layer flow over a permeable stretching sheet, where the sheet is along y direction. A non uniform aligned magneticfield $B(x) = B_0 x^{1/3}$ is applied to the flow. Aligned magneticfield with acute angle gama (γ) applying along y direction. At $\gamma = \pi/2$ this magneticfield acts like transverse magneticfield (because $\sin(\pi/2) = 1$). A uniform stretching velocity $u_x(x) = cx^{1/3}$ is considered, where c is constant. The convective heat transfer is taken in to account. The boundary layer equations that governs the present flow subject to the Boussinesq approximations can be expressed as

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} + g\beta_T(T - T_\infty) + g\beta_c(C - C_\infty) - \frac{\sigma B^2(x)}{\rho}\sin^2(\gamma)u \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 T}{\partial y^2} \tag{4}$$

where u and v are the velocity components in the directions of x and y respectively, υ is the kinematic viscosity, ρ is the fluid density, σ is the electrical conductivity, g is the acceleration due to gravity, β_T is the coefficient of Thermal expansion, β_c is the coefficient of volumetric expansion, α is the thermal conductivity, c_p is specific heat