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Research Article

INFLUENCE OF VISCOUS DISSIPATION AND THERMAL RADIATION ON HEAT AND MASS TRANSFER OF MHD FLUID PAST A STRETCHING SHEET WITH BUOYANCY EFFECTS

Venkata Madhu J*

Department of Mathematics, SNIST, Ghatkesar, Hyderabad-501301, Telangana State, INDIA

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ABSTRACT

This paper numerically studies the influence of Viscous dissipation and thermal radiation of the nonlinear MHD flow with heat and mass transfer characteristics of an incompressible, viscous, electrically conducting and Boussinesq fluid along a permeable vertical stretching sheet with buoyancy effects. A magnetic field is applied transversely to the direction of the flow. The basic equations governing the flow, heat transfer, and concentration are reduced to a set of non linear ordinary differential equations by using appropriate similarity transformation. The non linear ordinary differential equations are first linearised using Quasi-linearization and solved numerically by an implicit finite difference scheme. Then the system of algebraic equations is solved by using Gauss-Seidal iterative method. The effects of physical parameters on the velocity, temperature, and concentration profiles are illustrated graphically.

INTRODUCTION

The analysis of the flow field in a boundary-layer near a stretching sheet is an important part in fluid dynamics and heat transfer occurring in a number of engineering processes such as extrusion of plastic and rubber sheets, polymer processing and metallurgy [1]. The interaction of moving fluids with magnetic field provides a rich variety of phenomena associated with mechanical energy conversion such as metals processing, heating and flow control or power generation from two-phase mixtures [2], but the major use of MHD is in plasma physics. The study of magneto hydrodynamics is also stimulus due to its vast applications to the delineation of space and astrophysical plasmas.

Considering suction/injection effects, Erickson *et al*. [3] studied heat and mass transfer over a moving surface. Pal [4] illustrated the impact of different parameters on velocity, temperature and concentration profiles for both assisting and opposing flows in stagnation-point flow over a stretching surface with thermal radiation numerically. In recent years, MHD flow problems have become more important industrially. Indeed, MHD laminar boundary layer behavior over a stretching surface is a significant type of flow having considerable practical applications in chemical engineering, electrochemistry and polymer processing. In his pioneering work, Sakiadis [5] developed the flow field due to a flat surface, which is moving with a constant velocity in a quiescent fluid.

In recent years, MHD flow problems have become important industrially. Indeed, MHD laminar boundary layer behavior over a stretching surface is a significant type of flow having considerable practical applications in chemical engineering, electrochemistry and polymer processing. The study of hydrodynamic flow and heat transfer over a stretching sheet may find its applications in polymer technology related to the stretching of plastic sheets. Also, many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and while drawing, these strips are sometimes stretched. The rate of cooling can be controlled by drawing such strips in an electrically conducting fluid subjected to a magnetic field in order to get the final products of desired characteristics. For the non-Newtonian power-law fluids, the hydrodynamic problem of the MHD boundary layer flow over a continuously moving surface has been dealt by Andersson *et al*. [6], Cortell [7] and Mahmoud and Mahmoud [8]. All the above mentioned investigators confined their analyses to MHD flow and heat transfer over a linearly stretching sheet.

Corresponding author:* **Venkata Madhu J
Department of Mathematics, SNIST, Ghatkesar, Hyderabad-501301, Telangana State, INDIA

Further investigations on boundary layer flow and heat transfer of viscous fluids over a flat sheet are very important for development in many manufacturing processes, such as polymer extrusion, drawing of copper wires, continuous stretching of plastic films and artificial fibers, hot rolling, wire drawing, glass-fiber, metal extrusion and metal spinning. Both the kinematics of stretching and the simultaneous heating or cooling during such processes has a decisive influence on the quality of the final products (Magyari & Keller [9]). Among these studies, Sakiadis [10] initiated the study of the boundary layer flow over a stretched surface moving with a constant velocity and formulated a boundary-layer equation for two-dimensional and axi-symmetric flows.

Bujurke *et. al*. [11] made an investigation on the heat transfer analysis in a second order fluid flow past a stretching surface. Datta *et. al*. [12] has studied the distribution of temperature in a continuous stretching sheet with uniform wall heat flux. Further, flow and heat transfer from a linearly stretching sheet gained more importance due to practical applications in industrial processes. Abel and Veena [13] have analyzed visco-elastic fluid flow and heat transfer in a porous medium over a stretching sheet.

Understanding MHD is strongly related to the comprehension of physical effects which take place in MHD. When a conductor moves into a magnetic field, electric current is induced in the conductor and creates its own magnetic field (Lenz's law). Since the induced magnetic field tends to eliminate the original and external supported field, the magnetic field lines will be excluded from the conductor. Conversely, when the magnetic field influences the conductor to move it out of the field, the induced field amplifies the applied field. The net result of this process is that the lines of force appear to be dragged accompanied by the conductor. In this paper the conductor is the fluid with complex motions. To understand the second key effect which is dynamical we should know that when currents are induced by a motion of a conducting fluid through a magnetic field, a Lorentz force acts on the fluid and modifies its motion. In MHD, the motion modifies the field and vice versa. This makes the theory highly non-linear [14, 15]. Sparrow and Abraham[16] studied Universal solutions for the stream-wise variation of the temperature of moving sheet in the presence of moving fluid. Numerical simulation of the radiative heating of a moving sheet was analysed by Boetcher *et al* [17]. Sparrow and Abrahim [18] studied New buoyancy model replacing the standard Pseudo-density difference for internal natural convection in gases.

However in the existing convective heat transfer literature on the non-Newtonian fluids, the effect of the viscous dissipation has been generally disregarded. J Venkata Madhu *et al* [19] have studied the Dufour and soret effect on unsteady mhd free convection flow past a semi-infinite moving vertical plate in a porous medium with viscous dissipation. J Venkata Madhu *et al* [20] have studied MHD Effects And Heat Transfer On A Boundary Layer Flow Past A Stretching Plate With Heat Source/Sink In The Presence Of Viscous Dissipation. Kishan and Shashidar Reddy [21] have studied the MHD effects on non-Newtonian power-law fluid past a continuously moving porous flat plate with heat flux and Viscous Dissipation.

The main aim of this paper is to find the numerical solution for the velocity, temperature and concentration distributions to study the steady magneto hydrodynamic fluid flow over a stretching sheet under the influence of Viscous Dissipation and Thermal radiation with buoyancy forces. The effects of different involved parameters such as suction parameter, Prandtl number, Eckert number, buoyancy parameters due to temperature and concentration effects, Schmidt number, Biot number and radiation parameter on the fluid velocity, temperature and concentration distributions are plotted and discussed

Mathematical Formulation

In this paper we examine heat and mass transfer in a steady laminar two-dimensional boundary-layer flow of an incompressible electrically conducting fluid over a permeable stretching sheet (Fig.1). It is assumed that the stretching velocity is in the form of $u_w(x) = c(x)^{1/3}$ (two equal and opposite forces are applied along the x – axis with the fixed origin) where c is a constant and the surface of the sheet is heated by convection from a hot fluid at temperature h_f. The flow will be induced through the stretching sheet. A magnetic field of non-uniform strength $B(x) = B_0(x)^{-1/3}$ is applied normal to the sheet. The left surface of the sheet is heated by convective heat transfer and all of the fluid properties are considered as constant properties except density. The boundary-layer governing equations and boundary conditions with the Boussinesq and the boundary-layer approximations are as contained [22]. The induced magnetic field is neglected in comparison with the applied magnetic field and the viscous dissipation is small. The governing equations are

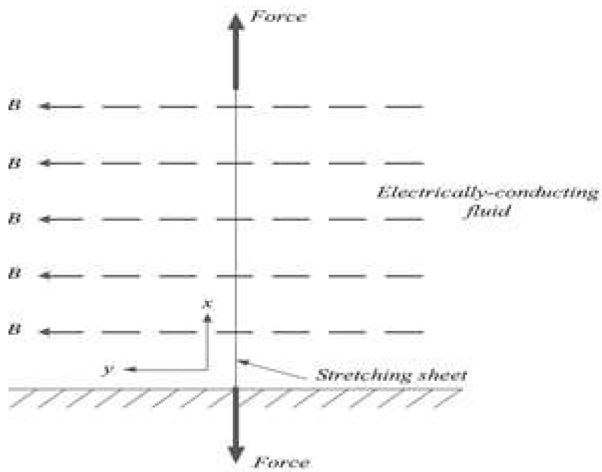

Figure a The schematic diagram of the stretching sheet problem.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad \text{-- (1)}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B^2(x)}{\rho}\mu + g\big(\beta_T(T - T_\infty) + \beta_C(C - C_\infty)\big), \quad \text{-- (2)}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma^* T_\infty^3}{3\rho C_p K_1}\frac{\partial^2 T}{\partial y^2} + \frac{\nu}{C_p}\left(\frac{\partial u}{\partial y}\right)^2, \quad \text{-- (3)}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2}. \quad \text{-- (4)}$$

where u and v are velocity components in the direction of x and y along and normal to the surface respectively (as shown in fig a). ν is kinematic viscosity, σ is the electric conductivity, ρ is the fluid density, B(x) is non-uniform magnetic field parameter, g is the acceleration due to gravity, β_T is coefficient of thermal expansion, β_C is coefficient of thermal expansion with concentration, T is the fluid temperature, C is fluid concentration, α is the thermal diffusivity, C_p is specific heat at constant pressure, σ^* is the Stephan-Boltz-man constant, K_1 is the Rosseland mean absorption coefficient and D is the coefficient of mass diffusivity. It should be made clear that the last term in Eq. (3) refers to the radiation parameter. In this case, the Rosseland approximation has been supposed and the radiative heat flux is given by $q_r = -\frac{4\sigma^*}{3k_1}\frac{\partial T^4}{\partial y}$. Using the Taylor series T^4 is defined as a linear function of temperature $T^4 \cong 4T_\infty^3 T - 3T_\infty^4$ [23]. The thermal radiation is quite significant and the quality of final product can be controlled by the control of cooling rate via radiation parameter. In polymer industry, the thermal radiation effect may play an important role in the control of heat transfer process which is directed in a thermally controlled environment. The desired quality of the final product can be reached by the knowledge of radiative heat transfer [24] The corresponding boundary conditions are as follow [25]:

$$u = u_w(x),\ \ v = v_w,\ \ -k\frac{\partial T}{\partial y} = h_f(x)(T_w - T),\ C_w = C_\infty + bx \ at\ y = 0,$$
$$u \to 0, T \to T_\infty, C \to C_\infty \ as\ y \to \infty \qquad \text{-- (5)}$$

By introducing stream function Ψ and similarity variable η, the partial differential equations are transformed into ordinary differential equations. It is assumed that the temperature varies in the x-direction, and $T_w = T_\infty + ax$.

$$\eta = ycx^{-1/3}v^{1/2}, \Psi = c^{1/2}x^{2/3}v^{1/2}f(\eta),$$
$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, \qquad \text{-- (6)}$$

$$f''' + \frac{2}{3}ff'' - \frac{1}{3}f'^2 - Mf' + (\lambda_r\theta + \lambda_c\varphi) = 0, \qquad \text{-- (7)}$$

$$(1 + N_r)\theta'' + \frac{p_r}{3}(2f\theta' - 3f'\theta) + p_r E_c(f'')^2 = 0, \qquad \text{-- (8)}$$

$$\varphi'' + \frac{1}{3}S_c(2f\varphi' - 3f'\varphi) = 0 \qquad \text{-- (9)}$$

where

$Re_x = \frac{U_w x}{v}$ is Reynolds number

$\lambda_T = \frac{g\beta_T(T_w - T_\infty)}{c^2}x^{1/3}$ is Buoyancy parameter

$\lambda_C = \frac{g\beta_C(C_w - C_\infty)}{c^2}x^{1/3}$ is Concentration Buoyancy parameter

$P_r = \frac{\upsilon}{\alpha}$ is Prandtl number

$S_c = \frac{v}{D}$ is Schmidt number

$M = \frac{\sigma\beta_0^2}{\rho c}$ is Magnetic parameter

$N_r = \frac{16\sigma^* T_\infty^3}{3\rho C_p K_1}$ is Thermal Radiation parameter

The corresponding boundary conditions are as follows

$$f(\eta) = f_w, f'(\eta) = 1, \theta'(\eta) = -B_i[1 - \theta(0)],$$
$$\phi(\eta) = 1 \text{ at } \eta = 0,$$
$$f'(\eta) \to 0, \theta(\eta) \to 0, \phi(\eta) \to 0 \text{ as } \eta \to \infty \qquad \text{-- (10)}$$

Where $f_w = -\frac{3x^{1/3}v_w}{2v^{1/2}c^{1/2}}$ is the suction/injection parameter ($f_w >$ 0 for suction and $f_w < 0$ for injection) and $B_i = \frac{v^{1/2}x^{1/3}h_f}{kc^{1/2}}$ is the Biot number. Since we have considered free convective flow, the velocity at the infinity is equal to zero

The set of governing Equations (7) - (9) is highly nonlinear, so it is difficult to obtain closed form solution. Hence these equations together with the boundary conditions (10) are solved numerically using finite difference technique. The momentum equations is first linearized using Quasi-linearization technique and then these linear ordinary differential equations are transformed into a system of linear equations by using implicit Finite difference Scheme. Now the computation procedure is employed to obtain the numerical solutions in which first the momentum equation is solved to obtain the values of *f* using which the solution of energy and concentration equations are solved under the given boundary conditions (10) using Thomas algorithm for various parameters entering into the problem and computations were carried out by using The numerical solutions of *f* are considered as (n+1)th order iterative solutions and F are the nth order iterative solutions. After each cycle of iteration the convergence check is performed, and the process is terminated when $|F - f| < 10^{-4}$

RESULTS AND DISCUSSIONS

The parametric study is performed to explore the effects of Viscous dissipation, Buoyancy parameter, and Thermal radiation parameter. In order to get a clear insight of the physical problem, numerical results are displayed with the help of graphical illustrations.

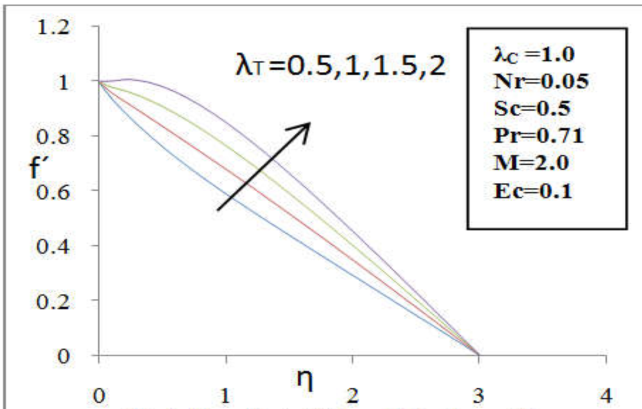

Fig 1: The effect of λT on Velocity profiles

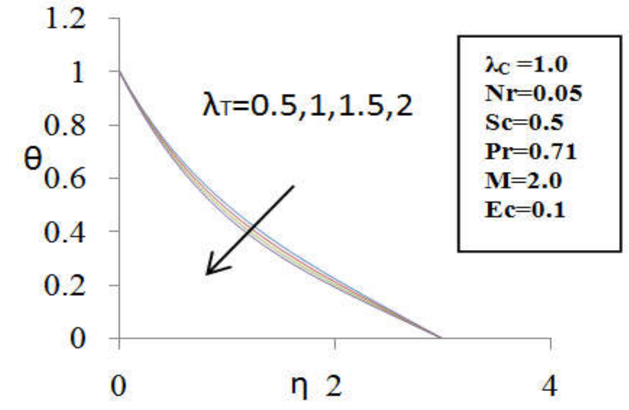

Fig 2: The effect of λT on Temperature profiles

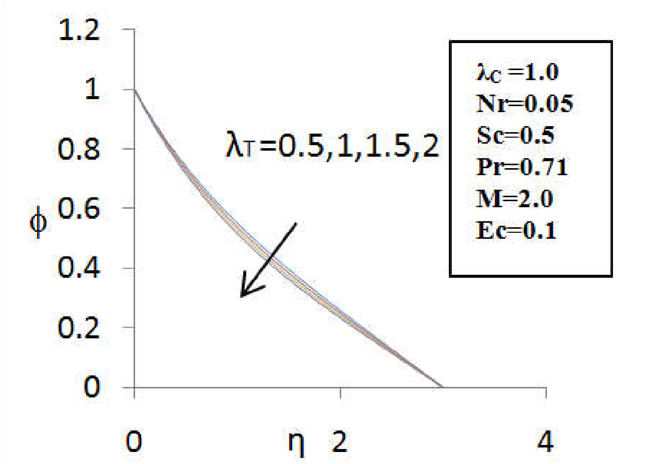

Fig 3: The effects of λT on Concentration profiles

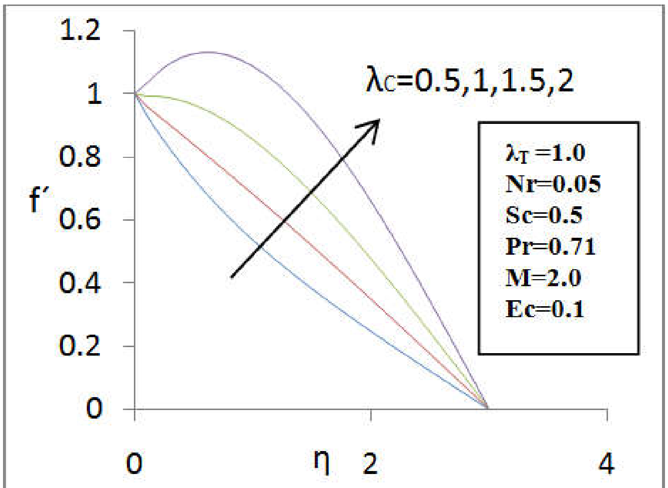

Fig 4: The effect of λc on Velocity profiles

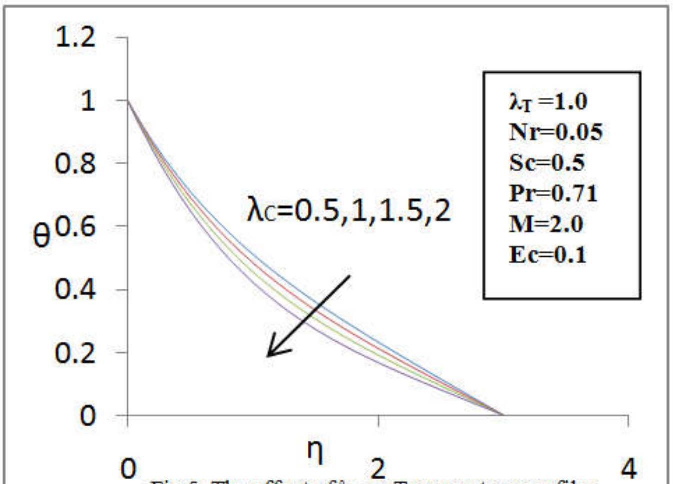

Fig 5: The effect of λc on Temperature profiles

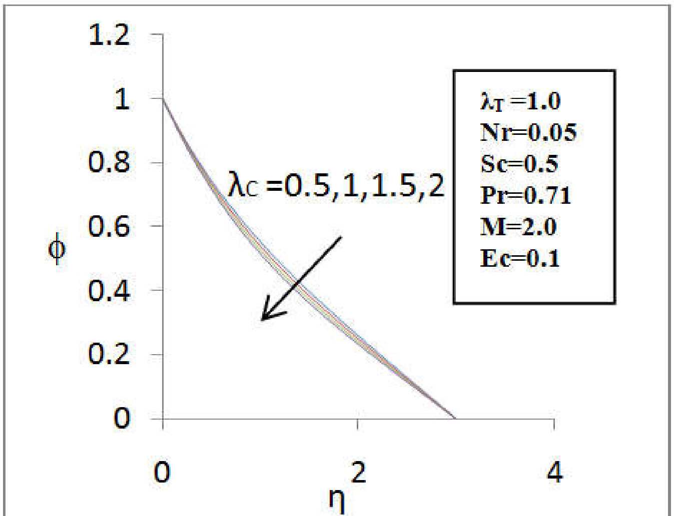

Fig 6: The effects of λc on Concentration profiles

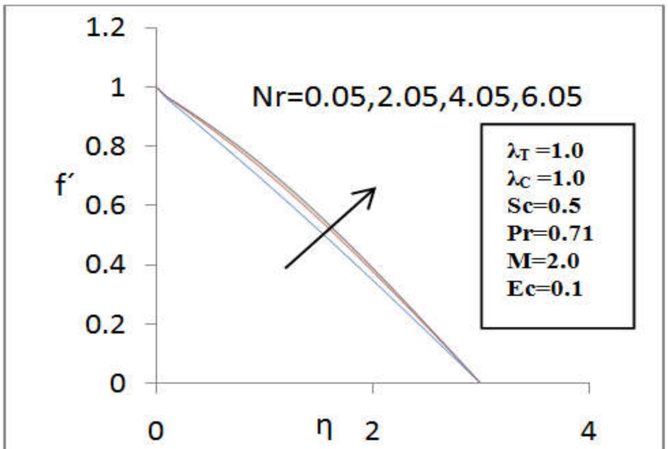

Fig 7: Velocity profiles for different values of Nr

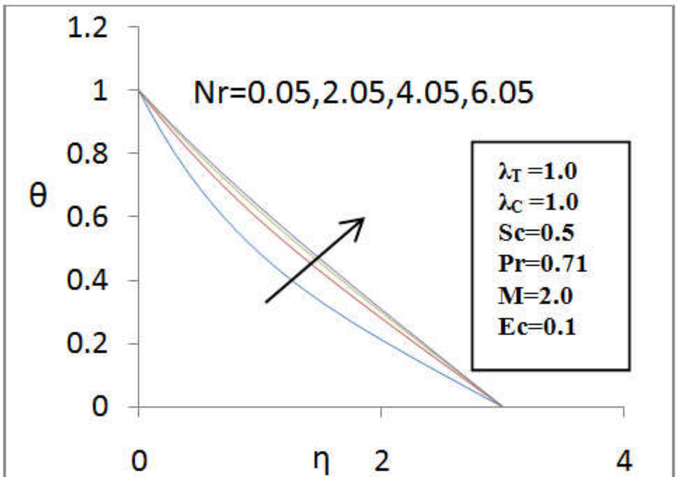

Fig 8: Temperature profiles for different values of Nr

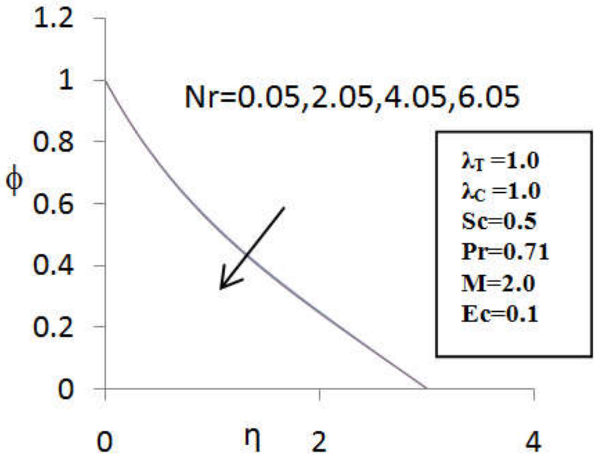

Fig 9: Concentration profiles for different values of Nr

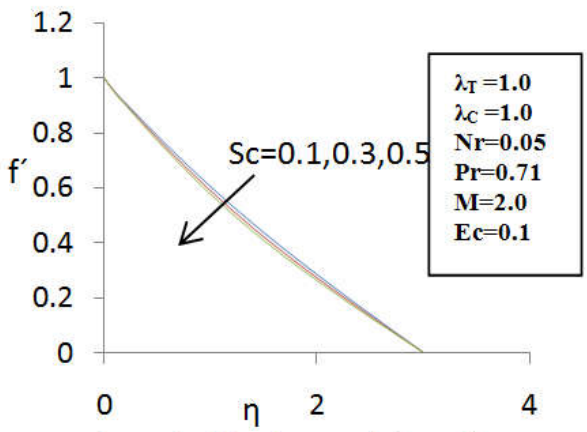

Fig 10: The effect of Sc on Velocity profiles

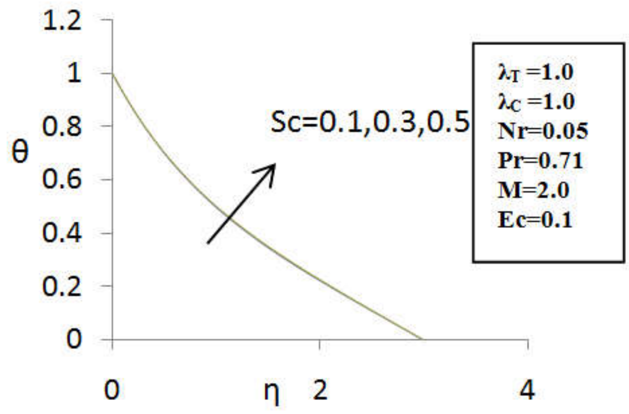

Fig 11: The effect of Sc on Temperature profiles

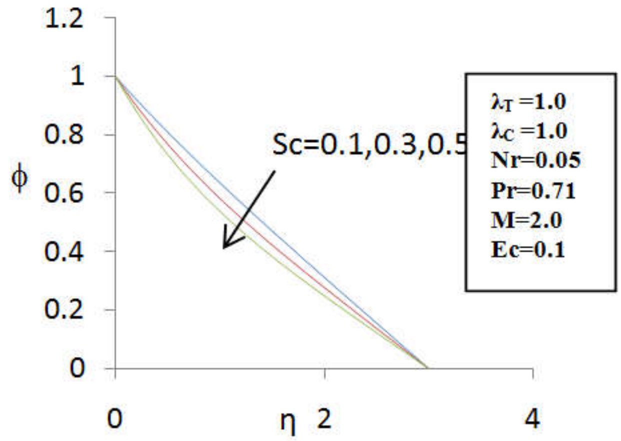

Fig12: The effect of Sc on Concentration profiles

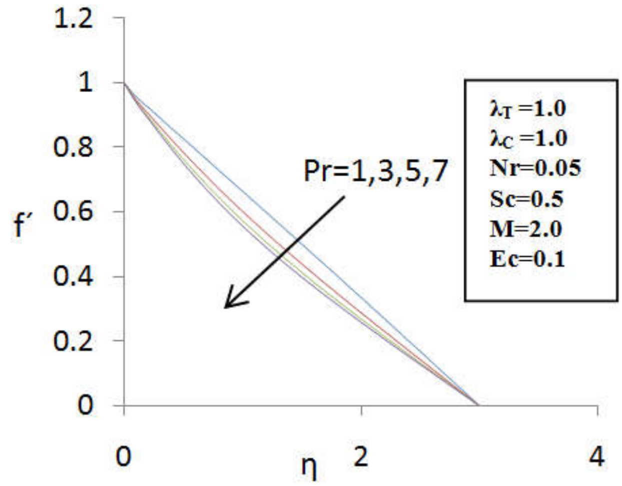

Fig13: The effect of Pr on Velocity profiles

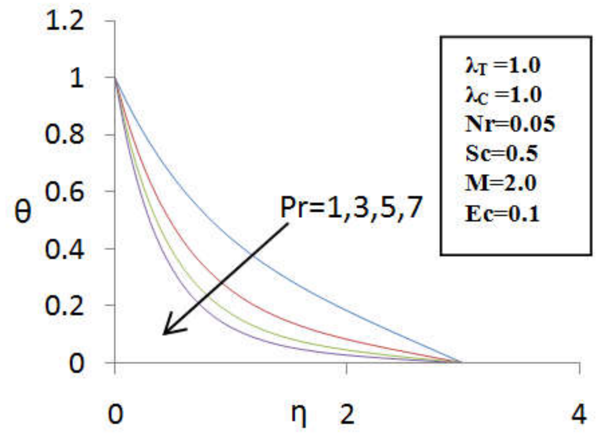

Fig14: The effect of Pr on Temperature profiles

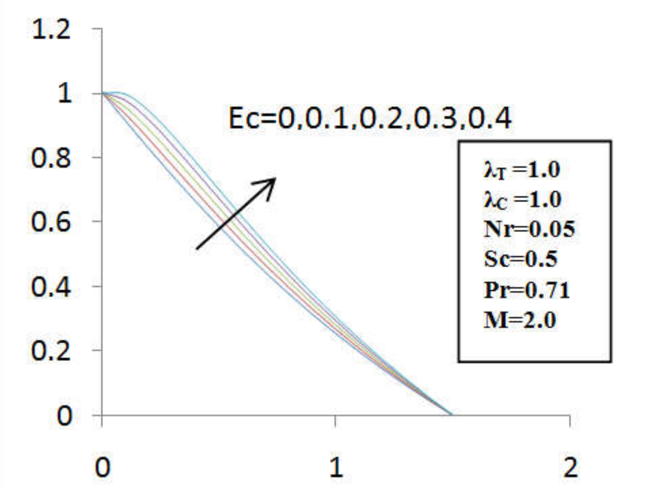

Fig15:The effect of Ec on temperature profiles

Fig. (1-6) demonstrates the dimensionless velocity, temperature and concentration profiles for different values of buoyancy parameters (λ_T, λ_C) with constant thermal radiation parameter, suction parameter, prandtl number, Eckert number and Schmidt number and the uniform magnetic field. It is seen that the velocity increases with the increase of buoyancy parameter, whereas temperature and concentration decreases.

Fig. (7-9) illustrates the dimensionless velocity, temperature and concentration profiles for different values of Thermal radiation parameter N_r with constant Buoyancy parameter, suction parameter, prandtl number, Eckert number and Schmidt number and the uniform magnetic field. It is seen that the velocity and temperature of fluid increases with the increase of N_r, whereas concentration decreases, but the variation in concentration is very less.

The effect of Schmidt number on the dimensionless velocity, temperature and concentration profiles for constant Buoyancy parameter, suction parameter, prandtl number, Eckert number and the uniform magnetic field are shown in Fig. (10-12). It is observed from the figures that velocity and concentration of fluid decreases and temperature increases with increase of Schmidt number.

Fig. (13-14) illustrates the dimensionless velocity and temperature profiles for different values of prandtl number with constant Buoyancy parameter, suction parameter, Eckert number, Schmidt number and the uniform magnetic field. It is seen that the velocity and temperature of fluid decreases with the increase of prandtl number.

Fig. (15) illustrates the dimensionless temperature profiles for different values of Eckert number with constant Buoyancy parameter, suction parameter, Schmidt number and the uniform magnetic field. It is seen that the temperature of fluid increases with the increase of Eckert number.

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