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Radiation effect on soret and dufour, MHD free convection heat and mass transfer in a doubly stratified darcy porous medium with viscous dissipation

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ABSTRACT

This paper analyzes the influence of thermal radiation on Soret and Dufour, steady MHD free convection heat and mass transfer from a vertical surface in a doubly stratified Darcy porous medium with viscous dissipation. The governing non–linear partial differential equations have been reduced to the coupled ordinary differential equations by the similarity transformations. The resulting equations are then solved numerically by using the implicit finite difference scheme. The effects of various parameters entering into the problem have been examined on the flow field. The non dimensional velocity, wall temperature and concentration profiles are displayed graphically and discussed in detail.

Introduction

Radiation and on the optical properties of the emitter, with its internal energy being converted to is the process of heat propagation by means of electromagnetic waves, depending only on the temperature radiation energy. The process involving the convection of internal energy of the solution in to radiation energy is known as radiation heat transfer. In contrast to the mechanism of conduction and convection, where energy transfer through a material medium is involved, heat also be transferred through regions where a perfect vacuum exists. The mechanism in this case is electromagnetic radiation. The electromagnetic radiation which is propagated as a result of temperature differences, this is called thermal radiation.

The effect of radiation on MHD flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effect can be quite significant. Many processes in engineering are as occur at high temperature and a knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. Olajuwon and Oahimire [1] have studied the effect of unsteady free convection heat and mass transfer in an MHD micropolar fluid in the presence of thermo diffusion and thermal radiation. Bala Anki Reddy and Bhaskar Reddy [2] investigated the thermal radiation effects on hydro-magnetic flow due to an exponentially stretching sheet. Singh and Shweta Agarwal [3] studied Heat transfer in a second grade fluid over an exponentially stretching sheet through porous medium with thermal radiation and elastic deformation under the effect of magnetic field. Makinde and Ogulu [4] discuss the effect of thermal radiation on the heat and mass transfer flow of a variable viscosity fluid past a vertical porous plate permeated by a transverse magnetic field. Vempati and Laxmi-Narayana-Gari [5] studied Soret and Dufour effects on unsteady MHD flow past an infinite vertical porous plate with thermal radiation. Shateyi and Petersen [6] discuss the effect of thermal radiation and buoyancy effects on heat and mass transfer over a semi-infinite stretching surface with suction and blowing. Chamkha *et al*. [7] studied radiation effects on free convection flow past a semi- infinite vertical plate with mass transfer.

Combined heat and mass transfer by free convection in a porous media has attracted considerable attention in the last several decades, due to its many important engineering and geophysical applications. A comprehensive review on this area have been made

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by many researchers some of them are Nield and Bejan [8] . Several studies have been found to analyze the influence of the combined heat and mass transfer process by natural convection in a thermal and /or mass stratified porous medium, owing to its wide applications, such as development of advanced technologies for nuclear waste management, hot dike complexes in volcanic regions for heating of ground water, separation process in chemical engineering, etc. Here stratified porous medium means that the ambient concentration of dissolved constituent and/or ambient temperature is not uniform and varies as a linear function of vertical distance from the origin. The importance of the Soret effect at a low Rayleigh number has been analyzed by Bergman and Srinivasan [9], while Hurle and Jakerman [10] Studied the thermo solutal convection due to a large temperature gradient. Effect of doubly stratification on free convection in Darcian porous medium have been studied by Murthy *et al.* [11]. The science of magneto hydrodynamics (MHD) was concerned with geophysical and astrophysical problems for a number of years. In recent years, the possible use of MHD is to affect a flow stream of an electrically conducting fluid for the purpose of thermal protection, braking, propulsion and control. From the point of applications, model studies on the effect of magnetic field on free convection flows have been made by several investigators. The quality of product depends on the rate of heat transfer and therefore cooling procedure has to be controlled effectively. The MHD flow in electrically conducting fluid can control the rate of cooling and the desired quality of product can be achieved. Sharma and Singh [12] studied the effect of variable thermal conductivity and heat source/sink on MHD flow near a stagnation point on a linearly stretching sheet.

Dursukanya and Worek [13] studied diffusion–thermo and thermal –diffusion effects in transient and steady natural convection from a vertical surface where as Kafoussias and Williams [15] studied the same effects on mixed free–forced convective and mass transfer boundary layer flow with temperature dependent viscosity. Partha *et al.* [14] studied the effect of magnetic field and double dispersion on free convection heat and mass transport considering the Soret and Dufour effects in a non – Darcy porous medium. The MHD free- convection and Mass Transfer flow with Hall current, viscous dissipation, Joule heating and thermal diffusion is studied by Singh [16]. Kishan *et al.* [17] studied the MHD free convection flow of an incompressible viscous dissipative fluid in an infinite vertical oscillating plate with constant heat flux. Anghel *et al.* [18] investigated the Dufour and Soret effects on free convection boundary layer over a vertical surface embedded in a porous medium. Postelnicu [19] studied numerically the influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Anjalidevi [20] investigated thermal radiation effect over an electrically conducting, Newtonian fluid in a steady laminar magneto hydrodynamic convective flow over a porous rotating infinite disk with the consideration of heat and mass transfer in the presence of Soret and Dufour effects. Stanford Shateyi *et al.* [21] investigated the influence of magnetic field on heat and mass transfer by mixed convection from vertical surface in the presence of Hall, radiation,Soret and Dufour effects.

Our aim is to extend the work of Lakshmi Narayana and Murthy [22]. They have neglected effect of MHD, Viscous dissipation and thermal radiation. The objective of the present paper is to analyze the effect of thermal radiation, viscous dissipation on free convection heat and mass transfer characteristics in a Darcian, fluid-saturated, doubly stratified porous medium under the influence of transversely applied magnetic field. The governing equations are transformed by using similarity transformation and the resultant dimensionless equations are solved numerically using the finite difference method. The effects of various governing parameters on the velocity, temperature, and concentration are shown in figures and analyzed in detail.

Mathematical Analysis

We consider the combined free convection heat and mass transfer from a vertical wall in a doubly stratified, fluid saturated, Darcy porous medium with thermal diffusion (Soret) and diffusion-thermo (Dufour) effects. Viscous resistance due to the solid boundary is neglected under the assumption that the medium has low permeability. The wall heat and mass fluxes are assumed to be constant, and the porous medium is vertically stratified with respect to both temperature and concentration. The non-uniform transverse magnetic field B_0 is imposed along the y-axis. The governing boundary layer equations, along with the equation of continuity, may written as

$$u_x + v_y = 0 \tag{1}$$

$$u - \frac{K\sigma\mu_e{}^2 H_0{}^2}{\rho} u = \frac{Kg}{\upsilon}\left\{\beta_T (T - T_\infty) + \beta_C (C - C_\infty)\right\} \tag{2}$$

$$uT_x + vT_y = \alpha T_{yy} + \frac{D_m k_T}{C_s C_p} C_{yy} + \mu\left(u_y\right)^2 - \frac{1}{\rho C_p} q_{r_y} \tag{3}$$

$$uC_x + vC_y = vC_{yy} + \frac{D_m k_T}{C_s C_p} T_{yy} \tag{4}$$

With the boundary conditions

$$\left.\begin{aligned} &y = 0 : v = 0, -kT_y = q_w, \ -DC_y = q_m \\ &y \to \infty : u \to 0, T = T_\infty(x), C = C_\infty(x) \end{aligned}\right\} \tag{5}$$

Thermal and solutal stratifications are considered to have the form

$$T_\infty(x) = T_{\infty,0} + Ax^{1/3}$$

$$C_\infty(x) = C_{\infty,0} + Bx^{1/3}$$

Where A and B are constants, varied to alter the intensity of stratification in the medium. The subscripts $w, (\infty, 0)$ and ∞ indicate the conditions at the wall, at some reference point in the medium, and at the outer edge of the boundary layer respectively.

Making use of the following similarity transformation derived using order magnitudes.

Using the Rosseland approximation for radiation Sparrow and Cess [23], radiative heat flux is simplified as

$$q_r = -\frac{4\sigma}{3\alpha^*}\frac{\partial T^4}{\partial y} \tag{5a}$$

Where σ and α^* are the Stefan-Boltzman constant and the mean absorption coefficient, respectively. We assume that the temperature differences within the flow are such that the term T^4 may be expressed as a linear function of temperature. Hence, expanding T^4 in a Taylor series about T_∞ and neglecting higher order terms we get:

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{5b}$$

Using equations (5a) and (5b) equation (3) becomes:

$$uT_x + vT_y = \alpha\ T_{yy} + \frac{D_m}{C_s}\frac{k_T}{C_p} C_{yy} + \frac{16\sigma T_\infty^3}{3\alpha^* \rho C_p} T_{yy} + \mu\left(u_y\right)^2 \tag{6}$$

Equations 1, 2, 4, 5, 6, are now nondimensionalized using the following quantities:

$$\left.\begin{aligned} &\eta = \frac{y}{x} Ra_x{}^{1/3}, \psi = \alpha Ra_x{}^{1/3} f(\eta) \\ &T - T_\infty(x) = \frac{q_w x}{k} Ra_x{}^{-1/3} \theta(\eta) \\ &C - C_\infty(x) = \frac{q_m x}{k} Ra_x{}^{-1/3} \varphi(\eta) \end{aligned}\right\}$$

(7)

(8)

Where the stream function ψ is defined in the usual way $u = \psi_y,\ v = -\psi_x$

The governing Equations 2, 6, 4 become

$$f''(1+M) = \theta' + N\phi' \tag{9}$$

$$\left(1+\frac{16}{3R}\right)\theta'' + D_f\varphi'' = \frac{1}{3}(\varepsilon_1 f' + f'\theta - 2f\theta') - E_c(f'')^2 \tag{10}$$

$$\varphi'' + S_r Le\theta'' = \frac{Le}{3}(\varepsilon_2 f' + f'\varphi - 2f\varphi') \tag{11}$$

and the boundary conditions (5) transform into

$$\left.\begin{array}{l} \eta = 0;\ f = 0,\ \theta' = -1,\ \ \phi' = -1 \\ \eta \to \infty;\ \ f' = 0,\ \ \theta = 0,\ \phi = 0 \end{array}\right\} \tag{12}$$

The Darcy-Rayleigh number $Ra_x = \dfrac{(K_g \beta_T q_w x^2)}{(\alpha v k)}$

The diffusivity ratio $Le = \dfrac{\alpha}{D}$

And the buoyancy ratio $N = \left(\dfrac{\beta_C q_m}{\beta_C q_w}\right)\left(\dfrac{k}{D}\right).$

($N > 0$ indicates aiding buoyancy, where both the thermal and solutal buoyancies are in the same directions, and $N < 0$ indicates opposing buoyancy, where the solutal buoyancy is in the opposite direction to the thermal buoyancy).

With specific forms for $T_\infty(x)$ and $C_\infty(x)$ considered in the present analysis, the thermal and solutal stratification parameters are given by

$\varepsilon_1 = \left(\dfrac{3k}{q_w}\right) Ra_x{}^{1/3}\left(\dfrac{\partial T_\infty}{\partial x}\right)$ and $\varepsilon_2 = \left(\dfrac{3k}{q_m}\right) Ra_x{}^{1/3}\left(\dfrac{\partial C_\infty}{\partial x}\right)$ both are constants.

$D_f = \left(\dfrac{Dk}{C_S C_P \alpha}\right)\left(\dfrac{q_m}{q_w}\right)$ is the Dufour parameter,

$S_r = \left(\dfrac{Dk}{C_S C_P \alpha}\right)\left(\dfrac{q_m}{q_w}\right)$ is the Soret parameter,

The magnetic parameter $M = \dfrac{K\sigma\mu_e{}^2 H^2{}_0}{\rho \quad q_w x} Ra_x^{\frac{1}{3}},$

The Eckert number $E_C = \dfrac{\mu^2 \alpha k}{q_w x^3} Ra_x,$

The Radiation parameter $R = \dfrac{\alpha^* \rho C_p}{\sigma T_\infty{}^3}.$

Mathematical Solution

The set of non-linear ordinary differential equations (9) - (11) with boundary conditions (12) have been solved numerically, by using Crack Nicolson implicit finite difference method. A step size of $\Delta\eta$ = 0.01 was selected to be satisfactory for a convergence criteria of 10^{-5} in all cases. The value of η_∞ was found to each iteration loop by the statement $\eta_\infty = \eta_\infty + \Delta\eta$. In order to see the effect of step size $\Delta\eta$ we ran the code for our model with two different step sizes $\Delta\eta$ = 0.01, $\Delta\eta$ = 0.001 and each case we found very good agreement between them. The convergence is achieved only in 100 iterations.

Result and discussion

Numerical calculations carried out for different values of $D_f, S_r, M, N, \varepsilon_1, \varepsilon_2, E_c, R$ The computation were carried out by the crack Nicolson finite difference method with the help of C-programming results are good agreement with the previous results Lakshmi Narayana and Murthy [22]. The effect of various parameters on the flow behavior some numerical calculations have been carried out for non-dimensional velocity f', temperature θ, and concentration ϕ. In Figure 1- 2 the velocity profiles f' are presented. For fixed $\varepsilon_1 = 0, \varepsilon_2 = 0, D_f = 0.09, S_r = 0.01,$ for the aiding buoyancies (N>0) for different parameters M, Le .The non dimensional velocity f' decreases with the increasing the value of Le, as indicated in Figure 1. It is also observed that the non dimensional velocity f' decreases with the increases of magnetic parameter M for the aiding buoyancy $(N = 1)$ from the Figure 2.

The non dimensional temperature profiles are plotted in the Figures 3- 11. For the following range of parameter $0 \le \varepsilon_1, \varepsilon_2 \le 0.5$; $0 \le Le \le 5$; $-0.1 \le N \le 1$ and $0 \le S_r$, $D_f < 0.5$ (to avoid change of sign of temperature concentration value in the boundary layer).

From the Figure 3 it is observed that the temperature profiles θ increases with the increase of Lewis number Le for aiding buoyancy $(N = 1)$, where as temperature profiles increases with the increases of magnetic parameter M for aiding buoyancy $(N = 1)$ is shown in Figure 4. In Figure 5, temperature profiles for aiding buoyancy $(N = 1)$ when $\varepsilon_1 < \varepsilon_2$ and $\varepsilon_1 > \varepsilon_2$ for different Soret number S_r is plotted. From this, an increasing in Soret number S_r is observed to decreases the temperature distribution when $\varepsilon_1 < \varepsilon_2$, where as the temperature profiles increases with the increase of Soret number when $\varepsilon_1 > \varepsilon_2$. The effect of Lewis number on the temperature profiles are shown in Figure 6, the temperature profiles θ increases with the increases of Lewis number Le for opposing buoyancy $(N = -0.5)$.The Figure 7 is plotted for temperature profiles for $(N = -0.5)$ (opposing buoyancy) for $\varepsilon_1 > \varepsilon_2$. It has been observed that the temperature profiles increases with the increase of S_r for $\varepsilon_1 > \varepsilon_2$ and fixed D_f = 0.09. With the increasing of Lewis number Le , the temperature profile decreases for $\varepsilon_1 > \varepsilon_2$.

Figure 8 is plotted for temperature profile for $(N = -0.5)$ (opposing buoyancy) for $\varepsilon_1 > \varepsilon_2$ and $\varepsilon_1 < \varepsilon_2$. It has been observed that the temperature profile increases with the increase of S_r for $\varepsilon_1 > \varepsilon_2$, $\varepsilon_1 < \varepsilon_2$ and fixed Le= 1 , D_f = 0.05. It is observed that when the medium is free from the stratification for fixed S_r, Le the temperature profiles decreases with increases of N , and increasing the Dufour parameter D_f decreases the temperature in both aiding and opposing buoyancies as shown in Figure 9.

From Figure 10, we observed that the increasing in viscous dissipation effects is leads to increases in temperature profile. From Figures 11 and 12 for both aiding and opposing buoyancy, it is observed that the effect of increasing in the radiation parameter is increases in the temperature profiles. The effect of the magnetic parameter increases the concentration profiles for aiding buoyancies is observed from Figure 13. From Figure 14, it is observed that with the increase of the Le concentration profiles decreases for aiding buoyancy. Soret effect on the concentration field is shown in Figures 15 and 16. With the increasing in the Soret number the concentration profiles increases for $\varepsilon_1 < \varepsilon_2$ and $\varepsilon_1 > \varepsilon_2$ and $\varepsilon_1 = \varepsilon_2$ is observed from Figures 15 and 16. The effect of radiation parameter on concentration profiles are plotted in Figures 17 and 18. It is observed that for both aiding and opposing buoyancies the increasing in the radiation parameter is increases in the concentration profiles.

Nomenclature

T -temperature

C -concentration

C_P -specific heat at constant pressure

C_S -concentration susceptibility

D_f -Dufour parameter

u, v -Velocity components in x and y directions respectively

υ - kinematic viscosity

α - thermal diffusivity

θ -dimension less temperature

ϕ -dimensionless concentration

K -permeability parameter

E_c -Eckert number

N -buoyancy ratio

β_T -coefficient of thermal expansion

β_C -coefficient of solutal expansion

ε_1 -thermal stratification parameter

ε_2 - solutal stratification parameter

k - thermal diffusion ratio

α^* -mean absorption coefficient

D –solutal diffusivity

x, y –cartesian co-ordinates

ψ –stream function

g -acceleration

q_w -constant heat flux

q_m -constant mass flux

Ra_x -Darcy-Reyleigh number

S_r -Soret parameter

Le -Lewis number

M -magnetic parameter

β_T -coefficient of thermal expansion

σ -Stefen-Boltzman constant

T_{∞} -free streem temperature

μ -dynamic viscosity of the fluid

η -similarity variable

R – Radiationparameter

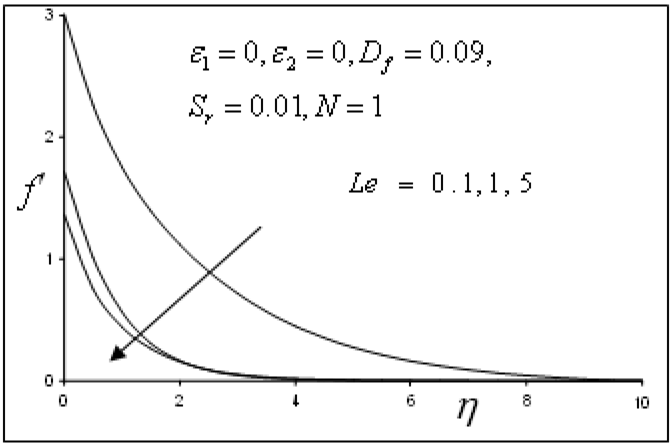

Figure 1: Velocity profiles for N=1 (aiding buoyancy)

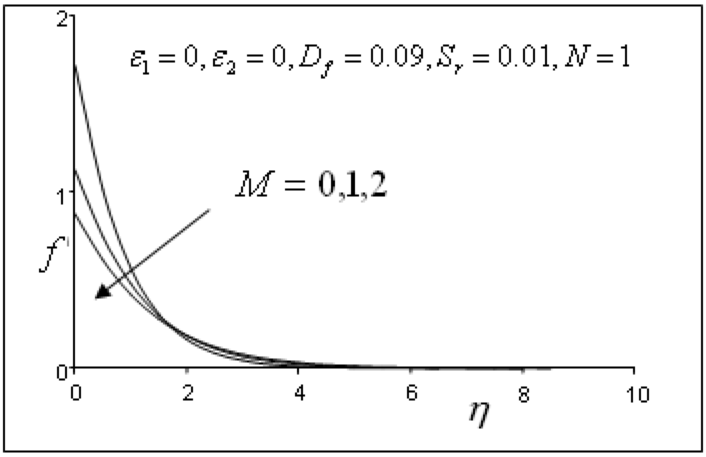

Figure 2: Velocity profiles for different magnetic parameter for N=1(aiding buoyancy)

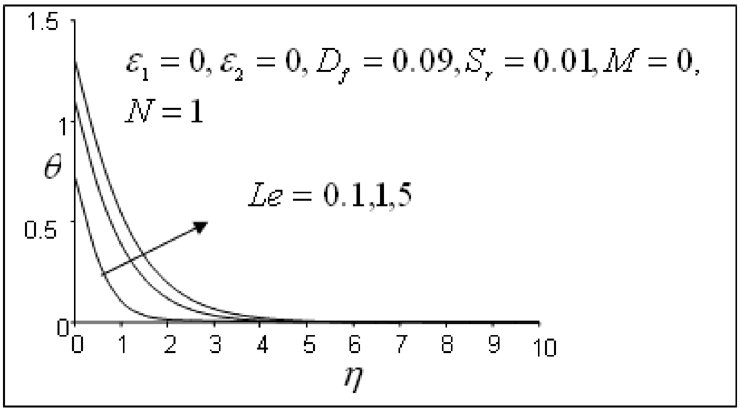

Figure 3: Temperature profiles for N=1(aiding buoyancy)

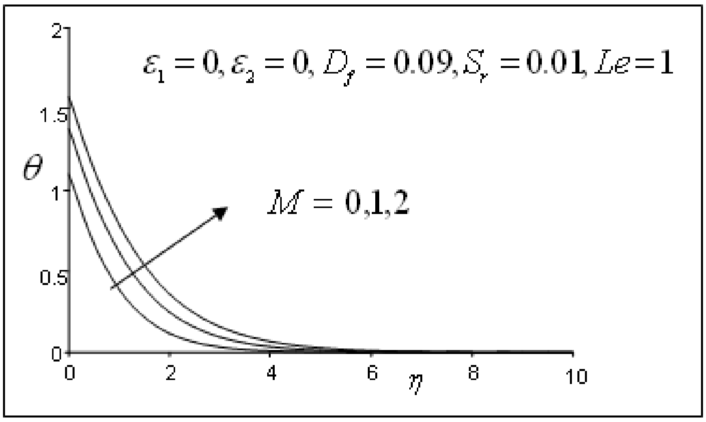

Figure 4: Temperature profiles for different magnetic parameter for N=1(aiding buoyancy)

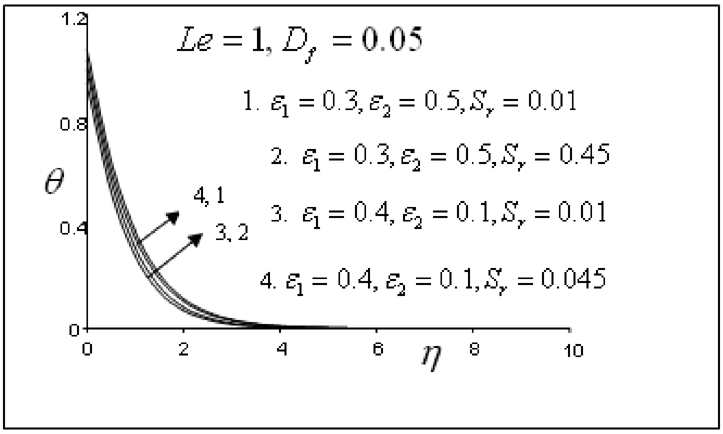

Figure 5: Temperature profiles for N=1(aiding buoyancy)

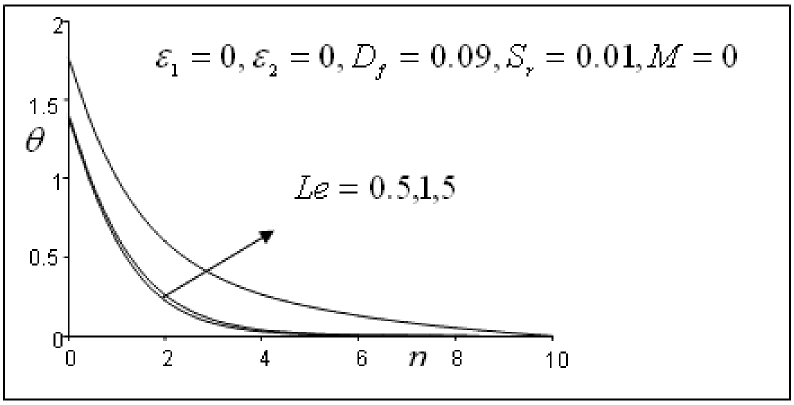

Figure 6: Temperature profiles for N=-0.5(opposing buoyancy)

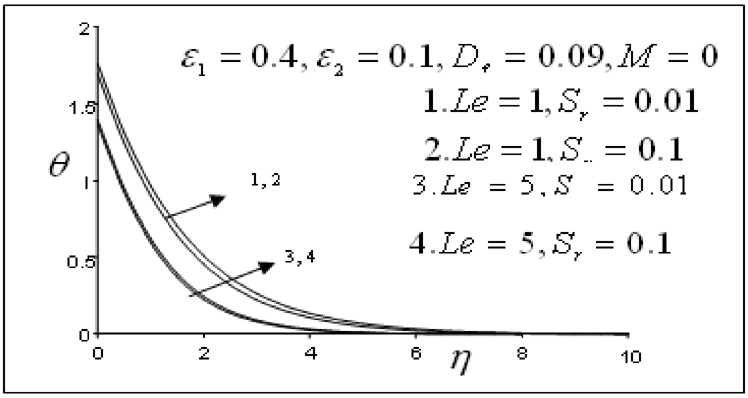

Figure 7: Temperature profiles for $\varepsilon_1 > \varepsilon_2$ for N=-0.5(opposing buoyancy)

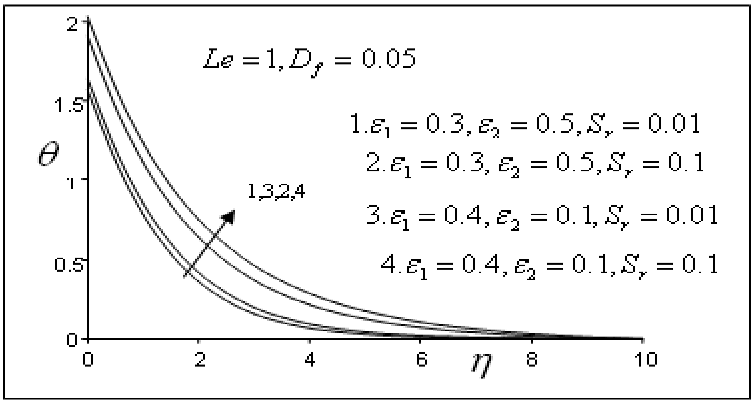

Figure 8: Temperature profiles for N=-0.5(opposing buoyancy)

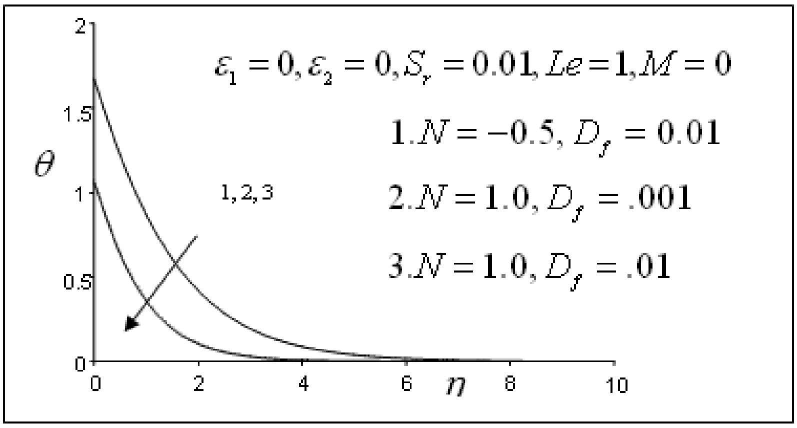

Figure 9: Variation of temperature both in aiding and opposing buoyancy

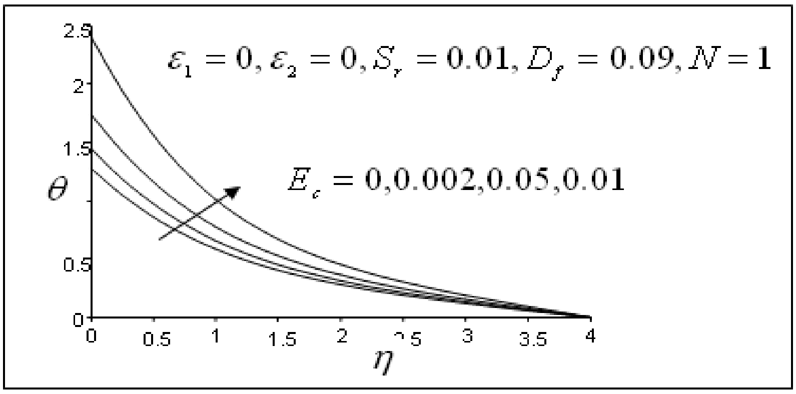

Figure 10: Variation of θ for different E_c parameter for $N=1$ (aiding buoyancy)

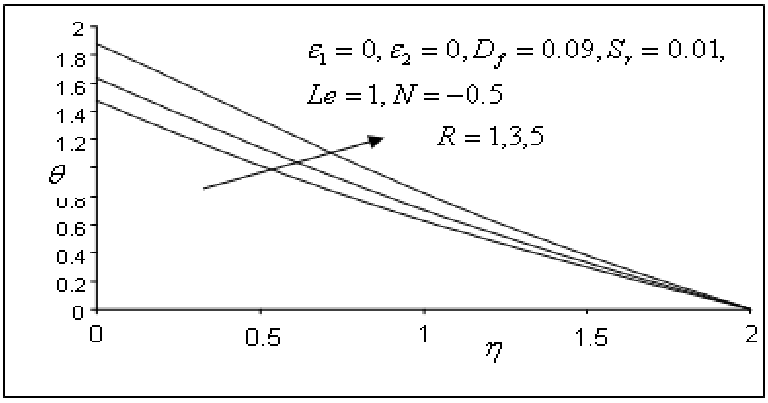

Figure 11: Variation of θ for different R parameter for $N=-0.5$ (opposing buoyancy)

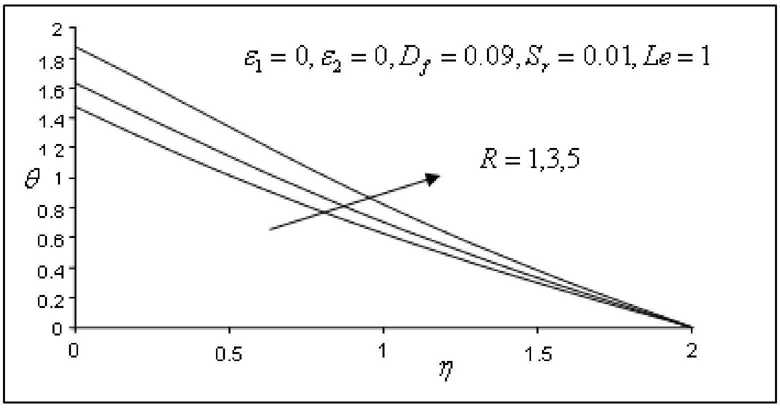

Figure 12: Variation of θ for different R parameter for $N = 1$(aiding buoyancy)

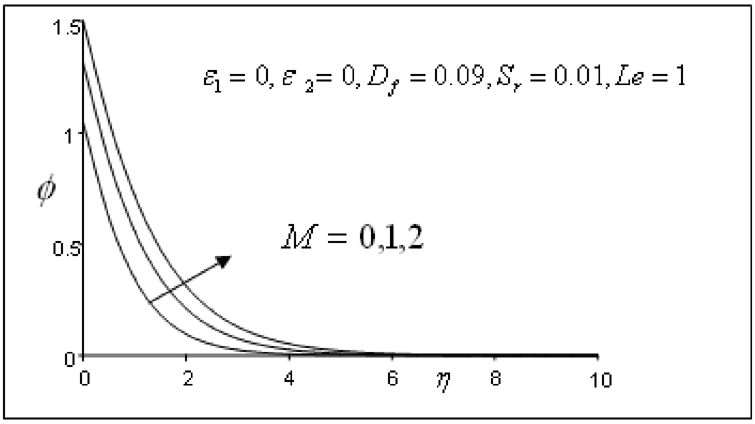

Figure 13: Concentration profiles for different magnetic parameter N=1(aiding buoyancy)

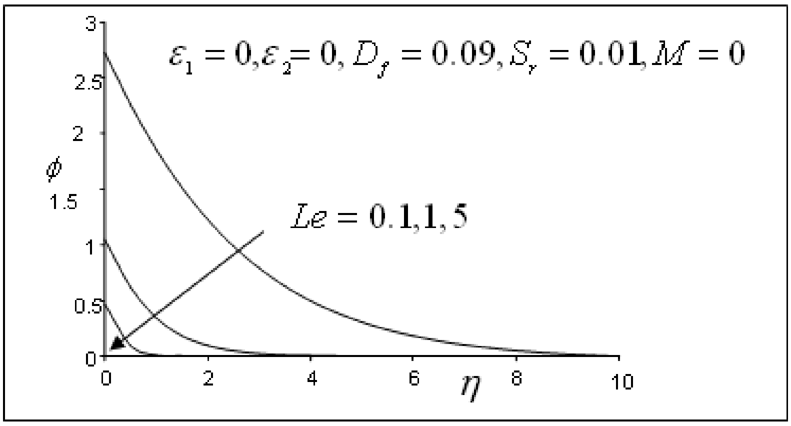

Figure 14: Concentration profile for N=1(aiding buoyancy)

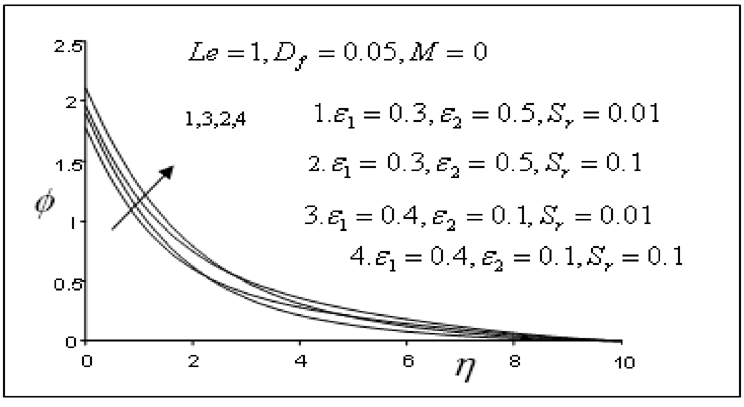

Figure 15: Concentration profiles for N=-0.5(opposing buoyancy)

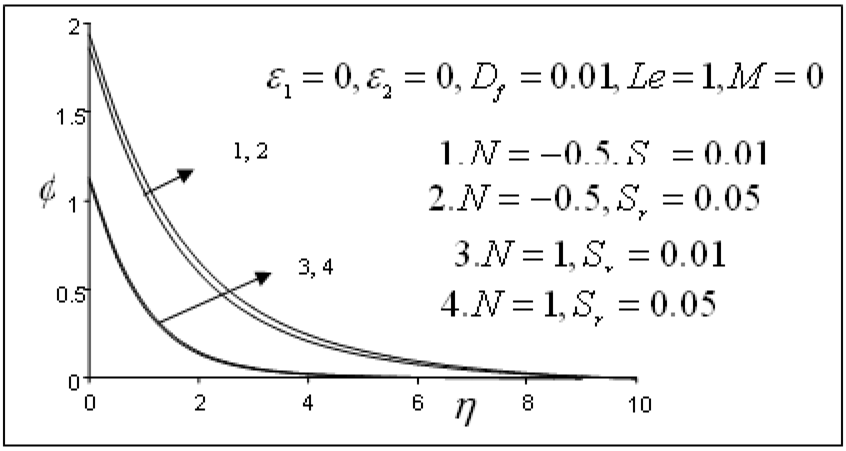

Figure 16: Variation of ϕ both opposing and aiding buoyancy

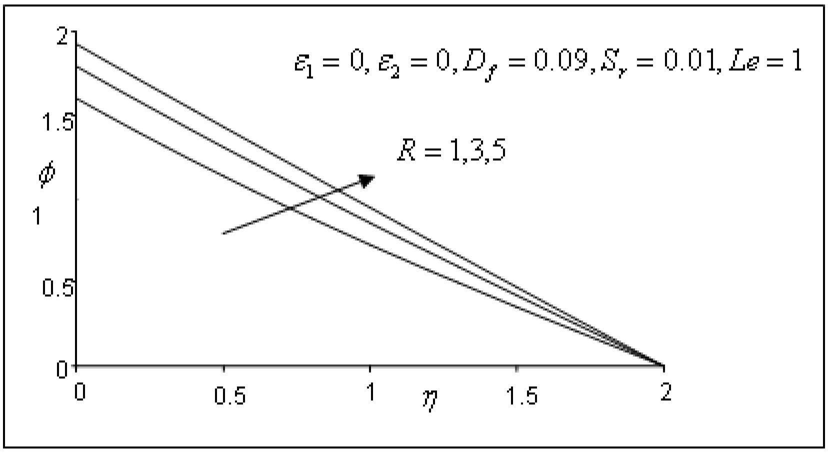

Figure 17: Variation of ϕ for different R parameter for $N = -0.5$ (opposing buoyancy)

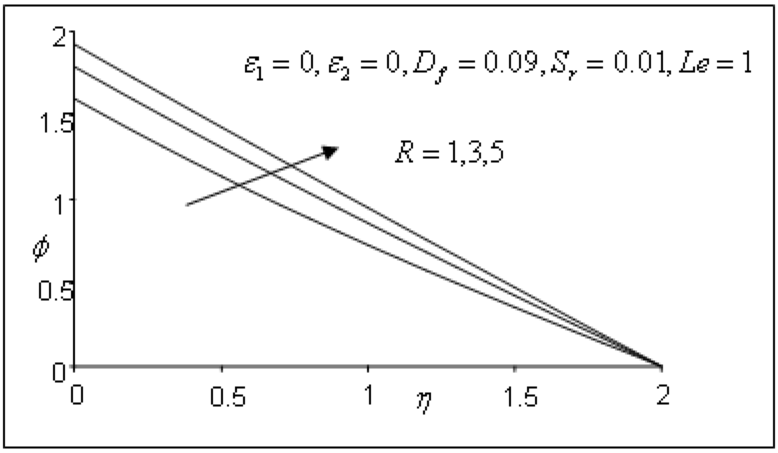

Figure 18: Variation of ϕ for different R parameter for $N = 1$ (aiding buoyancy)

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