Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 8s (2025)

MHD Three-Dimensional Porous Flow with Heat Source and Chemical Reaction: a Numerical Study

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Article History:

Received: *27-10-2024*

Revised:*26-11-2024*

Accepted:*28-12-2024*

Abstract:

In prior research on three-dimensional flow problems has predominantly focused on deriving analytical solutions. However, numerical studies addressing such three-dimensional flow problems are still relatively limited. So, In the present paper numerical attempt is made to study the impact of a heat source and chemical reaction on the free convection flow of a viscous, incompressible fluid within a porous medium, confined by an infinite vertical porous plate subject to constant suction and periodic permeability. A magnetic field is applied perpendicular to the flow. To solve this problem, the governing non-linear equations with boundary conditions are first transformed into ordinary and partial differential equations of zeroth and first order, respectively, using the perturbation method. Subsequently, the partial differential equations, which describe three-dimensional flow, are reduced to coupled non-linear differential equations using appropriate substitutions. These resulting coupled non-linear equations are then approximated into a system of equations via finite difference methods. The findings for the velocity and temperature profiles are presented and analyzed graphically. It is found that both velocity and temperature increase with the introduction of the heat source parameter.

Keywords: Heat source, Magnetic field; Porous medium; Periodic permeability; Finite deference scheme.

Introduction:

The combined heat and mass transfer process in porous media is attracting increasing interest due to its significant practical applications. These processes are commonly encountered in industries such as chemicals, reservoir engineering related to chemical recovery, and the study of hot and saline springs in the sea. Additional applications include the underground spread of chemicals and pollutants, grain storage, and evaporative cooling. In recent years, the issue of free convection flow through porous media has garnered considerable attention from researchers. Given these applications, a number of studies have been conducted by Raptis et al. [1-3] on steady flow past a vertical surface. Raptis [4] examined the unsteady flow through a porous medium bounded by an infinite porous plate under constant suction and variable temperature. Raptis and Perdikis [5] further explored the issue of free convective flow through a porous medium bounded by a vertical porous plate with constant suction, where the free stream velocity oscillates around a constant mean value.

In all the aforementioned studies, the permeability of the porous medium has been assumed to be constant. However, a porous material containing fluid is inherently non-homogeneous, and various in homogeneities may exist within the medium. As a result, the permeability of the porous medium may not always remain constant. Sing and Suresh Kumar [6] investigated free convective, two-dimensional, unsteady flow through a highly porous medium bounded by an infinite vertical porous plate, where the permeability of the medium fluctuates over time around a constant average value

Most researchers have focused primarily on two-dimensional flows, assuming either constant or time-dependent permeability of the porous medium. However, there are situations where the flow may be fundamentally three-dimensional, such as when the permeability distribution varies transversely to the potential flow. The impact of such a transverse permeability distribution in a porous medium bounded by a horizontal flat plate has been examined by Sing and Verma [7] and Singh et al. [8]. Singh and Sharma [9] explored three-dimensional free convective flow and heat transfer through a porous medium with periodic permeability. N.K. Vershney et al. [10] investigated the mass transfer effects on three-dimensional free convective flow through a porous medium with periodic permeability. Additionally, Jain et al. [11] analyzed the effects of periodic temperature and periodic permeability on three-dimensional free convective flow through a porous medium in the slip flow regime. Srihari and Anandrao [12] studied the influence of a magnetic field on three-dimensional free convective flow through a porous medium with periodic permeability

In many of the previous studies, the effect of a heat source does not appear to have been given significant attention, despite its crucial role in maintaining heat transfer at the desired level in applications such as nuclear power plants, gas turbines, and various propulsion systems for aircraft, missiles, satellites, and space vehicles. Furthermore, in all the previous three-dimensional studies, significant emphasis was placed on obtaining an analytical solution. Additionally, numerical investigations related to such types of three-dimensional flow problems remain quite limited. Therefore, in the present paper, a numerical attempt is made to investigate the influence of heat source and chemical reaction on free convection flow of a viscous, incompressible fluid through a porous medium bounded by an infinite vertical porous plate with constant suction. A uniform magnetic field is applied perpendicular to the fluid flow.

To derive an approximate solution and better understand the physics of the problem, the non-linear boundary value problem is first transformed into ordinary and partial differential equations of zeroth and first order, respectively, using the perturbation method. Since obtaining an exact solution for the partial differential equations with boundary conditions is highly challenging, appropriate substitutions are made to simplify these equations into coupled non-linear ordinary differential equations. These equations are then solved numerically using the finite difference method

Mathematical analysis:

We now consider the flow of a viscous fluid through a highly porous medium bounded by an infinite vertical porous plate with constant suction. The plate is positioned vertically in the x*-z* plane, with the x*-axis aligned along the plate in the upward direction. The y*-axis is taken normal to the plane of the plate and directed into the fluid flowing laminar with a uniform free stream velocity U. As the plate is considered infinite in the x*-direction, all physical quantities will be independent of x*. A magnetic field of uniform strength is applied perpendicular to the flow, along the $-y^*$ axis.

The permeability of the porous medium is assumed to have the form

$$K^*(z^*) = \frac{K_0^*}{(1+\varepsilon\cos \pi z^*/L)} \tag{1}$$

Here, k represents the mean permeability of the medium, L is the wavelength of the permeability distribution, and ε (<<1) is the amplitude of the permeability variation. This variation in permeability makes the problem three-dimensional. All fluid properties are assumed to be constant, except that the effect of density variation with temperature and concentration is considered only in the body force term. The influence of fluid saturation and spatial variation on permeability is neglected and not addressed in this context

Thus, denoting the velocity components by u^*, v^*, w^* in the respective directions, and the temperature by T^* and concentration by C^*, the flow through a highly porous medium is governed by the following non-dimensional equations

$$\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{2}$$

$$v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = Gr\,\mathrm{Re}\,\theta + Gm\,\mathrm{Re}\,\phi + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) - \frac{(u-1)\,(1+\varepsilon\cos\pi z)}{\mathrm{Re}\,K_0} - \frac{M^2}{\mathrm{Re}}u \tag{3}$$

$$v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) - \frac{(1+\varepsilon\cos\pi z)\,v}{\mathrm{Re}\,K_0} \tag{4}$$

$$v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) - \frac{(1+\varepsilon\cos\pi z)w}{\mathrm{Re}\,K_0} - \frac{M^2}{\mathrm{Re}}w \tag{5}$$

$$v\frac{\partial \theta}{\partial y} + w\frac{\partial \theta}{\partial z} = \frac{1}{\mathrm{Re}\,\mathrm{Pr}}\left(\frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2}\right) + \frac{S}{\mathrm{Re}\,\mathrm{Pr}}\theta \tag{6}$$

$$v\frac{\partial \phi}{\partial y} + w\frac{\partial \phi}{\partial z} = \frac{1}{\mathrm{Re}\,Sc}\left(\frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2}\right) - Ch\phi \tag{7}$$

with boundary conditions in non-dimensional form :

$$y = 0;\ u = 0,\ v = -1,\ w = 0,\ \theta = 1,\ \phi = 1 \tag{8}$$

$$y \to \infty;\ u \to 1,\ w \to 1,\ p \to p_\infty,\ \theta \to 0,\ \phi \to 0$$

where

$$y = \frac{y^*}{L}, \neq \quad z = \frac{z^*}{L},\ u = \frac{u^*}{U},\ v = \frac{v^*}{V},\ w = \frac{w^*}{V},$$

$$p = \frac{p^*}{\rho U^2},\ \theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty},\ \phi = \frac{C^* - C^*_\infty}{C^*_w - C^*_\infty},$$

$$Gr = \frac{\upsilon g\beta\left(T^*_w - T^*_\infty\right)}{UV^2} \text{ (Grashof number)},\ Ch = \frac{\overline{Ch}.L}{V}$$

$$Gm = \frac{\upsilon g\beta^*\left(C^*_w - C^*_\infty\right)}{UV^2} \text{ (Modified Grashof number)}$$

$$\mathrm{Re} = \frac{VL}{\upsilon} \text{ (Reynolds number)},\ \mathrm{Pr} = \frac{\mu C_p}{k} \text{ (Prandtl number)}$$

$$Sc = \frac{\upsilon}{D} \text{ (Schmidt number)}, \quad K_0 = \frac{K_0^*}{L^2} \text{ (Permeability parameter)}$$

$$M = B_0 L\sqrt{\frac{\sigma}{\mu}} \text{ (Magnetic parameter)}, \quad S = \frac{QL^2}{k} \text{ (Heat source parameter)}$$

To solve the above equations, we assume the solution takes the following form, given that the amplitude $\varepsilon(\langle\langle 1)$ is very small:

$$f(y, z) = f_0(y) + \varepsilon f_1(y, z) + \varepsilon^2 f_2(y, z) + \ldots \tag{9}$$

where f stands for u, v, w, p, θ and ϕ.

When ε is considered small, equations (2) to (7) are reduced to two-dimensional free convective flow through a porous medium with constant permeability, described by the following equations:

$$\frac{dv_0}{dy} = 0 \tag{10}$$

$$\frac{d^2 u_0}{dy^2} - v_0 \operatorname{Re}\frac{du_0}{dy} - \left(M^2 + \frac{1}{K_0}\right)u_0 = -Gr\operatorname{Re}^2\theta_0 - Gm\operatorname{Re}^2\phi_0 - \frac{1}{K_0} \tag{11}$$

$$\frac{d^2\theta_0}{dy^2} - v_0 \operatorname{Re}\Pr\frac{d\theta_0}{dy} + S\theta_0 = 0 \tag{12}$$

$$\frac{d^2\phi_0}{dy^2} - v_0 \operatorname{Re} Sc\frac{d\phi_0}{dy} - Ch.\operatorname{Re}.Sc.\phi_0 = 0 \tag{13}$$

The corresponding boundary conditions are reduced to:

$$y = 0;\ u_0 = 0,\ v_0 = -1,\ \theta_0 = 1,\ \phi_0 = 1 \tag{14}$$

$$y \to \infty;\ u_0 \to 1,\ p_0 \to p_\infty,\ \theta_0 \to 0,\ \phi_0 \to 0$$

The solutions of equations (10) to (13) under the boundary conditions (14) are expressed as:

$$u_0 = 1 + (Gr\lambda_0 + Gm\lambda_1 - 1).\, e^{-\bar{R}y} - Gr\lambda_0 e^{-ry} - Gm\lambda\, e^{-r_1 y}$$

$$\theta_0 = e^{-ry}, \qquad \phi_0 = e^{-r_1 y}$$

with

$$v_0 = -1,\ w_0 = 0 \text{ and } p_0 = p_\infty$$

where

$$\lambda_0 = \frac{\operatorname{Re}^2}{r^2 - \operatorname{Re} r - \left(M^2 + \frac{1}{K_0}\right)}, \quad r = \frac{\operatorname{Re}\Pr + \sqrt{\operatorname{Re}^2\Pr^2 - 4S}}{2} \quad \bar{R} = \frac{\operatorname{Re}}{2} + \sqrt{\frac{\operatorname{Re}^2}{4} + M^2 + \frac{1}{K_0}}$$

$$r_1 = \frac{\operatorname{Re} Sc + \sqrt{\operatorname{Re}^2 Sc^2 + 4Ch.\operatorname{Re}.Sc}}{2} \qquad \lambda_1 = \frac{\operatorname{Re}^2}{\operatorname{Re}^2 Sc(Sc-1) - \left(M^2 + \frac{1}{K_0}\right)},$$

When substituting equation (9) into equations (2) to (7) and comparing the coefficients of identical powers of ε (with higher-order terms $\varepsilon^2, \varepsilon^3$,........neglected since ε is small), the following equations are obtained:

$$\frac{\partial v_1}{\partial y} + \frac{\partial w_1}{\partial z} = 0 \tag{15}$$

$$v_1 \frac{\partial u_0}{\partial y} - \frac{\partial u_1}{\partial y} = Gr \operatorname{Re} \theta_1 + Gm \operatorname{Re} \phi_1 + \frac{1}{\operatorname{Re}}\left(\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial^2 u_1}{\partial z^2}\right) - \frac{(u_0 - 1)\varepsilon \cos \pi z + u_1}{\operatorname{Re} K_0} - \frac{M^2}{\operatorname{Re}} u_1 \tag{16}$$

$$-\frac{\partial v_1}{\partial y} = -\frac{\partial p_1}{\partial y} + \frac{1}{\operatorname{Re}}\left(\frac{\partial^2 v_1}{\partial y^2} + \frac{\partial^2 v_1}{\partial z^2}\right) - \frac{(v_1 - \cos \pi z)}{\operatorname{Re} K_0} \tag{17}$$

$$-\frac{\partial w_1}{\partial y} = -\frac{\partial p_1}{\partial z} + \frac{1}{\operatorname{Re}}\left(\frac{\partial^2 w_1}{\partial y^2} + \frac{\partial^2 w_1}{\partial z^2}\right) - \frac{w_1}{\operatorname{Re} K_0} - \frac{M^2}{\operatorname{Re}} w_1 \tag{18}$$

$$v_1 \frac{\partial \theta_0}{\partial y} - \frac{\partial \theta_1}{\partial y} = \frac{1}{\operatorname{Re} \Pr}\left(\frac{\partial^2 \theta_1}{\partial y^2} + \frac{\partial^2 \theta_1}{\partial z^2}\right) + \frac{S}{\operatorname{Re} \Pr} \theta_1 \tag{19}$$

$$v_1 \frac{\partial \phi_0}{\partial y} - \frac{\partial \phi_1}{\partial y} = \frac{1}{\operatorname{Re} Sc}\left(\frac{\partial^2 \phi_1}{\partial y^2} + \frac{\partial^2 \phi_1}{\partial z^2}\right) - Ch \phi_1 \tag{20}$$

with the boundary conditions:

$$y = 0;$$

$$u_1 = 0,\ v_1 = 0,\ w_1 = 0,\ \theta_1 = 0,\ \phi_1 = 0 \tag{21}$$

$$y \to \infty;\ u_1 \to 0,\ w_1 \to 0,\ p_1 \to 0,\ \theta_1 \to 0,\ \phi_1 \to 0$$

Equations (15) to (20) are the partial differential equations that describe free convective three-dimensional flow. To solve these equations, we separate the variables y and z in the following manner..

$$v_1(y, z) = -v_{11}(y) \cos \pi z \tag{22}$$

$$w_1(y, z) = \frac{1}{\pi} v'_{11}(y) \sin \pi z \tag{23}$$

$$p_1(y, z) = p_{11}(y) \cos \pi z \tag{24}$$

Using equations (22), (23), and (24) in equations (17) and (18) and eliminating the terms, we obtain:

$$\frac{d^4 v_{11}}{dy^4} + \operatorname{Re} \frac{d^3 v_{11}}{dy^3} - \left(M^2 + \frac{1}{K_0} + 2\pi^2\right)\frac{d^2 v_{11}}{dy^2} - \operatorname{Re} \pi^2 \frac{d v_{11}}{dy} + \left(\pi^4 + \frac{\pi^2}{K_0}\right) v_{11} = -\frac{\pi^2}{K_0} \tag{25}$$

The corresponding boundary conditions are

$$\begin{aligned} &y=0: v_{11}=0,\ v'_{11}=0 \\ &y\to\infty: v_{11}=0 \end{aligned} \quad . \tag{26}$$

In order to solve the differential equations (16), (19), and (20) for *u* and *v*, respectively, the following assumptions are made:

$$u_1(y,z)=u_{11}(y)\cos\pi z \tag{27}$$

$$\theta_1(y,z)=\theta_{11}(y)\cos\pi z \tag{28}$$

$$\phi_1(y,z)=\phi_{11}(y)\cos\pi z\ . \tag{29}$$

Substituting the above equations in (16), (19) and (20), the following equations are obtained:

$$u''_{11}+\mathrm{Re}\,u'_{11}-\left(M^2+\frac{1}{K_0}+\pi^2\right)u_{11}=-\mathrm{Re}\,v_{11}u'_0-Gr\,\mathrm{Re}^2\,\theta_{11}-Gm\,\mathrm{Re}^2\,\phi_{11}+\frac{u_0-1}{K_0} \tag{30}$$

$$\theta''_{11}+\mathrm{Re}\,\mathrm{Pr}\,\theta'_{11}-(\pi^2-S)\theta_{11}=-\mathrm{Re}\,\mathrm{Pr}\,v_{11}\theta'_0 \tag{31}$$

$$\phi''_{11}+\mathrm{Re}\,Sc\phi'_{11}-(Ch\,\mathrm{Re}\,Sc+\pi^2)\phi_{11}=-\mathrm{Re}\,Sc\,v_{11}\,\phi'_0 \tag{32}$$

with corresponding boundary conditions

$$\begin{aligned} &y=0:\quad u_{11}=0,\ \theta_{11}=0,\ \phi_{11}=0 \\ &y\to\infty: u_{11}\to 0,\ \theta_{11}\to 0,\ \phi_{11}\to 0\,. \end{aligned} \tag{33}$$

By employing finite difference schemes in equation (25), we obtain:

$$A_1v_{11}(i+2)-A_2v_{11}(i+1)+A_3v_{11}(i)-A_4v_{11}(i-1)+A_5v_{11}(i-2)+2\frac{\pi^2h^4}{K_0}=0 \tag{34}$$

where $A_1=2+\mathrm{Re}\,h$, $A_2=8+2\mathrm{Re}h+2h^2\left(M^2+\frac{1}{K_0}+2\pi^2\right)+\mathrm{Re}h^3\pi^2$

$$A_3=12+4h^2\left(M^2+\frac{1}{K_0}+2\pi^2\right)+2h^4\left(\pi^4+\frac{\pi^2}{K_0}\right)$$

$$A_4=8-2\mathrm{Re}h+2h^2\left(M^2+\frac{1}{K_0}+2\pi^2\right)-\mathrm{Re}h^3\pi^2,\quad A_5=2-\mathrm{Re}\,h\,.$$

By applying finite difference schemes to equations (30) to (32), we obtain the following equations

$$A_1u_{11}(i+1)-B_1u_{11}(i)+A_5u_{11}(i-1)=B(i) \tag{35}$$

$$D_1\theta_{11}(i+1)-D_2\theta_{11}(i)+D_3\theta_{11}(i-1)=D(i) \tag{36}$$

$$E_1\phi(i+1)-E_2\phi(i)+E_3\phi(i-1)=E(i) \tag{37}$$

where $A_1, A_5, \lambda_0, \lambda_1$ *and* $\overline{R}$ have already been defined and

$$D_1 = 2 + \mathrm{Re}\,\mathrm{Pr}\,h\,,\ D_2 = 4 + 2(\pi^2 - S)h^2\,,\quad D_3 = 2 - \mathrm{Re}\,\mathrm{Pr}\,h \qquad E_2 = 4 + 2h^2(\pi^2 + Ch\ \mathrm{Re}\ Sc),$$

$$D(i) = 2(h\,\mathrm{Re}\,P_r)^2 v_{11}(i)e^{-\mathrm{Re}\,\mathrm{Pr}\,ih}\,,\quad E_1 = 2 + \mathrm{Re}\,Sch\ ,\ E_3 = 2 - \mathrm{Re}\,Sc\,h$$

$$E(i) = 2(h\,\mathrm{Re}\,Sc)^2 v_{11}(i)e^{-\mathrm{Re}\,Scih}\,,\ B_1 = 4 + 2h^2\left(M^2 + \frac{1}{K_0} + \pi^2\right)$$

$$B(i) = -R_e v_{11}(i)B_2(i) - 2(h\,\mathrm{Re})^2\left(Gr\theta(i) + Gm\phi(i)\right) + \frac{2h^2}{K_0}B_3(i)$$

$$B_2(i) = Gr\lambda_0\,\mathrm{Re}\,\mathrm{Pr}\,e^{-\mathrm{Re}\,\mathrm{Pr}\,ih} + Gm\lambda_1\,\mathrm{Re}\,Sce^{-\mathrm{Re}\,Scih} - \bar{R}\left(Gr\lambda_0 + Gm\lambda_1 - 1\right)e^{-\bar{R}ih}$$

$$B_3(i) = -Gr\lambda_0 e^{-\mathrm{Re}\,\mathrm{Pr}\,ih} - Gm\lambda_1 e^{-\mathrm{Re}\,Scih} + \left(Gr\lambda_0 + Gm\lambda_1 - 1\right)e^{-\bar{R}ih}\,.$$

Equations (34), (35), (36), and (37) have been solved using the Gauss-Seidel iteration method, with the numerical code implemented in C. To verify the convergence of the finite difference scheme, computations were carried out for a slightly altered value of h, and the iterations continued until a specified tolerance 10^{-8} was reached. No significant changes were observed in the numerical values of the velocity and temperature profiles. Therefore, it is concluded that the finite difference scheme is both convergent and stable**.**

Results and discussion:

To gain physical insight into the problem, the three-dimensional free-convection flow of a viscous incompressible fluid between two infinite horizontal parallel porous flat plates with a heat source is solved approximately using finite difference and perturbation methods. The effects of the key controlling parameters, which appear in the governing equations, are discussed graphically in the context of the heat source.

Figure (1) illustrates the effect of the magnetic parameter M on the velocity field *u* in the presence of a heat source. From the figure, it is observed that increasing values of the magnetic parameter lead to a decrease in the flow velocity due to the Lorentz force, which acts in opposition to the flow when the magnetic field is applied perpendicular to the fluid flow. This resistive force slows down the flow, thereby reducing the velocity in the field.

Figure (2) shows that an increase in the cross-flow Reynolds number results in an increase in the velocity of the flow. Additionally, it is observed that in the presence of a heat source, the fluid velocity increases because the heat source in an electrically conducting fluid generates internal heat. In Figure (4), the effect of the free convection parameter Gr on the velocity field *u* is displayed by the curves, both with and without the heat source. It is observed that an increase in the Grashof number *Gr* leads to an increase in velocity. This is because a higher thermal Grashof number enhances the thermal buoyancy effect, which in turn raises the flow velocity. Furthermore, it is noteworthy that the fluid velocity increases when the heat source parameter is present.

Figure (3) illustrates the effect of the heat source parameter *S* on the velocity field *u*, while Figure (6) shows the temperature profile (**θ**) for different values of Reynolds number (Re) in the presence of a heat source. It is evident that both the temperature and velocity of the fluid increase with increasing values of the heat source parameter. This is because internal heat generation increases the rate of heat transfer to the fluid, which in turn raises the velocity of the flow particles. Furthermore, Figure (6) indicates that the temperature decreases as the cross-flow Reynolds number increases.

Figure (5) depicts the temperature profile (**θ**) for different values of the Prandtl number (Pr) in the presence of a heat source. A comparative analysis of the graph shows that increasing values of the Prandtl number lead to a decrease in the temperature of the fluid, as fluids with higher Prandtl numbers have relatively lower thermal conductivity. Additionally, this figure highlights a significant increase in the main flow velocity of the fluid with rising values of the heat source parameter.

From equation (7), it is observed that the concentration of the fluid decreases with increasing values of the chemical reaction parameter *Ch*. This is because the contribution from the chemical reaction parameter is directly dependent on the strength of the electrolytes, which in turn affects the absorption or adsorption effects.Figures (8) reveal that the velocity of the flow increases with an increase in GM. This is due to the reality that with the increasing values mass Grashof number has the tendency to increase the thermal and mass buoyancy effect

CONCLUSIONS

The following **conclusions** have been drawn from the above results:

1. The temperature of the fluid increases due to the heat source parameter, which consequently leads to an increase in the main flow velocity of the fluid particles. For the case of Re = 2.0, the effect of the heat source on both velocity and temperature is more significant compared to the case of Re = 5.0..

Nomenclature

g- Acceleration due to gravity, β - Coefficient of volumetric thermal expansion, β^* - Coefficient of mass expansion, p^* - Pressure, ρ -Density, υ - Kinematics viscosity, μ -**Viscosity** , **k-** Thermal conductivity, C_p -Specific heat at constant pressure, D -Concentration diffusivity, C_w^* -Concentration of the plate, T_w^* -Temperature of the plate, T_∞^* -Temperature of the fluid far away from the plate C_∞^* - Concentration of the fluid far away from the plate B_0-Magnetic field component V Q olumetric rate of Heat absorption Constant p_∞ -pressure in stream

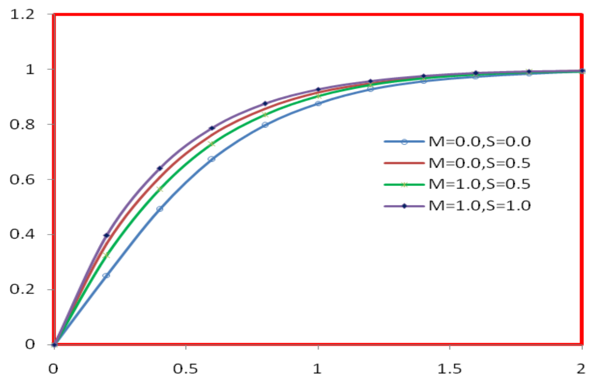

Fig.1: Effect of M in the presence of heat source on velocity field u
(Gr=1.0, Gm=1.0, Re=5.0, K_0 =1.0, Pr=0.71, Ch=0.5,Sc=0.66, ε =0.1 and Z=0.0)

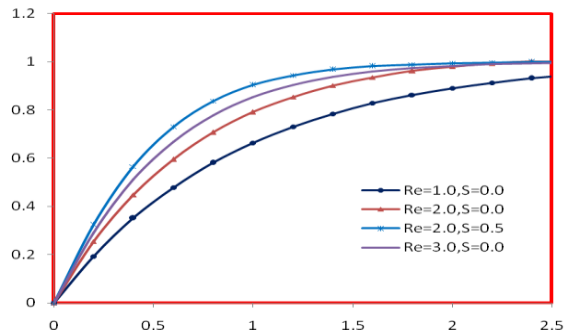

Fig.2: Effect of 'Re' on velocity field u in the presence of heat source
(Gr=1.0, Gm=1.0, Ch=0.5, M=1.0, K_0 =1.0, Pr=0.71, Sc=0.66, ε =0.1 and Z=0.0)

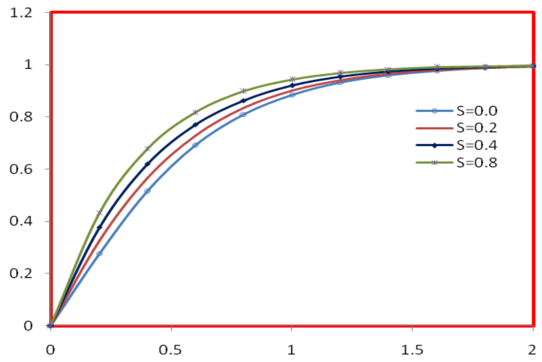

Fig.3: Effect of heat source on velocity field u
(Gr=1.0, Gm=1.0, M=1.0, Ch=0.5,Re=5.0, K_0 =1.0, Pr=0.71, Sc=0.66, ε =0.1 and Z=0.0)

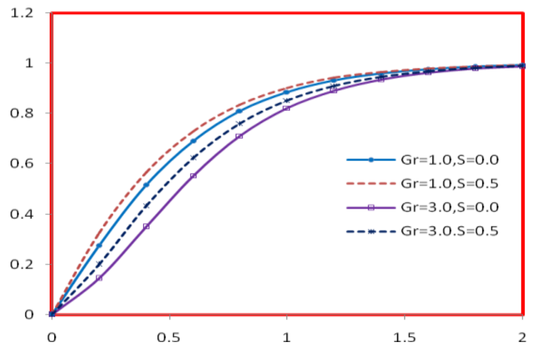

Fig.4-Effect of Gr on velocity field u in the presence of heat source
(Gm=1.0, Re=5.0, M=1.0, K_O=1.0, Pr=0.71, Sc=0.66, ε=0.1, Ch=0.5and Z=0.0)

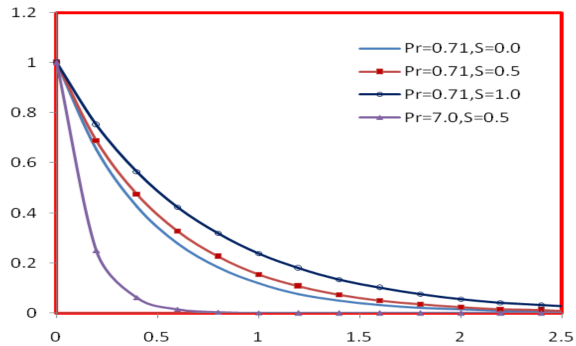

Fig.5-Effects of Pr on temperature profile θ in the presence of heat source
(M=1.0, K_0=1.0, ε=0.1 and Z=0.0)

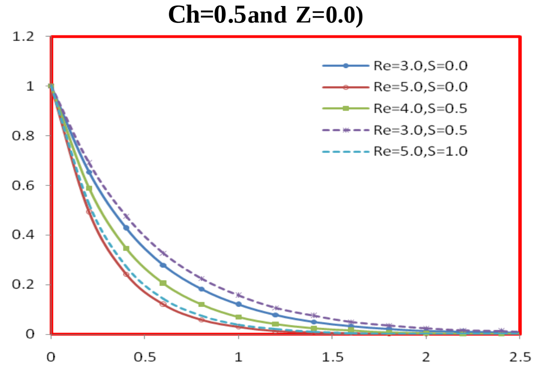

Fig.6: Effect of 'Re' on temperature profile θ in the presence of heat source
(M=1.0, K_0=1.0, ε=0.1 and Z=0.0)

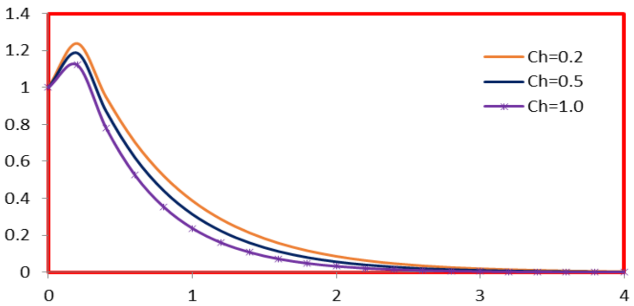

Fig 7- Chemical reaction effect on Concentration field
(Re=3.0, Sc=0.66, ε=0.1and Z=0.0)

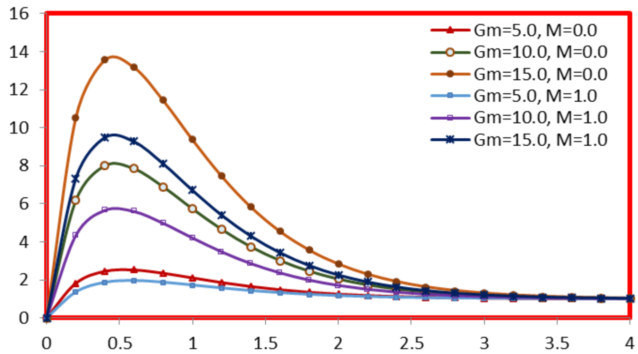

Fig 8-Effect of Gm on velocity field u in the presence of magnetic field
(Gr=1.0, Re=5.0, M=1.0, K_O=1.0, Pr=0.71, Sc=0.66, ε=0.1, Ch=0.5and Z=0.0)

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