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CHEMICAL REACTION AND RADIATION EFFECTS ON THE TRANSIENT MHD FREE CONVECTION FLOW OF DISSIPATIVE FLUID PAST AN INFINITE VERTICAL POROUS PLATE WITH RAMPED WALL TEMPERATURE

A finite-difference analysis is performed to study the effects of thermal radiation and chemical reaction on the transient MHD free convection and mass transform flow of a dissipative fluid past an infinite vertical porous plate subject to ramped wall temperature. The fluid considered here is a gray, absorbing/ /emitting radiation but a non-scattering medium. The dimensionless governing equations are unsteady, coupled and non-linear partial differential equations. An analytical method fails to give a solution. Hence an implicit finite difference scheme of Crank-Nicolson method is employed. The effect of the magnetic parameter (M), chemical reaction parameter (K), radiation parameter (F), buoyancy ratio parameter (N), Schmidt number (Sc) on the velocity field and skin friction for both air (P_r = 0.71) and water (P_r = 7) in the presence of both aiding (N>0) and opposing (N<0) flows are extensively discussed with the help of graphs.

Key words: first order chemical reaction; MHD; free convection; viscous dissipation; ramped temperature; thermal radiation.

Free convection flows past a vertical surface or plate were studied extensively in the literature due to its applications in engineering and environmental processes. Several investigations were performed using both analytical and numerical methods under different thermal conditions which are continuous and well-defined at the wall. Practical problems often involve wall conditions that are non-uniform or arbitrary. To understand such problems, it is useful to investigate problems subject to step change in wall temperature. Keeping this in view, Schetz [1] made an attempt to develop an approximate analytical model for free convection flow from a vertical plate with discontinuous wall temperature conditions. Several investigations were continued on this problem using an experimental technique [2], numerical methods [3], and by using series expansions [4,5]. Lee and Yovanovich [6] presented a new analytical model for the laminar natural convection from a vertical plate with step change in wall temperature. The validity and accuracy of the model is demonstrated by comparing with the existing results. Chandran *et al*. [7] have presented an analytical solution to the unsteady natural convection flow of an incompressible viscous fluid near a vertical plate with ramped wall temperature and they have compared the results with constant temperature. Saha *et al*. [8] investigated the natural convection boundary layer adjacent to an inclined semi-infinite flat plate subjected to ramp heating. The flow development from the start-up to an eventual steady state has been described based on scaling analysis and verified by numerical simulations. Recently Singh and Singh [9] analyzed transient MHD free convection flow near a semi-infinite vertical wall having ramped temperature.

Free convection flows occur not only due to temperature difference, but also due to concentration difference or the combination of these two. The study of combined heat and mass transfer plays an important role in the design of chemical processing equipment, nuclear reactors, formation and dispersion of fog etc. The effect of presence of foreign mass on the free convection flow past a semi-infinite vertical plate was first studied by Gebhart and Pera [10]. Soundalgekar [11] has studied mass transfer effects on flow past an

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impulsively started infinite isothermal vertical plate. Dass *et al.* [12] considered the mass transfer effects on flow past an impulsively started infinite isothermal vertical plate with constant mass flux. Muthucumaraswamy *et al.* [13] presented an exact solution to the problem of flow past an impulsively started infinite vertical plate in the presence of uniform heat and mass flux at the plate using the Laplace transform technique.

Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of the surrounding fluid is rather high, radiation effects play an important role, and this situation does exist in space technology. England and Emery [14] have studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Soundalgekar and Takhar [15] have considered the radiative free convective flow of an optically thin gray-gas past a semi-infinite vertical plate. Radiation effects on mixed convection along an isothermal vertical plate were studied by Hossain and Takhar [16]. Raptis and Perdikis [17] studied the effects of thermal radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Dass *et al.* [18] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. The governing equations were solved by the Laplace transform technique. Muthucumaraswamy and Janakiraman [19] studied MHD and radiation effects on moving isothermal vertical plate with variable mass diffusion. Rajesh and Varma [20] studied radiation and mass transfer effects on MHD free convection flow past an exponentially accelerated vertical plate with variable temperature. Recently, Rajesh and Varma [21] analyzed radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion.

The study of heat and mass transfer problems with chemical reaction are of great practical importance to engineers and scientists because of their almost universal occurrence in many branches of science and engineering. A few representative fields of interest in which combined heat and mass transfer along with chemical reaction play an important role in chemical process industries such as food processing and polymer production. Chambre and Young [22] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Dass *et al.* [23] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction were studied by Dass *et al.* [24]. The dimensionless governing equations were solved by the usual Laplace Transform technique. Recently, Muthucumaraswamy [25] studied chemical reaction effects on a vertical oscillating plate with variable temperature.

On the other hand, Gebhart [26] showed that in steady free convection flow, the viscous dissipation heat cannot be neglected for fluids with high Prandtl number or flow at high gravitational field - or in rotational flow. Hence it is essential to know the effects of viscous dissipative heat on the transient free convective flow past an infinite vertical plate with a step-change in temperature. So, Soundalgekar *et al.* [27] studied the effects of viscous dissipative heat on the transient free convection flow past an infinite vertical plate with a step-change in plate-temperature. The problem governed by nonlinear coupled partial differential equations was solved by finite-difference method. Kishore *et al.* [28] studied the effects of thermal radiation and viscous dissipation on MHD heat and mass diffusion flow past a surface embedded in a porous medium. The study of flow of viscous fluid past vertical porous plate is also of importance in industrial applications. Free convection flow past a semi-infinite vertical porous plate was studied by many by considering both suction and injection. Notable amongst them are by Nanda and Sharma [29], Singh [30], who studied the effect of suction on the transient free convection flow past a vertical porous plate. Recently, Rajesh [31] studied MHD free convection flow past an accelerated vertical porous plate with variable temperature through a porous medium using Laplace transform technique.

The objective of the present paper is to analyze the effects of thermal radiation and first order chemical reaction on the unsteady MHD free convection and mass transform flow of an incompressible viscous dissipative fluid past an infinite vertical porous plate subject to ramped wall temperature. The equations of continuity, linear momentum, energy and diffusion, which govern the flow field, are solved by using an implicit finite difference method of Crank-Nicolson type.

MATHEMATICAL ANALYSIS

The unsteady flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical porous plate, taking into account the effect of viscous dissipation, is considered. A transverse magnetic field of uniform strength, B_0, is assumed to be applied normal to the plate. The induced magnetic field is neglected as the magnetic Reynolds number of the flow is taken to be very small. The fluid considered here is a gray, absorbing/emitting radiation but a non--scattering medium. The flow is assumed to be in x'--direction which is taken along the plate in the vertically upward direction, and y'-axis is taken normal to the plate. Initially, for time $t \le 0$, both the fluid and the plate are assumed to be at the same temperature T'_∞ and concentration C'_∞. At time $t' > 0$, the temperature of the plate is raised or lowered to:

$$T'_\infty + \left(T'_w - T'_\infty\right)\frac{t'}{t_0}$$

When $t' \le t_0$, and thereafter, for $t' > t_0$, is maintained at the constant temperature T'_w and the concentration level at the plate is raised to C'_w. It is assumed that there exists a homogeneous first order chemical reaction between the fluid and species concentration. As the plate is infinite in extent, the physical variables are functions of y' and t'. Applying the Boussinesq approximation, the unsteady flow is governed by the following equations:

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2 u'}{\rho} \tag{2}$$

$$\rho C_p\left(\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'}\right) = \kappa\frac{\partial^2 T'}{\partial y'^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 - \frac{\partial q_r}{\partial y'} \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K_r\left(C' - C'_\infty\right) \tag{4}$$

with the initial and boundary conditions:

$$\begin{aligned}
&u' = 0,\ T' = T'_\infty,\ C' = C'_\infty, \text{ for all } y' \ge 0 \text{ and } t' \le 0\\
&u' = 0 \text{ at } y' = 0 \text{ for } t' > 0\\
&T' = T'_\infty + \left(T'_w - T'_\infty\right)\frac{t'}{t_0} \text{ at } y' = 0 \text{ for } 0 < t' \le t_0\\
&T' = T'_w \text{ at } y' = 0 \text{ for } t' > t_0\\
&C' = C'_w \text{ at } y' = 0 \text{ for } t' > 0\\
&u' = 0,\ T' \to T'_\infty,\ C' \to C'_\infty, \text{ as } y' \to \infty \text{ for } t' > 0
\end{aligned} \tag{5}$$

For constant suction velocity ($v_0 = \text{const.}>0$), Eq. (1) integrates to:

$$v' = -v_0$$

The local radiant for the case of an optically thin gray gas is expressed by:

$$\frac{\partial q_r}{\partial y'} = -4a^*\sigma\left(T'^4_\infty - T'^4\right) \tag{6}$$

It is assumed that the temperature differences within the flow are sufficiently small that T'^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T'^4 in a Taylor series about T'_∞ and neglecting the higher order terms, thus:

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{7}$$

By using Eqs. (6) and (7), Eq. (3) reduces to:

$$\rho C_p\left(\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'}\right) = \kappa\frac{\partial^2 T'}{\partial y'^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 + 16a^*\sigma T'^3_\infty\left(T'_\infty - T'\right) \tag{8}$$

On introducing the following non-dimensional quantities:

$$\begin{aligned}
&y = \frac{y'}{\sqrt{\nu t_0}},\ t = \frac{t'}{t_0},\ u = \frac{u'}{G_r}\sqrt{\frac{t_0}{\nu}},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\\
&P_r = \frac{\rho\nu C_p}{\kappa},\ G_r = \frac{g\beta\left(T'_w - T'_\infty\right)t_0^{\frac{3}{2}}}{\sqrt{\nu}},\ F = \frac{16a^*\sigma T'^3_\infty \nu t_0}{\kappa},\\
&C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ S_c = \frac{\nu}{D},\ G_m = \frac{g\beta^*\left(C'_w - C'_\infty\right)t_0^{\frac{3}{2}}}{\sqrt{\nu}},\\
&N = \frac{G_m}{G_r},\ K = K_r t_0,\ E = \frac{\nu}{t_0 C_p\left(T'_w - T'_\infty\right)},\\
&\lambda = v_0\sqrt{\frac{t_0}{\nu}},\ M = \frac{\sigma t_0 B_0^2}{\rho}
\end{aligned} \tag{9}$$

in Eqs. (1)-(4), leads to:

$$\frac{\partial u}{\partial t} - \lambda\frac{\partial u}{\partial y} = \theta + NC + \frac{\partial^2 u}{\partial y^2} - Mu \tag{10}$$

$$\frac{\partial \theta}{\partial t} - \lambda\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} + E\left(\frac{\partial u}{\partial y}\right)^2 - \frac{F}{P_r}\theta \tag{11}$$

$$\frac{\partial C}{\partial t} - \lambda\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - KC \tag{12}$$

According to the above non-dimensionalisation process, the characteristic time t_0 can be defined as:

$$t_0 = \frac{\nu^{\frac{1}{3}}}{\left[g\beta\left(T'_w - T'_\infty\right)\right]^{\frac{2}{3}}} \tag{13}$$

The initial and boundary conditions given by Eq. (5) now become:

$$\begin{aligned} &u=0,\ \theta=0,\ C=0 \text{ for all } y\ge 0 \text{ and } t\le 0\\ &u=0 \text{ at } y=0 \text{ for } t>0\\ &\theta=t \text{ at } y=0 \text{ for } 0<t\le 1\\ &\theta=1 \text{ at } y=0 \text{ for } t>1\\ &C=1 \text{ at } y=0 \text{ for } t>0\\ &u\to 0,\ \theta\to 0,\ C\to 0 \text{ as } y\to\infty \text{ for } t>0 \end{aligned} \tag{14}$$

All the physical parameters are defined in the nomenclature.

Eqs. (10)-(12) are coupled non-linear partial differential equations and are solved by using initial and boundary conditions of Eq. (14). However, exact or approximate solutions are not possible for this set of equations. And hence we solve these equations by an implicit finite difference method of Crank-Nicolson type for a numerical solution.

The equivalent finite difference scheme of Eqs. (10)-(12) is as follows:

$$\left[\frac{u_{i,j+1}-u_{i,j}}{\Delta t}\right]-\lambda\left[\frac{u_{i+1,j}-u_{i,j}}{\Delta y}\right]= =\frac{1}{2}\left[\frac{u_{i-1,j+1}-2u_{i,j+1}+u_{i+1,j+1}}{(\Delta y)^2}+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}\right]+\frac{1}{2}\left[\theta_{i,j+1}+\theta_{i,j}\right]+\frac{N}{2}\left[C_{i,j+1}+C_{i,j}\right]-\frac{M}{2}\left[u_{i,j+1}+u_{i,j}\right] \tag{15}$$

$$\left[\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}\right]-\lambda\left[\frac{\theta_{i+1,j}-\theta_{i,j}}{\Delta y}\right]= =\frac{1}{2P_r}\left[\frac{\theta_{i-1,j+1}-2\theta_{i,j+1}+\theta_{i+1,j+1}}{(\Delta y)^2}+\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}\right]+E\left[\frac{u_{i+1,j}-u_{i,j}}{\Delta y}\right]^2-\frac{F}{2P_r}\left[\theta_{i,j+1}+\theta_{i,j}\right] \tag{16}$$

$$\left[\frac{C_{i,j+1}-C_{i,j}}{\Delta t}\right]-\lambda\left[\frac{C_{i+1,j}-C_{i,j}}{\Delta y}\right]=\frac{1}{2S_c}\left[\frac{C_{i-1,j+1}-2C_{i,j+1}+C_{i+1,j+1}}{(\Delta y)^2}+\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}\right]-\frac{K}{2}\left[C_{i,j+1}+C_{i,j}\right] \tag{17}$$

Here, the suffix *i* corresponds to *y* and *j* corresponds to *t*.

Also, $\Delta t=t_{j+1}-t_j$ and $\Delta y=y_{i+1}-y_i$.

The complete solution of the discrete Eqs. (15)--(17) proceeds as follows:

1) Knowing the values of *C*, θ and *u* at a time *t* = *j*, calculate *C* and θ at time *t* = *j* + 1 using Eqs. (16) and (17) and solving the tri-diagonal linear system of equations.

2) Knowing θ and *C* at times *t* = *j* and *t* = *j* + 1 and *u* at time *t* = *j*, solve Eq. (15) (*via* tri-diagonal matrix inversion), to obtain *u* at time *t* = *j* + 1.

We can repeat steps 1 and 2 to proceed from t = 0 to the desired time value.

The implicit Crank-Nicolson method is a second order method $\left(0\left(\Delta t^2\right)\right)$ in time and has no restrictions on space- and time-steps, Δy and Δt, *i.e.*, the method is unconditionally stable (Potter, 1973). The finite differences scheme used, involves the values of the function at the six grid points. A linear combination of the "future" points is equal to another linear combination of the "present" points. To find the future values of the function, one must solve a system of linear equations, whose matrix has a tridiagonal form.

The computations were carried out for P_r = 0.71 (air), 7 (water), λ = 0.2, *E* = 0.5, *t* = 0.5; 1.3, M = 1; 3; 5, *K* = 3; 5; 7, *F* = 2; 4; 6, *N* = 0.2; 0.4; 0.6; -0.2; -0.4; -0.6, *Sc* = 0.22; 0.6; 0.78 and Δy = 0.1, Δt = 0.02 and the procedure is repeated till *y* = 7. In order to check the accuracy of numerical results, the present study is compared with the available theoretical solution of Narahari and Anwar Beg (2009) and they are found to be in good agreement.

Skin friction

We now calculate from the velocity field the skin riction. It is given in non-dimensional form as:

$$\tau=\left.\frac{du}{dy}\right|_{y=0} \tag{18}$$

Numerical values of τ (skin friction) are calculated by applying a fourth-order forward difference Newton's formula.

RESULTS AND DISCUSSION

In order to get physical insight into the problem, the numerical values of the velocity and skin friction are computed for different values of the physical parameters such as *M* (magnetic parameter), *K* (chemical reaction parameter), *F* (radiation parameter), *N* (buoyancy ratio parameter), *Sc* (Schmidt number). The buoyancy ratio parameter, *N*, represents the ratio between mass and thermal buoyancy forces. When $N = 0$, there is no mass transfer and the buoyancy force is due to the thermal diffusion only. $N > 0$ implies that mass buoyancy force acts in the same direction of thermal buoyancy force, *i.e.*, the buoyancy-assisted case, while $N < 0$ means that mass buoyancy force acts in the opposite direction, *i.e.*, the buoyancy-opposed.

Figures 1 and 2 represent the velocity profiles for different values of *M* (magnetic parameter) at $t = 0.5$ and 1.3 for both air ($Pr = 0.71$) and water ($Pr = 7$) in the presence of both aiding ($N > 0$) and opposing flows ($N < 0$). From Figures 1 and 2, it is observed that the velocity decreases with an increase in M for both air and water in the presence of aiding flows (N>0). This is because the application of transverse magnetic field will result in a resistive type force (Lorentz force) similar to drag force, which tends to resist the flow thus reducing its velocity. From Figure 2, the velocity is observed to increase with an increase in *M* for water in the presence of opposing flows. From Figure 1, it is found that at $t = 0.5$, the velocity increases with an increase in *M* for air in the presence of opposing flows. But at $t = 1.3$, it decreases with an increase in *M* up to certain *y* (distance) and after the reverse effect is observed.

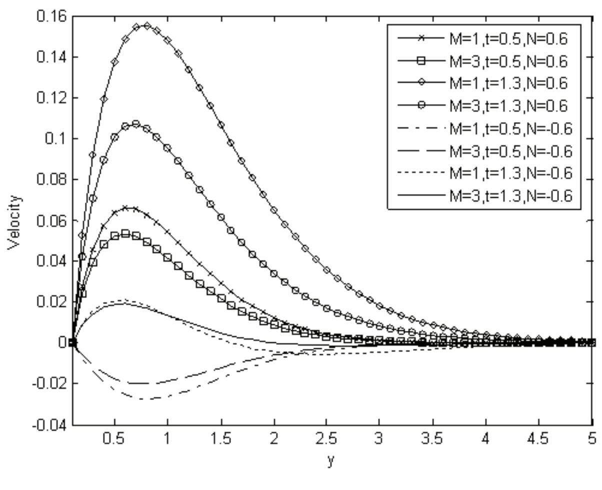

Figure 1. Velocity profiles when Pr = 0.71, K = 3, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

The velocity profiles for different values of *K* (chemical reaction parameter) are presented in Figures 3 and 4 at $t = 0.5$ and 1.3 for both air and water in the presence of both aiding ($N > 0$) and opposing flows ($N < 0$). It is observed that the velocity decreases with an increase in *K* for both air and water in the presence of aiding flows ($N > 0$). But the reverse effect is observed for both air and water in the presence of opposing flows ($N < 0$).

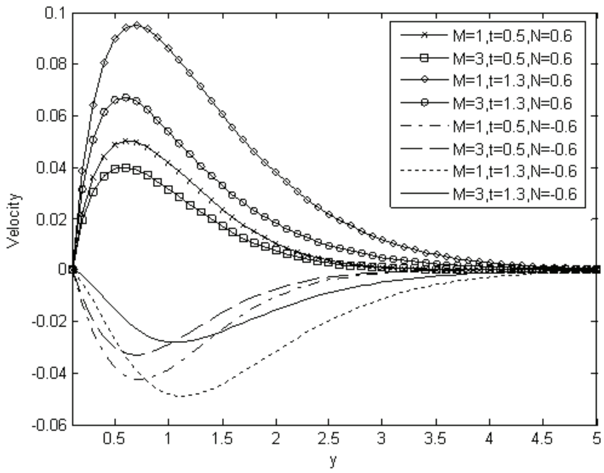

Figure 2. Velocity profiles when Pr = 7, K = 3, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

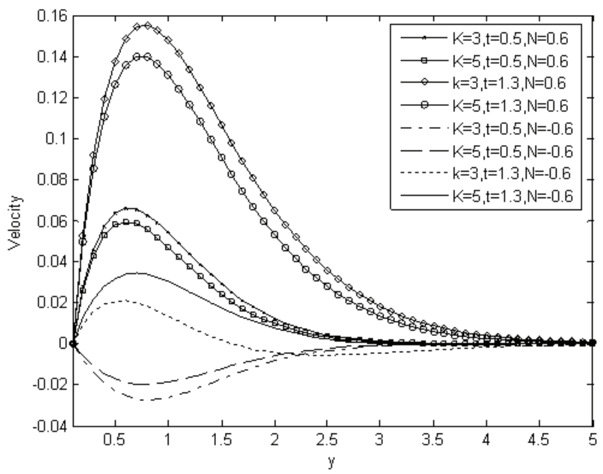

Figure 3. Velocity profiles when Pr = 0.71, M = 1, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

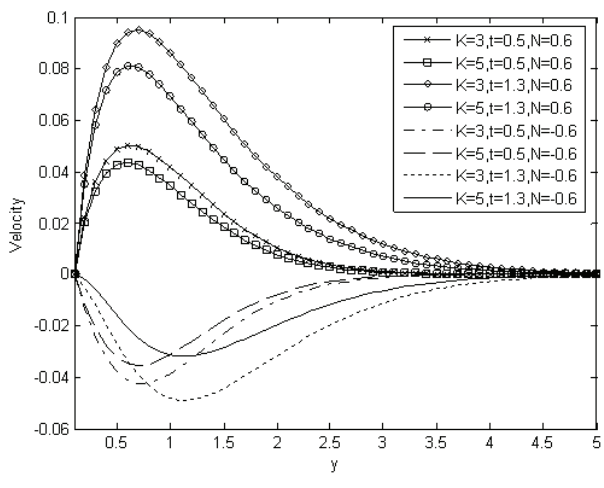

Figure 4. Velocity profiles when Pr = 7, M = 1, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

Figures 5 and 6 illustrate the influences of F (radiation parameter) on the velocity field at t = 0.5 and 1.3 for both air and water in the presence of both aiding (N > 0) and opposing flows (N < 0). From Figure 5, the velocity is found to decrease with an increase in F for air in the presence of both aiding and opposing flows. From Figure 6, it is found that at t = = 0.5, the effect of F (radiation parameter) on the velocity is negligible for water in the presence of both aiding and opposing flows. But at t = 1.3, the velocity is found to decrease with an increase in F up to certain y (distance) and after negligible effect is observed for water in the presence of both aiding and opposing flows.

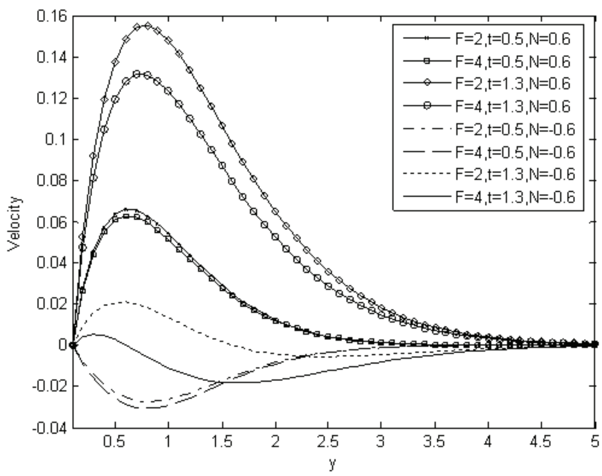

Figure 5. Velocity profiles when Pr = 0.71, K = 3, M = 1, Sc = 0.6, E = 0.5, λ = 0.2.

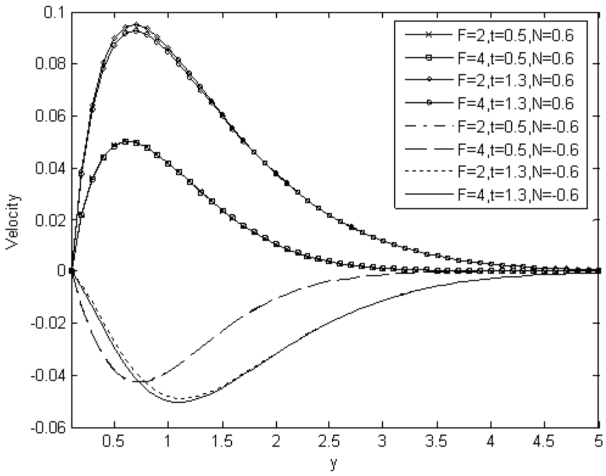

Figure 6. Velocity profiles when Pr = 7, K = 3, M = 1, Sc = 0.6, E = 0.5, λ = 0.2.

Figures 7 and 8 display the effects of N (buoyancy ratio parameter) on the velocity field at t = 0.5 and 1.3 for both air and water in the presence of both aiding (N > 0) and opposing flows (N < 0). It is found that the velocity increases with an increase in N for both air and water in the presence of aiding flows (N > 0). This indicates that the buoyancy force due to concentration dominates in the region near the plate over thermal buoyancy force on velocity. But the velocity decreases in the presence of opposing flows (N < 0).

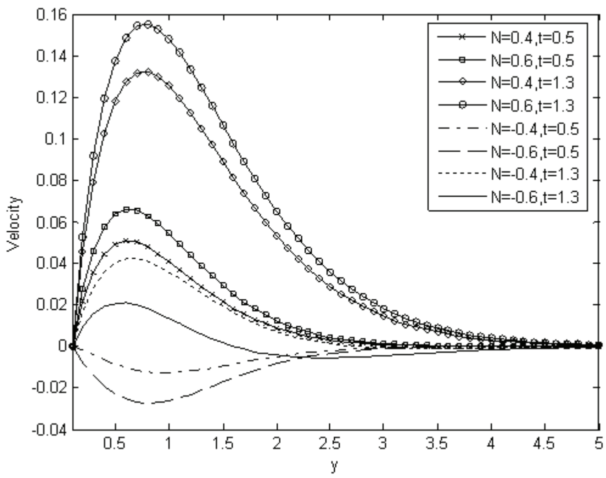

Figure 7. Velocity profiles when Pr = 0.71, K = 3, F = 2, M = 1, Sc = 0.6, E = 0.5, λ = 0.2.

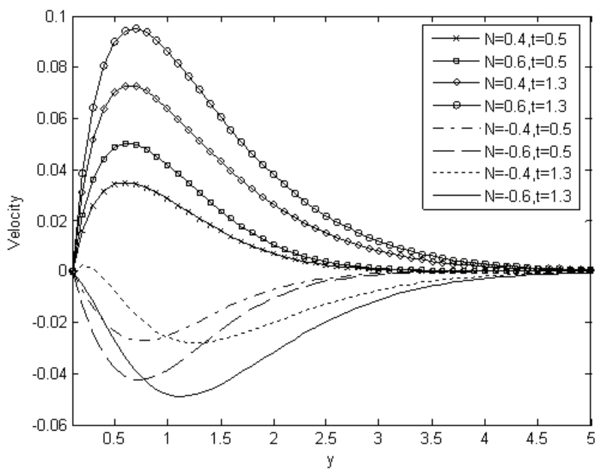

Figure 8. Velocity profiles when Pr = 7, K = 3, F = 2, M = 1, Sc = 0.6, E = 0.5, λ = 0.2.

In Figures 9 and 10 the velocity profiles are shown for different values of Sc (Schmidt number) at t = 0.5 and 1.3 for both air and water in the presence of both aiding (N > 0) and opposing flows (N < 0). It is observed that the velocity decreases with increasing Schmidt number for both air and water in the presence of aiding flows (N > 0). An increasing Schmidt number implies that viscous forces dominate over the diffusional effects. Schmidt number in free convection flow regimes, in fact, represents the relative effectiveness of momentum and mass transport by diffusion in the velocity (momentum) and concentration (species) boundary layers. Therefore an increase in *Sc* will counter-act momentum diffusion since viscosity effects will increase and molecular diffusivity will be reduced. The flow will therefore be decelerated with a rise in *Sc*. But the reverse effect is observed in the presence of opposing flows ($N < 0$).

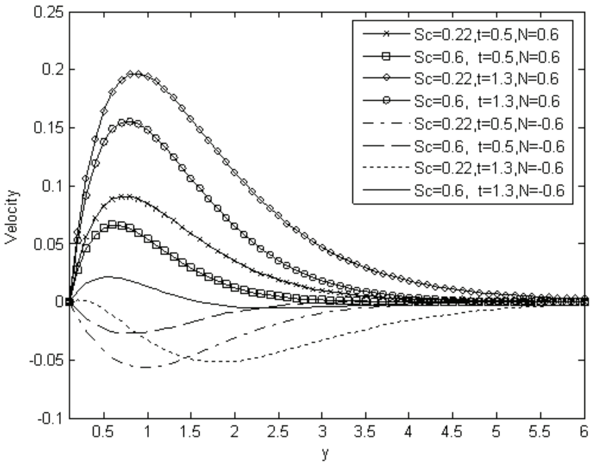

Figure 9. Velocity profiles when Pr = 0.71, K = 3, F = 2, M = 1, E = 0.5, λ = 0.2.

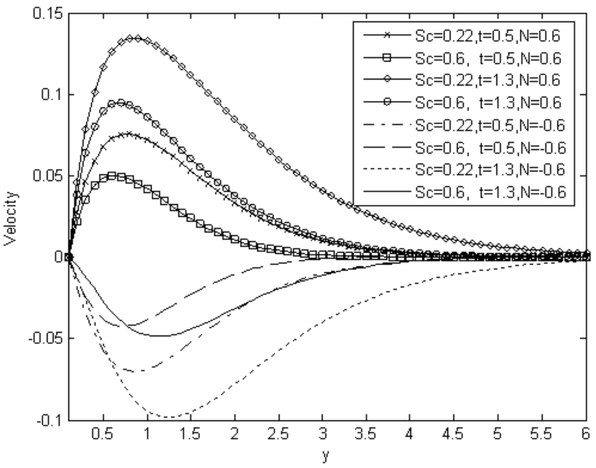

Figure 10. Velocity profiles when Pr = 7, K = 3, F = 2, M = 1, E = 0.5, λ = 0.2.

Skin friction is studied in Figures 11-15 against time *t*. From Figure 11, the skin friction is found to decrease with an increase in *M* (magnetic parameter) for both water and air in the presence of aiding flows ($N > 0$). It is also found that the skin friction increases with an increase in *M* for water in the presence of opposing flows ($N < 0$). But, when $Pr = 0.71$ (air), skin friction increases with *M* for $0 < t < 1$ and decreases for $t > 1$ in the presence of opposing flows ($N < 0$). From Figures 12, 14 and 15, it is observed that the skin friction decreases with an increase in *K* (chemical reaction parameter) or *Sc* (Schmidt number) but increases with an increase in *N* (buoyancy ratio parameter) for both air ($Pr = 0.71$) and water ($Pr = 7$) in the presence of aiding flows ($N > 0$). But the reverse effect is observed in the presence of opposing flows ($N < 0$). From Figure 13, the skin friction is observed to decrease with an increase in *F* (radiation parameter) for both water and air in the presence of both aiding ($N > 0$) and opposing flows ($N < 0$).

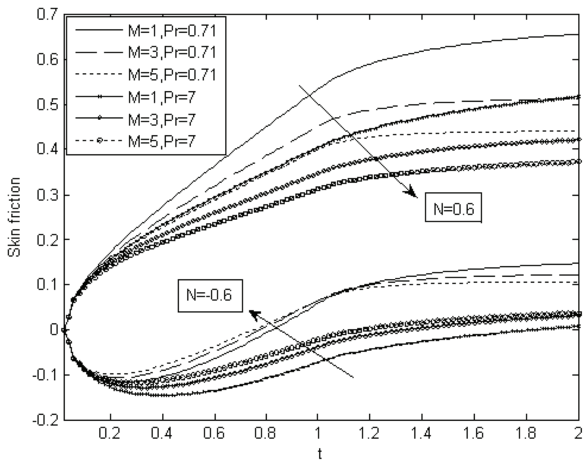

Figure 11. Skin friction when K = 3, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

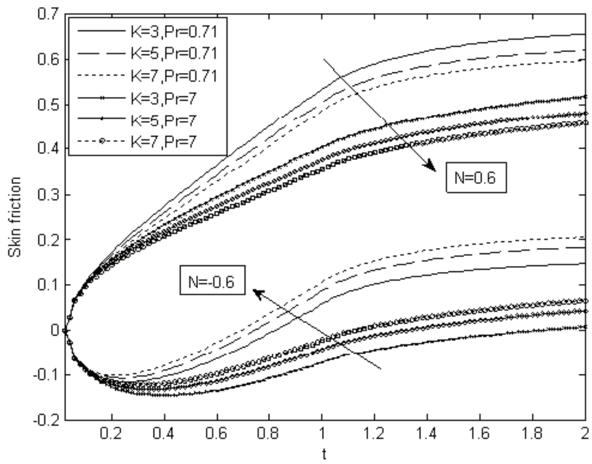

Figure 12. Skin friction when M = 1, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

The temperature profiles for air ($Pr = 0.71$) and water ($Pr = 7$) are shown in Figure 16. We observe from this figure that there is a fall in the temperature of air or water due to an increase in the value of the radiation parameter (*F*). The concentration profiles are plotted in Figure 17. We observe from this figure that an increase in the value of the Schmidt number or the chemical reaction parameter leads to a decrease in the concentration profiles.

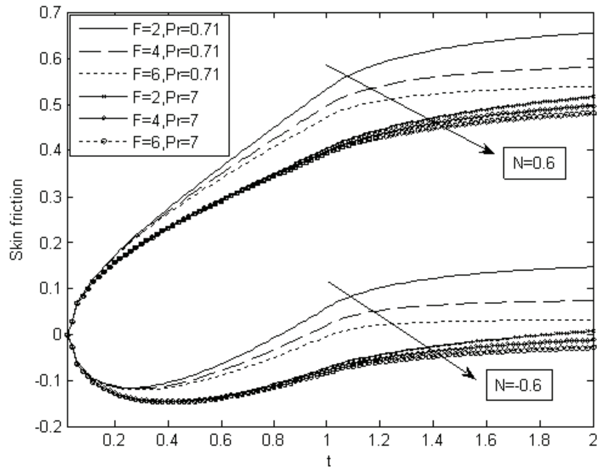

Figure 13. Skin friction when M = 1, K = 3, Sc = 0.6, E = 0.5, λ = 0.2.

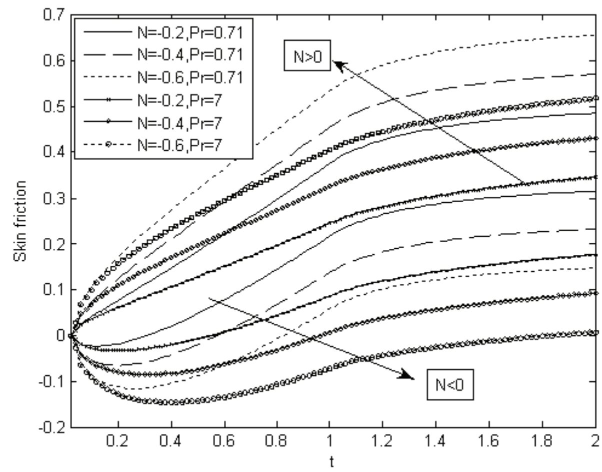

Figure 14. Skin friction when M = 1, K = 3, F = 2, Sc = 0.6, E = 0.5, λ = 0.2.

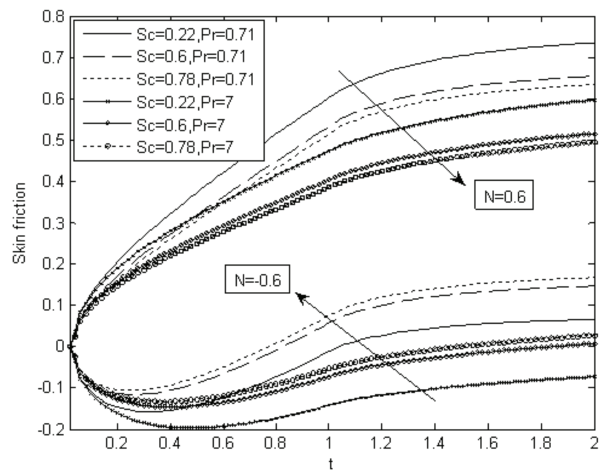

Figure 15. Skin friction when M = 1, K = 3, F = 2, E = 0.5, λ = 0.2.

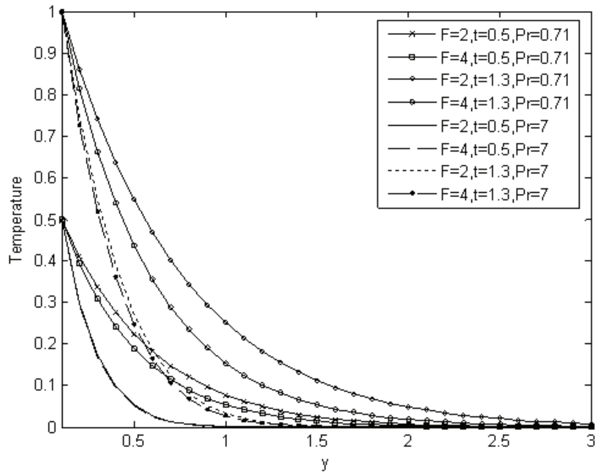

Figure 16. Temperature profiles when N = 0.6, K = 3, M = 1, Sc = 0.6, E = 0.5, λ = 0.2.

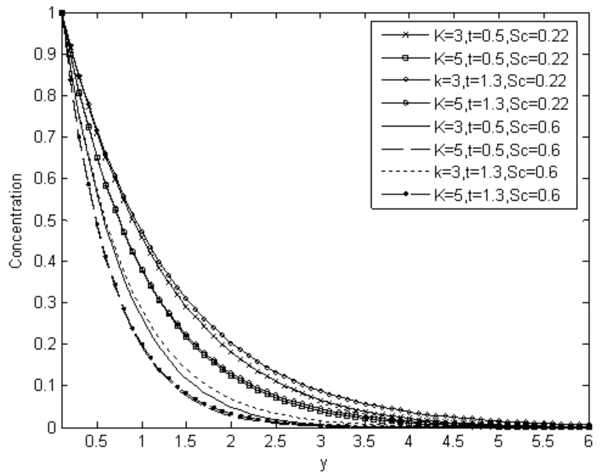

Figure 17. Concentration profiles when Pr = 0.71, N = 0.6, M = 1, F = 2, E = 0.5, λ = 0.2.

The present study is compared with the available theoretical solution of Narahari and Anwar Beg (2009) in Figure 18 and they are found to be in good agreement.

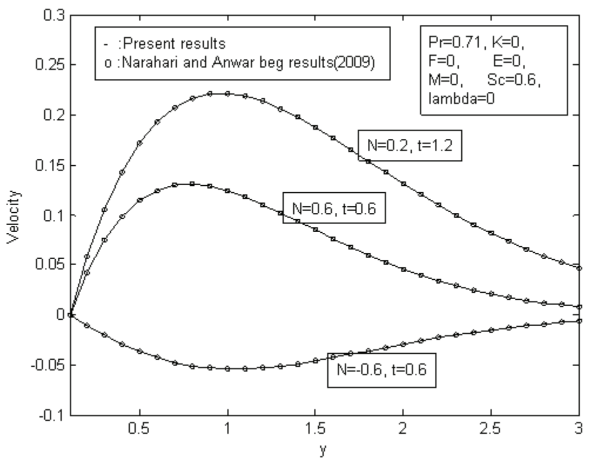

Figure 18. Comparison of velocity profiles.

CONCLUSIONS

A detailed numerical study has been carried out for the chemical reaction and radiation effects on transient MHD free convection and mass transfer flow of dissipative fluid past an infinite vertical porous plate with ramped wall temperature. The dimensionless governing equations are solved by an implicit finite-difference method of Crank-Nicolson type. In this paper it was found that velocity and skin friction decreases with an increase in K (chemical reaction parameter) or Sc (Schmidt number) but increases with an increase in N (buoyancy ratio parameter) for both fluids air and water in the presence of aiding flows ($N > 0$). But the reverse effect is observed in the presence of opposing flows ($N < 0$).

Nomenclature

a^* Absorption coefficient
C Dimensionless concentration
C' Species concentration in the fluid, mol m^{-3}
C_p Specific heat at constant pressure, J kg^{-1} K^{-1}
C'_w Concentration of the plate
C'_∞ Concentration in the fluid far away from the plate
D Chemical Molecular diffusivity, m^2 s^{-1}
E Eckert number or dissipation parameter
F Radiation parameter
g Acceleration due to gravity, m s^{-2}
G_m Mass Grashof number
G_r Thermal Grashof number
K Chemical reaction parameter
M Magnetic parameter
N Buoyancy ratio parameter
Pr Prandtl number
q_r Radiative heat flux in the y direction
Sc Schmidt number
t Dimensionless time
t_0 Characteristic time
t' Time, s
T' Temperature of the fluid near the plate, K
T'_w Temperature of the plate
T'_∞ Temperature of the fluid far away from the plate
u Dimensionless velocity
u', v' Velocity components in the x' and y' directions respectively, m s^{-1}
y Dimensionless coordinate axis normal to the plate
y' Coordinate axis normal to the plate, m.

Greek symbols

α Thermal diffusivity, m^2 s^{-1}
β^* Volumetric coefficient of expansion with concentration, K^{-1}
β Volumetric coefficient of thermal expansion, K^{-1}
θ Dimensionless temperature
κ Thermal conductivity of the fluid J m^{-1} K^{-1}
λ Suction parameter
μ Coefficient of viscosity, Pa s
ν Kinematic viscosity, m^2 s^{-1}
ρ Density of the fluid, kg m^{-3}
σ Electric conductivity, S m^{-1}
τ Dimensionless skin friction.

Subscripts

w Conditions on the wall
∞ Free stream conditions.

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NAUČNI RAD

UTICAJ HEMIJSKE REAKCIJE I RADIJACIJE NA NESTACIONARNI MHD PRIRODNO KONVEKTIVNI TOK REALNOG FLUIDA PORED BESKONAČNE VERTIKALNE POROZNE PLOČE SA ZADATOM TEMPERATUROM ZIDA

Metoda konačnih razlika je primenjena na izučavanje uticaja termalne radijacije i hemijske reakcije na nestacionarni MHD prirodno konvektivni tok realnog fluida pored beskonačne porozne ploče sa zadatom temperaturom zida. Razmatrani fluid je siv medijum koji apsorbuje i emituje zračenje ali ga ne rasipa. Bezdimenzione jednačine koje opisuju ovakav tok su nelinearne parcijalne diferencijalne jednačine. Pokušaj da se one reše analitički bio je bezuspešan. Zbog toga je primenjena implicitna Krank-Nikolsonova metoda konačnih razlika. Uticaj magnetnog parametra (M), parametra hemijske reakcije (K), parametra zračenja (F), parametra odnosa potisaka (N) i Šmitovog broja (Sc), na profil brzina i površinsko trenje za vazduh (Pr = 0,71) i vodu (Pr = 7) pri potpomagajućem (N > 0) i suprotstavljajućem (N < 0) toku je diskutovan uz pomoć dijagrama.

Ključne reči: hemijske reakcije prvog reda; MHD; slobodna konvekcija; viskozno rasipanje; promena temperature; termička radijacija.