International Journal of Mathematical Archive-8(11), 2017, 140-147
Available online through www.ijma.info ISSN 2229 – 5046

CHEMICAL REACTION AND THERMAL RADIATION EFFECTS ON AN UNSTEADY MHD FLOW THROUGH POROUS MEDIUM IN PRESENCE OF SORET EFFECTS

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(Received On: 03-10-17; Revised & Accepted On: 14-11-17)

ABSTRACT

In this research paper we have investigated the chemical reaction and thermal radiation effects on an unsteady MHD flow through porous medium past an infinite vertical plate in the presence of soret effects. The governing dimensionless coupled linear partial differential equations are solved numerically using finite difference method (FDM) by developing suitable codes in MATLAB software. The fluid velocity, temperature and species concentration profiles have been drawn for time and various flow parameters such as Radiation parameter (R), chemical reaction parameter (K_r) and Soret number (Sr) and results are discussed. Also the numerical values of the velocity, temperature and concentration have been tabulated.

Keywords: *Unsteady; MHD; infinite vertical plate; Thermal radiation; Chemical reaction; Soret effects; Finite Difference Method (FDM);*

1. INTRODUCTION

The study of unsteady MHD free convection flow with mass transfer along a vertical porous plate is receiving considerable attention of many researchers because of its various applications. Permeable porous plates are used in the filtration processes and also for a heated body to keep its temperature constant and to make the heat insulation of the surface more effective. Combined heat and mass transfer problems with chemical reaction are important in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously.

When technological processes take place at higher temperatures thermal radiation heat transfer has become very important and its effects cannot be neglected. The effects of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment.

Several workers have studied the problem of free convection flow with mass transfer. Singh *et al.* [1] have studied vertical porous plate by finite difference method. Free convection and mass transfer flow through porous medium bounded by an infinite vertical limiting surface with constant suction have been analyzed by Raptis *et al.* [2]. Unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate has been discussed by Sattar *et al.* [3]. Das *et al.* [4] have studied numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Das *et al.* [5] have studied Mass transfer effects on MHD flow and heat transfer past a vertical porous plate through porous medium under oscillatory suction and heat source. Applied magnetic field on transient convective flow in a vertical channel has been discussed by Jah [6]. Kim [7] has investigated the problem of unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Sharma and Dutta [8] have analyzed chemical reaction and thermal radiation effects on unsteady MHD flow over an infinite vertical oscillating porous plate with heat source. Singh and Kumar [9] have presented the effects of chemical reactions on unsteady MHD free convection and mass transfer flow of a viscous, incompressible, electrically-conducting fluid past an infinite hot vertical porous plate embedded in porous medium with heat generation/absorption. Mahapatra *et al.* [10] have studied the effect of chemical reaction on free convection flow through a porous medium bounded by vertical surface. Mohamad [11] studied the Soret effect on the unsteady magnetohydrodynamics (MHD) free convection heat and mass transfer flow past a semi-infinite vertical plate in a Darcy porous medium in the presence of chemical reaction and heat generation.

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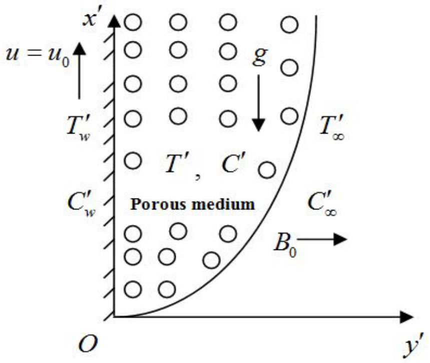
In spite of all these studies, the Chemical reaction and Soret effects on unsteady MHD free convective heat and mass transfer past an infinite vertical plate embedded in a porous medium in the presence of thermal radiation has received little attention. Hence, the main objective of the present investigation is to study the Chemical reaction and Soret effects on unsteady MHD flow through porous medium over an infinite vertical plate in the presence of thermal radiation. The dimensionless governing equations involved in the present analysis are solved numerically using finite difference method (FDM) by developing suitable codes in MATLAB. The fluid velocity, temperature and species concentration profiles have been drawn for time and various values of flow parameters such as Radiation parameter (R), chemical reaction parameter (K_r) and Soret number (Sr), and results are discussed.

2. MATHEMATICAL FORMULATION

An unsteady two-dimensional laminar free convection flow of a viscous, incompressible, electrically conducting, radiating fluid past an impulsively started infinite vertical plate through porous medium in the presence of transverse applied magnetic field and Soret effects are studied. The plate is taken along x' - axis in vertically upward direction and y' - axis is taken normal to the plate. Initially it is assumed that the plate and fluid are at the same temperature T'_∞ and concentration level C'_∞ in stationary condition for all the points. At time $t' > 0$, the plate is given an impulsive motion with a velocity $u = u_0$ in the vertical upward direction against the gravitational field, and at the same time the plate temperature is raised linearly with time t and also the mass is diffused from the plate to the fluid is linearly with time. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the direction of flow. The effects of viscous dissipation and induced magnetic field are assumed to be negligible. Further, a chemically reactive species is emitted from the vertical surface into the hydrodynamic flow field. It diffuses into the fluid, where it undergoes a homogeneous chemical reaction.



Flow configuration and coordinate system.

The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium. Then under by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \frac{\sigma B_0^2 u'}{\rho} - \nu \frac{u'}{k'} \tag{1}$$

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q'_r}{\partial y'} \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} + D_1 \frac{\partial^2 T'}{\partial y'^2} - k_r'(C' - C'_\infty) \tag{3}$$

with the following initial and boundary conditions

$$\left.\begin{aligned} & t' \le 0 : u' = 0, T' = T_\infty', C' = C_\infty' \text{ for all } y' \\ & t' > 0 : u' = u, T' = T_\infty' + (T_w' - T_\infty')At', C' = C_\infty' + (C_w' - C_\infty')At' \text{ at } y' = 0 \\ & u' = 0, T' \to T_\infty', C' \to C_\infty' \text{ as } y' \to \infty \text{ where } A = \frac{u_0^2}{\nu} \end{aligned}\right\} \tag{4}$$

where u' is the velocity of the fluid in the x' direction, t' is the time, y' is the co-ordinate normal to the plate, k' is the permeability parameter, β is the volumetric coefficient of thermal expansion , β^* is the volumetric coefficient of expansion for concentration, B_0 is the external magnetic field, ρ is the density, σ is the electrical conductivity , k is the thermal conductivity, g is the acceleration due to gravity, T' is the temperature, T'_w is the fluid temperature at the plate, T'_∞ is the fluid temperature in the free stream, C' is the species concentration, C_p is the specific heat at constant pressure, C'_∞ is the species concentration in the free stream, C'_w is the species concentration at the surface, D is the chemical molecular diffusivity, D_1 is the coefficient of thermal diffusivity, q'_r is the radiative flux and k'_r is the rate constant for first order chemical reaction.

The local radiant for the case of an optically thin gray gas ([12], [13]) is expressed by

$$\frac{\partial q'_r}{\partial y'} = -4a^*\sigma(T'^4_\infty - T'^4) \tag{5}$$

where σ and a^* are the Stefan-Boltzmann constant and the Mean absorption coefficient, respectively.

Following [12], [13] and others, we assumed that the temperature differences within the flow are sufficiently small and that T'^4 may be expressed as a linear function of the temperature. This is obtained by expanding T'^4 in a Taylor series about T'_∞ and neglecting the higher order terms, thus we get

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{6}$$

From equations (5) and (6), equation (2) reduces to

$$\rho C_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} + 16a^*\sigma T'^3_\infty (T'_\infty - T') \tag{7}$$

On introducing the following non-dimensional quantities:

$$\left.\begin{aligned} & u = \frac{u'}{u_0}, t = \frac{t'u_0^2}{\nu}, y = \frac{y'u_0}{\nu}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \Pr = \frac{\mu C_p}{k}, Sr = \frac{D_1(T'_w - T'_\infty)}{\nu(C'_w - C'_\infty)}, \\ & Gr = \frac{g\beta\nu(T'_w - T'_\infty)}{u_0^3}, Gm = \frac{g\beta^*\nu(C'_w - C'_\infty)}{u_0^3}, K = \frac{u_0^2 k'}{\nu^2}, Sc = \frac{\nu}{D}, M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, R = \frac{16a^*\nu^2\sigma T'^3_\infty}{k u_0^2}, \\ & K_r = \frac{k'_r}{u_0^2} \end{aligned}\right\} \tag{8}$$

We get the following governing dimensionless equations

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GmC - Mu - \frac{u}{K} \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{1}{\Pr}R\theta \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} - K_r C \tag{12}$$

The initial and boundary conditions in dimensionless form as follows:

$$\left.\begin{aligned} & t \le 0 : u = 0, \theta = 0, C = 0 \text{ for all } y \\ & t > 0 : u = 1, \theta = t, C = t \text{ at } y = 0 \text{ and} \\ & u \to 0, \theta \to 0, C \to 0 \text{ as } y \to \infty \end{aligned}\right\} \tag{13}$$

where u is the dimensionless velocity, y is the dimensionless ordinate normal to the plate, t is the dimensionless time, Gr is the thermal Grashof number, Gm is the mass Grashof number, M is the Magnetic field parameter, K is the Permeability parameter, $\Pr$ is the Prandtl number, R is the Radiation parameter, Sc is the Schmidt number, Sr is the Soret number, K_r is the Chemical reaction parameter, θ is the Dimensionless temperature, C is the Dimensionless concentration.

3. SOLUTION OF THE PROBLEM

The dimensionless governing differential equations (10) - (12) subject to the initial and boundary conditions (13) are reduced to a system of difference equations using the following finite difference scheme, and then the system of difference equations is solved numerically by an iterative method. The scheme for a variable u is given by

$$\frac{\partial u}{\partial y}=\frac{u_{i+1,j}-u_{i,j}}{\Delta y},\frac{\partial u}{\partial t}=\frac{u_{i,j+1}-u_{i,j}}{\Delta t},\frac{\partial^2 u}{\partial y^2}=\frac{u_{i+1,j}-2u_{i,j}+u_{i-1,j}}{(\Delta y)^2}$$

Equations (10) - (12) are of the form given below

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t}=\frac{u_{i+1,j}-2u_{i,j}+u_{i-1,j}}{(\Delta y)^2}+Gr\theta(i,j)+GmC(i,j)-Mu(i,j)-\frac{1}{K}u(i,j)$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{(\Delta y)^2}-\frac{1}{\Pr}R\theta(i,j)$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}=\frac{1}{Sc}\frac{C_{i+1,j}-2C_{i,j}+C_{i-1,j}}{(\Delta y)^2}+Sr\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{(\Delta y)^2}-K_rC(i,j)$$

4. RESULTS AND DISCUSSION

Chemical reaction, thermal radiation and Soret effects on the velocity, temperature and concentration profiles are studied for various values of the parameters. Numerical calculations have been carried out for different values of t, K_r, R, Sr and for fixed values of $\Pr, Sc, Gr, Gm, K$ and M. The values are taken for computation $t=0.2, K=0.5, Gr=1, Gm=1, M=1, \Pr=0.71, Sc=0.66, R=10, Sr=1, K_r=1$.

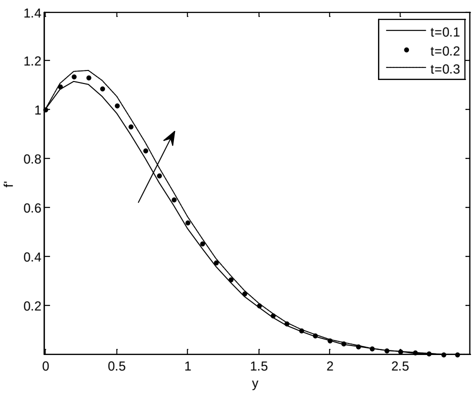


Figure-1: Velocity profile for variation of t.

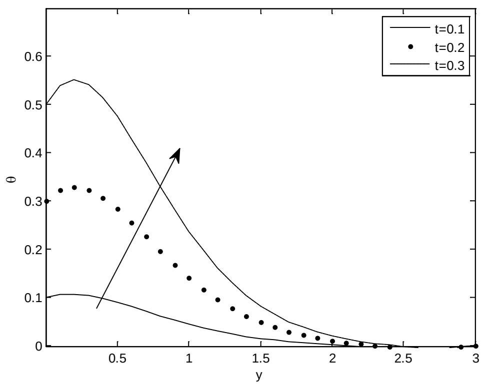


Figure-2: Temperature profile for variation of t.

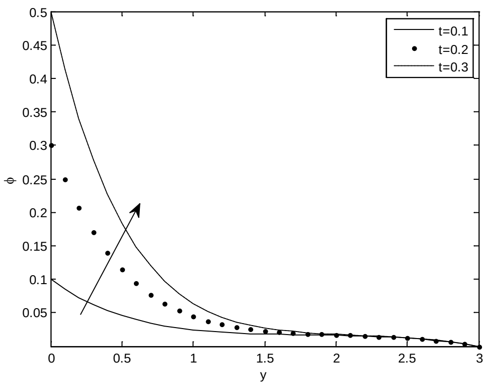


Figure-3: Concentration profile for variation of t.

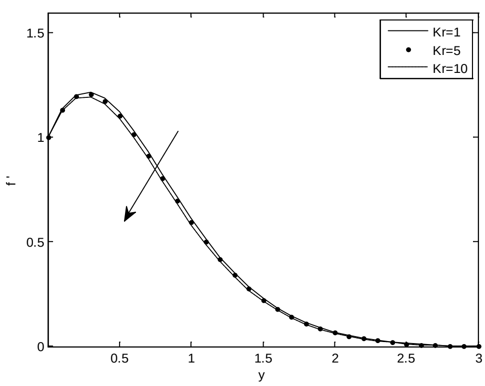


Figure-4: Velocity profile for variation of K_r

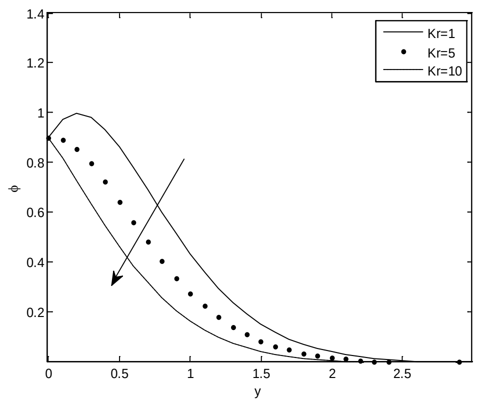


Figure-5: Concentration profile for variation of K_r

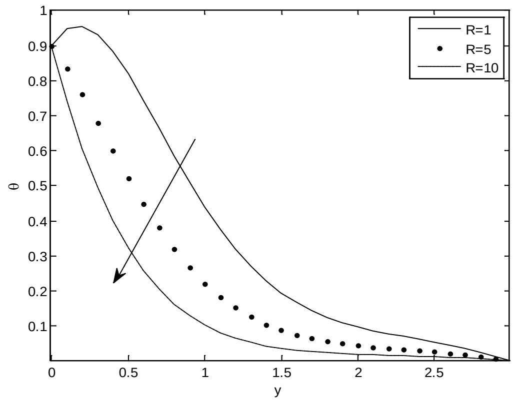


Figure-6: Temperature profile for variation of R.

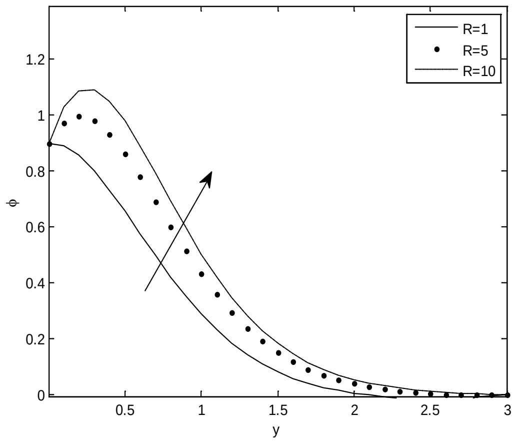


Figure-7: Concentration profile for variation of R.

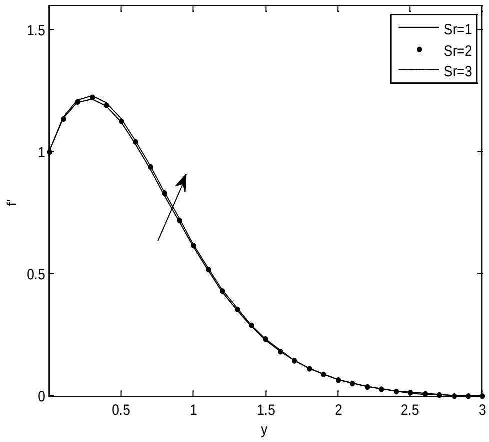


Figure-8: Velocity profile for variation of Sr.

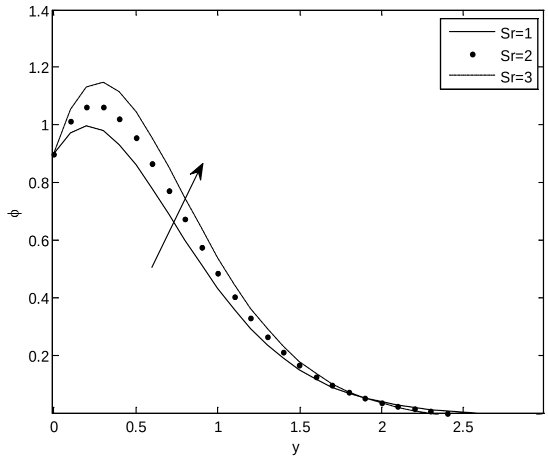


Figure-9: Concentration profile for variation of Sr.

Table-1: Velocity for different t with

$K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1, K_r = 1$

Y	$t = 0.1$	$t = 0.2$	$t = 0.3$
0.00	1.000000	1.000000	1.000000
0.10	1.082871	1.089229	1.095587
0.20	1.114161	1.125245	1.136329
0.30	1.102190	1.116479	1.130769
0.40	1.056162	1.072319	1.088477
0.50	0.985286	1.002198	1.019110

Table-2: Temperature for different t with

$K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1, K_r = 1$

Y	$t = 0.1$	$t = 0.2$	$t = 0.3$
0.00	0.100000	0.200000	0.300000
0.10	0.085352	0.167452	0.249551
0.20	0.072835	0.139750	0.206666
0.30	0.062217	0.116340	0.170463
0.40	0.053284	0.096714	0.140143
0.50	0.045838	0.080402	0.114966

Table-3: Concentration for different t with

$K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1, K_r = 1$

Y	$t = 0.1$	$t = 0.2$	$t = 0.3$
0.00	0.100000	0.200000	0.300000
0.10	0.105699	0.214170	0.322641
0.20	0.106547	0.217827	0.329108
0.30	0.103504	0.213016	0.322527
0.40	0.097546	0.201807	0.306069
0.50	0.089585	0.186156	0.282727

Table-4: Velocity for different K_r with

$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1$

Y	$K_r = 1$	$K_r = 5$	$K_r = 10$
0.00	1.000000	1.000000	1.000000
0.10	1.133736	1.129564	1.125528
0.20	1.202833	1.194606	1.186735
0.30	1.216506	1.204746	1.193635
0.40	1.185424	1.170897	1.157346
0.50	1.120581	1.104155	1.089027

Table-5: Temperature for different K_r with

$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1$

Y	$K_r = 1$	$K_r = 5$	$K_r = 10$
0.00	0.900000	0.900000	0.900000
0.10	0.973468	0.892426	0.816227
0.20	0.996793	0.854706	0.726023
0.30	0.979593	0.795457	0.634390
0.40	0.931638	0.722390	0.545218
0.50	0.862153	0.642064	0.461338

Table-6: Concentration for different K_r with

$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1$

Y	$K_r = 1$	$K_r = 5$	$K_r = 10$
0.00	0.900000	0.900000	0.900000
0.10	0.947371	0.835184	0.742148
0.20	0.955512	0.760547	0.608159
0.30	0.931834	0.680869	0.495203
0.40	0.884040	0.600208	0.400717
0.50	0.819503	0.521798	0.322351

Table-7: Concentration for different R with
$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, Sr = 1, K_r = 1$

Y	$R=1$	$R=2$	$R=3$
0.00	0.900000	0.900000	0.900000
0.10	0.793364	0.891682	0.973468
0.20	0.680353	0.856800	0.996793
0.30	0.567944	0.801813	0.979593
0.40	0.461326	0.733009	0.931638
0.50	0.364006	0.656098	0.862153

Table-8: Velocity for different Sr with
$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, K_r = 1$

Y	$Sr=1$	$Sr=2$	$Sr=3$
0.00	1.000000	1.000000	1.000000
0.10	1.133736	1.135795	1.137854
0.20	1.202833	1.206830	1.210827
0.30	1.216506	1.222113	1.227720
0.40	1.185424	1.192208	1.198992
0.50	1.120581	1.128081	1.135582

Table-9: Concentration for different Sr with
$t = 0.2, K = 0.5, Gr = 1, Gm = 1, M = 1, \Pr = 0.71, Sc = 0.66, R = 10, K_r = 1$

Y	$Sr=1$	$Sr=2$	$Sr=3$
0.00	0.900000	0.900000	0.900000
0.10	0.973468	1.013737	1.054006
0.20	0.996793	1.064258	1.131723
0.30	0.979593	1.063397	1.147202
0.40	0.931638	1.023116	1.114594
0.50	0.862153	0.954694	1.047235

5. CONCLUSION

(i) Effect of time (t): Figs 1, 2, 3 shows the velocity, temperature and concentration profiles respectively against y for several values of the time t. It is observed that an increase in t leads to an increase in the values of velocity, temperature and concentration.

(ii) Effect of Chemical reaction parameter (K_r): The effect of K_r on velocity and concentration profile is depicted in Figs. 4 and 5. It is observed that the velocity and concentration decreases with the increasing values of K_r. Due to increase in values of K_r, the concentration of fluid particles near the plate drops, which results in decreasing the effect of mass buoyancy forces and thus decrease the fluid velocity. Due to increase in K_r, the constituents from higher concentration zone (adherent to the plate) moves towards the species in lower concentration zone(free stream) results of which decreases the concentration boundary layer thickness, thus decreasing the values of concentration.

(iii) Effect of Radiation parameter (R): The effect of R on velocity and temperature profile is depicted in Figs.6 and 7. It is observed that the velocity decreases and temperature increases with the increasing values of R.

(iv) Effect of Soret parameter (Sr): The effect of Soret parameter (Sr) on velocity and Concentration profile is depicted in Figs. 8 and 9. It is observed that the velocity and Concentration increases with the increasing values of Sr. Soret effect is to increase both velocity and concentration distributions with formation of peak for higher values of Soret parameter in the solution boundary layer. Due to increase in Sr, the mass buoyancy forces increase which accelerates the flow rate and thus increase the value of velocity.

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