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Chemical Reaction and Variable Suction Velocity On Unsteady MHD Jeffery Flow past a Vertical Porous Plate with Soret-Dufour Effects

A.K. Shukla*, Aneesh Jayswal**, [3]Mohammad Suleman Quraishi***

[1,2]Department of Mathematics RSKD PG College Jaunpur-222001, India

Email:

[3]Department of Applied Sciences, Jahangirabad Institute of Technology, Barabanki, Uttar Pradesh, India.

Email: sulemanfornaths86@gmail.com

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Abstract:

This research aims to investigate the combined effects of Soret-Dufour, radiation, first order chemical reaction, and magnetic hydrodynamics (MHD) Jeffery flow across a vertical porous plate submerged in a porous medium at varying suction velocity. The Mathematical model of the problem is governed by set of non linear partial differential equations. The Crank-Nicolson implicit finite difference approach has been used to numerically solve the nonlinear partial differential equation of flow problem in this model. Graphical representations of the features of velocity, temperature, and concentration are used, while tables are used to illustrate the characteristics of skin friction, the Nusselt number, and the Sherwood number.

Keywords: **Jeffery Fluid, Magnetohydrodynamics, Heat Transfer, Mass Transfer, Soret and Dufour effects, Crank Nicolson finite difference method.**

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I. INTRODUCTION

Only the Newtonian fluid model was employed for all experiments in the literature evaluated in previous years. Despite the fact that the majority of industrial and biological fluids are non-Newtonian and the classical Newton's law of viscosity fails to describe the complex rheological properties of non-Newtonian fluids, very little research has been done to investigate how non-Newtonian fluids flow in porous-walled channels and tubes. The Jeffrey fluid model, which is regarded as the best model for physiological fluids, is one non-Newtonian fluid model that has caught the interest of researchers. Numerous mathematicians are interested in the unsteady MHD Jeffery flow on a vertical porous plate with Soret-Dufour and first order chemical reaction. It has been increasingly important in recent years to analyse how mass transfer impacts both Newtonian and non-Newtonian fluids. Solar energy, semiconductor wafer processing, the creation of transient crystals, energy transfer in furnaces, and many other sectors use heat transmission by radiation. To increase thermal efficiency, engines and combustion chambers are built to operate at higher temperatures. Due to a large variety of natural convection MHD applications in chemical industries such as drying, food processing, oil extraction, and others, flow occurs in solid mechanics. This is the reason why many researchers are drawn to this line of work. Additionally, radiative-convective flow is frequently used in astrophysical flows as well as thermal chamber heating and cooling. The burning oil pool, leaching by spray, and drying are examples of how the fluid dynamics theory of mass transfer is put to use. Due of its uses in engineering and science, such as isotope separation, many researchers looked into the effects of Soret and Dufour in flow problems. Sandeep and Babu [1] analyzed the numerical result of nonlinear radiation for heat transfer of nanofluid past a vertical plate. Rushi et al. [2] investigated unsteady nanofluid flow phenomena in the presence of chemical of a higher order. Mastroberardino et al. [3] worked on MHD boundary layer slip flow and heat transfer of a power-law fluid over a flat plate. Idowu and Falodun [4] look over change SoretDufour on MHD flow of viscoelastic fluid over a semi-infinite vertical plate. Saritha et al. [5] explored the combined effects of Soret and Dufour on MHD flow of a power-law fluid over a flat plate in a slip flow regime. Malik and Rahman [6] analyzed the effects of second-order chemical reaction on MHD free convection dissipative fluid flow past an inclined porous surface by way of Heat Generation. Imtiaz et al. [7] observed effects of Soret and Dufour in the flow of viscous fluid by a curved stretching surface. Anuradha and Harianand [8] studied Soret and Dufour effects on MHD mixed convection flow towards a vertical plate in a porous medium. Ahmed [9] explored the exact solution of Heat and mass transfer in MHD Poiseuille flow with porous walls. Das and Dorjee [10] analyzed the MHD flow with Soret and Dufour effects in the presence of heat source and chemical reaction. T. Hayat, et al. [11] , MHD flow of Jeffrey liquid due to a nonlinear radially stretched sheet in presence of Newtonian heating. M. Eswara Rao & S. Sreenadh [12], MHD Boundary Layer Flow of Jeffrey Fluid over a Stretching/Shrinking Sheet through Porous Medium. T. Hayat et al. [13], Simultaneous effects of melting heat and internal heat generation instagnation point flow of Jeffrey fluid towards a nonlinear stretching surface with variable thickness. M.A. Rana et al. [14], Three-dimensional Couette flow of a Jeffrey fluid along periodic injection/suction. M.A. Imran [15], MHD fractional Jeffrey's fluid flow in the presence of thermo diffusion, thermal radiation effects with first order chemical reaction and uniform heat flux. T. Hayat et al. [16], Radiative Flow of Jeffrey Fluid Through a Convectively Heated Stretching Cylinder. K. Das et al. [17], Radiative flow of MHD Jeffrey fluid past a stretching sheet with surface slip and melting heat Transfer. M.M. Bhatti & M. Ali Abbas [18], Simultaneous effects of slip and MHD on peristaltic blood flow of Jeffrey fluid model through a porous Medium. S. Sreenadh et al. [19], Peristaltic pumping of a power – Law fluid in contact with a Jeffrey fluid in an inclined channel with permeable walls. S. Farooq et al. [20], Magneto hydrodynamic peristalsis of variable viscosity Jeffrey liquid with heat and mass transfer. K. Venkateswara et al. [21], Unsteady MHD Mixed Convection Flow of Jeffrey Fluid Past a Radiating Inclined Permeable Moving Plate in the Presence of thermophoresis Heat Generation and Chemical Reaction. D. Dastagiri Babu et al. [22], Multivariate Jeffrey Fluid Flow past a Vertical Plate through Porous Medium.

The aim of the present work is to analyze the effects of Soret-Dufour, radiation, and first-order chemical reaction on unsteady MHD Jeffery flow of viscous incompressible fluid through a vertical porous plate immersed in a porous medium under consideration of variable suction velocity. The result of variation in different parameters on velocity, heat transfer, and mass transfer as well as in physical quantities like skin friction, Nusselt number, and Sherwood number are received by solving the governing equations of the flow field with considering changes with appropriate parameters using Crank-Nicolson implicit finite difference method.

II. MATHEMATICAL MODELING OF THE PROBLEM

In this model, we consider a fluid capable of a first-order chemical reaction and an unsteady Jeffery MHD boundary layer flow of a viscous incompressible electrically conducting fluid past a semi-infinite vertical porous plate immersed in a porous medium. Our assumption in starting the plate moves with velocity u_0 and concentration and temperature decrease exponentially with respect to time and the plate gets heated at temperature $\overline{\theta_w}$ and concentration $\overline{\emptyset}_w$. The $\bar{x}$-axis considered along with the semi-infinite plate in the vertically upward direction and $\bar{y}$-axis normal to it, the flow variables are functions of normal distance $\bar{y}$ and $\bar{t}$ only. A magnetic field B_0 is exerted normal to the plate, the induced magnetic field is neglected because of under low magnetic Reynolds number. Suction velocity is considered time-dependent and normal to the plate. We further consider that the plate is non-conducting. From the above model of the problem, the governing equations of flow field under the usual Boussinesq approximation are as follows:

A. Equation of Continuity :

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \qquad (1)$$

B. Momentum Equation

$$\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \left(\frac{\nu}{1+\lambda}\right)\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + g\beta_1(\bar{\theta}-\bar{\theta}_\infty) + g\beta_2(\bar{\phi}-\bar{\phi}_\infty) - \frac{\sigma B_0^{\,2}\bar{u}}{\rho} - \nu\frac{\bar{u}}{\bar{K}} \qquad (2)$$

C. Energy Equation

$$\rho_\infty C_p\left(\frac{\partial \bar{\theta}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{\theta}}{\partial \bar{y}}\right) = k\frac{\partial^2 \bar{\theta}}{\partial \bar{y}^2} - \frac{\partial q_r}{\partial \bar{y}} + \frac{\rho D_m K_T}{c_s}\frac{\partial^2 \bar{\phi}}{\partial \bar{y}^2} \qquad (3)$$

D. Concentration Equation

$$\frac{\partial \bar{\phi}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{\phi}}{\partial \bar{y}} = D\frac{\partial^2 \bar{\phi}}{\partial \bar{y}^2} + \frac{D_m K_T}{T_m}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - k_r\left(\bar{\phi}-\bar{\phi}_\infty\right) \qquad (4)$$

The boundary conditions for this model are assumed as:

$$\bar{t} \le 0; \quad \bar{u} = 0, \quad \bar{\theta} = \bar{\theta}_\infty, \quad \bar{\phi} = \bar{\phi}_\infty$$

$$\bar{t} > 0; \quad \bar{u} = u_0, \quad \bar{\theta} = \bar{\theta}_\infty + \varepsilon(\bar{\theta}_w - \bar{\theta}_\infty)e^{-At}, \quad \bar{\phi} = \bar{\phi}_\infty +$$

$$\bar{u} \to 0, \quad \bar{\theta} \to \bar{\theta}_\infty, \quad \bar{\phi} \to \bar{\phi}_\infty \quad as$$

(5)

where $\bar{\theta}$ and $\bar{\emptyset}$ are dimensional temperature and concentration $\overline{\emptyset_w}$ and $\overline{\theta_w}$ are concentration and temperature of free stream, in Equation 4; $k_r(\bar{\emptyset} - \overline{\emptyset_w})$ has been introduced for first order chemical reaction, k_r is chemical reaction constant, β_1 is volumetric coefficient of thermal expansion, β_2 is coefficient of volume expansion for mass transfer,

$q_r$is radiative heat along $\bar{y}$-axis, ν is kinematic viscosity and T_m is mean fluid temperature, $\bar{v}$ is suction velocity along $\bar{y}$-axis, $\bar{K}$ is permeability of porous medium, σ is electrical conductivity, D_m is molecular diffusivity, g is acceleration due to gravity, K_T is thermal diffusion ratio, μ is viscosity, ρ is fluid density, k is thermal conductivity of fluid, C_p is specific heat at constant pressure.

We obtain $\bar{v} = constant$ by integrating the two sides of the continuity equation (1). The suction velocity normal to the plate is clearly a constant function or can be thought of as a function of time. In this model, we suppose that it is expressed as a situation when it is both constant and time-dependent.

$$\bar{v} = -u_0(1+\in Ae^{\bar{n}\bar{t}}) \quad (6)$$

where u_0 is mean suction velocity, which is a non-zero positive constant and the minus sign indicates that the suction is outwards the plate. A is the suction parameter; ϵ is a small reference parameter and $\in A \ll 1$. The radiative flux term q_r by using the Rosseland approximation [24], is given by

$$q_r = -\frac{4\sigma_{st}}{3a_m}\frac{\partial \bar{\theta}^4}{\partial \bar{y}} \quad (7)$$

Here Stefan Boltzmann constant and absorption coefficient are σ_{st} and a_m respectively.

In this case temperature differences are very-very small within flow, such that $\bar{\theta}^4$ can be expressed linearly with temperature. It is realized by expanding in a Taylor series about $\bar{\theta}_\infty$, and neglecting higher order terms, so

$$\bar{\theta}^4 \cong 4\bar{\theta}_\infty{}^3\bar{\theta} - 3\bar{\theta}_\infty{}^4 \quad (8)$$

With the help of equations (7) and (8), we write the equation (4) in this way

$$\rho_\infty C_p\left(\frac{\partial\bar{\theta}}{\partial\bar{t}} + \bar{v}\frac{\partial\bar{\theta}}{\partial\bar{y}}\right) = k\frac{\partial^2\bar{\theta}}{\partial\bar{y}^2} + \frac{16\bar{\theta}_\infty{}^3\sigma_{st}}{3a_m}\frac{\partial^2\bar{\theta}}{\partial\bar{y}^2} + \frac{\rho D_m K_T}{c_s}\frac{\partial^2\bar{\varphi}}{\partial\bar{y}^2} \quad (9)$$

Let us introduce the following dimensionless quantities

$$\left.\begin{array}{l} u = \frac{\bar{u}}{u_0}, t = \frac{\bar{t}u_0{}^2}{\nu}, y = \frac{\bar{y}u_0}{\nu}, \theta = \frac{\bar{\theta}-\bar{\theta}_\infty}{\bar{\theta}_w-\bar{\theta}_\infty}, C = \frac{\bar{\varphi}-\bar{\varphi}_\infty}{\bar{\varphi}_w-\bar{\varphi}_\infty}, \\ G_m = \frac{\nu g\beta_2(\bar{\varphi}_w-\bar{\varphi}_\infty)}{u_0{}^3}, G_r = \frac{\nu g\beta_1(\bar{\theta}_w-\bar{\theta}_\infty)}{u_0{}^3}, K = \frac{u_0{}^2}{\nu^2}\bar{K}, \\ S_c = \frac{\nu}{D}, P_r = \frac{\mu C_p}{k}, M = \frac{\sigma B_0{}^2\nu}{\rho u_0{}^2}, R = \frac{4\sigma\bar{\theta}_\infty{}^3}{k_m k}, K_r = \frac{k_r\nu}{u_0{}^2}, \\ D_u = \frac{D_m K_T(\bar{\varphi}_w-\bar{\varphi}_\infty)}{c_s c_p \nu(\bar{\theta}_w-\bar{\theta}_\infty)}, S_r = \frac{D_m K_T(\bar{\theta}_w-\bar{\theta}_\infty)}{\theta_m \nu(\bar{\theta}_w-\bar{\varphi}_\infty)} \\ A = \frac{u_0{}^2}{\nu} \end{array}\right\} \quad (10)$$

Using substitutions of Equation 10, we get non-dimensional form of partial differential Equations 2, 9 and 4 respectively

$$\frac{\partial u}{\partial t} - (1+\varepsilon Ae^{nt})\frac{\partial u}{\partial y} = \left(\frac{1}{1+\lambda}\right)\frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m C - \left(M + \frac{1}{K}\right)u \quad (11)$$

$$\frac{\partial\theta}{\partial t} - (1+\varepsilon Ae^{nt})\frac{\partial\theta}{\partial y} = \frac{1}{P_r}\left(1 + \frac{4R}{3}\right)\frac{\partial^2\theta}{\partial y^2} + D_u\frac{\partial^2 C}{\partial y^2} \quad (12)$$

$$\frac{\partial C}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial C}{\partial y}=\frac{1}{S_c}\frac{\partial^2 C}{\partial y^2}+S_r\frac{\partial^2\theta}{\partial y^2}-K_rC \quad (13)$$

With initial and boundary conditions

$$\left.\begin{array}{l} t\leq 0; u=0,\theta=0,C=0\forall y \\ t>0; u=1,\theta=1+\varepsilon e^{-nt},C=1+\varepsilon e^{-nt} at y=0 \\ u\to 0,\theta\to 0,C\to 0 as y\to\infty \end{array}\right\} \quad (14)$$

The degree of practical interest includes the Skin friction coefficients τ, local Nusselt Nu, and local Sherwood Sh numbers are given as follows:

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}, N_u=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}, S\square=-\left(\frac{\partial C}{\partial y}\right)_{y=0} \quad (15)$$

III. NUMERICAL METHOD OF SOLUTION

Equations (11), (12), and (13) provide non-dimensional forms of velocity, heat transfer, and mass transfer equations, whereas equations (14), which shows non-dimensional forms of boundary conditions, show non-linear partial differential equations for these equations and boundary conditions. Therefore, it is impossible to find the exact solution to this kind of system of partial differential equations. To provide a numerical solution, Crank-Nicolson implicit finite difference approach is utilized. The computation is executed for Δy = 0.1, Δt = 0.002 and procedure is repeated till y = 4. Following the use of Crank-Nicolson finite difference, these systems of partial differential equations take the following form:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t}-(1+\varepsilon Ae^{nj\Delta t})\frac{u_{i+1,j}-u_{i,j}}{\Delta y}=\left(\frac{1}{1+\lambda}\right)\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}+u_{i-1,j+1}-2u_{i,j+1}+u_{i+1,j+1}}{2(\Delta y)^2}+G_r\left(\frac{\theta_{i,j+1}+\theta_{i,j}}{2}\right)+G_m\left(\frac{C_{i,j+1}+C_{i,j}}{2}\right)-\left(M+\frac{1}{K}\right)\left(\frac{u_{i,j+1}+u_{i,j}}{2}\right) \quad (16)$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}-(1+\varepsilon Ae^{nj\Delta t})\frac{\theta_{i+1,j}-\theta_{i,j}}{\Delta y}=\frac{1}{P_r}\left(1+\frac{4R}{3}\right)\left(\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}+\theta_{i-1,j+1}-2\theta_{i,j+1}+\theta_{i+1,j+1}}{2(\Delta y)^2}\right)+D_u\left(\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}+C_{i-1,j+1}-2C_{i,j+1}+C_{i+1,j+1}}{2(\Delta y)^2}\right) \quad (17)$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}-(1+\varepsilon Ae^{nj\Delta t})\frac{C_{i+1,j}-C_{i,j}}{\Delta y}=\frac{1}{S_c}\left(\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}+C_{i-1,j+1}-2C_{i,j+1}+C_{i+1,j+1}}{2(\Delta y)^2}\right)+S_r\left(\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}+\theta_{i-1,j+1}-2\theta_{i,j+1}+\theta_{i+1,j+1}}{2(\Delta y)^2}\right)+K_r\left(\frac{C_{i,j+1}+C_{i,j}}{2}\right) \quad (18)$$

Initial and boundary conditions are also rewritten as:

$$u_{i,0}=0,\theta_{i,0}=0,C_{i,0}=0\forall i$$
$$u_{0,j}=1,\theta_{0,j}=1+\varepsilon e^{-nj\Delta t},C_{0,j}=1+\varepsilon e^{-nj\Delta t}\forall j$$
$$u_{l,j}\to 0,\theta_{l,j}\to 0,C_{l,j}\to 0 \quad (19)$$

Where index i represents to y and j represents to time t, $\Delta t=t_{j+1}-t_j$ and $\Delta y=y_{j+1}-y_j$. Getting the values of u, θ and C at time t, we may compute the values of u, θ and C at time $t+\Delta t$ by following method: we substitute i = 1, 2, ..., l −1 , where l correspond to ∞ ,equations 16 to 18 give tridiagonal system of equations with boundary conditions in equation 19, are solved employing Thomas algorithm as discussed in Carnahan et al.[23], we find values of θ and C for all values of y at t + Δt. Equation 16 is solved by the same procedure to substitute these values of θ and C, we get solution for u till desired time t.

III. ANALYSIS AND RESULTS BASED DIFFERENT PROFILES

In this study, the Soret and Dufour effect is used to investigate the boundary layer unsteady MHD Jeffery flow past a porous vertical plate with variable suction velocity. The mass diffusion equation now includes the first order chemical reaction's influence. Skin friction coefficients, Nusselt number, and Sherwood number are presented with the use of tables, while numerical results of velocity profile u, temperature profile, and concentration profile C have been discussed with the aid of graphs in order to see a physical view of the work.

The following values are used for investigation
Gr = 5, Gm = 8, n = 5, K = 1.7, Kr = 1.7, Pr = 0.5, Du = 0.39, Sc = 0.9, Sr =1.7, R =1.3, t = 0.1.

It is noted from figure 6 that increasing radiation parameter R, velocity u increases. This is correct observation because the increase in radiation reveals heat energy to flow. It is analyzed that an increase in R, temperature θ increases in figure 12 and it is notable that an increase in R, concentration C near to plate decrease after that increases in figure 21. In figure 4, velocity decreases as Prandtl number Pr increases and temperature decreases rapidly in figure 11 when Pr increases. In figure 17 concentration C near to plate increases and after some distance from plate concentration decreases as Prandtl number increases. Figure 19, depicts the variation of Schmidt number Sc as concentration decreases rapidly with increase Sc while velocity and temperature profiles in figures 7 and 15 respectively decreases and increases near to plate and . In figure 1, 16 and 10, it is seen that velocity increases and concentration decreases as increase Dufour number Du, whereas temperature increases as Du increases. Figures 5 and 18 depict the behavior of chemical reaction parameter Kr on velocity and concentration respectively. It is seen that velocity decreases, concentration decreases rapidly as Kr increase. Figure 9, 14 and 22 reveals that velocity, temperature and concentration increase on increase of time. Figure 8, 20 and 13 depict that increment in Soret number Sr, velocity and concentration increases rapidly while temperature decreases slowly respectively. Figure 3 shows the effect of magnetic parameter M, on increasing the values of M velocity profile decrease which is consistent with the law of Lorentz's force. Jeffery fluid parameter λ effect has been shown through figure 2, velocity decreases with increase in Jeffery fluid parameter.

It is observed from **Table 1** that Change in Schmidt number Sc effects as skin friction coefficient and Nusselt number decreases whileSherwood number increases, a similar variation can be seen on chemical reaction parameter Kr increment. Pr effects as skin friction coefficient and Nusselt number increases while Sherwood number decreases.Skin friction coefficient and Nusselt number decreases whereas Sherwood numberSh increases with Dufour number Du increases. Increase in Soret number Sr,Skin friction and Nusselt number Nu increase whileSherwood numberSh decreases. On increasing Jeffrey fluid parameter λ and time t results in skin friction coefficient increases. On increasing magnetic parameter M results in skin friction coefficient decreases rapidly. It is also noted that increment in radiation parameter R skin friction coefficient and Sherwood number increases while Nusselt number decreases.

IV. CONCLUSION

On an unsteady MHD Jeffery flow over a vertical porous plate submerged in a porous material, the impacts of first order chemical reactions and changes in Soret-Dufour effects with variable suction in presence of magnetic field are examined. These findings from the investigation are as follows:

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- The effect of radiation on concentration is noteworthy. It is observed that increasing values of R, concentration falls down and after some distance from the plate, it goes up slowly-slowly while velocity and temperature increases rapidly.

- Interestingly, increment in concentration has been found on increasing Prandtl number P r.
- For increasing values of Kr, it is a considerable enhancement in velocity, i.e. velocity decreases slowly but concentration decreases rapidly.
- Increasing values of Dufour number, it is observed that velocity and temperature profile in the thermal boundary layer increases whereas concentration profile first decreases after then increases slowly in the boundary layer.
- Velocity and concentration profiles can be seen through Soret number Sr, velocity increases slowly but concentration rapidly increases.
- Schmidt number greatly influences the concentration profile in the concentration boundary layer, concentration decreases rapidly

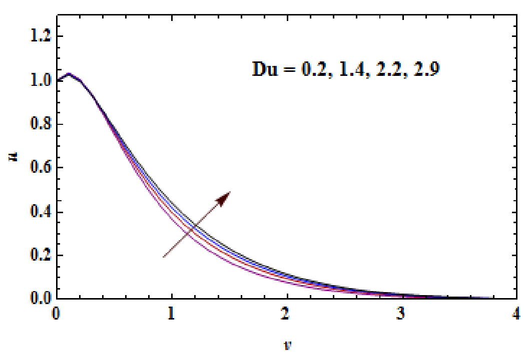

Fig. 1 Velocity Profiles for Different Values of Du

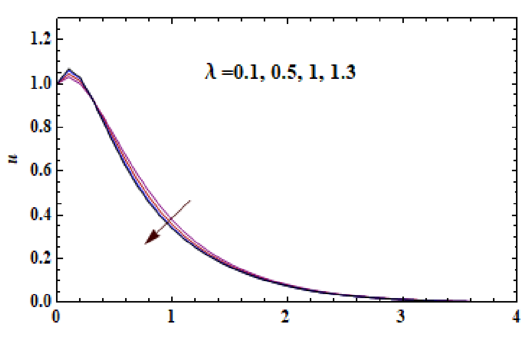

Fig. 2 Velocity Profiles for Different Values of λ

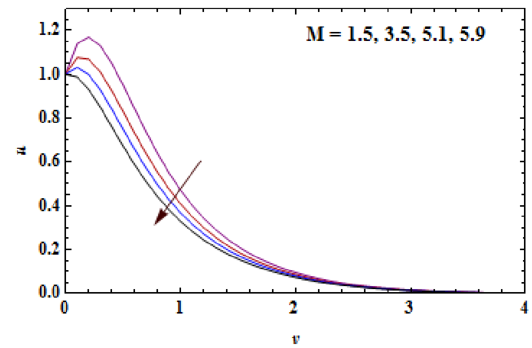

Fig. 3 Velocity Profiles for Different Values of M

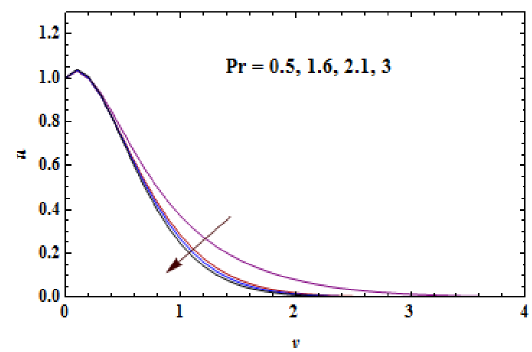

Fig. 4 Velocity Profiles for Different Values of Pr

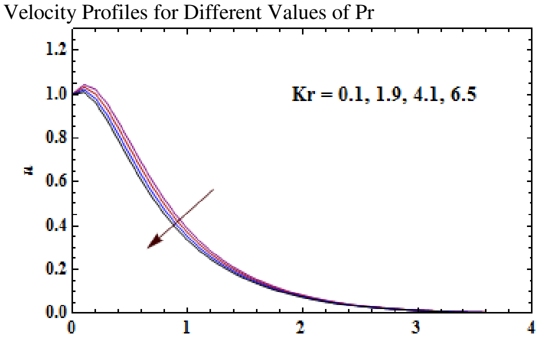

Fig. 5 Velocity Profiles for Different Values of Kr

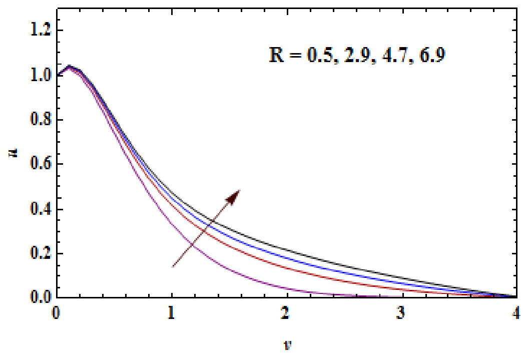

Fig. 6 Velocity Profiles for Different Values of Kr

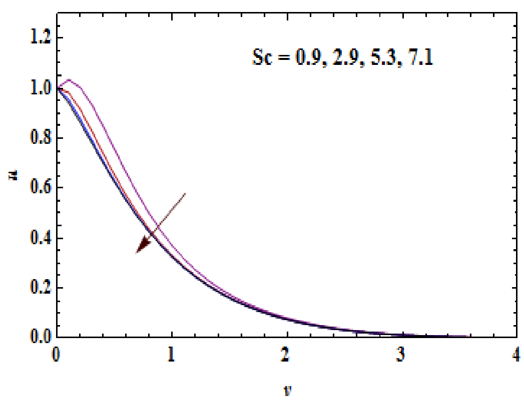

Fig. 7 Velocity Profiles for Different Values of Sc

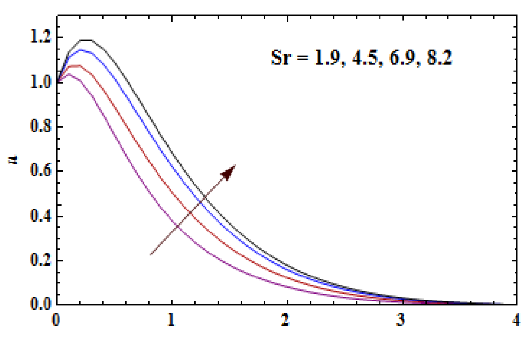

Fig. 8 Velocity Profiles for Different Values of Sr

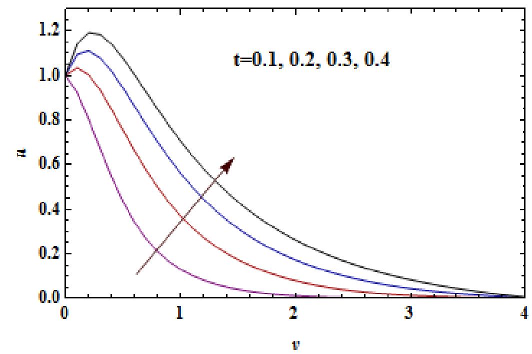

Fig. 9 Velocity Profiles for Different Values of t

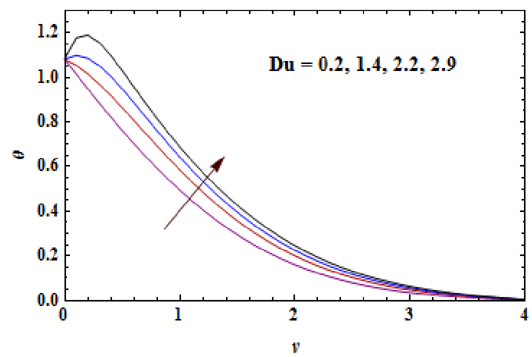

Fig. 10 Temperature Profiles for Different Values of Du

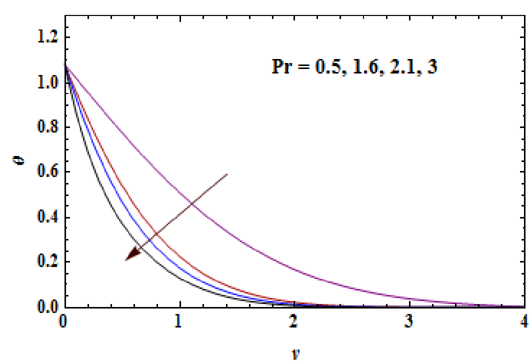

Fig. 11 Temperature Profiles for Different Values of Pr

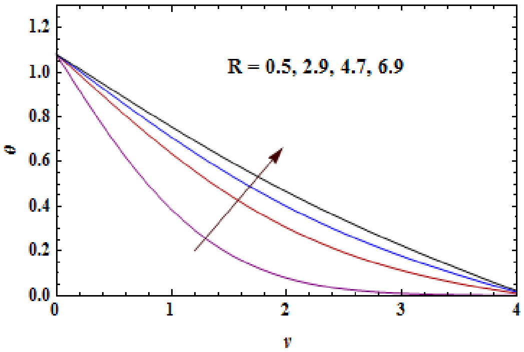

Fig. 12 Temperature Profiles for Different Values of R

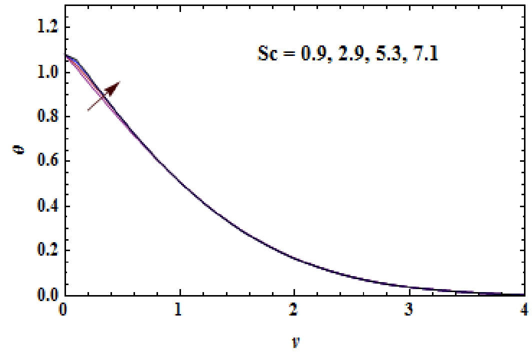

Fig. 15 Temperature Profiles for Different Values of Sc

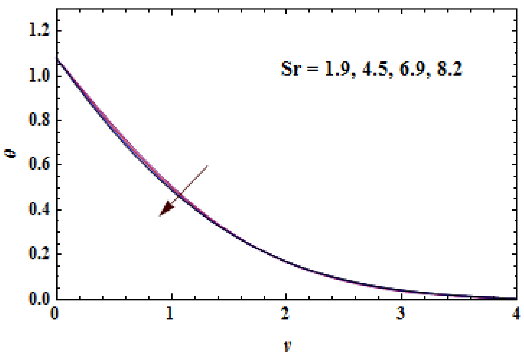

Fig. 13 Temperature Profiles for Different Values of Sr

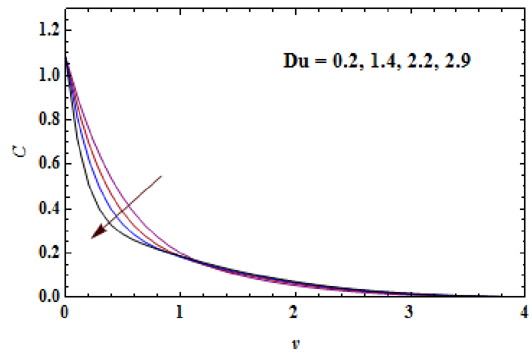

Fig. 16 Concentration Profiles for Different Values of Du

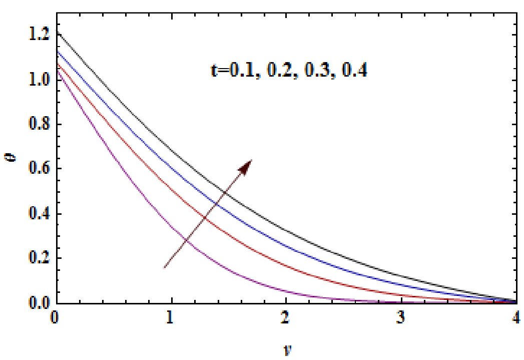

Fig. 14 Temperature Profiles for Different Values of t

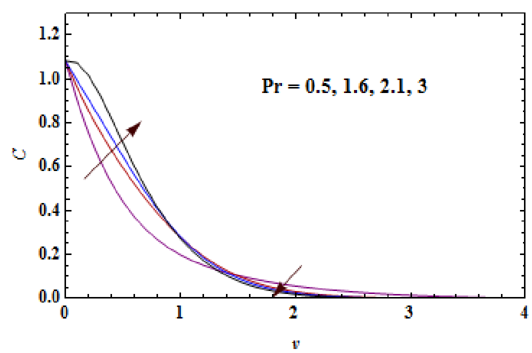

Fig. 17 Concentration Profiles for Different Values of Pr

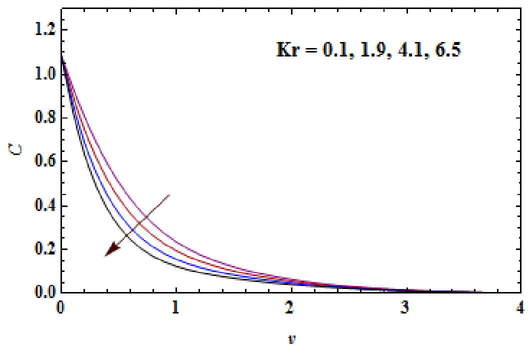

Fig. 18 Concentration Profiles for Different Values of Kr

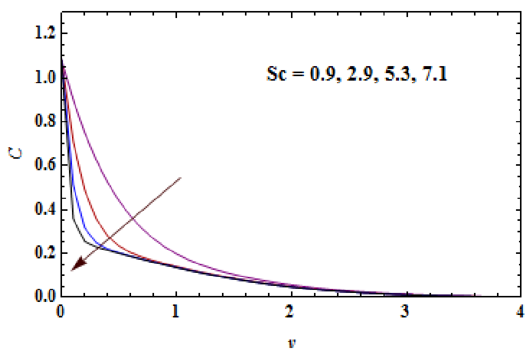

Fig. 19 Concentration Profiles for Different Values of Sc

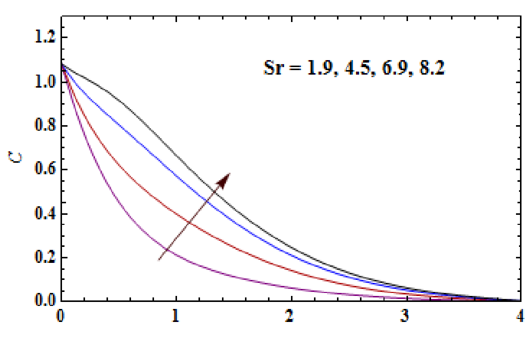

Fig. 20 Concentration Profiles for Different Values of Sr

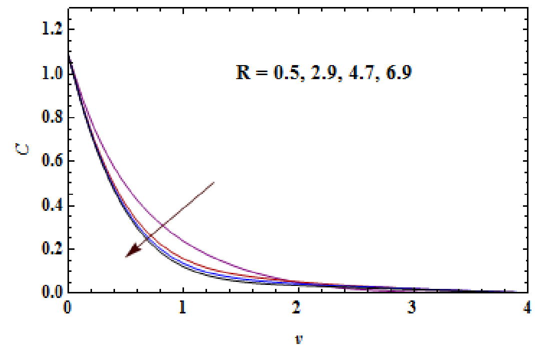

Fig. 21 Concentration Profiles for Different Values of R

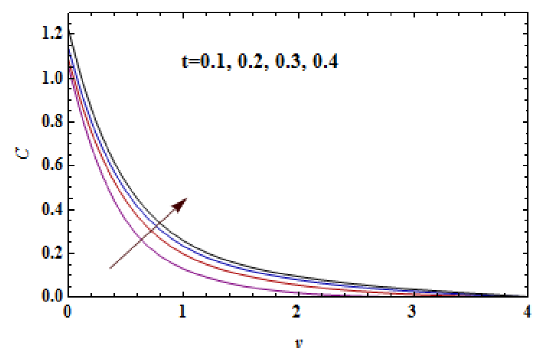

Fig. 22 Concentration Profiles for Different Values of t

Table 1. For Skin Friction τ, Nusselt Number Nu and Sherwood Number Sh

Du	Kr	λ	M	Pr	Sc	Sr	R	t	τ	Nu	Sh
0.2	1.7	0.2	5	0.5	0.9	1.7	1.3	0.2	0.340474	0.666361	1.75917
1.4	1.7	0.2	5	0.5	0.9	1.7	1.3	0.2	0.333004	0.275613	2.1728
2.2	1.7	0.2	5	0.5	0.9	1.7	1.3	0.2	0.311514	-0.177888	2.69661
2.9	1.7	0.2	5	0.5	0.9	1.7	1.3	0.2	0.265142	-0.965171	3.67581
0.39	**0.1**	0.2	5	0.5	0.9	1.7	1.3	0.2	0.44408	0.638438	1.46915
0.39	**1.9**	0.2	5	0.5	0.9	1.7	1.3	0.2	0.328437	0.614616	1.84809
0.39	**4.1**	0.2	5	0.5	0.9	1.7	1.3	0.2	0.20852	0.589701	2.23772
0.39	**6.5**	0.2	5	0.5	0.9	1.7	1.3	0.2	0.0991816	0.589701	2.59184
0.39	1.7	**0.1**	5	0.5	0.9	1.7	1.3	0.2	0.299995	0.617096	1.80893
0.39	1.7	**0.5**	5	0.5	0.9	1.7	1.3	0.2	0.450993	0.617096	1.80893
0.39	1.7	**1**	5	0.5	0.9	1.7	1.3	0.2	0.606353	0.617096	1.80893
0.39	1.7	**1.3**	5	0.5	0.9	1.7	1.3	0.2	0.686049	0.617096	1.80893
0.39	1.7	0.2	**1.5**	0.5	0.9	1.7	1.3	0.2	1.39115	0.617096	1.80893
0.39	1.7	0.2	**3.5**	0.5	0.9	1.7	1.3	0.2	0.75639	0.617096	1.80893
0.39	1.7	0.2	**5.1**	0.5	0.9	1.7	1.3	0.2	0.314317	0.617096	1.80893
0.39	1.7	0.2	**6.9**	0.5	0.9	1.7	1.3	0.2	-0.125539	0.617096	1.80893
0.39	1.7	0.2	5	**0.5**	0.9	1.7	1.3	0.2	0.34044	0.617096	1.80893
0.39	1.7	0.2	5	**1.6**	0.9	1.7	1.3	0.2	0.318229	1.24062	1.22525
0.39	1.7	0.2	5	**2.1**	0.9	1.7	1.3	0.2	0.35602	1.53242	0.89388
0.39	1.7	0.2	5	**3**	0.9	1.7	1.3	0.2	0.3836	2.18493	0.088206
0.39	1.7	0.2	5	0.5	**0.9**	1.7	1.3	0.2	0.34044	0.617096	1.80893
0.39	1.7	0.2	5	0.5	**2.9**	1.7	1.3	0.2	-0.181373	0.487248	3.70844
0.39	1.7	0.2	5	0.5	**5.3**	1.7	1.3	0.2	-0.456275	0.348109	5.7118
0.39	1.7	0.2	5	0.5	**7.1**	1.7	1.3	0.2	-0.591781	0.241704	7.23758
0.39	1.7	0.2	5	0.5	0.9	**1.9**	1.3	0.2	0.366635	0.619072	1.77786
0.39	1.7	0.2	5	0.5	0.9	**4.5**	1.3	0.2	0.731526	0.648866	1.31426
0.39	1.7	0.2	5	0.5	0.9	**6.9**	1.3	0.2	1.11852	0.686083	0.745597
0.39	1.7	0.2	5	0.5	0.9	**8.2**	1.3	0.2	1.35519	0.712523	0.346937
0.39	1.7	0.2	5	0.5	0.9	1.7	**0.5**	0.2	0.317207	0.811262	1.65229
0.39	1.7	0.2	5	0.5	0.9	1.7	**2.9**	0.2	0.381614	0.45722	1.91396
0.39	1.7	0.2	5	0.5	0.9	1.7	**4.7**	0.2	0.414331	0.375405	1.95883
0.39	1.7	0.2	5	0.5	0.9	1.7	**6.9**	0.2	0.44155	0.324595	1.98567
0.39	1.7	0.2	5	0.5	0.9	1.7	1.3	**0.1**	-0.768752	0.804494	1.99546
0.39	1.7	0.2	5	0.5	0.9	1.7	1.3	**0.2**	0.34044	0.617096	1.80893
0.39	1.7	0.2	5	0.5	0.9	1.7	1.3	**0.3**	0.946624	0.567696	1.84866
0.39	1.7	0.2	5	0.5	0.9	1.7	1.3	**0.4**	1.41954	0.588283	2.01446

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