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Research Paper

Multivariate Jeffrey Fluid Flow past a Vertical Plate through Porous Medium

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Abstract. An analysis is suggested to study the impact of Hall currents in Jeffrey fluid which is chemically reactive through a porous medium limited by a semi-infinite vertical permeable plate within the existence of heat generation. An evenly distributed magnetic field turns vertically on the porous surface which absorbs the Jeffrey fluid with a changed suction velocity with time. The analytical expressions are solved by means of three terms harmonic and non-harmonic functions. Statistical calculations are carried out for the point of resultant outcomes which are shown graphically and the impacts of the parameters velocity, temperature and concentration are listed. In addition, the results of skin-friction coefficient (τ), Nusselt number (Nu) and Sherwood number (Sh) are taken in to consideration. It is revealed that the impact of the Hall parameter on the channel velocities and skin friction coefficient is subjected to the estimation of the wall suction parameter.

Keywords: MHD flows, Jeffrey fluid flow, Porous medium, Unsteady flows.

1. Introduction

Nowadays, the examination of non-Newtonian liquid flows has become renowned for the reason of numerous applications in sciences and technical fields. Inspiration of researchers in these fluids is owed too many applications, precisely in food products, biological material and chemical material. Obviously, all non-Newtonian fluids are subjected to their effects happening within shear that are not specified by a single essential relationship. Consequently, few non-Newtonian fluids are instructed for the discussion relating to their many features. Non-Newtonian fluids are conferred through three chief classifications rate, differential and integral. The existing data witnesses that many studies given to the flow of different classes of many type materials. It is owed to focus that in several materials like shear and standard stresses are explained clearly in terms of velocity component. But, it is often not correct for two and three dimensional flows containing different classes of fluids. Currently, using Jeffrey fluid has grown in popularity for the modeling. It has a special influence of reduction and delay times. Few investigations show flow of Jeffrey fluid can be expressed. The authors [1, 2] have studied the nonlinear radially shrinking sheet through a permeable medium with MHD Jeffrey fluid. The examination reveals that the boundary layer thickness is studied in either stretching or shrinking sheet cases. Hayat et al. [3] investigated their research by considering the instantaneous influence of melting heat and inside heat production in stagnation point flow of Jeffrey fluid with variable thickness on a nonlinear stretching surface. Rana et al. [4] suggested a three-dimensional Couette flow of Jeffrey fluid alongside periodic suction. Imran et al. [5] projected Jeffrey fluid in the field of thermo diffusion; thermal radiation effects with chemical reaction using first-order evenly distributed heat flux. Hayat et al. [6] examined the radiative flow of Jeffrey fluid through a heated stretching cylinder.

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Das et al. [7] examined Jeffrey fluid (MHD) flow on a stretching sheet that has a slip surface. Bhatti et al. [8] studied the immediate impact of MHD and slip on peristaltic blood flow of Jeffrey fluid via a porous medium. Sreenadh et al. [9] investigated peristaltic pumping of a fluid using power-law with Jeffrey fluid at the ending path with permeable walls. Farooq et al. [10] proposed MHD peristalsis of changed viscosity Jeffrey liquid with heat and mass transfer. Ramzan and Bilal [11] have discussed the time-dependent MHD Nano-second grade fluid flow induced by a permeable vertical sheet with a mixed convection and thermal radiation. Lu et al. [12] suggested upshot of chemical species and nonlinear thermal radiation on Oldroyd-B Nano fluid flow past a bi-directional stretched surface with heat absorption in a porous media. Suleman et al. [13] studied entropy analysis of 3D non-Newtonian MHD Nano fluid flow with nonlinear thermal radiation past over exponential stretched surface.

The Radiation is the method used to study the heat transfer of material through a magnetic environment. The radiative convective flows may occur in almost all industrial processes. For instance, heating and cooling chambers, fuel combustion energy processes evaporation from massive open water reservoirs, etc. The term radiative plays a substantial role in the field of heat and mass transfer studies of a problem. Raju et al. [14] discussed the unsteady MHD mixed convection flow of Jeffrey fluid past over a radiating inclined permeable moving plate in the presence of thermophoresis heat generation and chemical reaction. Cui et al. [15] examined the effect of convection and radiation of heat transfer upon cooling performance over radiative panel. The unsteady MHD free convective Couette flow among vertical permeable plates through thermal radiation discussed by Jha et al. [16]. The authors [17, 18] have examined their effects of joule heating and chemical process on unsteady MHD mixed convection flow of a viscous fluid that is scattering a vertical plate in a permeable media through thermal radiation and heat generation. Hossain and Alim [19] have investigated radiation interaction and natural convection upon boundary layer flow in a vertical cylinder. Hsiao [20] presented that radiative and viscous dissipation impacts on an electrically MHD heat transfer thermal system by means of Maxwell fluid. The authors [21, 22] explained that the radiation and natural convection flow through with thermal radiation and mass transfer past a moving perpendicular permeable plate. Ibrahim et al. [23] contributed the effect of radiation and viscous dissipation upon unsteady MHD mixed convection stagnation point flow of fluids like micro polar. Rashad [24] discussed the effect of thermal radiation upon MHD slip flow of a ferro-fluid over a non-isothermal force. Srinivasacharya et al. [25] reported the radiation and chemical reaction effects upon mixed convection heat and mass transfer across a perpendicular plate inwards power-law fluid concentrated permeable medium. Pattnaik et al. [26] observed mass transfer and radiation effects upon MHD flow through a permeable medium past an exponentially accelerated disposed plate on flexible temperature. Luo et al. [27] contributed the influences of thermal radiation on MHD flow and heat transfer in a cubic cavity. Arifuzzaman et al. [28] presented chemically reactive and naturally convective fluid flow over an oscillating perpendicular permeable plate through heat and radiation absorption effect. Murthy et al. [29] developed heat and mass transfer effects on MHD natural convective flow through a vertical permeable plate with thermal radiation and hall current.

The flow through a porous media could be a most interesting subject and it became emerging analysis for the explanation of heat and mass transfer in a wet medium which is incredibly related to nature and will even be used in many technical processes. Cheng et al. [30] have proposed a mathematical analysis of unstable heterodyne convection margin layer flow nearby the stagnation point with a vertical surface in a porous medium. Babu et al. [31] have proposed the heat and mass transfer of MHD flow characteristics of a Non-Newtonian fluid over an infinite perpendicular porous plate using the principle of Hall effects. Tripathy et al. [32] have demonstrated the chemical characteristics of magneto hydrodynamics over a stirring perpendicular plate within porous medium. Haq et al. [33] have analyzed MHD expected convection flow supplement in a flat hollow occupied through a permeable media. Chauhan and Rastog [34] examined radiation characteristics of accepted convection MHD flow through a rotating upright porous passage partly occupied using a porous medium. Lin and Cheng [35] discussed momentary varied convection heat transfer through gentle effect from the perpendicular plate in a liquefied saturated permeable medium. Ibrahim and Makinde [36] considered the influence of radiation over the chemically countering MHD margin level flow characteristics of heat and mass transfer passing through a porous plate. Pattnaik et al. [37] discussed the influence of Soret and Dufour with the hall current over instable hydro magnetic flow earlier in a vertical porous plate. Chamkha and Ahmed [38] have suggested similar description for unstable MHD flow exactly about a stagnation idea of three-dimensional porous frame over the heat and mass transfer substance reaction and the heat generation. Batti and Lu [39] discussed the analytical study of the Head-on collision process between hydro elastic solitary waves in the presence of a uniform current. Ahamad et al. [40] analyzed the flow analysis of particulate suspension on an asymmetric peristaltic motion in a curved configuration with heat and mass transfer.

The objective of the present study is to assess the influence of thermal radiation, Hall-currents and the first-order chemical response over the heat and mass transfer. This study is mainly intended to extend the work addressed by Raju et al. [14], who pointed out an unstable MHD heterodyne convection flow characteristics of Jeffrey fluid passing through a plate in the existence of heat generation and chemical reaction. This paper also extends the proposal described by Babu et al. [31]. In their analysis, they proposed an analytical solution using a two-term harmonic and non-harmonic. The present paper analyzes a three-term harmonic and non-harmonic terms perturbation approach to achieve more accuracy. The proposed method focuses on improvement in behavior of velocity, temperature, concentration, Skin-friction, Nusselt number and Sherwood number for various values of thermo-physical parameters are calculated and results are presented graphically and are mentioned qualitatively.

2. Formulation and Solution:

The MHD flow of Jeffrey fluid is an electrically conducting-heat absorbing through a vertical permeable moving plate fixed in a porous medium with a uniform diagonal Magnetic field. Figure 1 shows the consideration of Hall currents into account. It is projected that the voltage which is applied can direct the non-appearance of cross-section magnetic field and magnetic Reynolds number. As a consequence of the low magnetic Reynolds number, it separates the Navier-Stokes conditions from the Maxwell's conditions. Followed by Raju et al. [11] and Babu et al. [28], for this analysis, the governing equations can be arranged by the following Cartesian frame as:

$$\frac{\partial w}{\partial z}=0 \tag{1}$$

$$w\frac{\partial u}{\partial z}+\frac{\partial u}{\partial t}=\frac{\nu}{1+\lambda_1}\frac{\partial^2 u}{\partial z^2}-\frac{1}{\rho}\frac{\partial p}{\partial x}+B_0 J_y-\frac{\nu}{k}u+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty) \tag{2}$$

$$w\frac{\partial v}{\partial z}+\frac{\partial v}{\partial t}=\frac{\nu}{1+\lambda_1}\frac{\partial^2 v}{\partial z^2}-\frac{1}{\rho}\frac{\partial p}{\partial y}-B_0 J_x-\frac{\nu}{k}v \tag{3}$$

$$w\frac{\partial T}{\partial z}+\frac{\partial T}{\partial t}=\alpha\frac{\partial^2 T}{\partial z^2}-\frac{1}{\rho C_p}\frac{\partial q}{\partial z}-\frac{Q_0}{\rho C_p}(T-T_\infty) \tag{4}$$

$$w\frac{\partial C}{\partial z}+\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial z^2}-K_c(C-C_\infty) \tag{5}$$

$$C=C_w+\varepsilon(C_w-C_\infty)e^{nt},\ T=T_w+\varepsilon(T_w-T_\infty)e^{nt},\ u=U_p,\ v=0 \quad at\ z=0 \tag{6a}$$

$$C\to C_\infty, u\to U_\infty,\ T\to T_\infty, v\to 0=u_0(1+\varepsilon e^{nt}) \quad at\ z\to\infty \tag{6b}$$

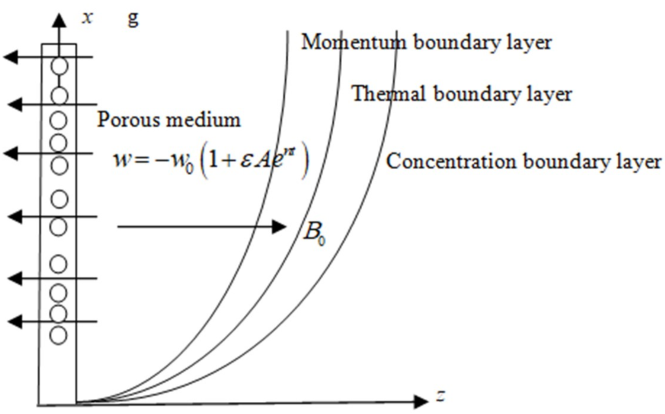

Fig. 1. Physical configuration

It is understood from equation (1), on the surface of the plate, the suction velocity depends on time under assumption of

$$w=-w_0(1+\varepsilon Ae^{nt}) \tag{7}$$

If magnetic field strength is more, the conventional Ohm's law is rearranged as to consider the hall current such that

$$J+(J\times B)\frac{w_e\tau_e}{B_0}=\sigma\left[(V\times B)+E+\left(\frac{1}{e\eta_e}\nabla P_e\right)\right] \tag{8}$$

We additionally accept that $E = 0$ under presumptions decreases to

$$mJ_y+J_x=\sigma B_0 v \tag{9}$$

$$mJ_x-J_y=\sigma B_0 u \tag{10}$$

Here, $m=\tau_e\omega_e$ is Hall parameter. By solving the equations (9) and (10)

$$J_x = \frac{\sigma B_0}{1+m^2}(v+mu) \tag{11}$$

$$J_y = \frac{\sigma B_0}{1+m^2}(mv-u) \tag{12}$$

Now, with substituting equations (11) and (12) in (3) and (2), we get

$$w\frac{\partial u}{\partial z}+\frac{\partial u}{\partial t}=\frac{\nu}{1+\lambda_1}\frac{\partial^2 u}{\partial z^2}-\frac{1}{\rho}\frac{\partial p}{\partial x}-\frac{\nu}{k}u+B_0J_y+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty) \tag{13}$$

$$w\frac{\partial v}{\partial z}+\frac{\partial v}{\partial t}=\frac{\nu}{1+\lambda_1}\frac{\partial^2 u}{\partial z^2}-\frac{1}{\rho}\frac{\partial p}{\partial y}-\frac{\nu}{k}v+B_0J_x \tag{14}$$

Combining equations (13) and (14), let $z = x - iy$ and $q = u + iv$, we obtain

$$w\frac{\partial q}{\partial z}+\frac{\partial q}{\partial t}=\frac{\nu}{1+\lambda_1}\frac{\partial^2 q}{\partial z^2}-\frac{1}{\rho}\frac{\partial p}{\partial z}-\left[\frac{\sigma B_0}{\rho(1+m^2)}+\frac{\nu}{k}\right]q+g\beta_C(C-C_\infty)+g\beta_T(T-T_\infty) \tag{15}$$

$$-\frac{1}{\rho}\frac{\partial p}{\partial z}=\frac{\nu}{k}U_\infty+\frac{\partial U_\infty}{\partial t}+\frac{\sigma}{\rho\left(1+m^2\right)}U_\infty \tag{16}$$

The non-dimensional variables are as:

$$v^*=\frac{v}{w_0},u^*=\frac{u}{w_0},z^*=\frac{w_0 z}{\nu},U_p{}^*=\frac{u_p}{w_0},U_\infty{}^*=\frac{U_\infty}{w_0},\ t^*=\frac{tw_0{}^2}{\nu},\ \theta=\frac{T-T_\infty}{T_w-T_\infty},\ \phi=\frac{C-C_\infty}{C_w-C_\infty}$$

$$K=\frac{kw_0{}^2}{\nu^2},\ \Pr=\frac{\nu\rho C_p}{\alpha},\ Gr=\frac{g\beta_c\nu(C_w-C_\infty)}{w_0{}^3},\ M^2=\frac{\sigma B_0{}^2\nu}{\rho w_0{}^2},\ Gm=\frac{g\beta_T\nu(T_w-T_\infty)}{w_0{}^3}$$

$$K_r=\frac{K_c\nu}{w_0{}^2},\ S_c=\frac{\nu}{D},\ F=\frac{4I\nu}{\rho C_p w_0{}^2},\ \varphi=\frac{Q_0\nu}{\rho C_p w_0{}^2}$$

By the inclusion of the above variables, the governing equations can be reduced as:

$$\frac{\partial q}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial q}{\partial z}=\frac{\partial u_\infty}{\partial t}+\frac{1}{1+\lambda_1}\frac{\partial^2 q}{\partial z^2}-\left[\frac{M^2}{(1+m^2)}+\frac{1}{k}\right][U_\infty-q]+Gr\theta+Gm\phi \tag{17}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial \theta}{\partial z}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-\chi\theta \tag{18}$$

$$\frac{\partial \phi}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial \phi}{\partial z}=\frac{1}{S_c}\frac{\partial^2 \phi}{\partial z^2}-K_r\phi \tag{19}$$

The dimensionless form of boundary conditions equations become

$$\phi=1+\varepsilon e^{nt},\ U=1+\varepsilon e^{nt},\ u=U_p,\ \theta=1+\varepsilon e^{nt}\quad at\ z=0 \tag{20a}$$

$$\phi\to 0,\ U\to 0,\ q\to U_\infty,\theta\to 0\qquad at\ z\to\infty \tag{20b}$$

Equation (9) and (10) represents a set of PDEs that cannot be worked out in closed form, however, it can be diminished to a set of ODEs in dimensionless form that can be worked out by analytical process and it can be done constituting the velocity, temperature and concentration as

$$q=q_0(z)+\varepsilon e^{nt}q_1(z)+\varepsilon^2e^{2nt}q_2(z)+O(\varepsilon^3) \tag{21}$$

$$\theta=\theta_0(z)+\varepsilon e^{nt}\theta_1(z)+\varepsilon^2e^{2nt}\theta_2(z)+O(\varepsilon^3) \tag{22}$$

$$\phi = \phi_0(z) + \varepsilon e^{nt}\phi_1(z) + \varepsilon^2 e^{2nt}\phi_2(z) + O(\varepsilon^3) \tag{23}$$

Substituting equations (21), (22) and (23) into equation (17), (18) and (19), equating harmonic and non-harmonic terms and ignoring the higher order terms of $O(\varepsilon^3)$, the following pairs of equations are obtained

$$\frac{d^2q_0}{dz^2} + (1+\lambda_1)\frac{dq_0}{dz} - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right)q_0 = -(1+\lambda_1)Gr\theta_0 - (1+\lambda_1)G_m\phi_0 - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right) \tag{24}$$

$$\begin{aligned}&\frac{d^2q_1}{dz^2} + (1+\lambda_1)\frac{dq_1}{dz} - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right)q_1 - (1+\lambda_1)nq_1 = \\ &\quad -(1+\lambda_1)n - (1+\lambda_1)Gr\theta_1 - (1+\lambda_1)G_m\phi_1 - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right) - (1+\lambda_1)A\frac{dq_0}{dz}\end{aligned} \tag{25}$$

$$\begin{aligned}&\frac{d^2q_2}{dz^2} + (1+\lambda_1)\frac{dq_2}{dz} - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right)q_2 - 2(1+\lambda_1)nq_2 = \\ &\quad -2(1+\lambda_1)n - (1+\lambda_1)Gr\theta_2 - (1+\lambda_1)G_m\phi_2 - (1+\lambda_1)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right) - (1+\lambda_1)A\frac{dq_1}{dz}\end{aligned} \tag{26}$$

$$\frac{d^2\theta_0}{dz^2} + \Pr\frac{d\theta_0}{dz} + \Pr\chi\theta_0 = 0 \tag{27}$$

$$\frac{d^2\theta_1}{dz^2} + \Pr\frac{d\theta_1}{dz} + \Pr(\chi+n)\theta_1 = -A\Pr\frac{d\theta_0}{dz} \tag{28}$$

$$\frac{d^2\theta_2}{dz^2} + \Pr\frac{d\theta_2}{dz} + \Pr(\chi+2n)\theta_2 = -A\Pr\frac{d\theta_1}{dz} \tag{29}$$

$$\frac{d^2\phi_0}{dz^2} + Sc\frac{d\phi_0}{dz} - KrSc\phi_0 = 0 \tag{30}$$

$$\frac{d^2\phi_1}{dz^2} + Sc\frac{d\phi_1}{dz} - Sc(Kr+n)\phi_1 = -ASc\frac{d\phi_0}{dz} \tag{31}$$

$$\frac{d^2\phi_2}{dz^2} + Sc\frac{d\phi_2}{dz} - Sc(Kr+2n)\phi_2 = -ASc\frac{d\phi_1}{dz} \tag{32}$$

The corresponding boundary conditions are as:

$$\phi_0 = 1,\ \phi_1 = 1,\ \theta_0 = 1,\ \theta_1 = 1,\ q_0 = U_p,\ q_1 = 0, \quad \text{at} \quad z = 0 \tag{33a}$$

$$\phi_0 \to 0,\ \phi_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ q_0 = 1,\ q_1 = 1, \quad \text{at} \quad z \to \infty \tag{33b}$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer becomes:

$$\begin{aligned}q &= q_0(z) + \varepsilon e^{nt}q_1(z) + \varepsilon^2 e^{2nt}q_2(z) \\ &= \left(b_1e^{-m_8z} + b_2e^{-m_2z} + b_3e^{-m_{14}z} + 1\right) + \varepsilon e^{nt}\begin{pmatrix} b_5e^{-m_{10}z} + b_7e^{-m_4z} + b_{10}e^{-m_{14}z} + b_{11}e^{-m_8z} \\ +b_{12}e^{-m_2z} + b_{13}e^{-m_{16}z} + 1\end{pmatrix} \\ &\quad + \varepsilon^2e^{2nt}\begin{pmatrix} b_{16}e^{-m_{12}z} + b_{19}e^{-m_5z} + b_{22}e^{-m_{14}z} + b_{25}e^{-m_{16}z} + b_{26}e^{-m_2z} + b_{27}e^{-m_4z} + b_{28}e^{-m_8z} \\ +b_{29}e^{-m_{10}z} + b_{30}e^{-m_{18}z} + 1\end{pmatrix}\end{aligned} \tag{34}$$

$$\theta = \theta_0(z) + \varepsilon e^{nt}\theta_1(z) + \varepsilon^2e^{2nt}\theta_2(z) = e^{-m_8z} + \varepsilon e^{nt}\left(a_6e^{-m_8z} + a_7e^{-m_{10}z}\right) + \varepsilon^2e^{2nt}\left(a_8e^{-m_{10}z} + a_9e^{-m_8z} + a_{10}e^{-m_{12}z}\right) \tag{35}$$

$$\phi = \phi_0(z) + \varepsilon e^{nt}\phi_1(z) + \varepsilon^2 e^{2nt}\phi_2(z) = e^{-m_2 z} + \varepsilon e^{nt}\left(a_1 e^{-m_2 z} + a_2 e^{-m_4 z}\right) + \varepsilon^2 e^{2nt}\left(a_3 e^{-m_4 z} + a_4 e^{-m_2 z} + a_5 e^{-m_5 z}\right) \tag{36}$$

The parameters τ, Nu, Sh are defined and determined as

$$\tau = \left[\frac{\partial q}{\partial z}\right]_{Z=0} = b_{31} + \varepsilon e^{nt}\left(b_{32}\right) + \varepsilon^2 e^{2nt}\left(b_{33}\right) \tag{37}$$

$$Nu = \left[\frac{\partial \theta}{\partial z}\right]_{Z=0} = b_{34} + \varepsilon e^{nt}\left(b_{35}\right) + \varepsilon^2 e^{2nt}\left(b_{36}\right) \tag{38}$$

$$Sh = \left[\frac{\partial \phi}{\partial z}\right]_{Z=0} = b_{37} + \varepsilon e^{nt}\left(b_{38}\right) + \varepsilon^2 e^{2nt}\left(b_{39}\right) \tag{39}$$

This paper uses a perturbation technique which is based on the assumption of the presence of a small parameter in the differential equation governing the non-linear physical phenomena and approximate solutions obtained and, in most cases, these are valid only for the small values of the small parameter. The equation obtained using perturbation method is of the form $f + \varepsilon g_1 + \varepsilon^2 g_2 + ...$, etc., in which $g_1, g_2, ...$, etc., are unknown, and then these are submitted in the series, which results in a collection of equations to solve corresponding to each power of ε.

3. Results and Discussion

To analyze the characteristics, Prandtl number are chosen as Pr = 7 and 0.71 for water and air respectively. For instance, Schmidt number is used as Sc = 0.22 for the presence of species by hydrogen. The velocity (q) diminishes with intensity in the force of M, and it is shown in Fig. 2. This effect is clearly observed at the boundary layer. The attractive (magnetic) field parameter's influence on velocity is presented in Fig. 2. The velocity obviously diminishes with an increment in Hartmann number. Naturally, the application of transverse attractive (magnetic) field acts as a resistive force namely Lorentz force that slows down the fluid velocity.

Figure 3 illustrates the effect of K on the profile of velocity distribution and it is indicated that as K increases, the velocity component increases with the boundary layer thickness. It is due to the larger number of holes present in a porous medium. Figure 4 displays the behavior of Grashof number on velocity for fixed values of other parameters. As estimated, there is a growth in velocity in the presence of thermal buoyancy force. Clearly, the peak values of the velocity are observed close to the permeable plate and there after it reaches the free stream velocity. Figure 5 witnesses the magnitude of velocity which diminishes with increasing values of suction parameters.

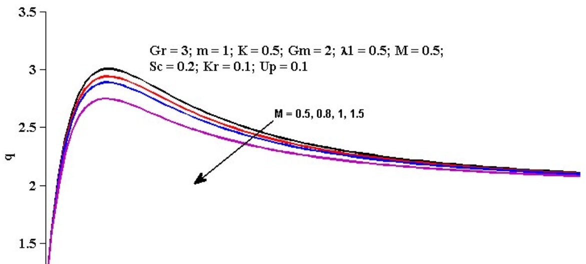

Fig. 2. Magnetic field (M) effect on velocity

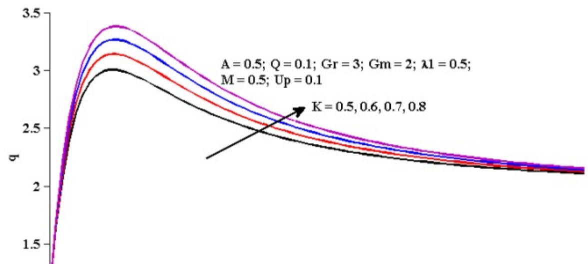

Fig. 3. Permeability parameter (K) effect on velocity

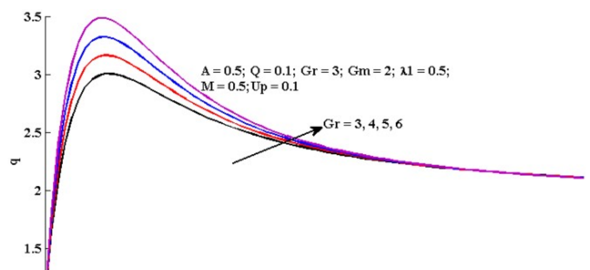

Fig. 4. Grashof Number (Gr) effect on velocity

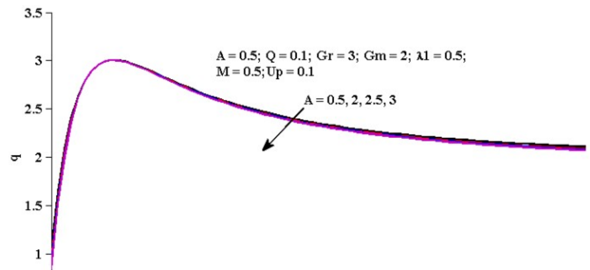

Fig. 5. Suction parameter (A) effect on velocity

Deviations in velocity for altered values of Prandtl number such as, Air [Pr = 0.71] and Water [Pr = 7.00] etc., are presented through Fig. 6. From this figure, it is seen that the velocity diminishes with increasing Pr. Figure 7 shows that an increase in scalar constant (ε) leads to a rise in the resultant velocity distribution through boundary layer. The velocity reduces first and then increases whereas velocity rises with increasing scalar constant (ε). Figure 8 shows the impact of n on the velocity distribution; the primary velocity component diminishes with increasing the n. The resultant velocity reduces with increasing q during the fluid medium.

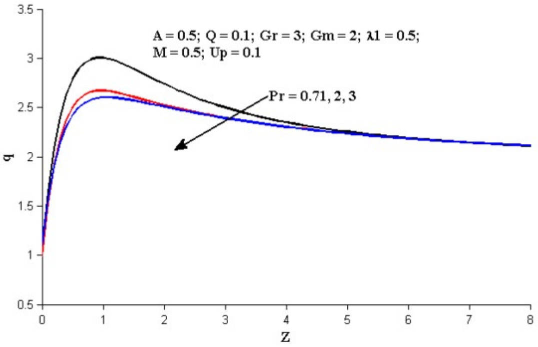

Fig. 6. Prandtl number (Pr) effect on velocity

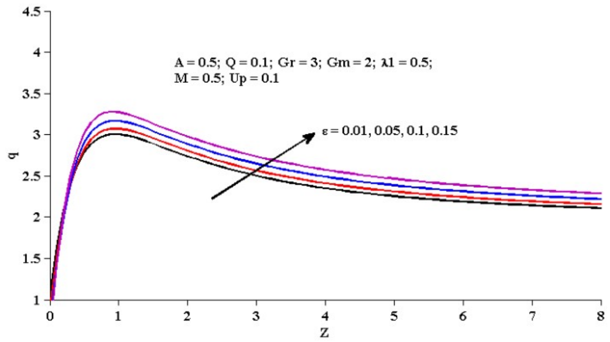

Fig. 7. Scalar constant effect (ε) on velocity

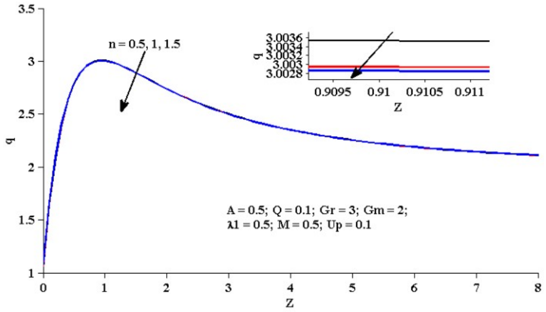

Fig. 8. Frequency of oscillation (n) effect on velocity

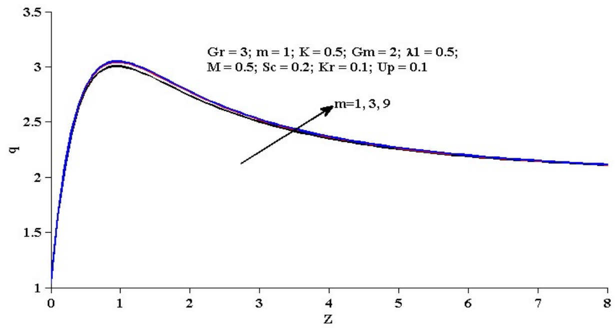

Fig. 9. Hall parameter (m) effect on velocity

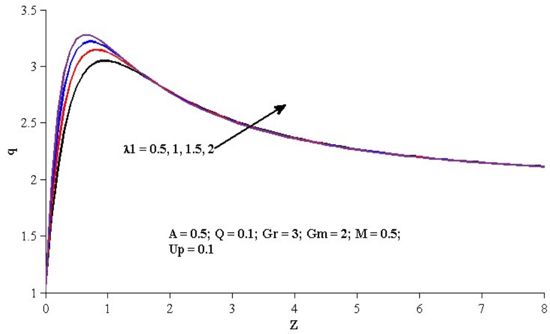

Fig. 10. Jeffrey fluid parameter (λ_1) effect on velocity

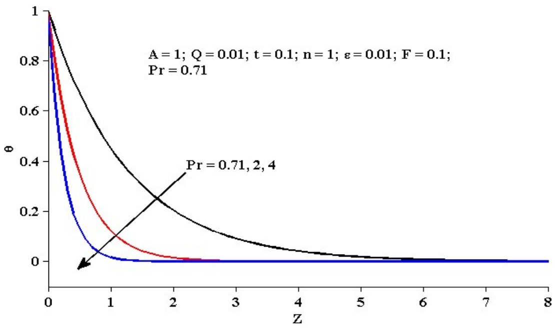

Fig. 11. Prandtl number (Pr) effect on temperature

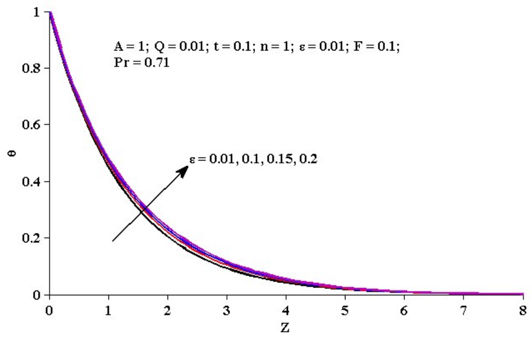

Fig. 12. Scalar constant (ε) effect on temperature

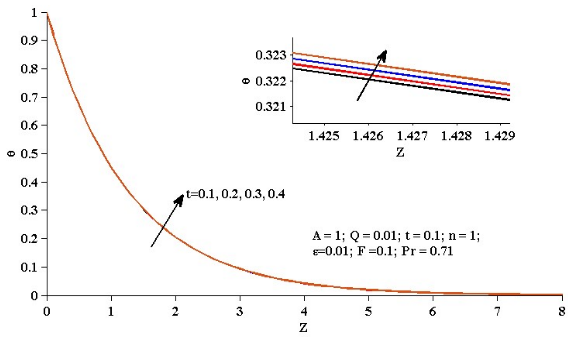

Fig. 13. Time (t) effect on temperature

Figure 9 displays that an expansion in m prompts to rise in resulting distribution during the boundary layer. It is observed that the primary velocity increases with an increase in m as it acts as a perpendicular force to the Lorentz force. This implies Hall currents tend to build fluid essential velocity component. The velocity enhances with increasing Hall parameter m. Figure 10 shows that Jeffrey fluid parameter increases the velocity. It is justifying the physical nature of the fluid.

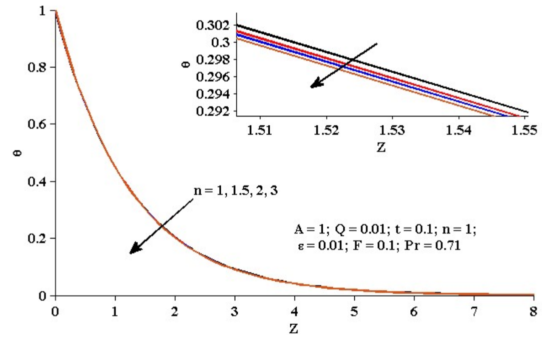

Fig.14. Oscillation (n) effect on temperature

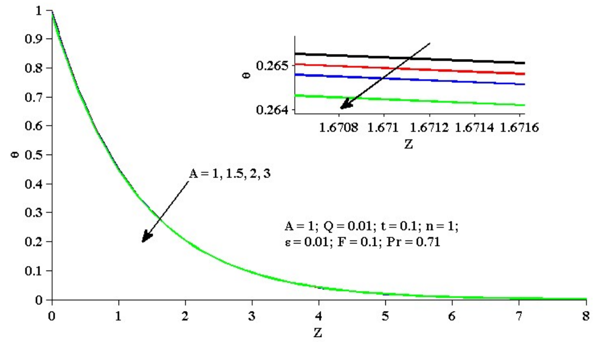

Fig. 15. Suction Velocity (A) effect on temperature

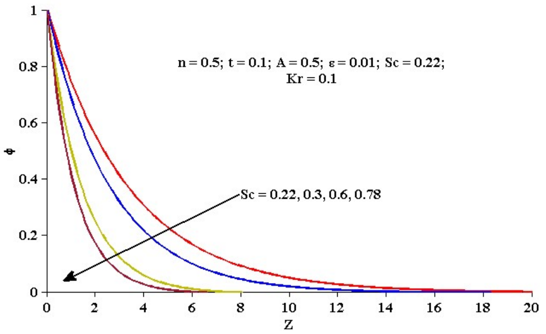

Fig. 16. Schmidth number (Sc) effect on concentration

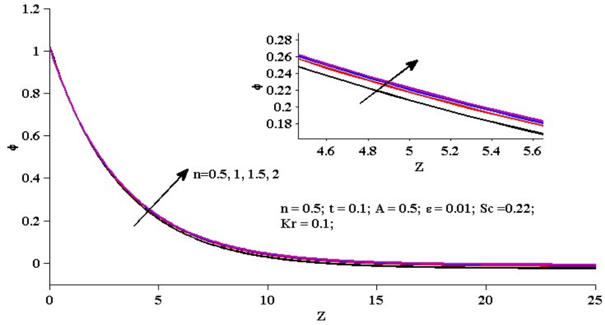

Fig. 17. Frequency of oscillation (n) effect on concentration

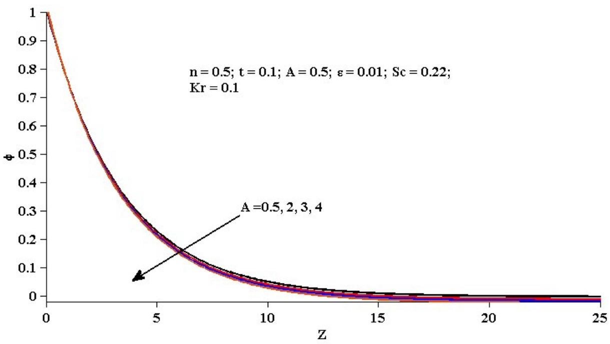

Fig. 18. Suction parameter (A) effect on concentration

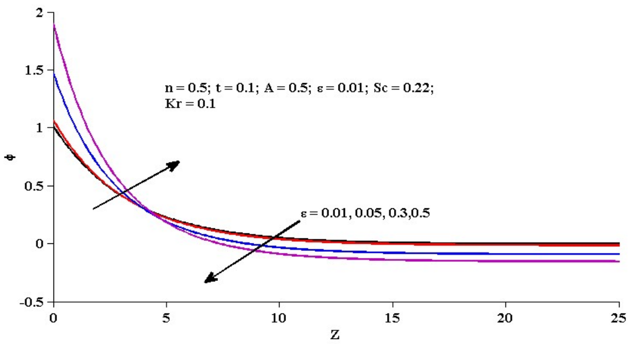

Fig. 19. Scalar constant (ε) effect on concentration

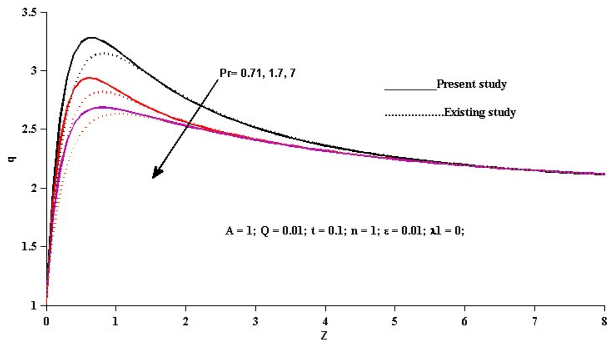

Fig. 20. Prandtl Number (Pr) on velocity

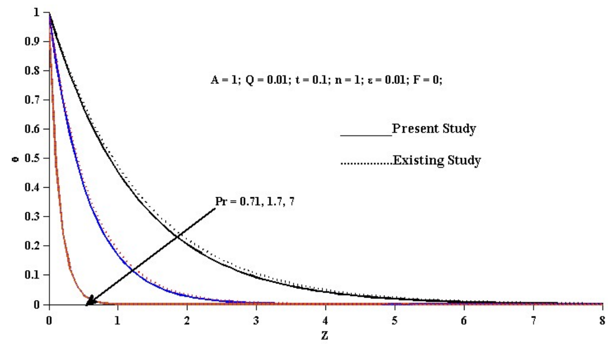

Fig. 21. Prandtl number (Pr) on temperature

In Fig. 11, a tendency is depicted that Prandtl number reduces the temperature field due to the dominance of momentum diffusivity and less conductivity. Likewise, the temperature field falls more quickly for water as compared to air and also the temperature curve is closely linear for mercury, which is more sensitive towards change in temperature. From this perception, it is concluded that mercury is the simplest material for keeping temperature contrasts and can be utilized with efficiency within the laboratory. Air will supplant mercury, the viability of keeping up temperature changes are significantly less than mercury. However, air can be better and modest from an industrial point of view. Fig. 12 and Fig. 13 illustrate that temperature increases as increasing the time t or scalar coefficient (ε), respectively. In Fig. 14 and Fig. 15, it is shown that the temperature reduces with enhancing the frequency of oscillation 'n' or suction parameter (A), respectively.

The perceivance in concentration due to differences in Schmidt number is noted through Fig. 16. As predicted for enhanced values of Schmidt number concentration declines because of dominance of viscous forces. From Fig. 17, the profiles of concentration over the span wise coordinates 'n' for several scalar constant ε. From Fig. 18, concentration profile increases while increasing suction parameter. Figure 19 shows that the numerical impact of increased ε results in increasing the concentration boundary layer thickness and evenly distributed concentration over the boundary layer.

For comparison purpose, the method proposed by Raju et al. [11] is considered. The profiles of fluid velocity versus boundary layer coordinate is shown in Fig. 20 for a few estimations of Pr by taking $\lambda_1 = 0$. Whereas, the profiles of fluid temperature versus boundary layer coordinate is presented in Fig. 21 for several profiles of Pr with $F = 0$. Our outcomes are in good concurrence with the performance of Raju et al. [11] without Jeffery fluid and radiation effect.

In Table 1, the surface skin friction coefficient against certain parameters is listed. The component stress τ diminishes with raising the intensity of magnetic field (M), Sc or suction parameter A or Jeffrey fluid parameter or scalar constant ε. The reversal behavior is examined everywhere throughout the area with increasing hall parameter (m) or Gr. The stress component τ enhances with permeability parameter K or frequency of oscillation n, whereas τ decreases with increasing Pr.

Table 1. Skin friction coefficient (τ)

K	M	Gr	m	A	Sc	Pr	n	ε	λ_1	τ
0.50	**0.50**	**3.0**	**1.0**	**0.50**	**0.22**	**0.71**	**0.50**	**0.01**	**0.50**	6.7749
	1									6.5750
	2									6.1884
1										7.8738
1.5										8.6800
			2							6.8236
			3							6.8407
		4								7.5358
		5								8.2966
				1						6.7580
				1.5						6.7262
						3				5.5551
						7				5.0392
					0.3					6.6642
					0.6					6.3453
								0.03		6.8491
								0.05		6.8489
							1			6.7823
							1.5			6.7861
									1	8.4330
									1.5	10.0282

Table 2. Nusselt number (Nu)

A	ε	N	Pr	Nu
0.50	**0.01**	**0.50**	**0.71**	-0.8131
	0.03			-0.8426
	0.05			-0.8735
1				-0.8156
1.5				-0.8182
			3	-3.1479
			7	-7.2134
		1		-0.8158
		1.5		-0.8184

Table 3. Sherwood number (Sh)

A	Sc	n	ε	Sh
0.50	**0.22**	**0.50**	**0.01**	-0.3004
			0.03	-0.3122
			0.05	-0.3243
1				-0.3010
1.5				-0.3016
	0.3			-0.3864
	0.6			-0.6995
		1		-0.3020
		1.5		-0.3035

The Nusselt number is presented in Table 2 with the reference to governing expressions. The magnitudes of Nusselt number rises throughout fluid region on enhancing the scalar constant ε, A, Pr and frequency of oscillation, n. The Sherwood number (Sh) is also characterized in Table 3. The magnitudes of Sherwood number rising up all over the fluid region on enhancing the scalar constant ε, suction velocity A, Sc, and frequency of oscillation n.

4. Conclusions

From the results obtained in the proposed method called Multivariate Jeffrey fluid flow past a vertical plate through porous medium, the following characteristics have been observed:

1. As raising the strength of magnetic field, Suction parameter, Prandtl number, Frequency of oscillation and Jeffrey fluid parameter, the velocity decreases while it increases the incremental values of permeability parameter, Grashof number, and scalar constant.
2. When the values of Prandtl number, frequency of oscillation, suction parameter turned up, the temperature is getting down.
3. Whenever the values of Schmidt number (Sc), frequency of oscillation (n) enhanced, the concentration decreased.
4. It is familiar that there are many methods which would be deliberated so as to describe certain reasonable solution for this specific kind of problem.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

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Nomenclature

n	Frequency of oscillation [Hz]	β_T	Coefficient of volumetric thermal expansion [K^{-1}]
g	Gravitational acceleration [ms^{-2}]	K_r	Chemical reaction parameter
m	Hall parameter	Q_0	Dimensional heat observation coefficient
Q	Heat absorption parameter	T_∞	Free steam dimensional temperature [K]
M	Magnetic field parameter	U_∞	Free steam dimensional velocity [m/s]
K	Permeability parameter	G_r	Grashof number
A	Suction parameter	β_1	Kinematic visco-elasticity [m^2/s]
q	Velocity [ms^{-1}]	B_0	Magnetic induction [T]
T	Dimensional temperature [K]	G_m	Modified Grashof number
ρ	Fluid density [kg/m]	P_r	Prandtl number
σ	Fluid electrical conductivity	S_c	Schmidth number
ν	Kinematic velocity [m^2/s]	λ_1	Jeffrey fluid parameter
ε	Scalar constant	χ	Dimensionless material parameter
α	Thermal diffusivity	ϕ	Dimensionless concentration
θ	Dimensionless temperature		

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