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Chemical reaction effect on convective flow through a Porous Medium in a Vertical Wavy Channel

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ABSTRACT: *We analyze the effect of chemical reaction and radiation absorption on transient free connective heat and mass transfer flow through a porous medium in a vertical wavy channel. The unsteadiness in the flow is due to the oscillatory flux in the flow region. The analytical solutions for the governing equations are found by utilization of Laplace transformation methodology. The utilization of external magnetic or electric fields, markedly enhances flow dynamics by mitigating frictional forces and turbulent fluctuations, thereby facilitating superior flow management. Such improvements are especially beneficial in optimizing the operational efficiency of machinery and turbines. Our research focuses on the behavior of a weakly ionized fluid within a porous, infinitely extended. This model integrates the cumulative repulsions of an abruptly apply pressure gradients, electro-magnetic force, electromagnetic radiation, as well as chemical reactions. The graphical results of velocity, temperature and concentration distributions on the analytical solutions are displayed and discussed with reference to pertinent parameters.*

KEY WORDS*: Chemical reaction, Porous medium, Wavy channel*

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I. INTRODUCTION

In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications viz., polymer production, manufacturing of ceramics or glassware and food processing. Das et al[1] have studied the effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. Muthukumaraswamy[2] has studied the effects of reaction on a long surface with suction. Radiation and mass transfer on an unsteady two-dimensional laminar convective boundary layer flow of a viscous incompressible chemically reacting fluid along a semi-infinite vertical plate with suction by taking into account the effects of viscous dissipation. Kandaswamy et al[3] have discussed the Effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection.

The study of heat transfer and mixed convection flow in enclosures of various shapes has received attention [4] due to its practical applications. Interest in these convection flow and heat transfer in porous medium has been motivated by a broad range of applications to geothermal systems, crude oil production, storage of nuclear waste materials, ground water pollution, fiber and granular insulations solidification of castings. In a wide range of such problems, the physical system can be modeled as a two-dimensional rectangular enclosure with vertical walls held at different temperatures and the connecting adiabatic horizontal walls. Convective heat transfer in a rectangular porous duct whose vertical walls are maintained at two different temperatures and horizontal walls insulated received attention by several investigators [5]. Furthermore, in references [6 and 7] numerical results are being presented.

Several researchers have contributed to this field, including Chauhan and Rastogi [6], who explored the dominion of Coriolis forces on magnetic flow within a vertically aligned partially porous channel. Seth et al. [7] examined gravity-modulated flow in a channel under rigid rotation, focusing on wall conductivity. Hayat et al. [8] analyzed the rotational movement of the hybrid nanofluids, considering heat generation and absorption. The impact of magnetic forces, chemical reactions, and Soret and Dufour outcomes onto thermal movement in a vertically oriented perforated conduit was studied by Ahammad and Krishna [9]. Sharma et al. [10] have explored the thermal dynamics of the nanofluids around a gyratory Riga disk within the Darcys-Forchheimers porous media, accounting for heat radiatind and chemical reactions. The exploration of ionized fluid flows through electromagnetic channels or ducts in rotational settings, encompassing plasmas, liquid metals, electrolytes, and ionized gases, has garnered increasing interest due to its extensive applications across industrial and natural phenomena. These applications span metallurgical science, plasma dynamics, aerodynamics, metalworking processes, and engineering of composites or ceramics. A key focus is on the conduction mechanisms in ionized gases under strong magnetic fields, which exhibit distinct behaviors compared to metallic conductors. In ionized gases, the electric current is predominantly carried by electrons through successive collisions, leading to unique electrical conduction patterns, contrasting with the linear current-potential relationship in metals under weak electric fields. The introduction of a magnetic field significantly alters the electrical conductivity in ionized gases under strong electric fields, manifesting the Hall effect, which renders the conductivity anisotropic and induces secondary flows. This effect is pivotal in various applications, including Hall accelerators, thrusters, sensors, and electromagnetic generators, influencing their performance and efficiency. Moreover, the ion-slip phenomenon, denoting the relative motion between ions and neutral particles under an electric field, holds critical importance in plasma dynamics, astrophysics, and the development of plasma-based devices like Hall thrusters for spacecraft propulsion. It played the fundamental responsibility into understanding the behaviour of ionized gases into fusion reactors and astrophysical contexts such as solar winds and ionized gases in stellar environments. Additionally, the interaction between Coriolis and electromagnetic forces in rotating flows is crucial for thermo-fluid carrying modelling within magnetic geo-system, meteorological sciences, turbo-machinery, metallurgical solidifications development, as well as astro-physical concerns, giving unique flow characteristics and behaviors that necessitate thorough investigation. Several studies have contributed significantly to this field: Ghosh [11] moreover, Ghosh as well as Pop [12] explored the ascendance of Hall currents on magnetized fluid flows in revolving systems; Jha as well as Apere [13] studied the amalgamated effectuates of Hall moreover ion-slips fields onto magnetically modulated fluid flows. Further contributions to the understanding of flows have been influenced by Hall moreover ion-slips fields and are documented in following and enriching the comprehensive study of ionized fluid dynamics in electromagnetic and rotating environments. Attia [14] explored the ions slips upshots on the unstable Couettes movement with the warmth transports underneath exponentially decomposing pressure gradients. Seth et al. [15] conferred the Hall outcomes on the oscillating MHD Couettes flows into the gyratory systems. Krishna along with Chamkha [16] explored the Hall upshots on the MHD compressing movement of the water-supporting nanofluids among the corresponding disks. Krishna et al. [17] explores the Hall currents on the MHD peristalsis movement of the Jeffreys liquid during a spongy media within the straight up layer. Krishna et al. [18] discussed the Soret, Joules moreover Hall upshots on the MHD gyratory varied convection movement over a countless vertically permeable plate. Krishna along with Chamkha [19-21] examined the Hall furthermore ions slip outcomes on the unstable MHD convection gyratory movement of nanofluid.

II. MATHEMATICAL MODEL

We consider the motion of viscous, incompressible fluid through a porous medium in a vertical channel bounded by flat walls. The thermal buoyancy in the flow field is created by a traveling thermal wave imposed on the boundary wall at y =L while the boundary at y = -L is maintained at constant temperature T_1 while both the walls are maintained at uniform concentration. The Boussinesq approximation is used so that the density variation will be considered only in the buoyancy force. We choose a rectangular Cartesian system 0 (x, y) with x-axis in the vertical direction and y-axis normal to the walls. The walls of the channel are at y=±L.

The equations governing the unsteady flow, heat and mass transfer in terms of stream function ψ.

$$[(\nabla^2\psi)_t + \psi_x(\nabla^2\psi)_y - \psi_y(\nabla^2\psi)_x] = \nu\nabla^4\psi - \beta g(T-T_0)_y - \beta^* g(C-C_0)_y - (\frac{\nu}{k})\nabla^2\psi \tag{2.1}$$

$$\rho_e C_p(\frac{\partial\theta}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}) = \lambda\nabla^2\theta - Q(T-T_o) + Q_1(C-C_o) \tag{2.2}$$

$$(\frac{\partial\phi}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial\phi}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\phi}{\partial y}) = D\nabla^2\phi - k_1(C-C_o) \tag{2.3}$$

The boundary conditions for the velocity and temperature fields are

$$\frac{\partial\psi}{\partial y} = 0, \quad \frac{\partial\psi}{\partial x} = 0, \quad T = T_1, \quad C = C_1 \quad \text{on } y = -L$$

$$\frac{\partial\psi}{\partial y}=0,\quad \frac{\partial\psi}{\partial x}=0,\quad T=T_2+\Delta T_e\ Sin(mx+nt),\quad C=C_2 \quad \text{on } y=L \tag{2.4}$$

Introducing the non-dimensional variables as

$$x'=mx,\ y'=y/L,t'=t\nu m^2,\Psi'=\Psi/\nu,\theta=\frac{T-T_2}{T_1-T_2},\phi=\frac{C-C_2}{C_1-c_2} \tag{2.5}$$

the governing equations in the non-dimensional form (after dropping the dashes) are

$$\delta R(\delta(\nabla_1^2\psi)_t+\frac{\partial(\psi,\nabla_1^2\psi)}{\partial(x,y)})=\nabla_1^4\psi+(\frac{G}{R})(\theta_y+N\phi_y)-D^{-1}\nabla_1^2\psi-M^2\frac{\partial^2\psi}{\partial y^2} \tag{2.6}$$

$$\delta P(\delta\frac{\partial\theta}{\partial t}+\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y})=\nabla_1^2\theta-\alpha\theta+Q_2\phi \tag{2.7}$$

$$\delta Sc(\delta\frac{\partial\phi}{\partial t}+\frac{\partial\psi}{\partial y}\frac{\partial\phi}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial\phi}{\partial y})=\nabla_1^2\phi-\gamma\phi \tag{2.8}$$

where

$R=\frac{UL}{\nu}$ (Reynolds number) $G=\frac{\beta g\Delta T_e L^3}{\nu^2}$ (Grashof number)

$P=\frac{\mu c_p}{k_1}$ (Prandtl number), $D^{-1}=\frac{L^2}{k}$ (Darcy parameter),

$Sc=\frac{\nu}{D_1}$ (Schmidt number) $M^2=\frac{\sigma\mu_e^2H_o^2L^2}{\nu^2}$ (Hartmann Number)

$\alpha=\frac{QL^2}{\lambda}$ (Heat source parameter) $Q_2=\frac{Q_1(C_1-C_2)L^2}{(T_1-T_2)}$ (Radiation absorption parameter)

$\gamma_1=\frac{K_1L^2}{D_1}$ (Chemical reaction parameter) $\delta=mL$ (Aspect ratio)

$\gamma=\frac{n}{\nu m^2}$ (non-dimensional thermal wave velocity)

$$\nabla_1^2=\delta^2\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}$$

The corresponding boundary conditions are

$$\psi(+1)-\psi(-1)=-1$$

$$\frac{\partial\psi}{\partial x}=0,\ \frac{\partial\psi}{\partial y}=0\quad at\ y=\pm1 \tag{2.9}$$

$$\theta(x,y)=1\quad ,C=1\quad on\ y=-1 \qquad \theta(x,y)=Sin(x+\gamma t),C=1$$

$$\theta(x,y)=Sin(x+\gamma t)\quad ,C=0\quad on\quad y=+1$$

$$\frac{\partial\theta}{\partial y}=0,\frac{\partial C}{\partial y}=0\quad at\quad y=0 \tag{2.10}$$

The value of ψ on the boundary assumes the constant volumetric flow in consistent with the hypothesis. Also the wall temperature varies in the axial direction in accordance with the prescribed arbitrary function t.

III. NUSSELT NUMBER AND SHERWOOD NUMBER

Knowing the temperature & concentration the local rate of heat and mass transfer on the walls have been calculated using the formula

$$Nu=\frac{1}{\theta_m-\theta_w}(\frac{\partial\theta}{\partial y})_{y=\pm1}$$

where $\theta_m=0.5\int_{-1}^{1}\theta\,dy$ and $Sh=\frac{1}{C_m-C_w}(\frac{\partial C}{\partial y})_{y=\pm1}$

where $$C_m = 0.5\int_{-1}^{1} C\,dy$$

where $d_1 . d_2 ,........................., d_{14}$ are constants.

IV. DISCUSSION OF THE NUMERICAL RESULTS

Fig. 1 unravels the supremacy of the electric field's strengths, denoted as M, on the profile for resultant velocity within an electromagnetic channel, revealing a direct correlation between amplified M and the augmentation of resultant velocity. The underlying physical principle is that a stronger electric field exerts amore considerable influence on the channel's flow dynamics by interacting with the fluid's inherent electrical conductivity. This interaction between the magnetic component of the electromagnetic field and the electrically conductive fluid modifies the flow properties, leading to an enhanced the resultant velocity. Essentially, the increased M intensifies the electromagnetic forces acting on the liquid, this in turned, accelerates the fluids particles, in this manner elevating the velocity profile across the channel. This observation underscores the significant role that electromagnetic forces play in manipulating fluid dynamics, particularly in contexts where electric and magnetic fields are utilized to control or optimize fluid flow.

The impacts of the permeability parameter for the resultant velocity profiles are displayed in Fig. 2. Since of these, the velocity is increasing owing to the improving permeability quantity. Hence, an increase in the penetrability of the absorbent medium leads to an enhancement in the liquid flow whereas every one of this is departing on. The liquid velocity is demonstrating to be lowered above the entire fluid area while the permeability is reducing. Those discoveries are also utilized in the petroleum extracting from crudes oils, these falls contained by the purviews of petroleum process engineering.

Fig. 3 is explored the domination of rotations parameter R on the resultant velocity profile within a rotary Riga channel. The study finds that an upheaval in R, which quantifies the squared magnitude of the rotation rate, correlates with a rise in the resultant velocity. This correlation can be ascribed to the enhanced rotational forces imparted by the channel's rotation. Specifically, as R escalates, it amplifies the Coriolis force, a pivotal force in rotating systems that acts orthogonally to both the velocity of the flow and the axis of rotation. The augmentation of this force alters the flow dynamics inside the channel, manifesting in an elevated the resultant velocity. Such an upsurge in rotational forces boosts the flow, making the interplay between R and the resultant velocity fundamental for understanding the flow dynamics in electromagnetic channels, where rotation profoundly influences the flow properties.

Fig.4 examines the dominion of Ra on the resultant velocity profile in the Riga channel, revealing that, an escalation in the radiation parameters Ra lead to a perceptible improvement of the resultant velocity. These enhancements are due to the role of thermal radiation in the flow system, where heat radiation represents the transfers of energy through electro-magnetic wave, mainly infrareds radiating, playing the pivotal roles in thermally driven flows. As Ra goes up, it indicates a heightened up shot of thermal radiation, which directly impacts the energy as well as momentum balance of the fluid's particles. The additional energy provided by thermal radiation disrupts the uniform motion of particles, preserving as a catalyst for boosting flow momentum. This process not only injects more energy into the fluid system but also translates into a higher resultant velocity, demonstrating thermal radiation as a reinforcing mechanism for fluid movement. The escalation of Ra underscores the significant impact thermal radiation has on altering flow dynamics, essential for understanding and predicts the performance of fluids system where heat energy transfer is crucial, particularly in applications involving heat transfer and flow enhancement within electromagnetic channels.

Fig. 5 elucidates the sequel of thermal Grashofs number Gr on the resultant velocity profile within an electromagnetic channel, highlighting that an upheaval in Gr lead to the significant enhancement of the resultant velocity. A higher Gr indicates a stronger upshot of buoyancy force relative to glutinous force, resulting in more pronounced fluids motion and, consequently, an escalation in the resultant velocity. As Gr multiplies, it reduces the viscosity's restraining effect on the fluids motion, permitting buoyancy to exert a greater influence on the flow dynamics. This shift facilitates a further more aggressive acceleration of the fluid's particles, thus elevating the resultant velocity profile. The dynamics between buoyant in addition viscosity, adapted by Gr, are particularly crucial in the context of electro-magnetic conduits, where the flow is further complicated by the presence of electromagnetic forces. Predicting how variations in Gr affect flow manner in these specialized channels is essential for the design and operation of systems that exploit electromagnetic flow properties, providing valuable insights into optimizing flow dynamics under varying conditions.

Fig. 6 explored into the upshot of Gm on the resultant velocity profile in a Riga channel, revealing that, an uprising in Gm led to a marked enhancement of the resultant velocity. As Gm makes higher, it denotes a stronger solutal buoyancy force, which results from more pronounced concentration differences or species aggregation in the liquid. This heightened buoyant force propels the liquid particles faster, there by intensifying the velocity distribution across the channel. The observed correlation underlines the significant role of concentration-driven buoyancy in altering fluid flow dynamics, with elevated Gm values notably boosting the fluid's velocity in the Riga channel. This phenomenon highlights the importance of considering solutal buoyancy effects in understanding and predicting the flow behavior in environments where concentration gradients are significant.

Fig. 7 illustrates the repulsion of chemically reactions parameter Kr on the resultant velocity profile in a Riga channel, showing an emaciation in the resultant velocity as Kr grows. This trend can be understood by considering the interaction between chemical reactions within the fluid and its flow dynamics. The parameter Kr quantifies the intensity or rate of these chemically reaction, which can range from processes that directly consume momentum to those that altered the fluids physical features, they are an increase in viscosity or the formation of flow obstructing substances. Such chemical activities can introduce additional resistance to the fluid pace, effectively acting as a drag that diminishes the fluid's velocity. This observed attenuation in the resultant velocity with higher Kr underscore the noteworthy impacts that chemicals kinetics have on flow dynamics, especially in environment like the Riga channels where chemically reaction can play the fundamental roles in the shaping flow behavior as well as properties.

Fig.8 examines the impacts of Schmidt numbers Sc on the resultant velocity profiles within the Riga channel, showing an increase in the resultant velocity at Sc values of 0.22, 0.3, 0.6, 0.78. The balance favors momentum transfer, enhancing resultant velocity as the fluid's ability to sustain shear forces exceeds its capacity to diffuse mass. However, as Sc makes expansion, mass transfer becomes increasingly sluggish compared to momentum transfer. This shift can result in decreased resistance to flow and an increase in the resultant velocity. This dynamic highlight the intricate relationship between fluid viscosity, mass diffusivity, and the velocity distribution within electromagnetic channels, underscoring how changes in Sc can significantly influence fluid flow behavior by altering the balance between momentum and mass transfer processes.

Fig. 9 delves into how the expansion of the widths of magnets together with electrodes, encapsulated with the parameter S, influences the flow resultant velocity in the Riga conduit, demonstrating a notable decrease in the resultant velocity as S widens. This phenomenon can be physically rationalized by acknowledging that a broader S disperses the electromagnetic forces across a more extensive area, diminishing their local concentration. As the spatial extent of magnets in addition electrodes widens, the generated electro-magnetic fields spread out, reducing the strengths of magnetic force as well as electric force exerted on the liquid in any given locality. This dispersed force application leads to a lessened impact on the fluid's movement, thereby slowing down the flow. The association between S and the resultant velocity highlights the crucial influence of the physical arrangement of electromagnetic sources on the fluid dynamics within the channel, illustrating how variations in the configuration of electromagnetic components can significantly alter flow behavior by modulating the distribution and intensity of the forces acting upon the fluid.

Fig. 10 investigates the significant influence of βe on the shape of the resultant velocity in a Riga channel. The findings clearly demonstrate that an upsurge in βe correlates with a marked rise in the resultant velocity, signifying a stronger presence of Hall currents enhances the stream momentum in the primary path (i.e., x-axis). The Hall parameter βe represents a crucial dimensionless metric indicative of the ascendancy of Hall currents within the flow domain. These currents arise from the interactions between the fluid's magnetic field and its electric currents, producing a perpendicular electric field according to the Hall effect. This relationship accentuates the pivotal role of Hall currents in modulating the stream dynamics in the Riga conduit, as higher βe values lead to an acceleration of the resultant velocity. This observation aligns that, reinforcing the critical impact of Hall effect-induced currents on fluid velocity within electromagnetic flow contexts.

Fig. 11 scrutinizes how ion slip parameter βi impacts the resultant velocity profile in a Riga channel, where βi is linked to the phenomenon of ion collisions within the flow of plasma or ionized fluids. These collisions are critical for understanding the dynamics of such fluids as they influence the momentum transfer between ions and neutral particles, leading to the ion-slip effect. This effect describes the situation where ions move or drift at a different speed compared to the overall fluid flow. A rising in βi reflects a more substantial ion-slip effect, which could be due to intensified ion collisions or other factors enhancing ion mobility. As βi rises, a consequent rise in the resultant velocity is noted, signifying that the ion-slip mechanism plays a vital role in the flow dynamics within electromagnetic channels like the Riga channel. This pattern, observed across different applied pressure gradients, highlights the importance of ion dynamics, particularly ion-slip, in shaping the flow characteristics of plasma or ionized fluids. The correlation between βi and the resultant velocity illustrates the potential of the ion-slip mechanism to significantly affect the performance and behavior of systems utilizing plasma-based or ionized fluids in various technological applications.

Fig. 12 showcases a clear trend where, the resultant velocity profiles within the Riga channel diminish as the species generations/absorptions parameters Q increases. This parameter Q encapsulates the rates in which species are either produced or absorbed within the fluid, impacting its density and, consequently, its flow characteristics. An upsurge in Q implies a more significant influence of these processes on the fluid dynamics. When species are generated or absorbed, it can lead to deviations in the fluid density as well as viscosity, affecting the buoyancy forces and the fluid's resistance to flow. These changes can introduce additional drag or alter the driving forces within the fluid, leading to the reductions in the resultant velocity values. The observed downturn in the resultant velocity with increasing Q values highlights the deceptive interaction between chemical species dynamics and fluid motion, illustrating how changes in the concentration of species within the fluid can significantly influence its flow behavior within electromagnetic channels like the Riga channel.

The observation that shear stress τ_L is lower than shear stress τ_R at the vibrating left wall due to the dynamics of the primary flow. The primary flow typically aligns with the main axis of flow, which suggests that the stress is associated with the flow parallel to the gradient of velocity that is most directly influenced by the wall's vibration. The vibration induces more significant disturbances and hence greater shear stress in the direction perpendicular to the wall, due to the enhanced energy and momentum transfer in this orientation. Conversely, the stresses at the left plate, representing in a direction tangential to the flow, experiences lower values as this direction is less directly impacted by the vibrational energy input from the wall. The discrepancy in these shear stress values highlights the anisotropic nature of fluid shear stress response to boundary conditions and the predominant role of the channel's vibrational energy in amplifying shear stress in directions most susceptible to energy transfer from the wall motion. The observed distribution of shear stresses at the channel walls, with positive shear stresses at the vibrating left wall and negative shear stresses (modulus) at the stationary right wall, can be physically explained by the differential effects of wall motion on the fluid dynamics adjacent to these boundaries. The vibration of the left wall induces additional momentum into the fluid, leading to an increase in the velocity gradient at this interface, which results in positive shear stresses as the fluid attempts to adhere to the moving boundary. This action enhances the fluid's kinetic energy near the vibrating wall, translating to higher shear forces. Conversely, the stationary right wall imposes a condition of zero velocity relative to the wall, creating a drag effect on the fluid motion that decelerates the fluid particles close to this boundary. This deceleration generates negative shear stresses, as the fluid 30. velocity gradient opposes the direction of the wall's inertial frame, leading to a retardation effect on the fluid's motion. The contrast in shear stress signs across the channel underscores the significant impact of wall motion (or lack thereof) on the fluid's mechanical behavior, illustrating how boundary conditions directly influence the distribution and magnitude of shear stresses within a fluid flow system (Table.1)

The observed decay in Nu_L in the represents of stronger heat radiating could be due to an upsurge in radiative heat flux away from the left wall, possibly because the left wall is more exposed to cooling effects or less directly exposed to heat sources compared to the right wall. On the other hand, the augment in Nu_R with higher Ra values can be ascribed to the right wall receiving a more direct or concentrated radiative heat flux, enhancing heat transfer at this location. This difference in heat transfer rates between the two walls underscores the spatial variability of radiative heat transfer within the system, reflecting how the distribution and intensity of thermal radiation can lead to varying heat transfer efficiencies at different locations within the system (Table.2).

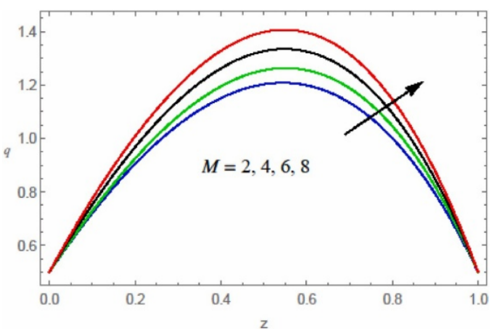


Fig.1. The velocity profiles against *M*

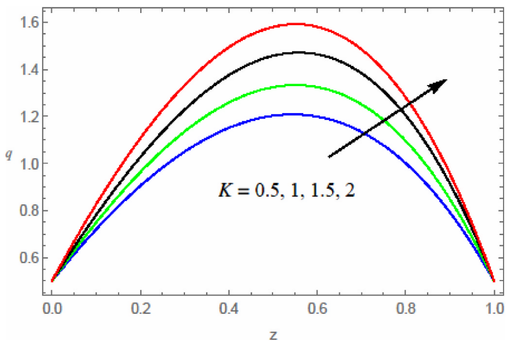


Fig.2. The velocity profiles against *K*

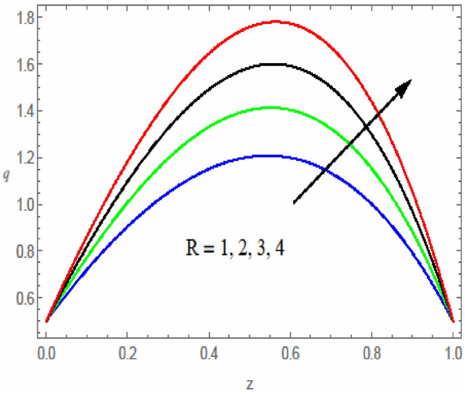


Fig.3. The velocity profiles against *R*

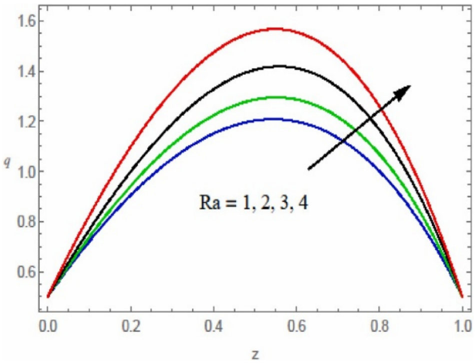


Fig.4. The velocity profiles against Ra

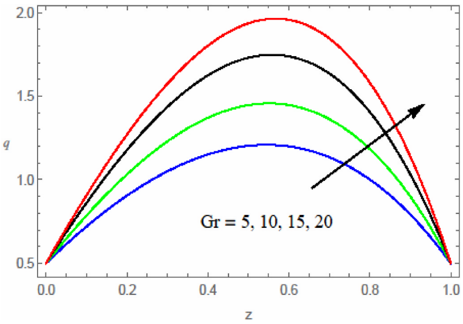


Fig.5. The velocity profiles against *Gr*

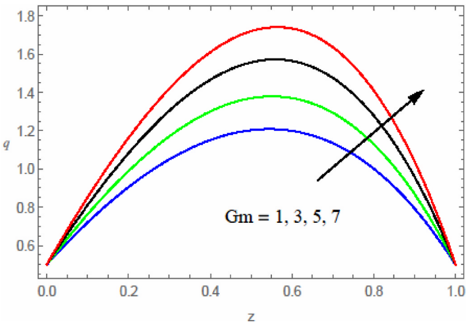
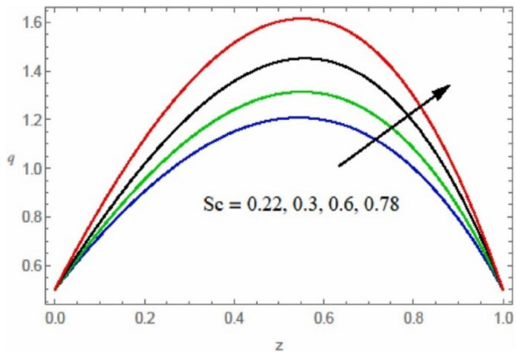
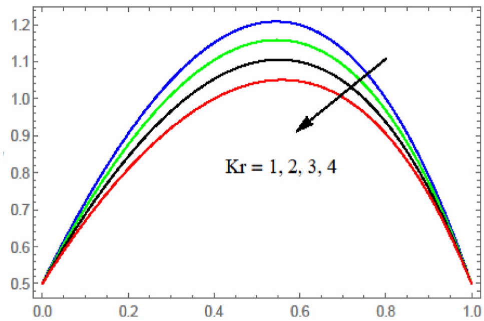


Fig.6. The velocity profiles against Gm





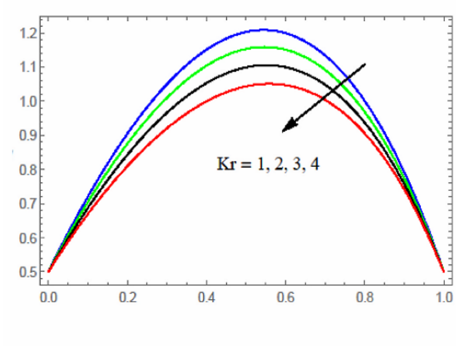


Fig.7. The velocity profiles against Kr

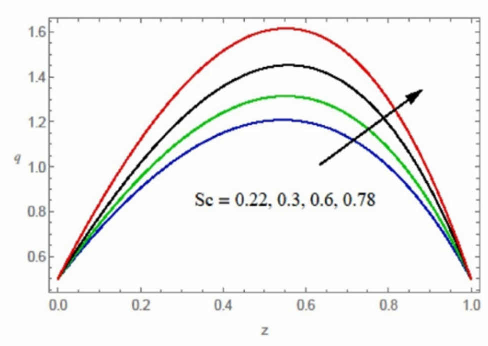


Fig.8. The velocity profiles against Sc

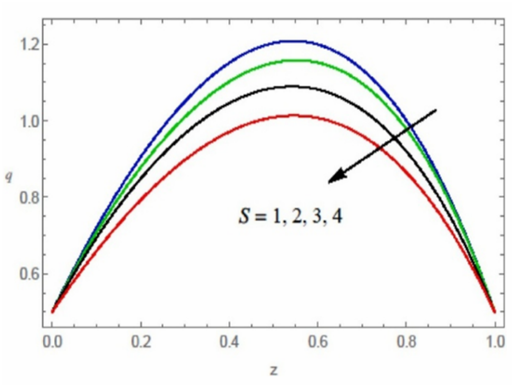


Fig.9. The Velocity Profiles against S

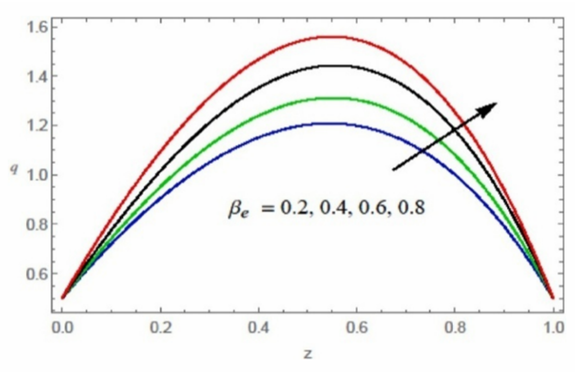


Fig.10. The velocity profiles against β_e

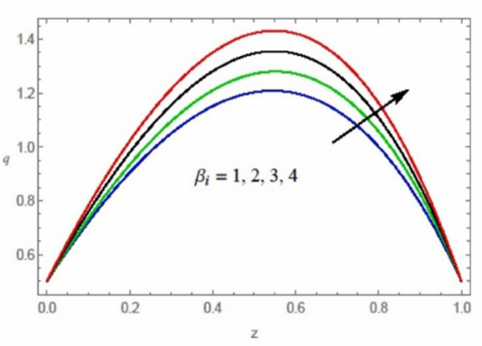


Fig.11. The velocity profiles against β_i

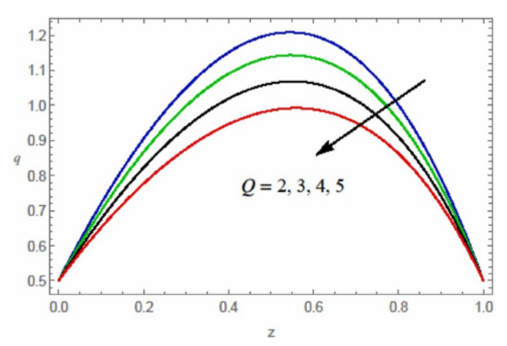


Fig.12. The velocity profiles against Q

Table.1 Shear stresses (t=0.5)

M	K	R	Ra	Gr	Gm	Kr	Sc	S	βe	βi	Q	Pr	τL	τR
2	0.5	1	1	5	3	1	0.22	1	0.2	1	2	0.71	0.690956	0.995939
4													0.790255	1.11558
6													0.886513	1.210152
	1.0												0.719426	1.00202
	1.5												0.749059	1.065695
		2											0.813645	1.125535
		3											0.953645	1.479836
			2										0.475423	0.763166
			3										0.316957	0.483525
				10									0.583848	0.90568
				15									0.483402	0.775695
					5								0.793526	1.024676
					7								0.917186	1.059006
						2							0.573852	0.80235
						3							0.469097	0.605701

							0.3						0.793737	1.12047
							0.6						0.896989	1.3798
								2					0.782526	0.684232
								3					0.896979	0.36999
									0.4				0.886097	1.110154
									0.6				1.086999	1.555683
										2			0.602297	1.08202
										3			0.465621	1.39428
											3		0.892425	0.805559
											4		1.159099	0.604225
												3	0.726399	0.879046
												6	0.788988	0.765705

Table.2 Rate of Heat transfer (Nusselt number)

Ra	Q	Pr	Kr	t	Nu_L	Nu_R
1.00	2.00	0.71	1.00	0.2	1.329553	1.401522
2.00					1.299559	1.487123
3.00					1.266445	1.598226
	3.00				2.31463	1.20667
	4.00				3.39298	0.238237
		0.30			1.289563	2.027012
		0.60			1.254123	2.670363
			2.00		1.315012	1.998255
			3.00		1.311699	2.526857
				0.5	1.322885	1.49702
				0.8	1.305021	1.615896

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