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RADIATION AND HEAT SOURCE/SINK EFFECTS ON MHD CASSON FLUID FLOW OVER A STRETCHING SHEET WITH SLIP CONDITIONS

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Abstract: An analysis has been carried out on the study of the Radiation impact of MHD Casson fluid flow, over an exponentially stretching sheet embedded in a porous medium, with slip effects in the presence of the heat source /sink and viscous dissipation. The governing partial differential equations (PDEs) are simplified to a set of non-linear ordinary differential equations (ODEs) by using appropriate similarity transformations and numerical solutions are obtained by using the MATLAB in built solver bvp4c package. The impacts of the non- dimensional parameters on the velocity, temperature, and concentration distributions are discussed graphically and the Nusselt rate of heat and mass transfer coefficients values are tabulated to elucidate the effect of the numerous physical parameters.

Keywords: MHD; viscous dissipation; Casson fluid; heat source/sink.

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1. INTRODUCTION

The analytical review pertaining to laminar flow, along with phenomenon of heat transfer allowed fluid through stretching sheet assumes larger area of importance for the research in fluid mechanics owing to wider scale of applications in different product processing's across the industry sectors, like polymer sheet extrusions, wire drawing, hot rolling, manufacturing of paper, plastic films, and oil production. An extensive study was pursued on Newtonian fluids. The foremost one was Crane [1] who made elaborate study in the direction over a linear liquid surface. The computational solutions were investigated by Mukhopadhyay and Gorla [2] for steady boundary layer and radioactive heat transfers flows over an exponentially stretched surface with partial step at the boundary. Sajid and Hayat [3] pursued to know the effect of radiation on the flow of boundary layer, and transfer of heat of a viscous fluid across the stretched sheet. Al-odat et al. [4] made an investigation of computational solutions in the functional aspect of magnetic field for the thermal boundary layer of stretched surface with variation in temperature. Pramanik [5] has studied extensively heat flow while blowing or through suctioning at the surface. Heat transfer with slip effects of Casson has been duly studied by Saidulu and Venkata Lakshmi [6]. Jawad Raza [7] investigated the impact cumulatively in terms of thermal radiation and velocity step on a layer that is convectively extended. The behaviour of magneto hydrodynamic (MHD) beside the stagnation point has been explained by Mackinde and Ibrahim [8]. They investigated the impact of slip and convection on MHD stagnant point flows and heat transfer due to Casson nanofluid part stretching layer. Ibrahim et al. [9] briefs the impact of chemical reaction and heating source on MHD mixed convection of flow of a Casson nanofluid on non-linear stretched sheet. The focus on this was pinned by many of the scholars and have formulated relative solutions, namely Hari Singh Naik et al. [10], Magyari and Keller [11], Bidin and Nazara [12], Shankar Goud [13], Ishak [14], Sumitra et al. [28] and others. A brief narration of boundary layer flow and transferring of heat passed over a porous exponentially stretched sheet set in presence of an uniform magnetic field has been offered by Mukhopadhyay [15]. Harinath Reddy et al. [16] observed the radiation absorption and studied the impact of chemical reaction on MHD flow of

heat generating casson fluid past oscillating vertical porous plate. MHD free convective non-Newtonian flow over a stretched sheet enclosed in a porous medium with slip condition effects are extensively pursued by ImranUllah et al. [17]. Besides analysing the properties of the viscous dissipation, the flow of casson fluid into stagnation center area to a stretching sheet also was made out through report by Meraz Mustafa et al. [18]. B.S.Goud and et al. [19-22, 24, 26] pursued study on the moving plate with sort and radiation effects, behaviour of thermal radiation on MHD stagnation point flow, Hall effect and impact on inclined parabolic accelerated plate, radiation effect on exponentially stretched sheet, sourcing heat effect. Sriramulu et al. [23] has investigated the heat transfer effect on stretching sheet over a porous medium steady flow of a viscous incompressible fluid flow. The laminar MHD boundary flow of nano-fluid past and exponentially permeable stretch layer was verified by Kishan et al. [25]. Ibrahim et al. [27] reviewed a conceptual model analytically, which has been improvised to further analyze the blended convection over a non-linear permeable stretched layer on thermal radiation, viscous dissipation, heat sources and heat sinks. The objective of this analysis is to find numerical approximations for the steady state of MHD casson fluid over an exponentially stretched sheet with a steady and continuous viscous dissipation, suction/blowing and thermal radiation.

1.1 Nomenclature

μ_B	Plastic dynamic viscosity of the non-Newtonian fluid	π	Product of the component of deformation rate with itself
e_{ij}	$(i, j)^{th}$ component of the deformation rate	π_C	Critical value of this product based on the non-Newtonian model
P_y	Yield stress of the fluid	(u, v)	Velocity components along (x, y) direction
ν	Kinematic viscosity	ρ	Fluid density
μ	Coefficient of fluid viscosity	β	Casson fluid parameter

σ	Electrical conductivity	k	Thermal conductivity
q_r	Radiative heat flux	C_p	Specific heat at constant pressure
Q_0	Dimensional heat generation/absorption	U	Stretching velocity
N	Velocity slip factor which changes with x	N_0	Initial value of velocity slip factor
D	Thermal slip factor which changes with x	D_0	Initial value of thermal slip factor
M	Magnetic parameter	λ	Velocity slip parameter
Pr	Prandtl number	E_C	Eckert number
δ	Thermal slip parameter	R	Radiation parameter
Q	Heat source/sink parameter	C_{fx}	Skin friction coefficient
Nu_x	Local Nusselt number	V_0	Initial strength of suction

2. MATHEMATICAL FORMULATION

While considering 2D as an electrically conducting incompressible fluid flow of casson with respect to exponentially stretched sheet, whereas the x -axis and motion of the fluid are taken along with the stretching surface, y -axis is drawn and is normal to the surface in terms of referring to velocity U_0 , temperature T_0 , length as L and x -axis is supported with equally opposite powers in such manner that the wall is extended to maintain its origins. The flow presumably has been manifested by stretching sheet of elastic limit a slit with which a strong force is inclined therein to show that limit plate velocity of directional flow coordinate x has an exponential order.

The magnetic field $B(x) = B_0 \exp(x / 2L)$ where x is variable usually applied perpendicularly to the sheet and the induced magnetic field have been left without taking into account since the

magnetic flow Reynold's number was presumed to be very small.

Assume the rheological state equation for an insulating and incompressible movement of a

$$\text{Casson fluid is as } \tau_{ij} = \begin{cases} 2\left(\mu_B + \frac{P_y}{\sqrt{2\pi}}\right)e_{ij}; & \pi > \pi_c \\ 2\left(\mu_B + \frac{P_y}{\sqrt{2\pi}}\right)e_{ij}; & \pi < \pi_c \end{cases}, \text{ where } \pi = e_{ij} \cdot e_{ij}$$

In the context, the governing equations can be stated as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} = \nu \left(1 + \frac{1}{\beta}\right) \frac{\partial^2 u}{\partial x^2} - \frac{\sigma B^2}{\rho} u \quad (2)$$

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y}\right) = k \frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} + \mu \left(1 + \frac{1}{\beta}\right) \left(\frac{\partial u}{\partial y}\right)^2 + Q_0 (T - T_\infty) \quad (3)$$

The boundary conditions in the present flow are

$$\left. \begin{aligned} u = U + Nv \left(1 + \frac{1}{\beta}\right) \frac{\partial u}{\partial y}, \quad v = -V(x), \quad T = T_w + D \frac{\partial T}{\partial y} \quad \text{at } y \rightarrow 0 \\ u \rightarrow 0, \quad T \rightarrow T_\infty, \quad \text{as } y \rightarrow \infty \end{aligned} \right\} \quad (4)$$

Here $U = U_0 \exp(x/L)$, $T_w = T_\infty - T_0 \exp(x/2L)$, $N = N_0 \exp(x/L)$,

$$D = D_0 \exp(x/2L), V(x) = V_0 \exp(x/2L)$$

Thermal radiation is calculated by the approximation of Rosseland diffusion, and q_r defined by

$$q_r = -\frac{4\sigma^*}{3k^*} \frac{\partial T^4}{\partial y} \quad (5)$$

Here σ^* is the Stefan- Boltzmann constant, k^* denote coefficient. Assume that the T^4 can be

$$\text{written in the form of a linear function as } T^4 = 4T_\infty^2 T - 3T_\infty^4 \quad (6)$$

Using Eq.(4) and (5) then the eq.(3) changes to

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y}\right) = k \left(1 + \frac{16\sigma^* T_\infty^3}{3kk^*}\right) \frac{\partial^2 T}{\partial y^2} + \mu \left(1 + \frac{1}{\beta}\right) \left(\frac{\partial u}{\partial y}\right)^2 + Q_0 (T - T_\infty) \quad (7)$$

Now introducing the similarity transformation

Here $\xi = \sqrt{\frac{U_0}{2\nu L}} \exp(x/2L)y$, $u = U_0 \exp(x/L)f'(\xi)$,

$$v = -\sqrt{\frac{\nu U_0}{2L}} \exp(x/2L)(f(\xi) + \xi f'(\xi)), T - T_\infty = \theta(\xi) \exp(x/2L)$$

The system can be transformed to

$$(1 + \frac{1}{\beta})f''' + ff'' - 2(f')^2 - M^2 f' = 0 \quad (8)$$

$$\frac{1}{Pr}(1 + \frac{4R}{3})\theta' + (f\theta' - f'\theta) + Ec(1 + \frac{1}{\beta})(f'')^2 + Q\theta = 0 \quad (9)$$

and the BCs are

$$\left. \begin{aligned} f(0) = S, \quad f'(0) = 1 + \lambda \left(1 + \frac{1}{\beta}\right) f''(0), \quad \theta(0) = 1 + \delta \theta'(0) \quad \text{at } \xi \rightarrow 0 \\ f'(\xi) \rightarrow 0, \quad \theta(\xi) \rightarrow 0, \quad \text{as } \xi \rightarrow \infty \end{aligned} \right\} \quad (10)$$

where the prime denote the differentiation with respect to ξ , $M = \sqrt{\frac{2\sigma B_0^2 L}{\rho U_0}}$, $\lambda = N_0 \sqrt{\frac{U_0 \nu}{2L}}$,

$$S = \frac{V_0}{\sqrt{\frac{U_0 \nu}{2L}}}, \quad \delta = D_0 \sqrt{\frac{U_0}{2L\nu}}, \quad R = \frac{4\sigma^* T_\infty^3}{kk^*}, \quad Pr = \frac{\mu C_p}{k}, \quad Ec = \frac{U}{C_p T_0} e^{\frac{x}{2L}}, \quad Q = \frac{Q_0 2L}{\rho C_p U_0}, \quad \beta = \frac{\mu_B \sqrt{2\pi c}}{P_y}.$$

The substantial components and skin friction coefficient and local Nusselt number given by

$$Cf_x = \sqrt{\frac{2x}{L Re_x}} \left(1 + \frac{1}{\beta}\right) f''(0) \quad \text{and} \quad Nu_x = -\sqrt{\frac{x Re_x}{2L}} \left(1 + \frac{4R}{3}\right) \theta'(0) \quad Re_x = \frac{Ux}{\nu}$$

The variation in $f''(0)$ and $-\theta'(0)$ will impact Cf_x and Nu_x

The above skin friction coefficient and Nusselt numbers displays that its deviations depends on the changes of the aspects $f''(0)$ and respectively.

3. NUMERICAL METHOD

The set of ODEs (8) – (9) which has been transformed and the exact boundary conditions (10) have been formulated numerically, by adopting the bvp4c shooting techniques. Program pattern comprises the below given steps. Boundary conditions may be applied or used to ascertain three of the new (factors). Before establishing the required accuracy, the procedure will be to reduce Eqs (8) – (9) and arrange a set of the first order equations through proper substitution

given as

$$g(1) = g(\eta), g(2) = g'(\eta), g''(3) = g(\eta), g(4) = \theta(\eta), g(5) = \theta'(\eta)$$

The following first order set of equation are as

$$\begin{pmatrix} g'(1) \\ g'(2) \\ g'(3) \\ g'(4) \\ g'(5) \end{pmatrix} = \begin{pmatrix} g(2) \\ g(3) \\ \frac{-1}{1+\frac{1}{\beta}} \left\{ g(1) * g(3) - 2 * [g(2)]^2 + M * g(2) \right\} \\ g(5) \\ -\frac{P_R}{1+\frac{4R}{3}} \left\{ g(1)g(5) - g(2) * g(4) - \frac{E_c}{1+\frac{1}{\beta}} * [g(3)]^2 + Q * g(4) \right\} \end{pmatrix}$$

The associated initial conditions are

$$\begin{pmatrix} g_a(1) \\ g_a(2) \\ g_a(3) \\ g_a(4) \\ g_a(5) \end{pmatrix} = \begin{pmatrix} s \\ 1 + \lambda * \left(1 + \frac{1}{\beta}\right) * g_a(3) \\ 1 + \delta * g_a(5) \\ 0 \\ 0 \end{pmatrix}$$

4. RESULTS AND DISCUSSION

Different values of physical parameters and their numerical approximations are used to establish the definition of physically assumed model. To ensure the physical implication of the variety of parameters viz. Casson parameter (B), magnetic parameter (M), radiation parameter (R), velocity slip parameter (λ), Eckert number (E_c), suction/injection parameter (S), prandtl number (Pr), thermal slip parameter (δ), heat source/sink parameter (Q).

Fig. 1-2 exhibits the impact of casson fluid parameter on velocity temperature and profiles. The velocity levels presumeably come down with the exhalation (increase) of casson fluid parameter as and when the outcome velocity segregations are decreased. The rise in temperature profiles with increase of β was noticed due to predominant viscous nature.

With the increase in the magnetic parameter, there will be reduction in the rate of velocity on the surface. In contrast the transverse magnetic field demonstrates the fluid flow and crucially decreases the rate of transportation. This change can be attributed to the creation of Lorentz force by the magnetic field. It can be noticed that, the surface temperature has increased with respect to increase in parameter along the boundary layer. We understand that due to excessive heating, the latent temperature inside thermal boundary layer rises to an extent that the magnetic field becomes adaptive of monitoring the flow functioning.

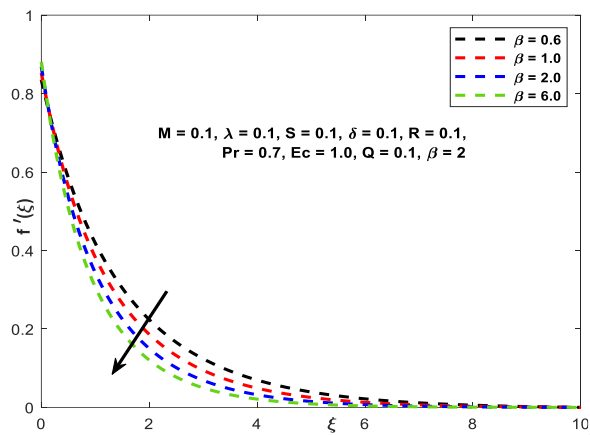


Fig.1. Velocity profiles Vs different values of Casson parameter.

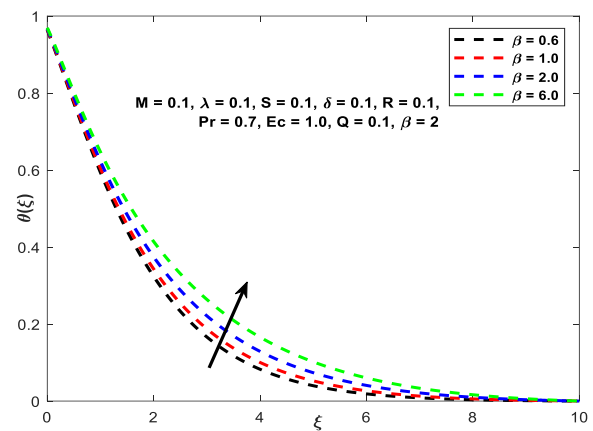


Fig.2. Temperature profiles Vs different values of Casson parameter.

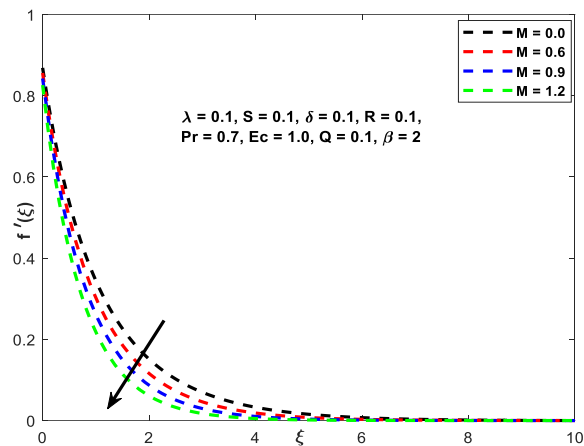


Fig 3. Velocity profiles Vs magnetic parameter.

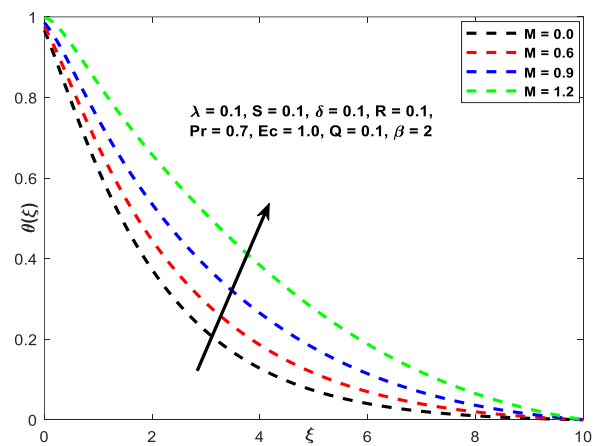


Fig 4. Temperature profiles Vs magnetic parameter

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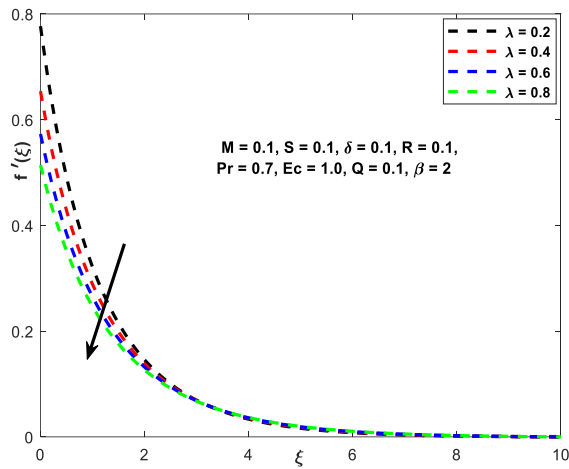


Fig 5. Velocity profiles Vs velocity slip parameter.

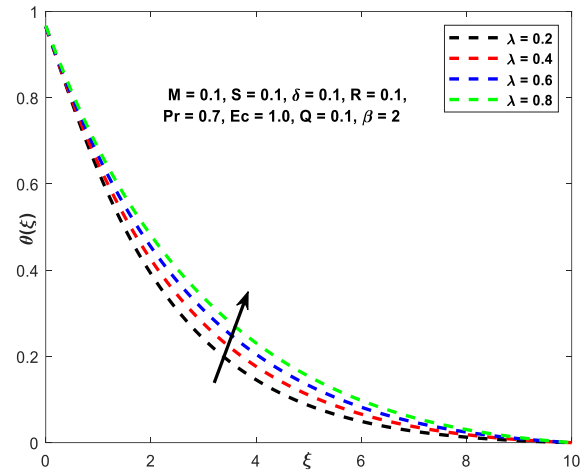


Fig 6. Temperature profiles Vs velocity slip parameter.

Fig. 5 - 6 depict the impact of velocity slip parameter on velocity and temperature. It has been observed that with an increase in temperature the fluid velocity decreases, whereas velocity slip parameter increases. When the pulling capacity of the stretching plate is not adequate or sufficient, the slipped fluid shows a reduced degree physically in the surface skin friction between the fluid and the stretching plate. As otherwise the pulling power of the stretching plate is transmissible to the fluid.

Fig. 7-8 represents the velocity and temperature distribution of the suction/blowing parameters. Suction has found to have presumably higher impact on thermal boundary layer thickness. The net result is a slowdown flow process to determine the rate of velocity and temperature. The blowing parameter will be just opposite and it assumes that the suction can easily be used to cool the sheet rapidly.

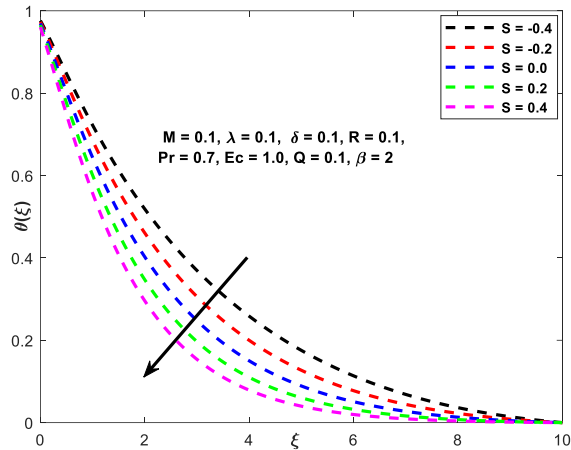


Fig.7. Velocity Vs suction/blowing parameter.

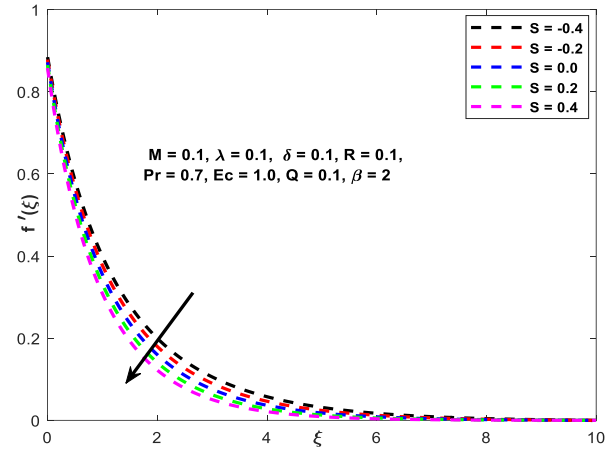


Fig.8. Temperature profiles Vs suction/blowing parameter.

Fig. 9 illustrates the change of thermal slip parameter with respect to temperature profiles and it is been found that the maximum impact is at stretching sheet surface. Fig 10 confirm to the impact of thermal radiation parameter on temperature distribution. It can be understood that the temperature profile increases with increase in thermal radiation parameter. As an aftermath, effect of divergence in radioactive heat flux increase while recording a reduction in Roseland radioactive absorption. Instantaneously for all practical purposes, the radioactive absorption leads to an upsurge in fluid heat transfer rate, which in turn result in an intercut of the temperature of fluid to the expected level consequent on the effect, the radiation impact will be more crucial and the effect of radiation can be set aside without taking into account when it is staked at $R = 0$.

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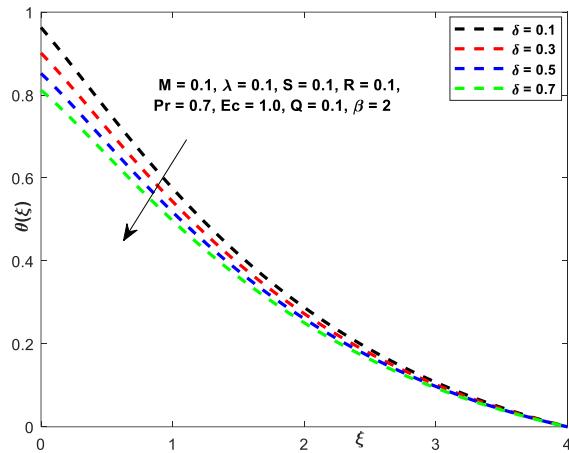


Fig.9. Temperature profiles Vs thermal slip parameter

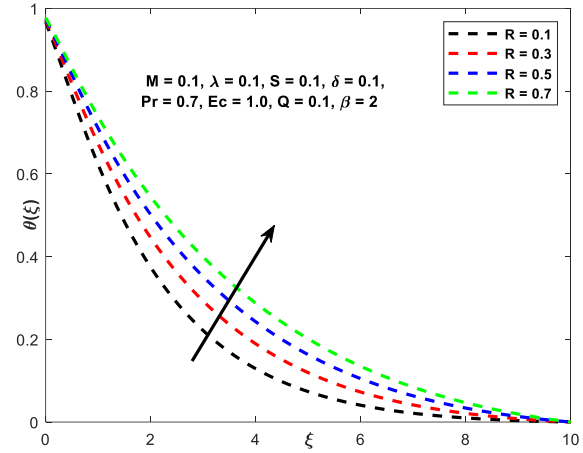


Fig.10. Temperature profiles Vs thermal radiation parameter

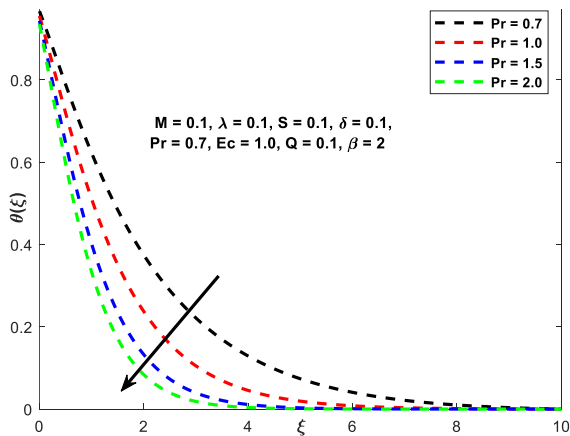


Fig.11. Temperature profiles Vs thermal Prandtl number.

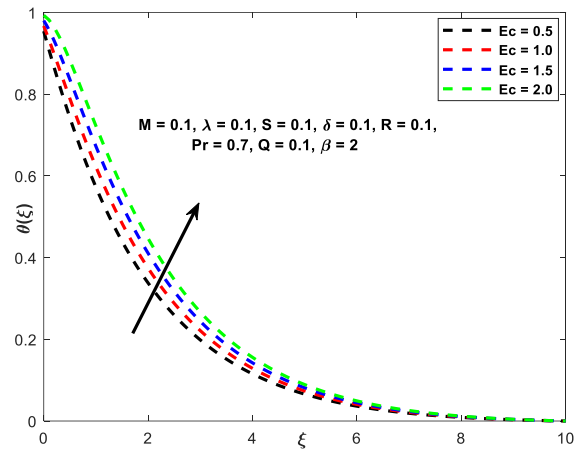


Fig.12. Temperature profiles Vs viscous dissipation parameter.

Fig.11 presented the influence of the Prandtl number on the temperature profile. Thermal surface and the temperature curves declines along the boundary layer with an increase in Prandtl number, as thickness of the layer is reduced. The Prandtl number is in proportion to lower diffusiveness. The influence of the Eckert number on the temperature profile is depicted in the Fig.12. It is seen that the thermal boundary layer thickness increases with an increase of the viscous dissipation parameter.

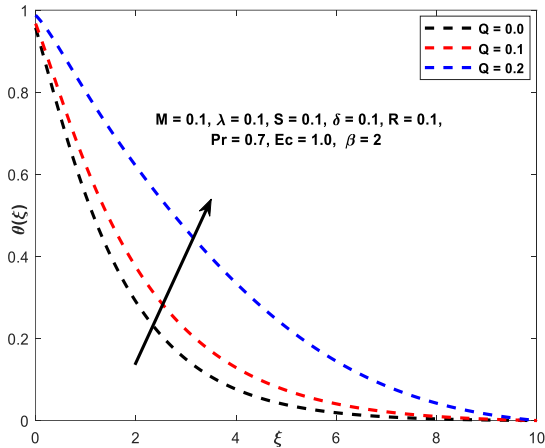


Fig.13. Temperature profiles Vs heat source/sink parameter.

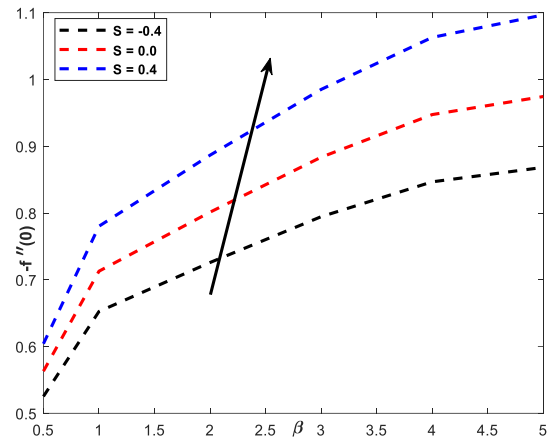


Fig.14. Skin-friction coefficient against Casson parameter Vs suction/blowing parameter.

The influence of heat source/sink parameter on the temperature field is shown in Fig.13. The temperature profile increases with increased quantum of the sources. Fig.15 explains the influence of Nusselt number against the Casson parameter. Verification of precision of Prandtl number for various Prandtl number and radiation values has been demonstrated in Table 1. It is significant to understand for Pr and R as the present findings are in correlation with earlier results.

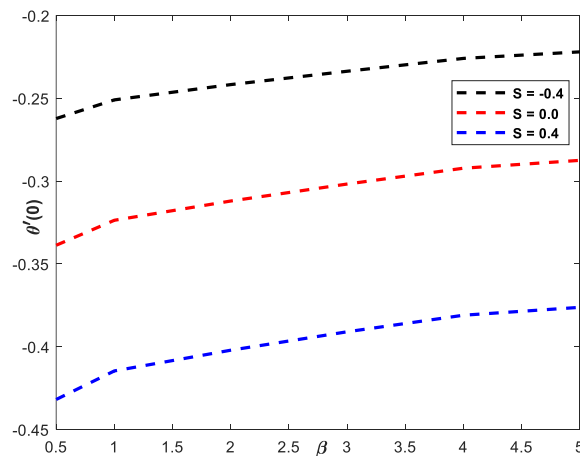


Fig.15. Wall temperature gradient against Casson parameter Vs suction/blowing parameter.

Table 1.

Pr	R	Magyari and Keller [11]	Badin and Nazar [12]	Ishak [14]	Mukhopadhyay [15]	Present Study
1	0	0.9548	0.9547	0.9548	0.9547	0.9548
2			1.4714	1.4715	1.4714	1.4715
3		1.8691	1.8691	1.8691	1.8691	1.8691
5		2.5001		2.5001	2.5001	2.5001
10		3.6604		3.6604	3.6603	3.6605
1	0.5		0.6765			0.6775
	1		0.5315	0.5312	0.5311	0.5353
2	0.5		1.0735		1.0734	1.0735
	1		0.8627		0.8626	0.8629
3	0.5		1.3807		1.3807	1.3807
	1		1.1214		1.1213	1.1214

5. CONCLUSION

The following conclusions can be drawn from the above analysis.

- Velocity decreases with an increase of β, M and a reverse effect in temperature profile is duly observed.
- An increase of λ, δ will result in a decrease of velocity and the opposite effect is observed in the temperature profile.
- Velocity and temperature decreases with an increase of s .
- The temperature decreases with increase of Pr, however we can also observe an increase of E_c, Q .
- The Skin friction parameter increases and wall temperature gradient decreases besides the increased value of s .

CONFLICT OF INTERESTS

The author(s) declare that there is no conflict of interests.

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