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Computational Investigation of Heat and Mass Transfer in Radiative MHD Casson Fluid Flow with Viscous Dissipation and Chemical Reaction under Prescribed Flux Conditions.

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Abstract:

Fluid movement, heat and mass transfer, chemical reactions, and other related processes that take place in engineering equipment, the natural world, and living things are all included in the study of systems. These procedures are essential in a wide range of real-world scenarios. Fluid flow and heat transfer are fundamental processes in almost all power generation techniques, and they control building heating and cooling. Furnaces, heat exchanges, condensers, and reactors are among the major parts of the chemical and metallurgical industries that use thermofluid processes. Fluid flow, heat transmission, and chemical reactions are essential to the operation of rockets and aeroplane. Heat transfer is frequently a limiting element in the design of electrical circuits and machines. Heat and mass transport, as well as storms, floods, and fires, are major contributors to environmental pollution. The human body uses heat and mass transfer to regulate its temperature when the weather changes. Heat, mass transfer, and fluid flow seem to be present in every facet of human existence.

FORMULATION OF THE PROBLEM:

The objective of this work is to investigate the MHD Casson fluid boundary layer flow over a porous stretched sheet with temperature dependent heat sink in the presence of heat and mass flux. The effects of viscous dissipation, thermal radiation, and chemical reactions on flow, heat, and mass transport are also considered. The Cartesian coordinate system is built so that the flow motion is along the x-axis and perpendicular to the y-axis. The rheological equation of state for the incompressible flow of the Casson fluid is given by Sumalatha & Bandari (2015).

$$\tau_{ij}=\begin{cases}2\left(\mu_B+\frac{P_y}{\sqrt{2\pi}}\right)e_{ij}, & \pi>\pi_c\\ 2\left(\mu_B+\frac{P_y}{\sqrt{2\pi_c}}\right)e_{ij}, & \pi<\pi_c\end{cases}$$

Where μ_B and P_y are the plastic dynamic viscosity on the and yield stress of the non newtonian fluid respectively. Similarly □ is the product of the component of deformation rate with itself $\pi = e_{ij}e_{ij}$, e_{ij} is the $(i, j)^{th}$ component of the deformation rate and π_c is a critical value of this product of the non-Newtonian model. Under the above mentioned conditions, the governing equations of the problem with boundary conditions are presented as follows

Equation of Continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad [1]$$

Equation of Momentum

$$u\frac{\partial u}{\partial x}+\mathrm{v}\frac{\partial v}{\partial y}=v\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0{}^2 u}{\rho}-\frac{v}{K_p}u \qquad [2]$$

Equation of Energy

$$u\frac{\partial T}{\partial x}+\mathrm{v}\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{\mu}{\rho C_p}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}-Q'\frac{\partial T}{\partial y} \qquad [3]$$

The boundary conditions are

$$\left.\begin{aligned} &u=ax,\ \mathrm{v}=-V_0\\ &-k\frac{\partial T}{\partial y}=q_w=E_0x^2\\ &-D_m\frac{\partial C}{\partial y}=m_w=E_1x^2 \end{aligned}\right\} \text{ at } y=0 \qquad [4]$$

$$u=0,\mathrm{v}\neq 0\ T\to T_\infty\ C\to C_\infty \text{ as } y\to\infty$$

The following similarity transformations are introduced to transform the Equations (3.1) - (3.5) into the Equations (3.7) - (3.10) as

$$\psi=\sqrt{av}xf(\eta),\ \eta=\sqrt{\frac{a}{v}}y$$

$$u=\frac{\partial\psi}{\partial y},\mathrm{v}=-\frac{\partial\psi}{\partial x}$$

$$\left.\begin{aligned} T-T_\infty&=\frac{E_0x^2}{k}\sqrt{\frac{v}{a}}g(\eta)\\ C-C_\infty&=\frac{E_1x^2}{D_m}\sqrt{\frac{v}{a}}\mathrm{h}(\eta) \end{aligned}\right. \qquad [5]$$

So the resulting nonlinear differential equations with boundary conditions are given by

$$f'''\left(1+\frac{1}{\beta}\right)+(ff''-f'^2)-\left(\frac{1}{R_p}+M\right)f'=0 \qquad [6]$$

$$g''+D(1+Q)fg'-2Df'g=-E_cD\left(1+\frac{1}{\beta}\right)f''^2 \qquad [7]$$

$$\mathrm{h}''+S_cf\mathrm{h}'-2S_cf'\mathrm{h}-\gamma S_c\mathrm{h}=0 \qquad [8]$$

$$\left.\begin{aligned} &f'(\eta)=1, f(\eta)=S\\ &g'(\eta)=-1,\ \mathrm{h}'(\eta)=-1 \end{aligned}\right\} \text{ at } \eta=0$$

$$f'(\eta)=0,f(\eta)\neq 0,\ g(\eta)=0,\ \mathrm{h}(\eta)=0 \text{ as } \eta\to\infty \qquad [9]$$

Where

$$D=\frac{3P_rR_d}{3R_d+4},\beta=\mu_B\frac{\sqrt{2\pi_c}}{P_y}\text{ (Casson fluid parameter), }R_d=\frac{k\alpha^{\square}}{4\sigma^{\square}T_\infty{}^3}$$

Where

$$D=\frac{3P_rR_d}{3R_d+4},\beta=\mu_B\frac{\sqrt{2\pi_c}}{P_y}\text{ (Casson fluid parameter), }R_d=\frac{k\alpha^{\square}}{4\sigma^{\square}T_\infty{}^3}$$

(radiation parameter), $R_p=\frac{K_pa}{v}$ (permeability parameter), $P_r=\frac{\mu C_p}{k}$ (Prandtl number), $\gamma=\frac{k_1}{a}$ (chemical reaction parameter), $E_c=\frac{a^2}{C_p\frac{E_0}{k}\sqrt{\frac{v}{a}}}$ (Eckert number), $S_c=\frac{v}{D_m}$ (Schmidt number), $S=\frac{V_0}{\sqrt{va}}$ (suction parameter), $M=\frac{\sigma B_0{}^2}{a\rho}$ (magnetic parameter) and Q (heat sink parameter).

SOLUTION OF THE PROBLEM :

The set of nonlinear differential equations (6) – (7) with the boundary conditions is a boundary value problem that is solved analytically using the Confluent hyper geometric function. The boundary condition (9) subject to the Equation (6) yields the exact solution.

$$\left.\begin{aligned}f(\eta)&=S+\frac{1-e^{-E\eta}}{E}\\ f'(\eta)&=e^{-E\eta}\end{aligned}\right\} \qquad [10]$$

Where

$$E=\frac{1}{2}\left[S+\sqrt{S^2+4\frac{1}{\left(1+\frac{1}{\beta}\right)}\left(1+M+R_p^{-1}\right)}\right]$$

In order to solve the energy Equation (7) and the species concentration Equation (8), new similarity variables ξ and ς are defined respectively as follows

$$\xi^{-1}=\frac{-E^2e^{E\eta}}{D(1+Q)},\ \zeta^{-1}=\frac{-E^2e^{E\eta}}{S_c} \qquad [11]$$

Using the Equation (3.12) in the Equations (3.8) - (3.10), the following equations are obtained with the boundary conditions

$$\xi\frac{d^2g}{d\xi^2}+[(1-K_1)-\xi]\frac{dg}{d\xi}+S_1g=-\frac{E_cE^4\xi}{D(1+Q)^2}\left(1+\frac{1}{\beta}\right) \qquad [12]$$

$$\zeta\frac{d^2\mathrm{h}}{d\zeta^2}+[(1-K_3)-\zeta]\frac{d\mathrm{h}}{d\zeta}+\left(2-\frac{\gamma S_c}{E^2\zeta}\right)\mathrm{h}=0 \qquad [13]$$

$$g(\xi=0)=0,\frac{dg}{d\xi}\left(\xi=\frac{-D(1+Q)}{E^2}\right)=\frac{-E}{D(1+Q)} \quad [14]$$

$$g(\xi=0)=0,\frac{dg}{d\xi}\left(\xi=\frac{-D(1+Q)}{E^2}\right)=\frac{-E}{D(1+Q)}$$

$$\mathrm{h}(\zeta=0)=0,\ \frac{d\mathrm{h}}{d\zeta}\left(\zeta=\frac{-S_c}{E^2}\right)=\frac{-E}{S_c}$$

Utilizing the Equations (13) and (14), the solution of the Equations (12) and (13) can be obtained in terms of Confluent hyper geometric function and the same is given as follows

$$g(\xi)=-\frac{E_cE^4\xi^2}{D(1+Q)S_1(S_1-K_1)}\left(1+\frac{1}{\beta}\right)+$$

$$\frac{\xi^{K_1}\ {}_1F_1[K_1-S_1;K_1+1;\xi]\left[\frac{E}{D(1+Q)}+\frac{E_cE^2}{(S_1-K_1)}\left(1+\frac{1}{\beta}\right)\right]}{\left[\frac{-D(1+Q)}{E^2}\right]^{K_1-1}\left[K_1\ {}_1F_1[K_1-S_1;K_1+1;-K_2]-K_2\frac{K_1-S_1}{K_1+1}\ {}_1F_1[K_1-S_1+1;K_1+2;-K_2]\right]} \quad [15]$$

$$\mathrm{h}(\zeta)=\frac{\left[\frac{-\zeta}{K_4}\right]^r\ {}_1F_1[r-2;A+1;\zeta]}{EK_4\left[\frac{r}{K_4}\ {}_1F_1[r-2;A+1;-K_4]-\frac{r-2}{A+1}\left[\ {}_1F_1[r-1;A+2;-K_4]\right]\right.} \quad [16]$$

where

$$K_1=\frac{D(1+Q)}{E^2}\left[E^2-R_p^{-1}\right],\ S_1=\frac{2}{(1+Q)},\ K_3=\frac{S_c}{E^2}[1+SE]$$

$$K_2=\frac{D(1+Q)}{E^2},\ K_4=\frac{S_c}{E^2},r=\frac{A+K_3}{2},\ A=\sqrt{\left[K_3^2+\frac{4\gamma S_c}{E^2}\right.}$$

The Equations (3.17) and (3.18) can also be expressed as

$$g(\eta)=-\frac{E_c\ D(1+Q)e^{-2E\eta}}{S_1(S_1-K_1)}\left(1+\frac{1}{\beta}\right)+$$

$$\frac{K_2e^{-EK_1\eta}\ {}_1F_1[K_1-S_1;K_1+1;-K_2e^{-E\eta}]\left[\frac{E}{D(1+Q)}+\frac{E_cE^2}{(S_1-K_1)}\left(1+\frac{1}{\beta}\right)\right]}{\left[K_1\ {}_1F_1[K_1-S_1;K_1+1;-K_2]-K_2\frac{K_1-S_1}{K_1+1}\ {}_1F_1[K_1-S_1+1;K_1+2;-K_2]\right]} \quad [17]$$

$$\mathrm{h}(\eta)=\frac{e^{-Er\eta}\ {}_1F_1[r-2;A+1;-K_4e^{-E\eta}]}{EK_4\left[\frac{r}{K_4}\ {}_1F_1[r-2;A+1;-K_4]-\frac{r-2}{A+1}\left[\ {}_1F_1[r-1;A+2;-K_4 1]\right.\right.}$$

The rate of heat and mass transfer, as well as shear stress, are represented by physical quantities such as the Nusselt and Sherwood numbers, and the skin friction coefficient can be written as

$$C_f=-\left(1+\frac{1}{\beta}\right)f''(0),N_u=\frac{1}{g(0)},S_h=\frac{1}{\mathrm{h}(0)} \quad [18]$$

$$g(0)=-\frac{E_c D(1+Q)}{S_1(S_1-K_1)}\left(1+\frac{1}{\beta}\right)+ \frac{K_2\ {}_1F_1[K_1-S_1;K_1+1;-K_2]\left[\frac{E}{D(1+Q)}+\frac{E_c E^2}{(S_1-K_1)}\left(1+\frac{1}{\beta}\right)\right]}{\left[K_1\quad {}_1F_1[K_1-S_1;K_1+1;-K_2]-K_2\frac{K_1-S_1}{K_1+1}\ {}_1F_1[K_1-S_1+1;K_1+2;-K_2]\right.}$$

RESULTS AND DISCUSSION :

Heat and mass transfer of MHD Casson fluid flow through a porous medium exposed to suction have been examined in relation to viscous dissipation, thermal radiation, chemical reaction, and temperature gradient dependent heat sink. By giving numerical values to the governing parameters encountered in the problem, graphs have been used to discuss the velocity, temperature, and concentration in order to obtain a physical significance of the problem. The current study examines how flow, heat, and mass transfer characteristics are affected by magnetic, suction, Casson, permeability, Prandtl, radiation, heat sink, Eckert, Schmidt, and chemical reaction parameters. Additionally, the Sherwood, Nusselt, and skin-friction coefficients are calculated at the surface.To validate the accuracy of the results, comparisons were made with the previously published journals. As shown in Tables 1-3, the results are found to be validates

Table 1 Comparison of Skin friction coefficient with the previously reported work (Rp = 0 & S = 0)

M	β	Gireesha *et al.*(2015)	Present Result
0.25	0.8	1.66897	1.59888
	1.4	1.46563	1.4.5770
	2.0	1.35432	1.37089
	3.0	1.3,0023	1.3.0022

Table 2 Comparison of g(0) with the previously reported work (Rp = 100, S = 0, Q= 0, Ec = 0, Rd = 0 & β→∞)

M	Pr	Abdul Hakeem *et al.*(2014)	Present Result
1	1	0.82252	0.82333
	5	0.31179	0.31156
	10	0.21321	0.21311

Table 3 Comparison of h(0) with the previously reported work
(Rp= 100, Sc = 0.62, γ= 0 & β→∞)

M	N	Anjali Devi & Kayalvizhi (2013)	Present Result
4	0.5	1.132800	1.132799
	1.0	0. 900561	0.900559
	1.5	0.737861	0.737862
	2.0	0.619963	0.619961
	2.5	0.531763	0.531764

The velocity, temperature, and species concentration patterns for various values of the Casson liquid parameter β are shown in Figures 1–3. It is evident that the action of β increases concentration while decreasing temperature and velocity. A decrease in yield stress P_y and an increase in the fluid's plastic dynamic viscosity μ_B are correlated with an increase in μ_B Momentum and the thickness of thermal boundary layers diminish as a result. Retarding force is triggered by the presence of plastic dynamic viscosity, which raises concentration. Figures 4–6 show how the magnetic parameter M affects the velocity, temperature, and concentration profiles, respectively. A Lorentz force is created as the magnetic field increases, and this force acts against the direction of the fluid flow. This force tends to increase the friction between the concentration layers, slow down the flow, and produce more heat in the fluid. Thus, M's impact raises temperature and concentration while decreasing velocity.

The effects of the permeability parameter Rp on temperature, concentration, and velocity are shown in Figures 10–11. These figures show that Rp decreases the temperature and species concentration profiles while increasing the velocity profile. The fluid can flow easily across the boundary layer due to the porous medium's increased permeability, which increases the size of the porosity. Heat and mass transmission rates increase as a result of this.

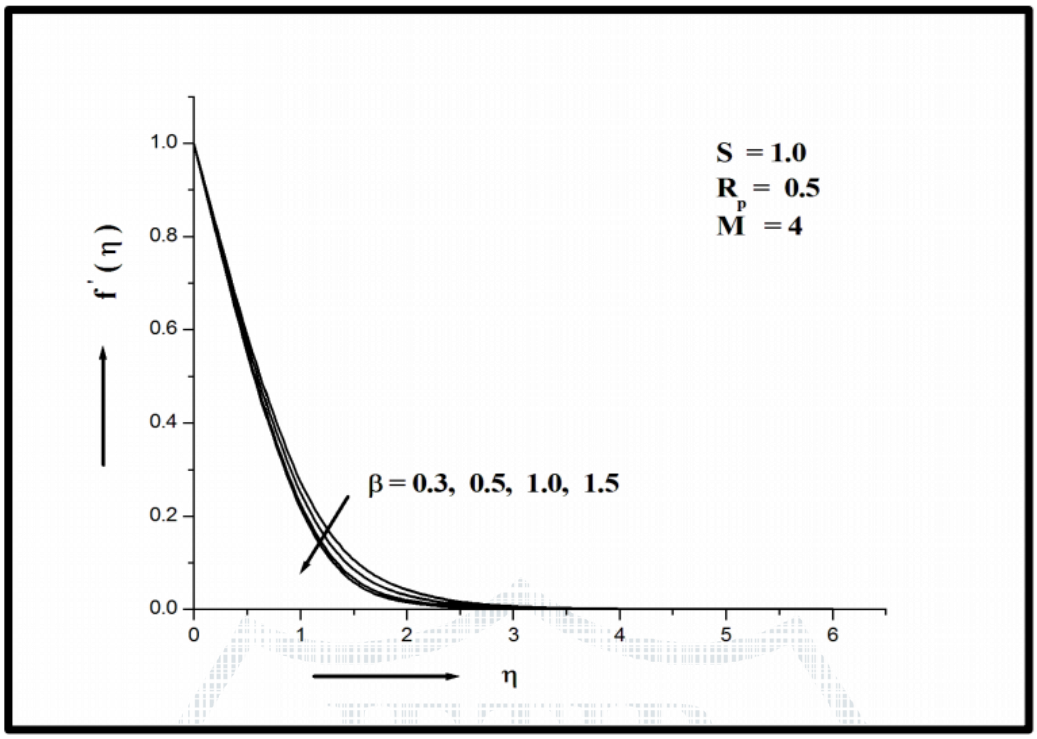


Figure 1 Velocity profile for various β

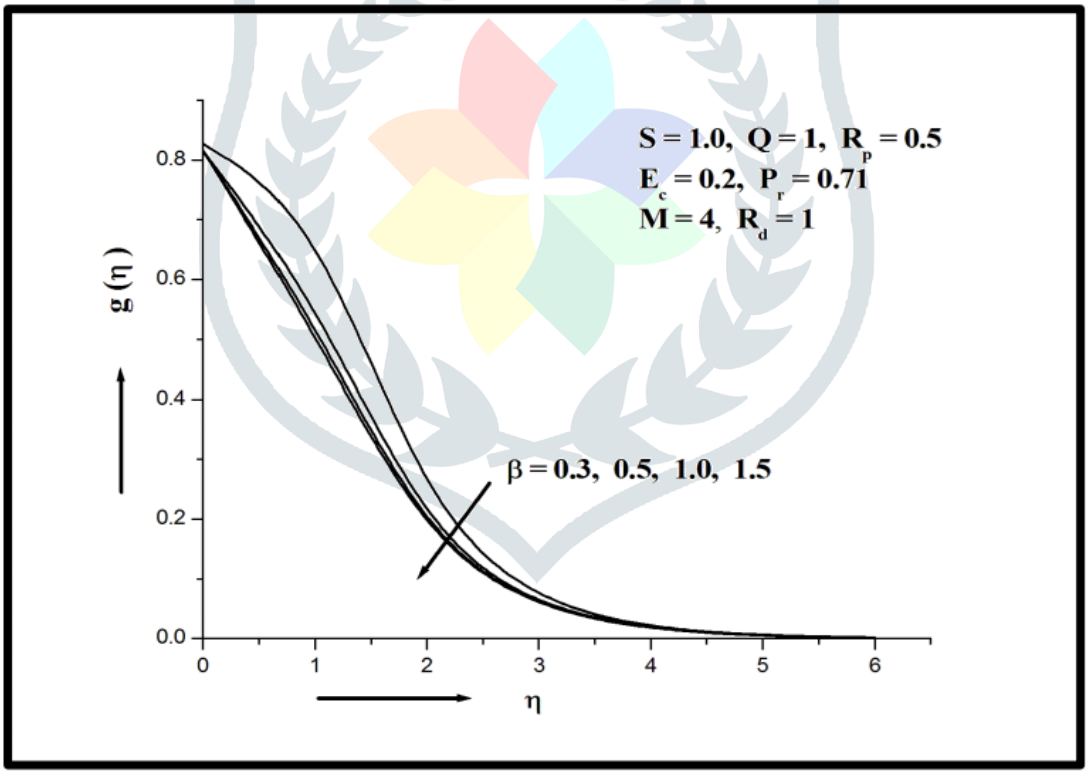


Figure 2 Temperature profile for various β

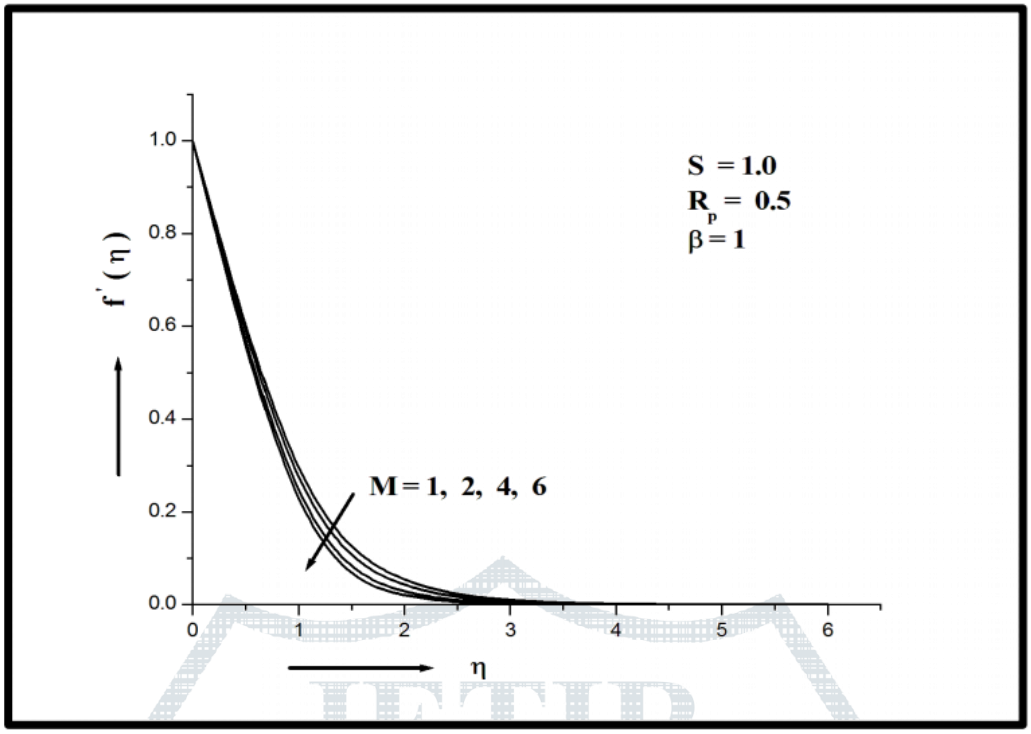


Figure 3 Velocity profile for various M

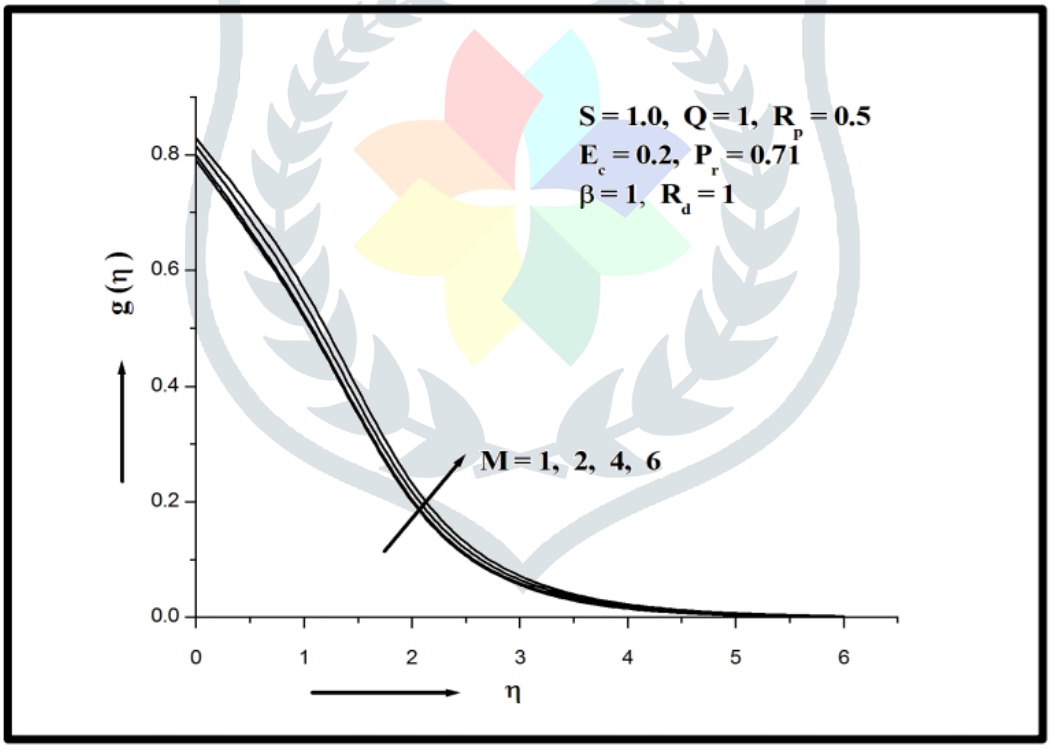


Figure 4 Temperature profile for various M

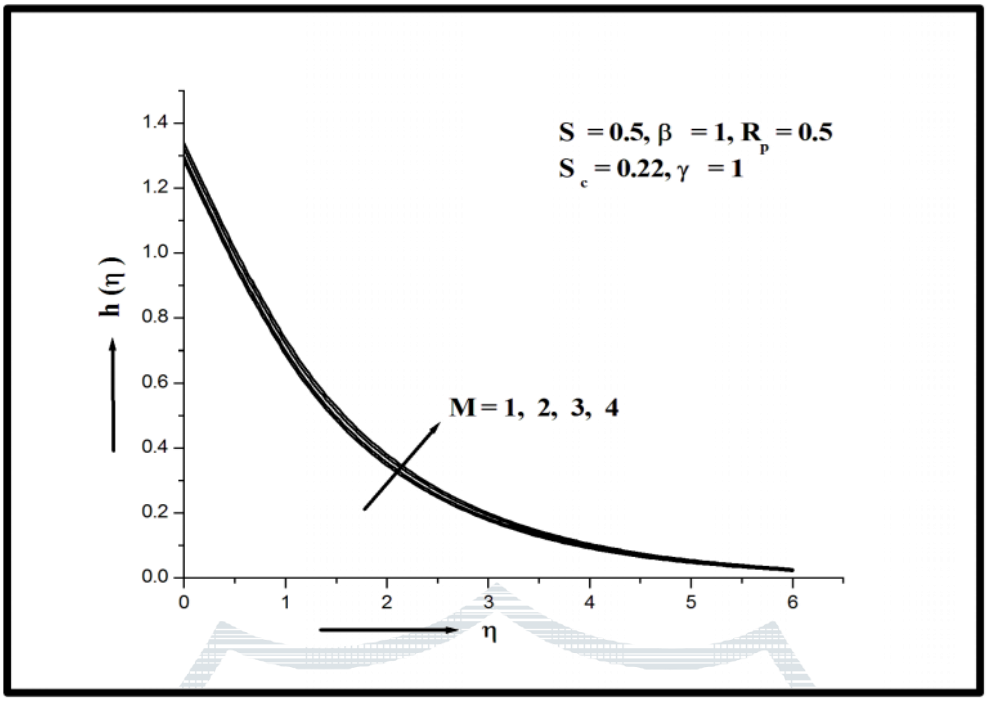


Figure 5 Concentration profile for various M

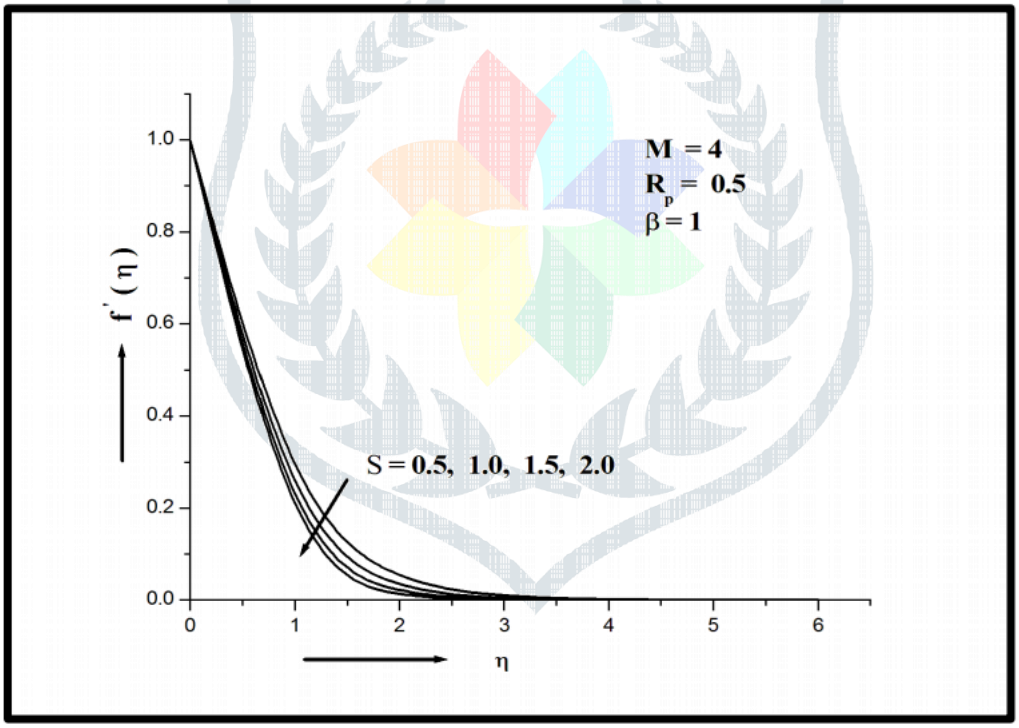


Figure 6 Velocity profile for various S

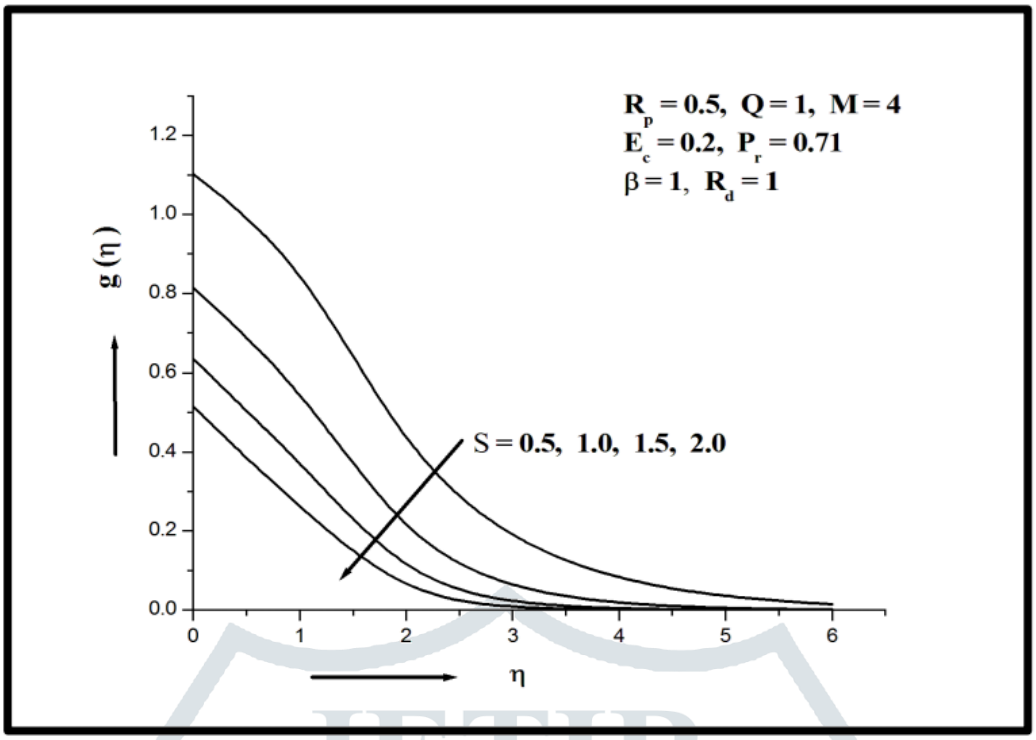


Figure 7 Temperature profile for various S

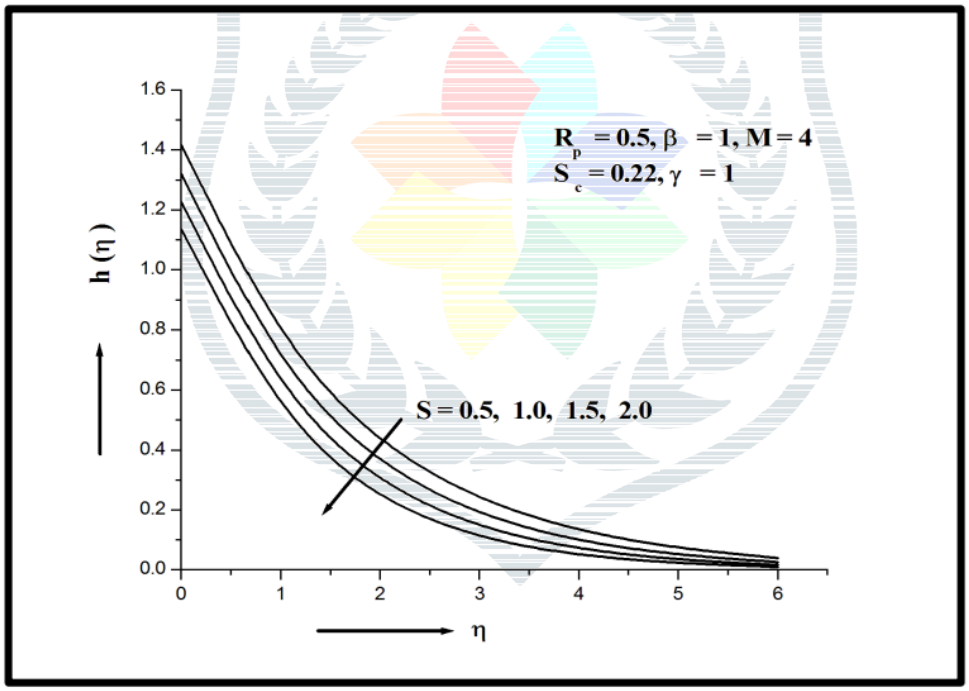


Figure 8 Concentration profile for various S

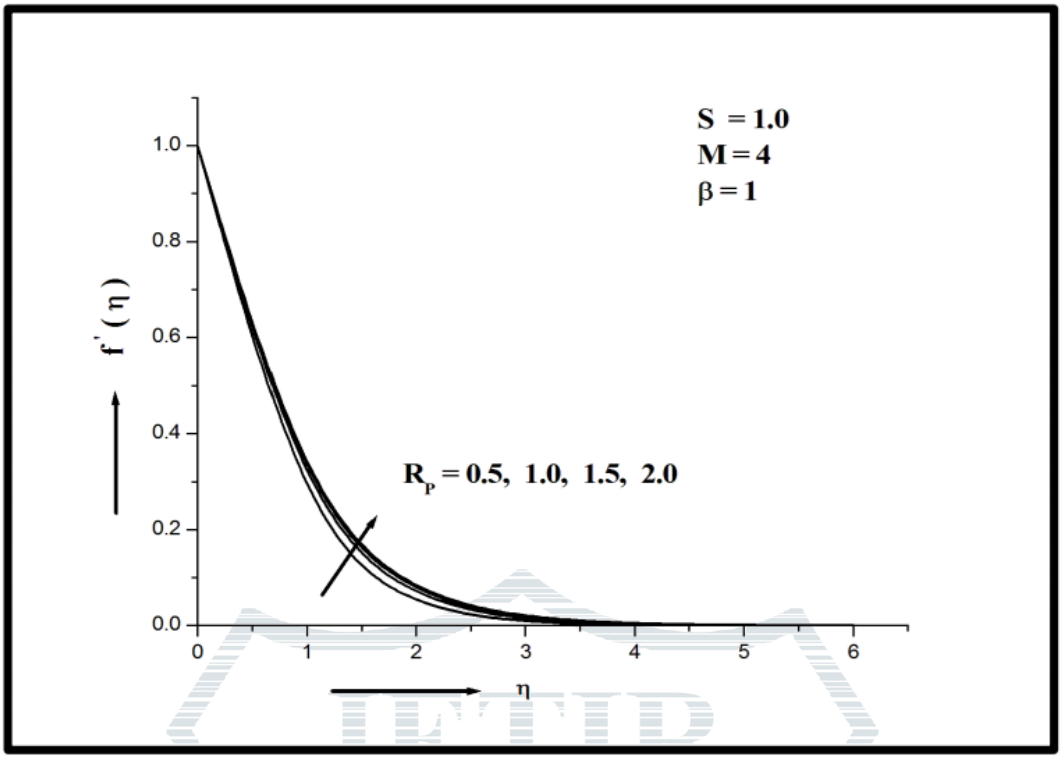


Figure 9 Velocity profile for various Rp

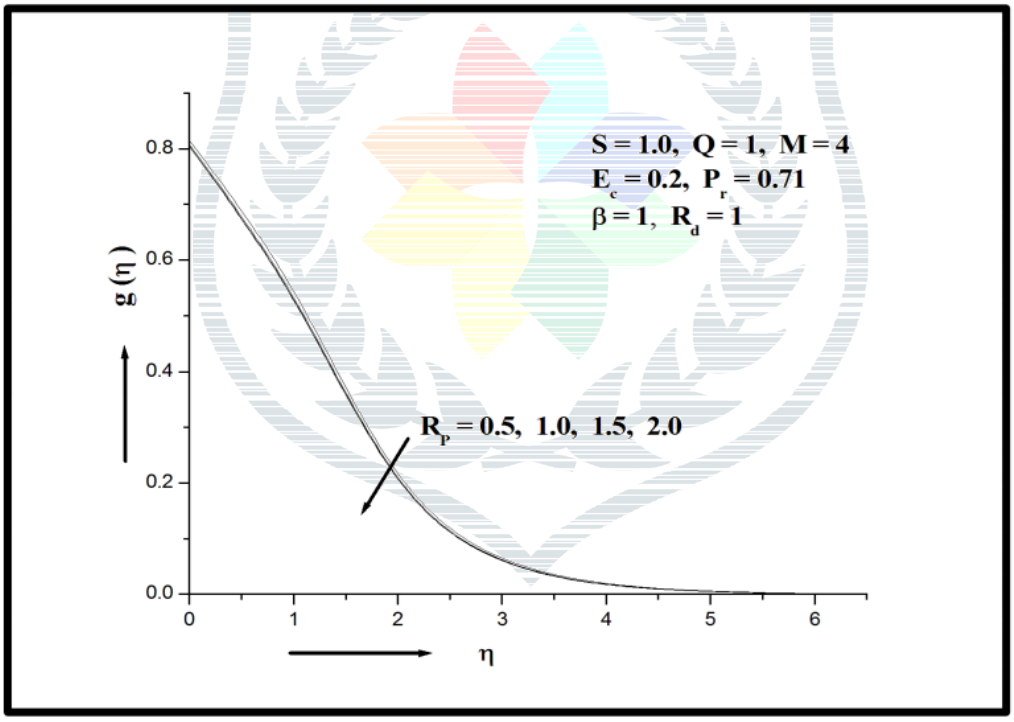


Figure 10 Temperature profile for various Rp

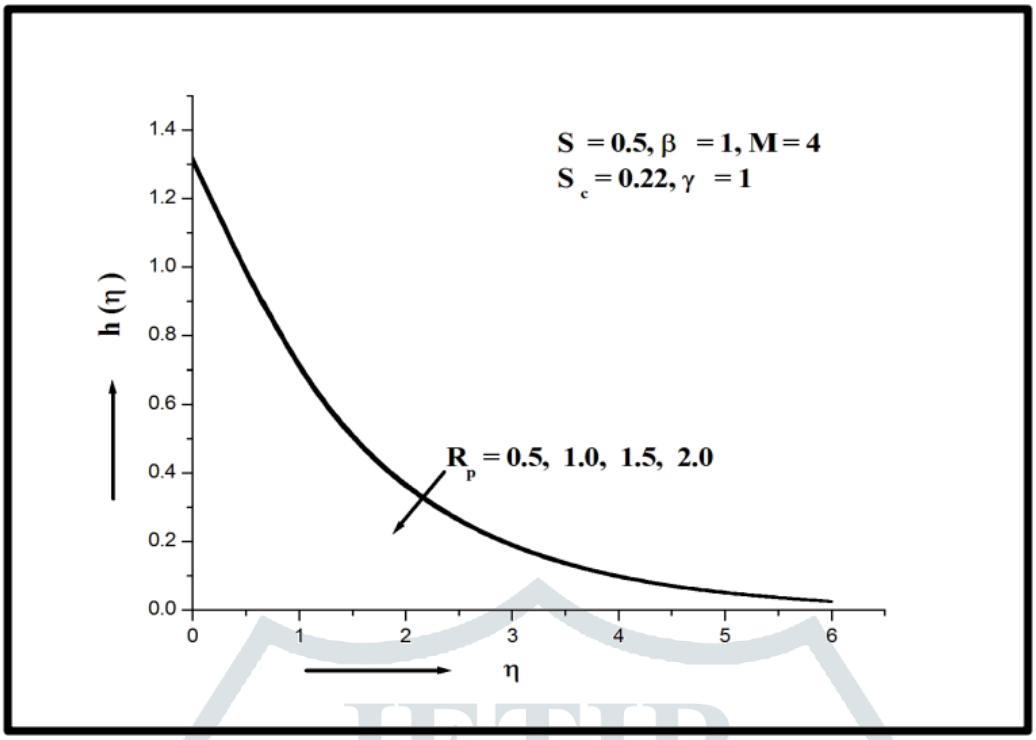


Figure 11 Concentration profile for various Rp

CONCLUSION:

MHD Casson fluid flow with viscous dissipation, thermal radiation, and chemical reaction with temperature gradient dependent heat sink under suction has been analysed. The MHD Casson fluid's velocity, temperature, species concentration, skin friction coefficient, Nusselt number, and Sherwood number are all generally influenced by the physical parameters.

The velocity rises as the permeability parameter grows and falls as the Casson fluid parameter, suction parameter, and magnetic parameter values rise. The temperature profile rises as the magnetic parameter and Eckert number grow and falls when the Casson fluid parameter, suction parameter, permeability parameter, Prandtl number, heat sink, and radiation parameters improve. The species concentration profile falls as the values of the suction parameter, permeability parameter, Schmidt number, and chemical reaction parameter increase and rises as the values of the Casson fluid parameter and magnetic parameter grow. The skin friction coefficient falls with the Casson fluid parameter and rises with the magnetic parameter. The Nusselt number decreases with the magnetic parameter and increases with the Casson fluid parameter. As the Casson fluid parameter and magnetic parameter grow, the Sherwood number drops.

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