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Effects of Viscous Dissipation and Non-Uniform Heat Source/Sink on Casson Fluid Flow Over an Unsteady Inclined Permeable Stretching Surface

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Abstract- An analysis has been carried out to study the effects of viscous dissipation, non-uniform heat source and sink on casson fluid flow for an unsteady inclined permeable stretching surface. Implementing similarity transformations, the governing equations are transformed to nonlinear ODEs and numerical computations are performed to solve those equations. The influence of various physical parameters on velocity, temperature and concentration distributions is illustrated graphically and the physical aspects are discussed in detail. Results indicate that temperature dependent heat source/sink plays a vital role on controlling the heat transfer however the surface-dependent heat source/sink also has notable influence on the heat transfer characteristics. Comparisons with previously published work are performed and the results are found to be in excellent agreement.

***Keywords*:** Stretching surface; Inclination; Casson fluid flow; Non-uniform heat source/sink; Viscous Dissipation.

I. INTRODUCTION

Many fluids used in industries such as chemicals, cosmetics, pharmaceuticals show non-Newtonian behavior, so the modern-day researchers and scientists are more interested in those wide applications. Naiver Stokes theory is inadequate for such fluids and no single equation can exhibit the properties of all fluids. Thus, many non-Newtonian fluid models are introduced to explain the characteristics of such fluids. Some of them are fourth grade, third grade, second grade, power law, Brinkman type, Oldroyd-B, Walters' B, Maxwell, micropolar, Jaffery, Burgers and generalized Burgers models. However, there is another popular model namely, Casson model. Casson fluid is one of the types of such non-Newtonian fluids, which exhibits the behavior of Newtonian fluid when the shear stress increases to a level much higher than the yield stress. It was proposed by Casson [1] in 1959 to predict the flow behavior of pigment-oil suspensions of printing ink. Now a day, Casson fluid model is widely accepted to depict the rheology of blood flow because yield stress of blood is a function of the volume fraction of red blood cells. Magnetic field effect on Poiseuille flow and heat transfer of single and multiple wall CNTs along a vertical channel filled with Casson nanofluids is observed by Aman et al. [2]. The inclined magnetic field effect on the boundary layer flow of a Casson model non-Newtonian fluid over a stretching sheet in the existence of thermal radiation and velocity slip boundary condition is investigated (AbdulHakeem et al. [3]) for both prescribed surface temperature and power law of surface heat flux cases. The researchers ([4-10]) presented their valuable contributions by considering the steady and unsteady Casson fluid flows over different channels.

The heat generation and absorption is a massive phenomenon in the industrial processes. The stability of the flow is significantly affected by their presence. The combined effects of Hall current and thermal radiation on flow and heat transfer characteristics of the flow past an unsteady stretching permeable sheet with non-uniform heat source/sink discussed by Pal [11]. Srinivas et al. [12] analyzed the unsteady hydromagnetic heat and mass transfer of blood in a time-dependent porous narrow blood vessel over an inclined permeable stretching surface under slip conditions. The heat transfer characteristics of a convective flow past a vertical plate under the influence of magnetic field over a vertical plate under the effects of thermal radiation in the presence of heat source/sink was examined by Reddy et al. [13]. The researchers ([14-16]) presented their valuable contributions by considering the MHD steady and unsteady flows over different channels. The study of heat source/sink effects on heat transfer is very important in view of several physical problems. Some researchers ([17-20]) are included the effect of a nonuniform heat source/sink in different channels. Recently some of the researchers ([21-22]) are studied about Finite thermal conductivity and finite thickness, Marangoni convection in superposed fluids also. Thus, the main objective of the present study is to analyze the effects of viscous dissipation and Non-Uniform Heat Source/Sink on Casson fluid flow over an unsteady inclined permeable stretching surface. The influence of various non-dimensional governing parameters on velocity, temperature and concentration profiles is discussed graphically.

II. MATHEMATICAL FORMULATION

We consider the unsteady 2D (two-dimensional) MHD free convection laminar boundary flow, heat and mass transfer of an incompressible Casson fluid over a stretching sheet with viscous dissipation, thermal radiation, and a first-order homogeneous chemical reaction species. The fluid is electrically conducting in the presence of a uniform magnetic field applied normal to the sheet, and the induced magnetic field is neglected as is is assumed to be small compared to the applied magnetic field. The unsteady fluid, heat and mass transfer start at $t=0,$ .The sheet is assumed to be emerging out of the slit at the origin $(x=0, y=0)$ and moves with non-uniform velocity, $U(x,t)=\dfrac{bx}{(1-at)},$ where $(b>0, a\geq 0)$ are constants with dimensions $(time)^{-1}, b$ is the initial stretching rate.

the rheological equation of the casson fluid is given y

$$\tau_{ij}=\begin{cases}2(\mu_B+p_y/\sqrt{2\pi})e_{ij}, & \pi>\pi_c,\\ 2(\mu_B+p_y/\sqrt{2\pi})e_{ij}, & \pi<\pi_c,\end{cases}$$

Where μ_B is the plastic dynamic viscosity on non-Newtonian fluid, $\pi=e_{ij}e_{ij}$ and e_{ij} is the $(i,j)th$ component of deformation rate, π denotes the product of the component of deformation rate with itself, is a critical value of this product based on the non-Newtonian fluid, and is the yield stress of the fluid.

the governing conservation are written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\begin{aligned}\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}&=\upsilon(1+\frac{1}{\beta})\frac{\partial^2 u}{\partial y^2}\\ &+g\beta_T(T-T_\infty)\cos\alpha_1\\ &+g\beta_c(C-C_\infty)\cos\alpha_1-\frac{\sigma B_o^2}{\rho}u,\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}&=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}\\ &+\frac{q'''}{\rho c_p}+\frac{\mu}{\rho c_p}(1+\frac{1}{\beta})\left(\frac{\partial u}{\partial y}\right)^2-\frac{\sigma B_o^2}{\rho c_p}u^2\end{aligned} \tag{3}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-K(C-C_\infty) \tag{4}$$

Here, u and v are the velocity components along the axes x and y respectively. T is the fluid temperature , α is thermal diffusivity, υ is the kinematic viscosity, is the dynamic viscosity , C is the concentration, C_∞ is the free stream concentration, D is the diffusion coefficient of the diffusing species in the fluid, K is the chemical reaction rate, β_T is thermal expansion coefficient, and β_C is concentration expansion coefficient.

Boundary conditions:

$$\begin{aligned}&u=U(x,t)=\frac{bx}{1-at}\\ &v=V_w(x,t)=-\frac{\upsilon_0}{\sqrt{1-at}},\\ &T=T_w(x,t), C=C_w(x,t)\ \ at\ \ y=0,\\ &u\to 0,\ T\to T_\infty, C\to C_\infty\ \ at\ \ y\to\infty\end{aligned} \tag{5}$$

We have $T_w=T_\infty, C_w=C_\infty\ \ at\ \ x=0$ we remark that $U(x,T), \mathrm{T(x,t)}\ \text{and}\ \mathrm{v}_w(t)$ are valid for $t<a^{-1}$,

By using the Rosseland diffusing approximation, the radiative heat flux, q_r is given by,

$$q_r=\frac{-4\sigma^*}{3K_S}\frac{\partial T^4}{\partial y}, \tag{6}$$

Where σ^* and K_S are the Stefan-Boltzmann constant and the Roseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature

$$T^4 \approx 4T_\infty^{\,3}T - 3T_\infty^{\,4}, \tag{7}$$

Using (6) and (7) in the last term of Eq. (3) We obtain

$$\frac{\partial q_r}{\partial y} = \frac{-16\sigma^* T_\infty^{\,3}}{3K_S}\frac{\partial^2 T}{\partial y^2},$$

And q''' is the rate of internal heat generation/absorption coefficient. The dimensionless form of q''' can be put in the form mentioned below

$$q''' = \frac{\kappa U_w(x)}{\chi \nu}\left[\begin{array}{l} Q_0^*(T_w - T_\infty)e^{-\eta} \\ +Q_1^*(T - T_\infty) \end{array}\right] \tag{8}$$

where Q_0 and Q_1 are parameters of space and temperature dependent internal heat generation/absorption respectively. It is noted that the case $Q_0 > 0$ and $Q_1 > 0$ corresponds to internal heat generation while $Q_0 > 0$ and $Q_1 > 0$ holds for internal heat absorption, *Tw* is the temperature of sheet and T_∞ is the constant temperature for away from the sheet

$(1+\varepsilon\theta)\left[Q_0 f' + Q_1\theta\right]$

we introduced the following similarity transformations

$$\eta = \sqrt{\frac{b}{\nu(1-at)}}\,y,\quad \varphi = \sqrt{\frac{\nu b}{(1-at)}}\,x f(\eta),$$

$$\mathrm{C}(\eta) = C_\infty + \frac{bx^2 C_0 (1-at)^{-3/2}}{2\nu}\varphi(\eta),$$

$$T(\eta) = T_\infty + \frac{bx^2 T_0 (1-at)^{-3/2}}{2\nu}\theta(\eta),$$

$$\kappa = \kappa_\infty(1+\varepsilon\theta(\eta)),\quad \theta(\eta) = \frac{T - T_\hbar}{T_w - T_\infty},$$

$$\varepsilon = {K_w - K_\infty}\big/{K_\infty}, \tag{9}$$

Where $f(\eta)$ is the dimensionless stream function and η is the dimensionless similarity coordinate, θ is the dimensionless temperature, and φ is the dimensionless concentration Substituting (9) into the Equations (2)-(8), We obtain the following system of nonlinear ordinary differential equations:

$$\begin{aligned}&(1+\frac{1}{\beta})f''' + ff'' - A\left(\frac{\eta}{2}f'' + f'\right) - M^2 f' \\ &\quad - f'^2 + \lambda_1\cos\alpha\theta + \lambda_2\cos\alpha\varphi = 0\end{aligned} \tag{10}$$

$$\begin{aligned}&\frac{1}{\Pr}\left(1+\frac{4}{3}R\right)\theta'' + \left(f - \frac{A}{2}\eta\right)\theta' \\ &-\left(\frac{3A}{2} + 2f'\right)\theta + (1+\varepsilon\theta)\left(Q_0 f' + Q_1\theta\right) \\ &+ Ec\left((1+\frac{1}{\beta})(f'')^2 - M^2(f')^2\right) = 0\end{aligned} \tag{11}$$

$$\begin{aligned}&\frac{1}{Sc}\varphi'' - \left(\frac{3A}{2} + 2f' + \gamma\right)\varphi \\ &\qquad + \left(f - \frac{A\eta}{2}\right)\varphi' = 0\end{aligned} \tag{12}$$

Subject to boundary conditions:

$$\begin{aligned}&f(0) = f_w,\ f'(0) = 1, \theta(0) = 1, \varphi(0) = 1, \\ &f' \to 0, \theta \to 0, \varphi \to 0,\ as\ \ \eta \to \infty\end{aligned} \tag{13}$$

Where primes denote differentiation with respect to η and is the suction/injection parameter.

$$A = \frac{a}{b},\ M = B_0\sqrt{\frac{\sigma(1-at)}{\rho b}},\ Ec = \frac{U^2_\infty}{c_p(T_w - T_\infty)},$$

$$R = \frac{4\sigma^* T^3_\infty}{3K_s k},\ \lambda_1 = \frac{T_0 g\beta_T x(1-at)^{\frac{1}{2}}}{2\upsilon b},\ \Pr = \frac{\upsilon}{a}$$

$$\lambda_2 = \frac{T_0 g\beta_c x(1-at)^{\frac{1}{2}}}{2\upsilon b},\ Sc = \frac{\upsilon}{D}, \tag{14}$$

The quantities of physical interest in this problem are the skin-friction coefficient, heat transfer rate and mass transfer, which are defined as

$$C_f = \frac{2\tau_w}{\sqrt{\rho U^2}},\qquad Nu_x = \frac{xq_w}{k_0(T_w - T_\infty)}$$

and $Sh_x = \dfrac{xJ_w}{D(C_w - C_\infty)}.$

Where $\tau_w = \left(1+\dfrac{1}{\beta}\right)\left(\mu\dfrac{\partial u}{\partial y}\right)_{y=0},\ q_w = -k\left(\dfrac{\partial T}{\partial y}\right)_{y=0}$

and $J_w = -D\left(\dfrac{\partial C}{\partial y}\right)_{y=0},\ k = k_0(1+\varepsilon),$

Using the dimensionless (9) the local skin friction coefficient, local Nusselt number and Sherwood number can be written as follows:

$$\frac{1}{2}C_f \operatorname{Re}_x^{1/2} = \left(1+\frac{1}{\beta}\right) f''(0), \quad Sh_x \operatorname{Re}_x^{-1/2} = -\varphi'(0).$$
$$Nu_x \operatorname{Re}_x^{-1/2} = -\left(1+\varepsilon\right)\theta'(0)$$
(15)

where $\operatorname{Re}_x = \dfrac{xU}{\upsilon}$ is the local Reynolds number.

III. RESULTS AND DISCUSSION

The computations have been made carried out by assuming various values of the parameters involved in the problem and the results are illustrated through the graphs and tables. The effects of velocity, temperature and concentration profiles for various values of the computations are illustrated through graphs. Fig.1 depicts the influence of f_w on the velocity profiles. The momentum boundary layer thickness and fluid velocity is reduced by increasing values of f_w. The effects of the magnetic field parameter M on the velocity is presented in fig.2. The increase in the value of M causes the reduction in velocity profiles across the boundary layer. Physically, the higher value of M implies the higher Lorentz force which has tendency to slow down the motion of the conducting fluid in the boundary layer. Fig.3 indicates that the effect of inclination angle α on the fluid velocity. It is observed the fluid velocity is decreases with an increasing value of α. Fig.4 illustrates that the influence of the Eckert number on the temperature profile. In the presence of a Eckert number significantly affects the temperature profiles. From this figure, we observed that the fluid temperature is greatly affected by the presence of viscous dissipation. Increasing the values of the Eckert number results in the increase of the temperature profiles.

Figs. 5 and 6 display the impact of non-uniform heat source parameters Q_1 and Q_0 on dimensional temperature field. The rising values of Q_1 and Q_0 enhanced the temperature fields for both Newtonian and non-Newtonian fluid cases. It is well known that the positive values of Q_1 and Q_0 indicate the heat generation of the system. In Fig. 7, we have the effect of the chemical reaction on the concentration distribution, in the presence and absence of Newtonian and non-Newtonian fluid cases. This in turn decelerates the fluid flow. Therefore, increasing values of the chemical reaction causes decreasing the solutal boundary layer thickness.

Table 1: Comparison of $(-f''(0))$ with previous published data

A	**M**	$\mathbf{f_w}$	**Gupta and Gupta (1997)**	**Mansur and Ishak (2013)**	**Butt and Ali (2014)**	**Present results**
0	1.0	0.5			1.68614	1.68615
0.5					1.80242	1.80243
1.0					1.91407	1.9141
1.3					1.97871	1.97872
0.5	0.0	0.5			1.4313	1.43181
	0.5				1.63018	1.63023
	1.0				1.80242	1.80243
0.5	1.0	0.0			1.53905	1.53906
		0.5			1.80242	1.80243
		1.0			2.10567	2.10567
0.0	0.0	2.0	2.4142	2.4142		2.41422
		2.5	2.8508	2.8508		2.85078
		3.0	3.3028	3.3028		3.30278

Table 2: Variation of skin-friction, Nusselt number and Sherwood number with different values of the governing parameters

M	β	λ_1	λ_2	α	R	ε	Q_0	Q_1	γ	$\left(1+\frac{1}{\beta}\right)f''(0)$	$-(1+\varepsilon)\theta'(0)$	$-\phi'(0)$
0.5	0.7	0.5	0.5	$\pi/4$	1.5	0.5	-0.1	-0.1	1.0	-2.19659	1.34676	1.69099
0.7	0.7	0.5	0.5	$\pi/4$	1.5	0.5	-0.1	-0.1	1.0	-2.31089	1.34858	1.68548
0.5	0.9	0.5	0.5	$\pi/4$	1.5	0.5	-0.1	-0.1	1.0	-2.05783	1.34374	1.68246
0.5	0.7	1.0	0.5	$\pi/4$	1.5	0.5	-0.1	-0.1	1.0	-1.99057	1.38508	1.70091
0.5	0.7	0.5	1.0	$\pi/4$	1.5	0.5	-0.1	-0.1	1.0	-2.05313	1.36781	1.69674
0.5	0.7	0.5	0.5	$\pi/3$	1.5	0.5	-0.1	-0.1	1.0	-2.30052	1.32826	1.68624
0.5	0.7	0.5	0.5	$\pi/4$	2.0	0.5	-0.1	-0.1	1.0	-2.18551	1.20545	1.69178
0.5	0.7	0.5	0.5	$\pi/4$	1.5	1.0	-0.1	-0.1	1.0	-2.19762	1.82268	1.69092
0.5	0.7	0.5	0.5	$\pi/4$	1.5	0.5	0.1	-0.1	1.0	-2.19095	1.26333	1.69138
0.5	0.7	0.5	0.5	$\pi/4$	1.5	0.5	-0.1	0.1	1.0	-2.19043	1.25925	1.69142
0.5	0.7	0.5	0.5	$\pi/4$	1.5	0.5	-0.1	-0.1	1.5	-2.20315	1.34504	1.8009

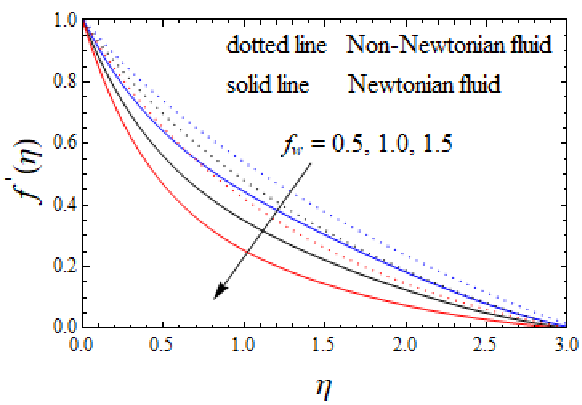

Figure. 1. Effect of thermal buoyancy parameter on velocity

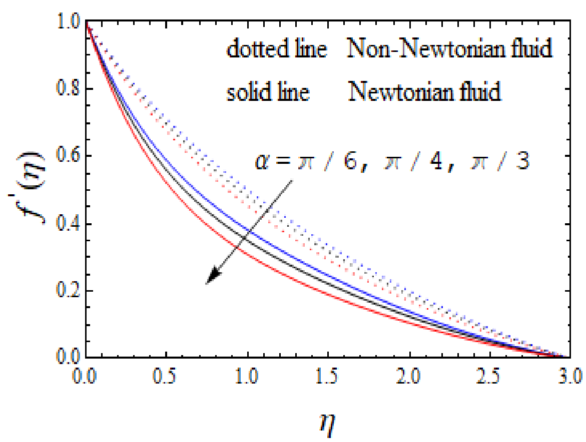

Figure. 3. Inclination on velocity

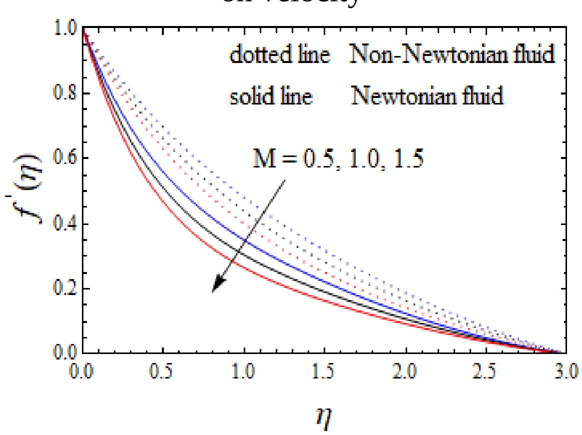

Figure. 2. Magnetic parameter on velocity

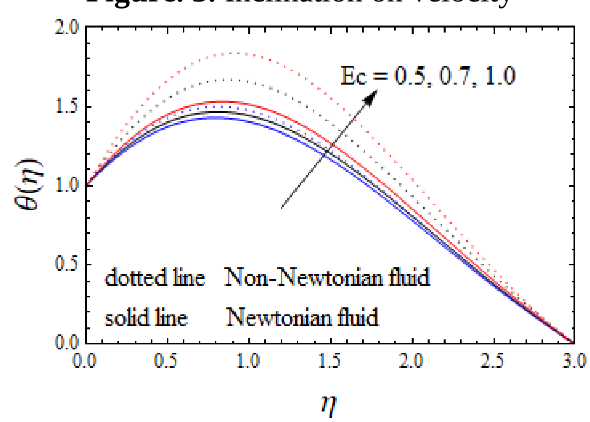

Figure. 4. Eckert number with temperature

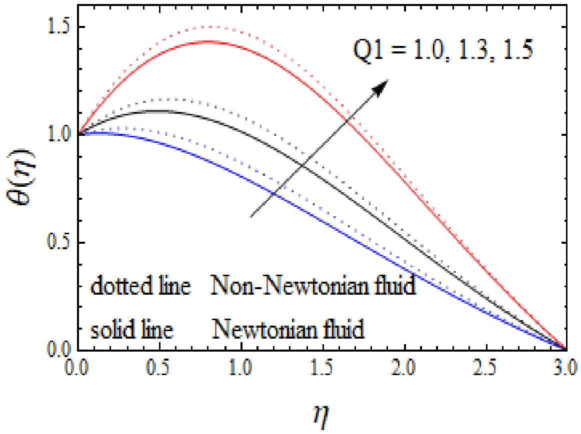

Figure. 5. Non-uniform heat source/ sink parameter(Q1) with temperature

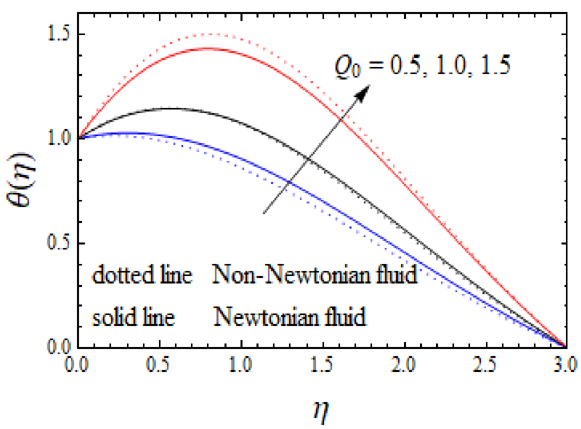

Figure. 6. Non-uniform heat source/ sink parameter(Q1) with temperature

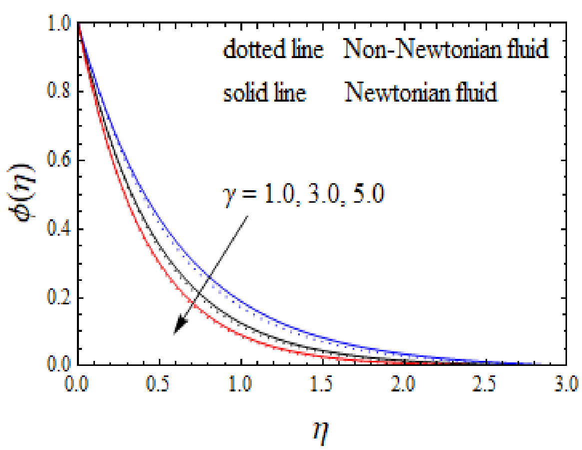

Figure. 7. Chemical reaction on concentration profile

To validate the present solution, comparisons have been made with previously published data from the literature for the $-f''(0)$ in Table 1, and they are found to be in favorable agreement. Table 2 depicts the effects of various important governing parameters on the skin friction, local Nusselt number and Sherwood number. We observe in this table that the skin friction increases with increasing values of the Casson fluid, thermal buoyancy parameter, heat source/sink, solutal buoyancy parameter, radiation parameter. Increasing the Casson fluid, inclined angle, radiation parameter, heat source/sink and chemical reaction parameter significantly reduces the local Nusselt number. The Sherwood number increases with increasing values of the thermal buoyancy parameter, heat source/sink, solutal buoyancy parameter, radiation parameter.

IV.CONCLUSION

This paper presents the study to analyze the effects of viscous dissipation and non-uniform heat source/sink on Casson fluid flow over an unsteady inclined permeable stretching surface. Appropriate similarity transformations are used to convert the governing partial differential equations into a system of coupled non-linear differential equations. The resulting coupled non-linear differential equations are solved numerically by using fourth order Runge-Kutta along with shooting technique. By increasing the non-dimensional parameters, the effects on velocity, temperature and concentration profiles are discussed and presented through graphs. The velocity profile decreases with magnetic parameter M, inclined angle and suction parameter. The temperature enhances with Eckert number Ec, heat source parameter. The concentration profile decreases with chemical reaction parameter γ . The value of skin-friction coefficient increases with Casson fluid parameter, thermal buoyancy parameter, solutal buoyancy parameter and radiation parameter. By increasing the inclined angle, chemical reaction parameter and Casson fluid parameter reduces the Nusselt number and Sherwood number.

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