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Research Paper

Nonlinear Convective Flow of Maxwell Fluid over a Slendering Stretching Sheet with Heat Source/Sink

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Abstract. In this study, the features of Maxwell fluid flow through a stretching sheet (variable thickness) with heat source/sink and melting heat transfer are analyzed. Leading equations of the course are transmuted with suitable similarity transmutations and resolved the subsequent equations mathematically with shooting technique. The effects of the valid parameters on the regular profiles (velocity, concentration, temperature) are elucidated through graphs in two cases (presence and absence of melting). And also, friction factor, transfer rates (mass, heat) are examined with the same parameters and the outcomes are presented in tabular form. A few of the findings are (a) the elastic parameter upsurges the velocity (b) heat source parameter raises the temperature (c) mass transfer rate is lowered by chemical reaction.

Keywords: Nonlinear convective flow, Heat source/sink, Maxwell fluid, Melting parameter, Shooting technique.

1. Introduction

Newtonian fluids are defined as those materials which in laminar flow show a linear connection among the imposed shear stress and the resultant shear rate. The increasing development of non-Newtonian fluids, for example, liquid plastics, pulps, emulsions, etc., as significant crude materials and products in a huge range of industrial procedures, has motivated a considerable amount of awareness in the behavior of such fluids when in movement. Therefore, the study of flow and heat transmission in non-Newtonian fluids is of practical importance. Maxwell fluid is a sub-branch of rate type fluids in which stress relaxation is predictable. That means it can address the behavior of fluid relaxation time on the boundary layer. This fluid model is especially useful for polymers of low molecular weight. Initially, Acrivos [1] made a theoretical analysis of the characteristics of heat transfer for the convective flow of non-Newtonian fluid (power-law fluid). He derived an expression which is useful to compute the average rates of heat transfer with good accuracy in laminar free convection. Sarpkaya [2] demonstrated that the impact of the magnetic field is to make the dissemination of velocity almost all identical in his work on the laminar flow of non-Newtonian fluids. By considering the geometry as a square duct, Chandrupatla and Sastri [3] concluded that pseudoplastic fluids appear to be superior functioning fluids in heat exchange tools contrasted with Newtonian fluids. By providing exact solutions, Rajagopal [4] established the fact that the firmness of the instable simplex non-Newtonian fluids was affected by normal stress moduli. Abel and Veena [5] and Prasad et al. [6] described the visco-elastic fluid flow across a stretching sheet submerged in a porous medium. Few of their findings are visco-elastic parameters which enrich the mass transfer rate and porosity parameter boost up the concentration gradient. Liao [7] and Hayat et al. [8] employed the homotopy analysis method to solve the equations which arose in their work on the non-Newtonian fluids across different geometries. They found that the skin friction was enhanced by the magnetic field and the suction/injection parameter lowers the thickness of the boundary layer. Keimanesh et al. [9] found the analytical solution for their problem of non-Newtonian fluid flow amongst two parallel plates and witnessed that the exactness of the technique is superb. Ramana Reddy et al. [10] seen that contrasted with Maxwell fluid, Eckert number displays a noteworthy effect on the rate of heat transfer in Casson fluid. Mahanthesh et al. [11] demonstrated the nonlinear convective Maxwell fluid flow using the homotopic procedure in the presence of nonlinear thermal radiation. Recently, few authors [12-15] contributed to the work on Maxwell fluid flow across various geometries.

In numerous problems, there might be a noticeable temperature variance among the surface and the surrounding fluid. This imposes the thought of temperature-dependent heat sources or sinks which may apply a solid influence on the heat transfer features. Precise modeling of the interior heat generation or absorption is somewhat difficult; some straightforward numerical models can express its average behavior for most physical conditions. So, there is a need for thinking about the external heat generation or absorption parameter (or heat source/sink). The study of heat generation or absorption in moving fluids is important in view of several physical problems such as fluids experiencing exothermic (heat releasing) or endothermic (heat absorbing) chemical reactions to control the heat transfer. In the numerical investigation of heat source/sink effect on the steady mixed convective stagnation flow, Yih [16] found that the values of local Nusselt number are in inversely proportional relation with the values of heat source/sink. Chamkha [17] and Sonth et al. [18] analyzed the features of mass and heat transfer of different fluid flows across different accelerating surfaces. Their observations include (a) temperature dissemination is lesser all through the field for negative estimations of heat source/sink parameter and it is greater for positive estimations of the same parameter (b) Grashof number helps in improving the velocity of the fluid. With the help of Laplace transform and state-space methods, Kamel [19] investigated the unsteady convective fluid flow through a vertical porous plate. By taking a stretching surface as a geometry, Khan [20] and Hayat and Sajid [21] and Abel and Nandeppanavar [22] discussed various non-Newtonian fluids in the manifestation of various parameters comprising heat source/sink. They found that (a) Prandtl number decelerated the temperature (b) Deborah number minimizes the skin friction coefficient (c) visco-elastic parameter elevate the wall temperature gradient in the non-appearance of the magnetic field. In the manifestation of non-uniform heat source/sink, Pal and Mondal [23] and Pal and Mandal [24] inspected different MHD fluid flows across a stretching sheet. Noor et al. [25] concluded that the higher estimation of the thermophoretic parameter adds to bring down fluid flow concentration on the slanted surface in their study about the features of mass and heat transfer of MHD flow with heat source/sink parameter. Later, several researchers [26-33] examined the influence of heat source/sink on various fluids including Jeffrey fluid across a stretching sheet. Giri et al. [34] used a shooting procedure based on the R-K-Fehlberg procedure to solve the problem of unsteady nanofluid thin-film flow through an elastic sheet. They saw that it works like the first observing parameter of the nanofluids flow and heat transmission rate. Recently, Ullah et al. and Kumar et al. [35-36] explained different fluid flows (Casson and micropolar) with various parameters comprising slip parameters. Furthermore, some researchers [37-39] analyzed the characteristics of the heat transfer of various models.

So far, no attempt has been tried to analyze the features of nonlinear convective Maxwell fluid flow across a stretching sheet (variable thickness) with melting parameter and heat source/sink. In this study, the shooting technique is employed to resolve the transmuted equations. We have provided solutions in two cases i.e., presence and absence of melting parameter. To capture the variations and inspect the common profiles (velocity, concentration, and temperature) against several parameters together with heat source/sink, plots were presented. And also, we have presented the physical values of friction factor, transfer rates (mass, heat) in the table for the same parameters. From the outcomes, it is seen that the wall thickness parameters boost all the common profiles. And also, it is worthy to mention that velocity profiles are high against Weissenberg number in the absence of melting parameter contrast to its presence. This investigation article is planned as follows. The research methodology is displayed in section two. The mathematical formulation is demonstrated in section three. A numerical procedure is mentioned in section four. Section five covers results and discussion. Section six contains conclusions.

2. Research Methodology

2.1 Review of Literature

We have collected some literature related to non-Newtonian fluid flows over various geometries and some literature related to various MHD flows over various geometries with heat source/sink.

2.2 Define Research Problem (Mathematical Formulation)

Motivated by the aforementioned literature, we have formulated a problem to analyze the features of nonlinear convective Maxwell fluid flow across a stretching sheet (variable thickness) with melting parameter and heat source/sink. The governing structure of the fluid flow (equations and boundary conditions) are transmuted as (partial) differential equations with the aid of appropriate similarity variables.

2.3 Method

We have employed a shooting technique (R-K 4th order based) to resolve the transmuted equations.

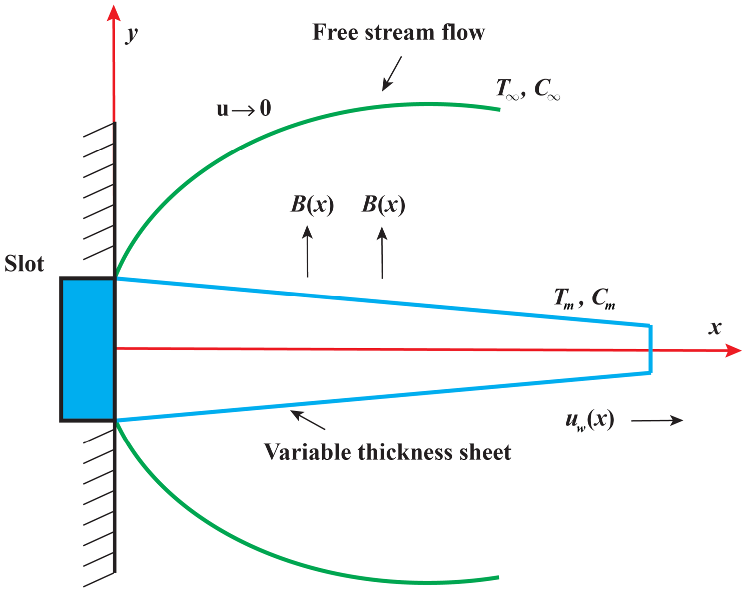

Fig. 1. Schematic diagram of Maxwell fluid flow over a slendering stretching sheet

2.4 Results and Discussion

To capture the variations and inspect the common profiles (velocity, concentration, and temperature) against several parameters together with heat source/sink, plots were presented. And also, we have presented the physical values of friction factor, transfer rates (mass, heat) in the table for the same parameters. And also, we have validated the results with the other techniques and found good agreement.

2.5 Conclusions

We have summarized the entire paper and displayed the vital outcomes from this work.

3. Mathematical Formulation

A steady, two-dimensional boundary layer flow of Maxwell fluid with heat source/sink and melting heat transfer is studied. Fluid flow is supported by a stretching sheet with non-uniform thickness. A transverse magnetic field of strength B_0 is forced perpendicular to the sheet as in Fig. 1. We assume that the stretching velocity is $u_w(x) = E(x+q)^r$ in the x-direction (E is a constant and r is the velocity power index parameter) and $y = \varepsilon(x+q)^{1-r/2}$. The concentration and temperature at the surface are denoted by C_m and T_m. Our assumption in this work is $r \neq 1$ (represents the non-uniform thickness of the sheet). Furthermore, magnetic Reynolds's number is thought to be extremely little with the goal that the stimulating magnetic field is dismissed. With these norms, the administering equations are:

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

$$\begin{aligned} &u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \lambda_0\left(u^2\frac{\partial^2 u}{\partial x^2} + 2uv\frac{\partial^2 u}{\partial x \partial y} + v^2\frac{\partial^2 u}{\partial y^2}\right) = \\ &\upsilon\frac{\partial^2 u}{\partial y^2} + g\beta_T\left(T - T_m\right) + g\beta_{1T}\left(T - T_m\right)^2 + g\beta_C\left(C - C_m\right) + g\beta_{1C}\left(C - C_m\right)^2 - \frac{\sigma B_0^2}{\rho}u \end{aligned} \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q_0\left(T - T_m\right)}{\rho C_p} \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} - k_0(C - C_m) \tag{4}$$

Furthermore, the comparing boundary conditions which are appropriate to the present issue are referenced as:

$$\left.\begin{array}{l} u=u_w, k\left(\dfrac{\partial T}{\partial y}\right)=\rho\left[\iota^{*}+c_s\left(T_m-T_0\right)\right]v, T=T_m, C=C_m \text{ at } y=0 \\ u\to 0, T\to T_\infty, C\to C_\infty \text{ as } y\to\infty \end{array}\right\} \tag{5}$$

The required transmutations to transmute the leading equations as (non-linear) ordinary differential equations are given underneath:

$$\left.\begin{array}{l} \varsigma=y\sqrt{\left(\dfrac{r+1}{2}\right)\dfrac{E}{\upsilon}}(x+q)^{r-1/2}, \\ u=E(x+q)^r f', v=-\sqrt{\left(\dfrac{r+1}{2}\right)E\upsilon}(x+q)^{r-1/2}\left[f(\varsigma)+\left(\dfrac{r-1}{r+1}\right)\varsigma f'(\varsigma)\right], \\ \theta(\varsigma)=\dfrac{T-T_m}{T_\infty-T_m}, \phi(\varsigma)=\dfrac{C-C_m}{C_\infty-C_m} \end{array}\right\} \tag{6}$$

By using (6), Eqs. (2 - 4) transmuted as the following equations:

$$\begin{array}{l} \left[1-\Upsilon\dfrac{r+1}{2}f^2\right]f'''-\Upsilon\left(\dfrac{2r(r-1)}{r+1}(f')^3-(r-1)\varsigma f''(f')^2-(3r-1)ff'f''\right)+ff''-\dfrac{2r}{r+1}f'^2 \\ +\dfrac{2}{r+1}\left[Gr\theta+Gr_1\theta^2+Gc\phi+Gc_1\phi^2-Mf'\right]=0 \end{array} \tag{7}$$

$$\theta''+\Pr\left[S\theta+f\theta'\right]=0 \tag{8}$$

$$\phi''+Sc\left(f\phi'-\frac{2}{r+1}Kr\phi\right)=0 \tag{9}$$

and the consequential boundary conditions are:

$$\left.\begin{array}{l} f'(0)=1, Me\theta'(0)+\Pr\left[f(0)+\dfrac{r-1}{r+1}\lambda\right]=0, \theta(0)=0, \phi(0)=0, \\ f'(\infty)=0, \theta(\infty)=1, \phi(\infty)=1 \end{array}\right\} \tag{10}$$

where $\lambda=\varepsilon\sqrt{(r+1)E/2\upsilon}$ is the wall thickness parameter. Here Υ, Gr, Gr_1, Gc, Gc_1, M, S, $\Pr$, Sc, Kr, Me are defined as follows:

$$\left.\begin{array}{l} \Upsilon=\lambda_0 E(x+q)^{r-1}, Gr=\dfrac{g\beta_T(T_\infty-T_m)(x+q)^3}{\upsilon^2\,\mathrm{Re}_x^2}, Gr_1=\dfrac{g\beta_{1T}(T_\infty-T_m)^2(x+q)^3}{\upsilon^2\,\mathrm{Re}_x^2}, \\ Gc=\dfrac{g\beta_C(C_\infty-C_m)(x+q)^3}{\upsilon^2\,\mathrm{Re}_x^2}, Gc_1=\dfrac{g\beta_{1C}(C_\infty-C_m)^2(x+q)^3}{\upsilon^2\,\mathrm{Re}_x^2}, M=\dfrac{\sigma B_0{}^2}{E\rho(x+q)^{r-1}}, S=\dfrac{Q_0}{\rho C_p(x+q)^{r-1}} \\ \Pr=\dfrac{\mu c_p}{k}, Sc=\dfrac{\upsilon}{D_m}, Kr=\dfrac{k_0}{E(x+q)^{r-1}}, Me=\dfrac{c_p(T_\infty-T_m)}{\left[\iota^{*}+c_s(T_m-T_0)\right]} \end{array}\right\} \tag{11}$$

The typical non-dimensionalization parameters of curiosity, skin friction coefficient Cf_x, the local Sherwood Sh_x and Nusselt number Nu_x are characterized as below:

$$\left.\begin{array}{l} Cf_x=(\mathrm{Re}_x)^{-0.5}\sqrt{\dfrac{r+1}{2}}f''(0), Nu_x=-(\mathrm{Re}_x)^{0.5}\sqrt{\dfrac{r+1}{2}}\theta'(0) \\ \mathrm{Sh}_x=-(\mathrm{Re}_x)^{0.5}\sqrt{\dfrac{r+1}{2}}\phi'(0) \end{array}\right\} \tag{12}$$

where Re_x is defined as $\mathrm{Re}_x=(x+q)\times u_w(x)/\upsilon$.

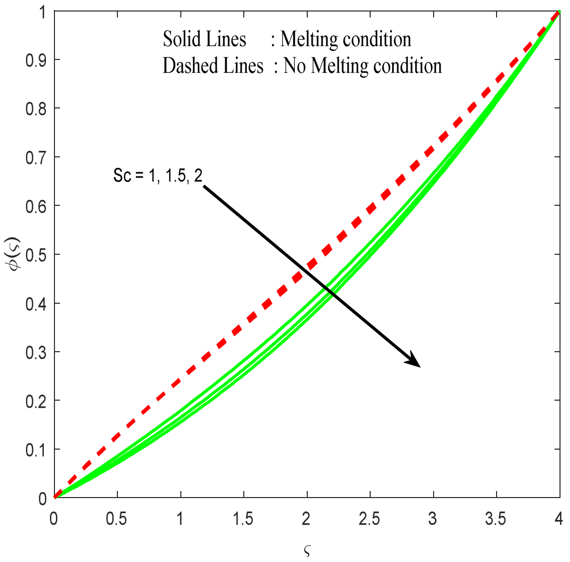

Fig. 2. Influence of Sc on $\phi(\varsigma)$

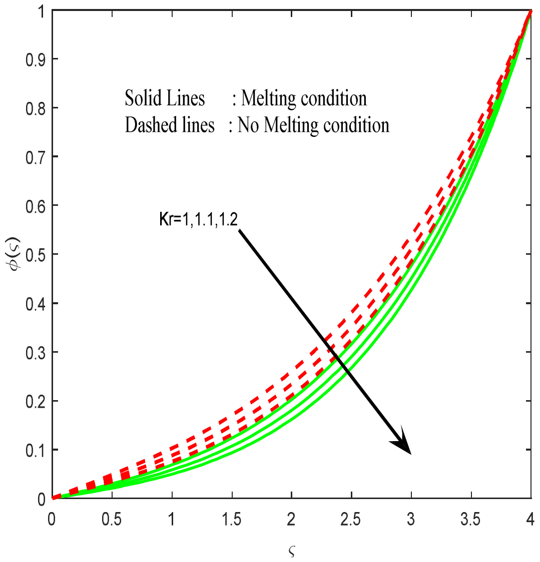

Fig. 3. Influence of Kr on $\phi(\varsigma)$

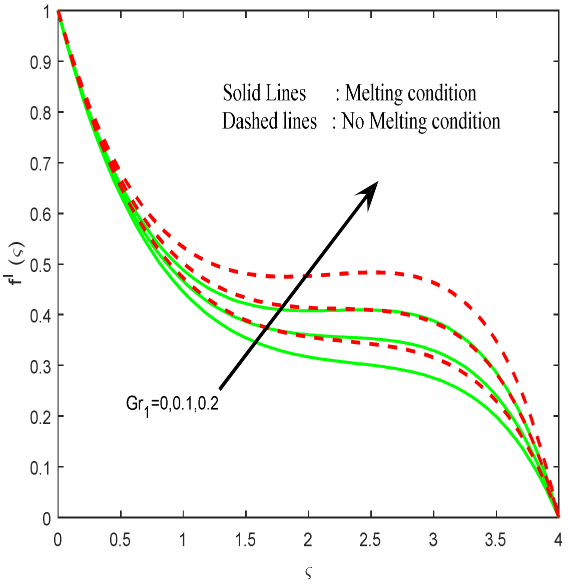

Fig. 4. Influence of Gr_1 on $f'(\varsigma)$

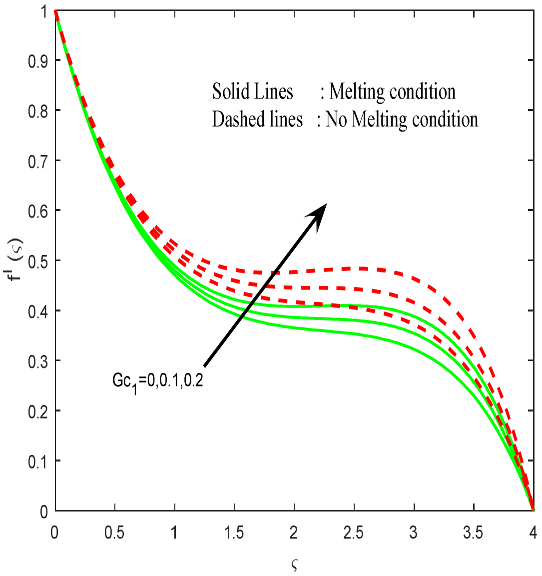

Fig. 5. Influence of Gc_1 on $f'(\varsigma)$

4. Numerical Procedure

The set of (nonlinear ordinary differential) Eqs. (7 - 9) with respect to the boundary conditions (10) are resolved numerically by applying the shooting procedure (R-K 4th order based).

5. Results and Discussion

The effects of non-dimensional parameters, for instance, Gr_1, Gc_1, S on common profiles (velocity, concentration, and temperature) are deliberated using plots and the effects of the similar parameters on the rate of transfers (mass, heat) and friction factor are conversed by means of a table. In this work, we analyse the outcomes in two cases i.e., presence and absence of melting parameter.

Figure 2 displays the influence of Sc (Schmidt number) on the concentration profile. Physically, Sc is the ratio of momentum to mass diffusivity. With the enhancement in Schmidt number, the mass diffusivity diminishes which is responsible for the weakening of concentration boundary layer thickness. So, the raise in Sc lowers the concentration. The effect of chemical reaction on the concentration profile is exhibited in Fig. 3. The concentration boundary layer becomes thin with the upsurge in the values of reaction. So, we can say that the rise in the values of chemical reaction lowers the concentration profile. The impact of Gr_1 and Gc_1 is visible in Figs. 4 and 5 respectively. It is known that convection parameters exert buoyancy forces and in turn, they intensify the momentum. We can observe this from these figures (both parameters boost the velocity profile).

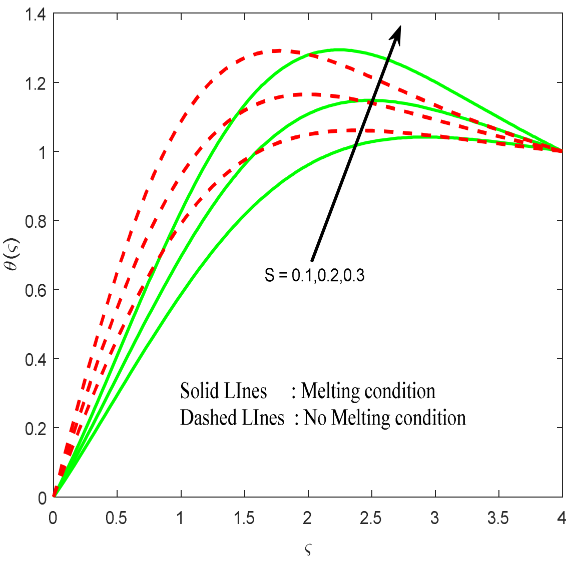

Fig. 6. Influence of S (as heat source) on $\theta(\varsigma)$

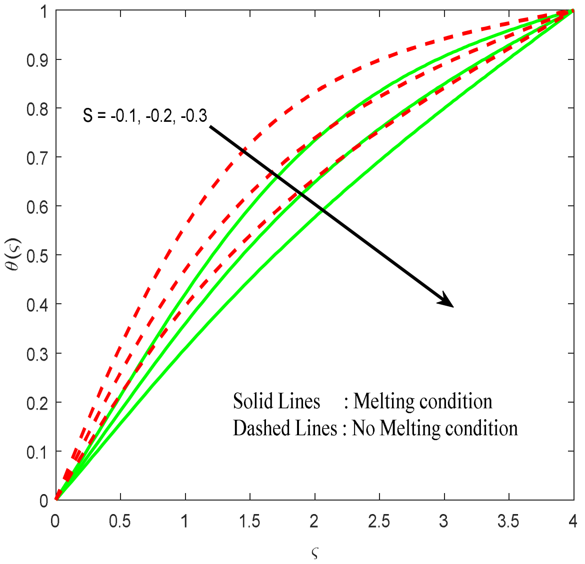

Fig. 7. Influence of S (as heat sink) on $\theta(\varsigma)$

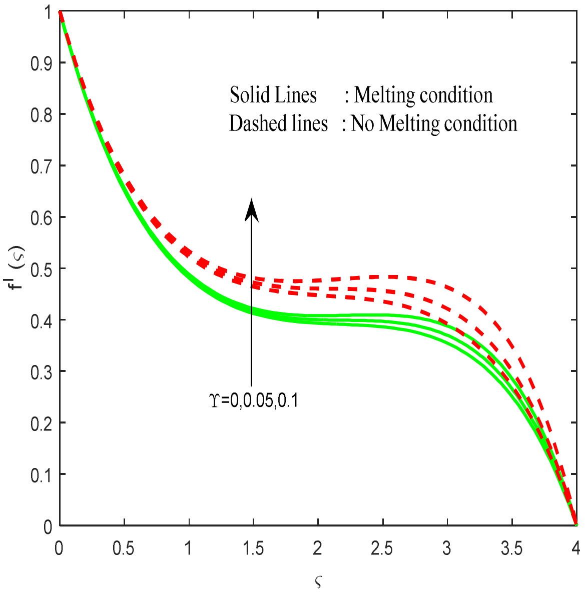

Fig. 8. Influence of Υ on $f'(\varsigma)$

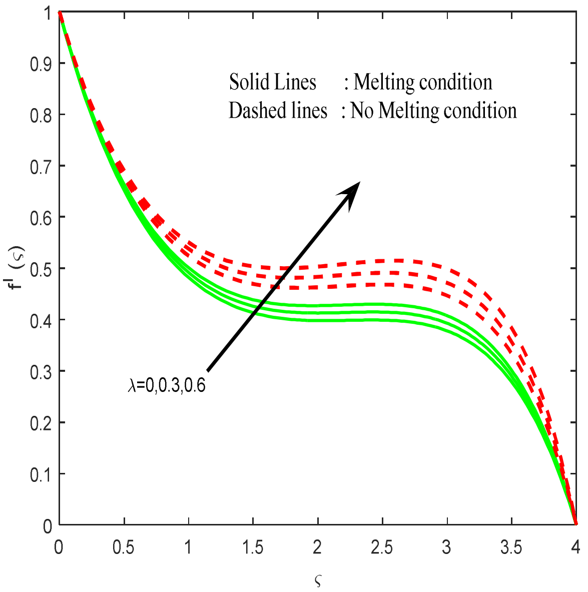

Fig. 9. Influence of λ on $f'(\varsigma)$

It is clear from Figs. 6 & 7, we can notice that as a heat source S upsurge the temperature but shows contrast behavior on the same profile when it is a heat sink. Usually, the occurrence of heat source parameters inside the flow field proliferates additional heat and this will offer support to the improvement of thermal boundary layer thickness. This upsurge in temperature delivers an intensification in the flow field because of buoyancy impact. The presence of a heat sink captivates energy which reasons a reduction in the fluid temperature. Note that $S>0$ indicates S is a heat source and $S<0$ indicates S is a heat sink. It is clear that Υ (elastic parameter) enhances the relaxation time of the fluid. So, when it rises, the thickness of the momentum boundary layer rises. As a consequence, velocity rises (Fig. 8). The influence of the wall thickness parameter is displayed on the regular three profiles (velocity, temperature) which can be seen in Figs. 9-10. Generally, increasing the wall thickness parameter acts as the slowdown factor for the velocity distribution. But Fig. 10 displays the quite opposite result which indicates that the wall thickness parameter exaggerates the momentum of the fluid. In a similar passion, Fig. 10 shows that the temperature is an increasing function of the same parameter. This may be due to the presence of other parameters discussed in this work.

Table 1 disclosed the influence of the relevant parameters on skin friction coefficient, transfer rates (mass, heat) in two circumstances i.e., melting condition and no melting condition. The results drawn in the case of presence of melting parameter are (a) Sc, Kr and S are worthwhile to improve the rate of mass transfer (b) Gr_1 and Gc_1 raise the skin friction coefficient (c) λ improves skin friction coefficient but lowers the transfer rates (d) Elastic parameter lowers the rate of heat transfer. The absence of the melting parameter exhibits that the parameters are taking precise behaviour as that of its presence.

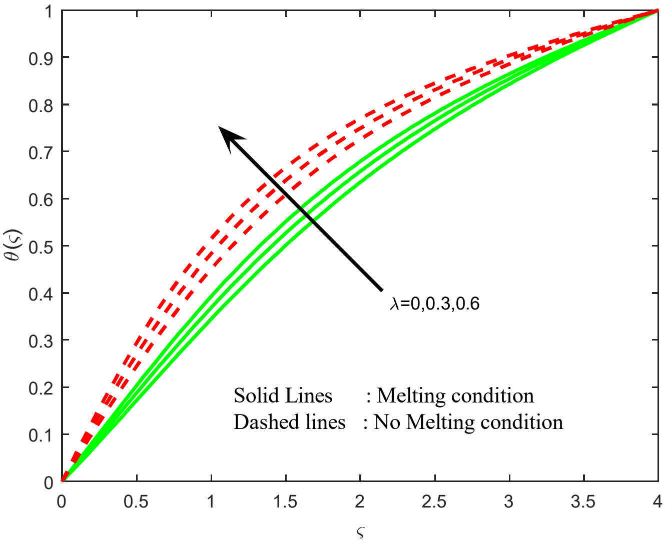

Fig. 10. Influence of λ on $\theta(\varsigma)$

Table 1. Magnitudes of skin friction coefficient, transfer rates (mass and heat) for various parameters in two cases i.e., presence and absence of melting parameter.

Sc	Kr	Gr_1	Gc_1	S	Υ	λ	Cf_x		Nu_x		Sh_x	
							$Me=0.2$	$Me=0$	$Me=0.2$	$Me=0$	$Me=0.2$	$Me=0$
1							-0.939595	-0.879409	-0.350791	-0.551837	-0.162291	-0.259623
1.5							-0.943372	-0.880058	-0.349796	-0.551433	-0.551433	-0.264781
2							-0.945811	-0.880459	-0.349168	-0.551170	-0.551170	-0.269953
	1						-1.390628	-1.318652	-0.488602	-0.764328	-0.764328	-0.138639
	1.1						-1.394962	-1.324702	-0.487169	-0.761492	-0.761492	-0.115738
	1.2						-1.398551	-1.329749	-0.485967	-0.759107	-0.053464	-0.097112
		0					-1.549721	-1.479948	-0.531891	-0.827454	-0.225957	-0.377008
		0.1					-1.520300	-1.437324	-0.542662	-0.849385	-0.234073	-0.394738
		0.2					-1.488375	-1.390942	-0.553921	-0.872239	-0.242793	-0.413741
			0				-1.512834	-1.428029	-0.544198	-0.851622	-0.235076	-0.396169
			0.1				-1.500964	-1.410140	-0.548965	-0.861698	-0.238802	-0.404656
			0.2				-1.488375	-1.390942	-0.553921	-0.872239	-0.242793	-0.413741
				0.1			-0.868538	-1.405652	-0.543944	-0.197255	-0.129815	-0.326267
				0.2			-0.828842	-1.423009	-0.629186	-0.126500	-0.122329	-0.319774
				0.3			-0.777476	-1.434054	-0.723960	-0.083714	-0.115681	-0.315438
					0		-1.361726	-1.295648	-0.497912	-0.779900	-0.216926	-0.365981
					0.05		-1.354936	-1.278112	-0.499661	-0.784432	-0.218305	-0.369868
					0.1		-1.347781	-1.259552	-0.501597	-0.789846	-0.219858	-0.374658
						0	-1.503200	-1.409622	-0.515149	-0.801277	-0.223380	-0.373969
						0.3	-1.481146	-1.381913	-0.573630	-0.908593	-0.252788	-0.434456
						0.6	-1.460177	-1.356079	-0.633965	-1.020981	-0.283899	-0.499888

Table 2. Comparison of the skin friction coefficient values when $\Upsilon = M = Gr = Gr_1 = Gc = Gc_1 = S = Sc = 0, r = 1$

Me	Bachok et al. [43]	Present values
1	1.0370034	1.037003
2	0.9468506	0.946851
3	0.8913811	0.891381

And also, the rate of heat transfer is high in melting surface conditions when compared to its absence. This result helps us to conclude that, for heating treatment, the melting surface is useful. Table 2 shows the comparison between the present results and the previous results (for the numerical values of the skin friction coefficient). We discovered a good agreement. This demonstrates the legitimacy of the present study.

6. Conclusions

Maxwell fluid is a subclass of rate kind fluids wherein stress relaxation is expectable and this fluid model is particularly beneficial for polymers of small molecular mass. By keeping these things in mind, the two-dimensional nonlinear convective Maxwell fluid flow across a slendering stretching sheet with heat source/sink and some other important parameters were analyzed. The shooting technique was employed to resolve the transmuted equations. Solutions in two cases i.e., presence and absence of melting parameter were provided. To capture the variations and inspect the common profiles (velocity, concentration, and temperature) against several parameters together with heat source/sink, plots were presented. And also, the physical values of friction factor, transfer rates (mass, heat) were displayed in the table for the same parameters. The vital remarks of this research are displayed as the following:

- The heat source parameter raises the temperature because it adds additional heat to the fluid flow and the heat sink parameter lowers the same because it absorbs heat from the fluid flow.
- The elastic parameter enhances the velocity and skin friction coefficient.
- The wall thickness parameter is useful to improve all three profiles (velocity, concentration, and temperature). As a consequence, it lowers both the transfer rates (mass and heat).
- Both nonlinear convection parameters (thermal and mass diffusion) enrich the velocity profile.
- The chemical reaction parameter lowers the thickness of the concentration boundary layer. That means, it lessens the concentration. As a consequence, it elevates the mass transfer rate.
- Sc (Schmidt number) is responsible for the weakening of the concentration boundary layer thickness. So, it lowers the concentration and elevates the transfer rate (mass).
- The rate of heat transfer is high in melting surface conditions when compared to its absence. This result helps us to conclude that, for heating treatment, the melting surface is useful.

Author Contributions

K. Jayarami Reddy planned the scheme, initiated the project and suggested the experiments; M. Jayachandra Babu conducted the experiments and analyzed the empirical results; M. Gayatri developed the mathematical modeling and examined the theory validation. The manuscript was written through the contribution of all authors. All authors discussed the results, reviewed and approved the final version of the manuscript.

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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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Data Availability Statements

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Nomenclature

B_0	Magnetic field strength $[T]$	C	Concentration of the fluid $[Kgm^{-2}]$
C_m	Concentration at the surface $[Kgm^{-2}]$	C_p	Specific heat capacitance $[JKgK^{-1}]$
C_s	Heat capacity of the fluid	C_∞	Concentration in free stream $[Kgm^{-2}]$
f	Dimensionless stream function	f'	Dimensionless velocity
g	Gravity field	Gc	Diffusion Grashof number
Gc_1	Nonlinear diffusion Grashof number	Gr	Thermal Grashof number
Gr_1	Nonlinear thermal Grashof number	k	Thermal conductivity $[Wm^{-1}K^{-1}]$
Kr	Non-dimensional chemical reaction parameter	k_0	Chemical reaction parameter
M	Non-dimensional magnetic field parameter	Me	Melting parameter
$\Pr$	Prandtl number	Q_0	Dimensional heat source/sink parameter
q	Parameter related to stretching sheet	Sc	Schmidt number
S	Dimensionless heat source/sink parameter	T_m	Temperature at the surface $[K]$

T	Temperature of the fluid $[K]$	T_∞	Temperature in free stream $[K]$
T_0	Temperature of the solid $[K]$	u, v	Velocity components in x, y directions $[ms^{-1}]$

Greek symbols

ρ	Density of the fluid $[Kgm^{-3}]$	σ	Electrical conductivity of the fluid $[m\Omega m^{-1}]$
Υ	Elastic parameter	υ	Kinematic viscosity $[m^2 s^{-1}]$
ι^*	Latent heat	θ	Non-dimensional temperature
ϕ	Non-dimensional concentration	λ_0	Relaxation time of the Maxwell fluid
ς	Similarity variable	β_C	Volumetric coefficient of the diffusion expansion
β_T	Volumetric coefficient of the thermal expansion		

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