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Heat Transfer and Stagnation-Point Flow of Non-Newtonian Casson Fluid over Stretching Surface

P. Suresh
M.Tech. Research Scholar
Department of Mathematics
Chaitanya Bharathi Institute of Technology
Hyderabad, (T. N.) [INDIA]
Email: Required

Hari Krishna
M.Tech Research Scholar
Department of Mathematics
Koneru Lakshmaiah Education Foundation
Guntur, (A. P.) [INDIA]
Email: Required

B. Mahaboob
M.Tech Research Scholar
Department of Mathematics
Koneru Lakshmaiah Education Foundation
Guntur, (A. P.) [INDIA]
Email: Required

M.Amarnath
M.Tech Research Scholar
Department of Mathematics
Chaitanya Bharathi Institute of Technology
Hyderabad, (T. N.) [INDIA]
Email: Required

P.V. Janardhana Reddy
M.Tech Research Scholar
Mahatma Gandhi Institute of Technology
Hyderabad, (T. N.) [INDIA]
Email: Required

ABSTRACT

This research paper focuses on the flow of a Casson fluid towards a stretching sheet in the stagnation point region and the characteristic properties of heat transfer with viscous dissipation. By applying proper similarity relations the partial differential equations governing the flow of the fluid and heat transfer are changed into ordinary differential equations and finally they are solved by using Runge-Kutta fourth order method along with the shooting technique. The flow is influenced by Eckert number (Ec), Prandtl number (Pr) and Casson parameter (β). In this paper interesting results have been proposed for Ec, Pr and β. It is observed that temperature increases with the increasing values of parameters Ec and. Moreover it is seen that the velocity and temperature decrease with the increasing values of β and Pr respectively.

Keywords:— *Casson Fluid; Heat Transfer; Eckert Number; Prandtl number.*

I. INTRODUCTION

The discourse of stagnation point flow and heat transfer of a Casson fluid towards a stretching sheet has many practical applications in the areas of technology and science and engineering. This phenomena place a major role in many technological branches namely such as geothermal system, nuclear reactor cooling, chemical industry, glass manufacturing, geophysics, paper production, and purification of crude oil etc. Krishnendu bhattacharya[1] in his paper discussed the 2-D MHD stagnation-point flow of electrically conducting non-Newtonian Casson fluid and heat transfer towards a stretching sheet and also investigated the effect of thermal radiation. Wubshet Ibrahim et al.[2] in their research article studied the influence of slip and convective boundary condition on MHD stagnation point flow and heat transfer due to Casson nanofluid past a stretching sheet. Samir Kumar Nandy [3] in his paper discovers the hydromagnetic boundary layer flow and heat transfer of a non-Newtonian Casson fluid in the nbd of a stagnation point on a stretched surface in the occurrence of velocity and thermal slips at the boundary. G. K. Ramesh et al [4] in their research article investigated the stagnation-point flow of an incompressible non-Newtonian fluid over a non-isothermal stretching sheet using Mathematical Analysis. Rashid Mehmood et al [5] in their research article inspected the combined influence of mixed convection and thermal radiation on non-aligned Casson fluid over a stretching surface. Moreover, a large number of important properties of Magneto-hydrodynamics flow on stretching sheet were depicted in articles [6-22].

Motivated by the previously mentioned investigations on the above study some innovative results are developed and they demonstrate the existence of similar solutions of the boundary layer equations per a class of general non-Newtonian fluids for a stretching sheet. The central equations are changed by applying similarity transformations. The changed ODEs are solved by using Runge-Kutta fourth order method along with Shooting Method. In order to examine the influence of parameters on the flow and heat transfer the appropriate numerical conclusions are described through diagrams.

II. Mathematical Formulation

the steady of 2-D flow of a Casson fluid near the stagnation-point on a heated stretching sheet matching with the plane y = 0, the flow being confined to y > 0, where y is the coordinate normal to the surface. Two equal and opposite forces are applied along the x-axis so that the surface is stretched keeping the origin fixed. It is assumed that the velocity distribution far from the surface is given by $u_e(x)=ax$ and $v_e(y)=-ay$, while the velocity of the stretching surface is $u_w(x)=cx$ where a and c are positive constants. It is also assumed that the temperature of the plate is Tw(x), while the uniform temperature of the ambient fluid is T_∞. We assume that the rheological equation of state for an isotropic and incompressible flow of a Casson fluid can be written as

$$\tau_{ij}=\begin{cases}2\left(\mu_B+Py/\sqrt{2\pi}\right)e_{ij},\pi<\pi_c,\\2\left(\mu_B+Py/\sqrt{2\pi}\right)e_{ij},\pi>\pi_c,\end{cases}\tag{1}$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0,\tag{2}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+u_e\frac{du_e}{dx}\tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\nu}{C_P}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2+\alpha\frac{\partial^2 T}{\partial y^2}\tag{4}$$

$$\begin{aligned}&u=u_w(x)=cx,\ v=0,T=T_w(x)=T_\infty+bx^2\ at\ y=0,\\&u\to u_e(x)ax,T\to T_\infty \qquad as\ y\to\infty,\end{aligned}\tag{5}$$

where b = a positive constant,

$\beta=\mu_B\sqrt{2\pi_c}/Py$ is the non-Newtonian (Casson) parameter, α = the thermal diffusivity, ν = the kinematic viscosity, and C_p= the specific heat.

We introduce the following similarity variables:

$$\psi=x\sqrt{c\nu}f(\eta),\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\eta=\sqrt{\frac{c}{\nu}}y,\tag{6}$$

where y is the stream function which is defined in the usual way as $u = \frac{\partial \psi}{\partial y}$ and $v = \frac{\partial \psi}{\partial x}$ Substituting (6) into (3) and (4), the set of ordinary differential equations results in

$$(1+1/\beta) f''' + ff'' - f'^2 + \frac{a^2}{c^2} = 0, \quad (7)$$

$$\theta'' + \Pr\left(f\theta' - 2f'\theta + \left(1+\frac{1}{\beta}\right) Ecf''^2 \right) = 0, \quad (8)$$

and the boundary conditions in (5) become

$$f(0)=0,\ f'(0)=1,\ \theta(0)=1,$$
$$f'(\infty) \to \frac{a}{c}, \quad \theta(\infty) \to 0. \quad (9)$$

Here $\Pr = \nu/\alpha$ is the Prandtl number, $Ec = u_w^2 \left[C_p (T_w - T_\infty) \right]$ is the constant Eckert number, and the prime denotes differentiation with respect to η It is worth mentioning that for a regular viscous fluid $(\beta \to \infty)$,

The physical quantities of interest are the skin friction coefficient C_f and the local Nusselt number NU_x, which are defined as

$$C_f = \frac{\tau_w}{\rho u_w^2(x)}, Nu_x = \frac{xqw}{k(T_w - T_\infty)}, \quad (10)$$

where τ_w is the skin friction or shear stress along the stretching surface and q_w is the heat flux from the surface, which are given by

$$\tau_w = \left(\mu_\beta + \frac{p_y}{\sqrt{2\pi_c}} \right) \left(\frac{\partial u}{\partial y} \right)_{y=0}$$
$$q_w = -k \left(\frac{\partial T}{\partial y} \right)_{y=0} \quad (11)$$

Using (6), we get

$$\mathrm{Re}_x^{1/2} C_f = (1+1/\beta) f''(0),$$
$$Nu_x / \mathrm{Re}_x^{1/2} = -\theta(0), \quad (12)$$

where $\mathrm{Re}_x = u_w(x) x / v$ is the local Reynolds number.

Method of solving the problem:

The pair of non-linear governing boundary layer equations (7) and (8) with (9) have been solved by applying Runge-Kutta fourth order method along with the shooting method. At first the higher order non-linear differential equations are (7) and (8) transformed into simultaneous linear differential equation of first order and they are converted into IVP by using shooting technique and then the IVP is solved by executing the Runge-Kutta fourth order method.

III. Results and Discussion

The analytical solution of the problem Stagnation-Point Flow and Heat Transfer of a Casson Fluid towards Stretching Sheet. The analytical solutions are solved numerically for different parameters are involved in the problem. Numerical calculations for non- dimensional velocity and temperature with different values of physical parameter such as Casson parameter, Eckert number and Prandtl number. In this present study we adopted the following default parametric values: $B = 0.5;\ Pr = 0.71;\ E = 1;\ a / c = 0.2$

Figure 1 depicts the influence of Casson parameter b on the velocity field. Owing to the boundary layer thickness for fixed value of a/c(=0:2), if Casson parameter increases then velocity decreases. While compared with the viscous fluid it is evident that the magnitude of velocity is greater in the case of the Casson fluid. The effect of Casson parameter on temperature is given in Figure 2 in which it is described that temperature is significantly increasing with increased values of Casson parameter. Figure 3 shows that results come out of an increasement in the Prandtl number (*Pr*). It is also evident from concept of Prandtl number (*Pr*) that a speed increment in Pr reduces the thermal conductivity so that there will be decrement in temperature and the thermal boundary layer thickness. Moreover it can be observed that the temperature profiles give a significant increment for minute values of Pr. Figure 4 illustrates that increment in Eckert number (*Ec*) leads to the same in the temperature field.

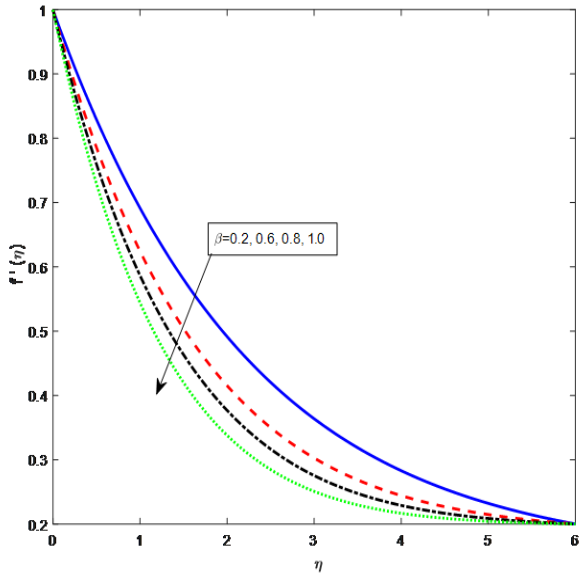

Figure 1: Velocity profiles for distinct values of Casson parameter (β)

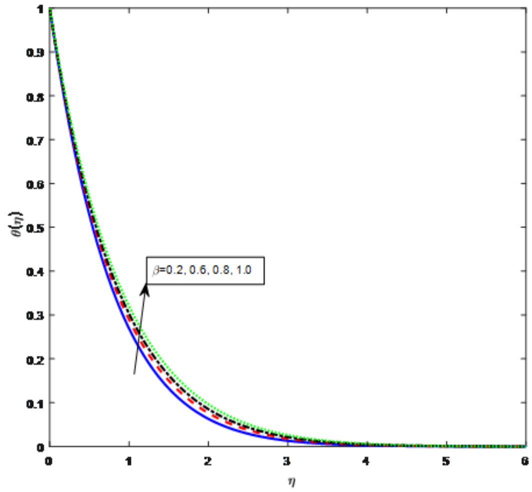

Figure 2: Temperature profiles for distinct values of Casson parameter (β)

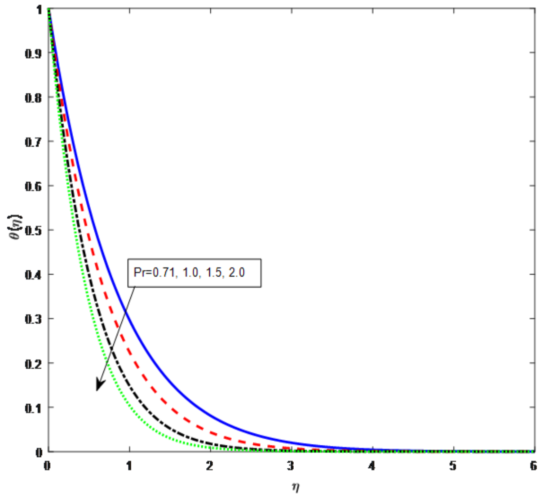

Figure 3: Temperature profiles for distinct values of Prandtl Number (Pr)

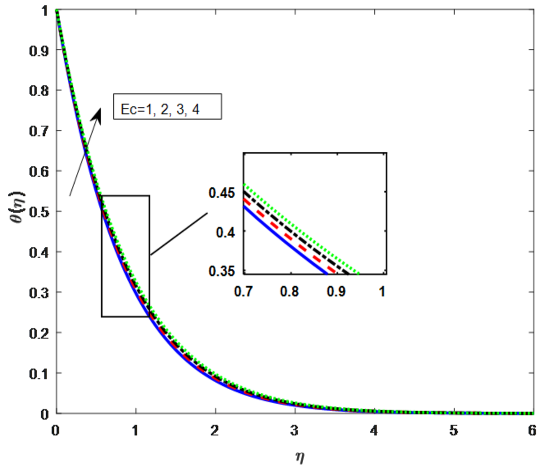

Figure 4: Temperature profiles for distinct values of Eckert Number (Ec)

Table 1: Values of $f''(0)$ and $-\theta'(0)$ for Distinct Values of $\beta, a/c, \Pr$ and Ec

(β)	a/c	Pr	Ec	$f''(0)$	$-\theta'(0)$
1	0.2	0.71	1	-0.379018	1.127343
2	0.2	0.71	1	-0.491987	1.170840
3	0.2	0.71	1	-0.562783	1.201286
4	0.2	0.71	1	-0.649402	1.242170
0.5	0.2	**0.71**	1		1.185083
0.5	0.2	**1**	1		1.426950
0.5	0.2	**2**	1		1.771978
0.5	0.2	**3**	1		2.062471
0.5	0.2	0.71	**1**		1.094745
0.5	0.2	0.71	**2**		1.124858
0.5	0.2	0.71	**3**		1.154971
0.5	0.2	0.71	**4**		1.185083

Table 1 shows that increasing values of (β) as velocity and temperature increases. Pr and Ec are increases as temperature increased.

IV. CONCLUSION

The flow and heat transfer of a Casson fluid is examined around a stagnation-point on a stretching surface. The central equations are changed into self- similar ODEs by applying similar transforms and further their solutions have been derived by applying Runge-Kutta fourth order along with Shooting Method. From the study, the following remarks can be summarized.

The important points of this discourse are:

The influence of Casson parameter (β) and Eckert number (Ec) on temperature is such that temperature is significantly increasing with increased values of (Ec) and (β).

The effects of Casson parameter (β) and Prandtl number (Pr) on velocity and temperature respectively are such that they are decreasing significantly with increased values of Casson parameter (β) and Prandtl number (Pr).

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