Stagnation Point Flow through a Porous Medium towards Stretching Surface in the Presence of Heat Generation

B. Shankar Goud, G. Narender, E. Ranjit Kumar

Abstract*: In this work, the permeable system of a viscous fluid which impacts a porous stretching surface by heat generation, an investigation has been conducted on a steady laminar flow. Governing equations are converted into nonlinear ordinary differential equations by using the similarities and the solutions are obtained by using the shooting technique. The influences of the dimensionless parameters on the momentum and energy equations. Impacts on together flow and heat transfer from porosity, stretching of the medium of the velocity of the surface and heat generation /absorption factor are exhibited through graphs and deliberated.

***Keywords*: Porous medium, Stagnation point flow, shooting method, Heat transfer, Heat generation.**

I. INTRODUCTION

Boundary layer flow and heat transfer of an incompressible, viscous fluid across an extending surface are assuming a critical job in various domains of the industrial manufacturing process and several engineering. Its various uses are fundamental for development in the metallurgy and chemical engineering field, for example, paper production, glass fiber, hot rolling, cooling of metal, drawing plastic films and numerous others. The ideal quality and parameters of conclusive items rely on the stretching surface upon the rate of heat transfer. Rao et. al [1] studied Heat absorption, chemical reaction impacts on the unsteady MHD flow, an embedded vertical plate into the porous medium; and a similar study was analyzed by BSGoud [5]. Hall effect, chemical reaction effects on hydromagnetic flow vertical surface with internal heat generation/absorption was deliberated by Salem et al [2], Abdul Aziz [3] and Shankar Goud[6]. Shokouhmand et.al [11] studied the similarity solution on a flat plate with convective boundary conditions for the thermal boundary layer of a laminar flow. The effect of radiation on MHD flow near a stagnation point of a nanofluid over an exponentially stretching sheet was analyzed by Anwar et.al [4]. Bhattacharyya et.al [7] examined the slip condition effects on boundary layer flow, an exponentially stretching sheet with thermal radiation was studied by Biliana Bidin and Roslinda Nazar[8]. Pal and Talukdar[9] looked into on combined effects of Joule heating and chemical reaction on unsteady MHD mixed convection dissipating flow over a vertical with thermal radiation. B. S Goud et.al[10] analyzed the radiation effect on a porous plate with dissipative fluid in a parallel channel. Stagnation point flow analysis to a stretching sheet was studied by Paullet and Weidman [12]. Suction and blowing effect of heat and mass transfer through an accelerating surface have investigated by Bhattacharya et.al [13], and Acharya et.al [14] and suction/injection effects are initiated by Kandasamy et.al [16]. Makinde et.al [15] studied heat transfer to a nanofluid with buoyancy effects on a stagnating point flow of MHD convectively heated stretching/shrinking sheet and the stretching sheet exponentially was analyzed by Bal Reddy et.al [17]. Anjali Devi and Kandasamy[18] taking the semi-infinite horizontal plate heat and mass transfer in laminar flow with chemical reaction effect and some other researchers are considered on MHD flow with various effects are presented viz, Shateyi[19], Sajid et.al[21],Mahapatra et.al[23] Jena et.al[20], Tripathy et.al[24], and Santosh et,al[22].

The purpose of this work is to study in a permeable medium of an electrically conducting viscous, laminar fluid flow with heat generation towards a stagnation point. The governing equations changed to nonlinear ODEs are answered by shooting technique. Graphs display the impact of the dimensionless parameter on flow characteristics.

II. PROCEDURE FOR PAPER SUBMISSION

Take into account the steady 2-D stagnation point flow in a permeable mechanism of an incompressible and viscous fluid close to stagnation point of the plane compatible with the level $y = 0$, The flow is on the surface at $y > 0$, When space is loaded with the permeable medium over the plane sheet as shown in Figure 1.

The x-axis is connected along with two equivalent opposing forces, which extend the surface, holding the origin stable. The potential flow from the y-axis impinges on a level wall at y = 0, splits into two wall flows, and leaves in either direction. The viscous flow must hold fast to the wall, though the potential flow slides along it. Everywhere (x, y), the velocity potential flows are (u, v).

Here $U(x) = ax$ $\&V(y) = -ay$ give the frictionless flow velocity profiles in the stagnation point area and where $a(>0)$ constant is proportional to the velocity of the stream far from the surface which is stretching.

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***** Correspondence Author

B. Shankar Goud*,Department of mathematics, JNTUH College of Engineering,Kukatpally,Hyderabad,India.Email:bsgoud.mtech@gmail.com

G.Narender, Department of H&S(Mathematics), CVR College of Engineering,Hyderabad, Telangana State, India.Email:gnriimc@gmail.com.

E. Ranjit Kumar, Department of Mathematics, Kakatiya Institute of Technology and Science, Warangal, Telangana.

The governing equations of the present study are:

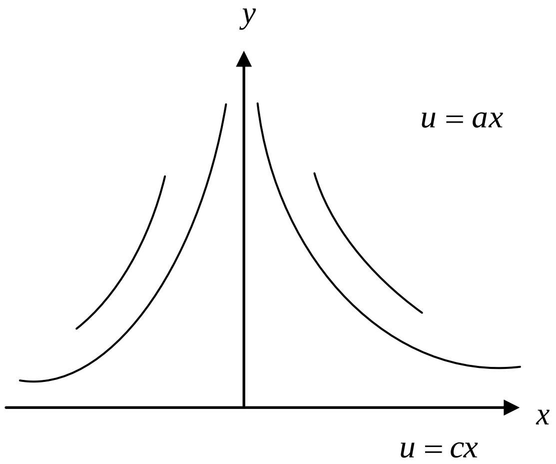

Fig.1: Schematic diagram of present flow.

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

Momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+U\frac{\partial U}{\partial x}+\frac{\upsilon}{K}\left[U(x)-u\right] \quad (2)$$

Energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{Q}{\rho C_p}\left[T-T_\infty\right] \quad (3)$$

The proper boundary conditions are given by

$$\begin{aligned} &u=u_w(x)=cx \quad v=0 \quad T=T_w \quad at\ y\to 0 \\ &u\to ax, \quad T\to T_\infty, \quad as\ y\to\infty \end{aligned} \quad (4)$$

Where c is a positive constant.

Imposing the stream functions $u=\frac{\partial\psi}{\partial y}$, $v=-\frac{\partial\psi}{\partial x}$ eqn(1) satisfies with using the similarity transformations $\psi=\sqrt{c\upsilon}xf(\eta)$ $u(x,y)=cxf'(\eta)$ $v(x,y)=-\sqrt{c\upsilon}f(\eta)$ $\eta=y\sqrt{\left(c/\upsilon\right)}$, and by bringing in the dimensionless variable $T=T_\infty+\left(T_w-T_\infty\right)\theta(\eta)$. Employing the above terms, eqns. (2) - (4) abbreviate to the following formula:

$$f'''+ff''-\left(f'\right)^2+M(s-f')+s^2=0 \quad (5)$$

$$\left(1+\frac{4}{3}K\right)\theta''+\Pr\left(f\theta'-f'\theta\right)+Ec\left(f''\right)^2=0 \quad (6)$$

The proper boundary conditions become as follows:

$$\left.\begin{aligned} f&=0,\\ f'&=1,\\ \theta&=1,\end{aligned}\right\} \ at\ \eta\to 0, \quad \left.\begin{aligned} f'&\to s,\\ \theta&\to 0,\end{aligned}\right\} \ as\ \ \eta\to\infty \quad (7)$$

Where prime signifies diff. with resp. to. η .

Where $\Pr(\text{Prandtl number})=\frac{\mu C_p}{k}$

$M(\text{Porosity parameter})=\frac{\upsilon}{cK}$

$s(\text{Stretching parameter})=\frac{a}{c}$,

,,

$B(\text{Heat generation/absorption coefficient})=\frac{Q}{C_p\rho c}$

III. SOLUTION OF THE PROBLEM

The numerical explanation in nonlinear DEs of the mathematical system (5) and the boundary conditions (7). In the present section, the shooting technique has been proposed to reproduce the same solution. The Adams-Bash forth Moulton Method of order four and Newton's technique for solving the non-linear algebraic equations, are the main components of the shooting method. Let us rewrite eqns(5) as

$$f'''=\left(f'\right)^2-ff'-M(s-f')-s^2 \quad (8)$$

To have a system of first-order ODEs, use the notations:

$$f=f_1,\ f'=f_2,\ f''=f_3,\ f'''=f_3' \quad (9)$$

By using the notations (9), we have the following IVP:

$$f_1'=f_2 \qquad f_1(0)=0 \quad (10)$$

$$f_2'=f_3, \qquad f_2(0)=1 \quad (11)$$

$$f_3'=M(f_2-s)-f_1f_3+\left(f_2\right)^2-s^2,\ f_3(0)=r \quad (12)$$

For the computational purpose, the unbounded domain $[0,\ \eta_\infty]$ has been replaced by the bounded area $[0,\ \eta_e]$, where η_e there are some appropriate finite values. It is chosen in such a way that the solutions of the problem start looking settled for $\eta>\eta_\infty$. In Eqs. (10-12) the missing initial condition r to be selected such that $f_2(\eta_\infty,r)-s=0$ (13)

To start the iterative process, choose $r=r_0$. To update the values of s and t, Newton's iterative scheme has been used $r_{n+1}=r_n-\frac{f_2(\eta_\infty,r)-s}{\frac{df_2}{dr}}$. (14)

Next, the IVP in the first-order ODEs given in (10-12) is solved by the Adams-Bash forth Moulton Method. After finding, $f(\eta)$ we solved the equation (6) with initial conditions.

To use the shooting method, first, we convert this Eq. (6) into a set of first-order ODEs. For these uses, we denote θ,θ' by f_4, f_5.

$$f_4'=f_5 \quad (15)$$

$$f_5'=-\Pr(f_1f_5+Bf_4) \quad (16)$$

Make the boundary conditions into forms as

$$f_4(0)=0,\ f_5(0)=p, \quad (17)$$

In the modeled problem, p is the initial guess which is essential to solving the above first-order system of ODEs. The iterative technique continues until the following standards are met. $\max(|f_1(\eta_\infty)|) < \varepsilon$ where $\varepsilon = 10^{-5}$ is the permissiveness. The boundary was steady to 10^{-5}. The decision $\eta_\infty = 6$ is taken in this methodology guarantees that for each numerical results method asymptotic characteristics exactly. For changed estimations of the nondimensional parameters of the numerical estimations of $f''(0)$ and $\theta'(0)$ are displayed in table 1-2.

IV. RESULT AND DISCUSSION

The velocity profiles of 'f' and 'f'' appear in figures 2 and 3, for different estimations of 's' and M. These figures demonstrate that the impacts of M depend on 's' both 'f' and 'f'' increases when the parameter 's' increases. For smaller values of 's' $(s < 1)$ expanding M rises velocity curves, while for larger estimates of 's' $(s > 1)$ expanding M diminishes them. These figures also show that for smaller estimates of ' M ' the impact of 's' on 'f' and 'f'' is increasingly marked. Additionally, the thickness of the boundary layer diminishes while expanding 's'. For fixed values of $\Pr = 0.7$ & $B = 0.1$, figure 4 introduces temperature curves for various estimations of 's' & 'M' and. Expanding s diminishes θ and its impact on θ turns out to be progressively evident for smaller estimations of 'M'. It demonstrates that the thickness of the thermal boundary layer diminishes when s it increases. Expanding M diminishes temperature for set values of 's' and for lower 's' its effect is stronger.

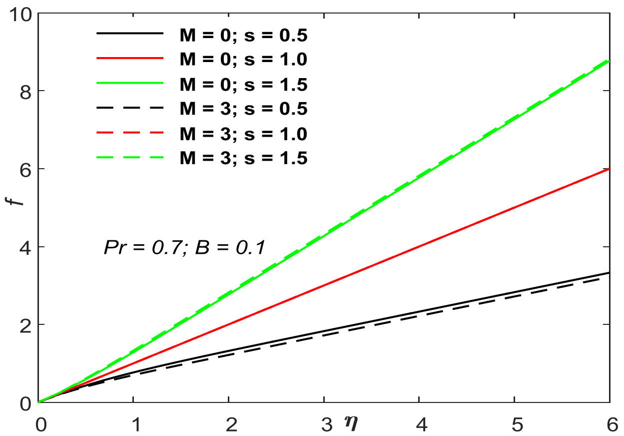

Fig. 2. Variations of the factors *(M, s)* on the f profile.

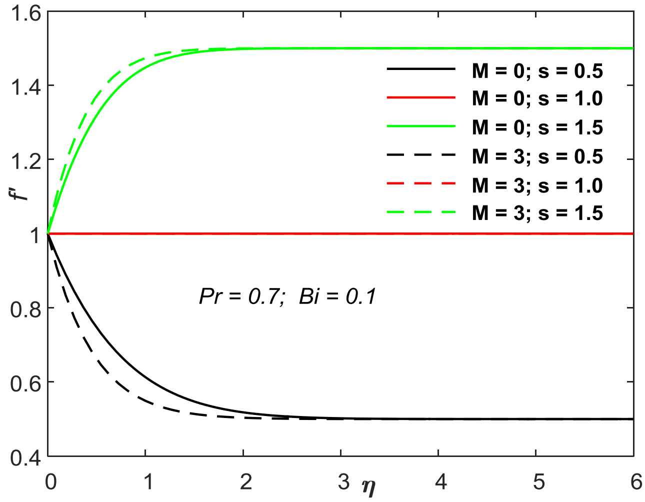

Fig. 3. Variations of the factors *(M, s)* on the f' profile,

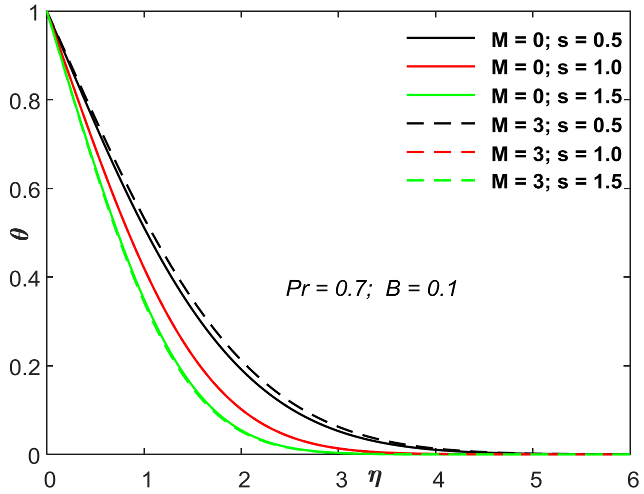

Fig. 4. Variations of the factors *(M, s)* on the temperature profile.

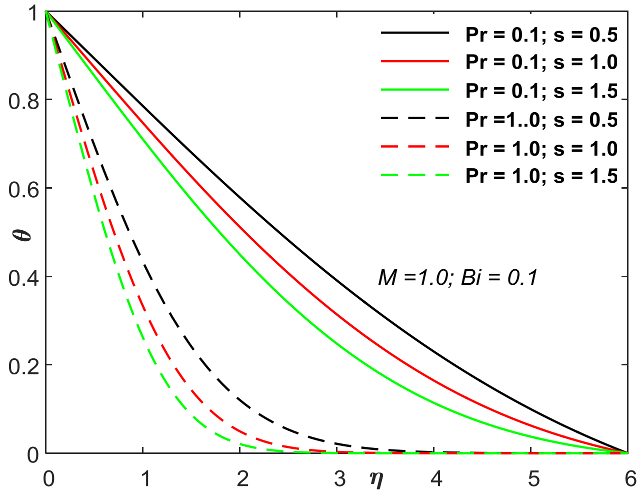

Fig. 5. Variations of the factors *(M, s)* on the θ profile.

Figure 5 shows the temperature curves for different estimations of 's' and Pr for $M=1$&$B=0.1$. This figure shows the influence of the Pr on the width of the thermal boundary layer.

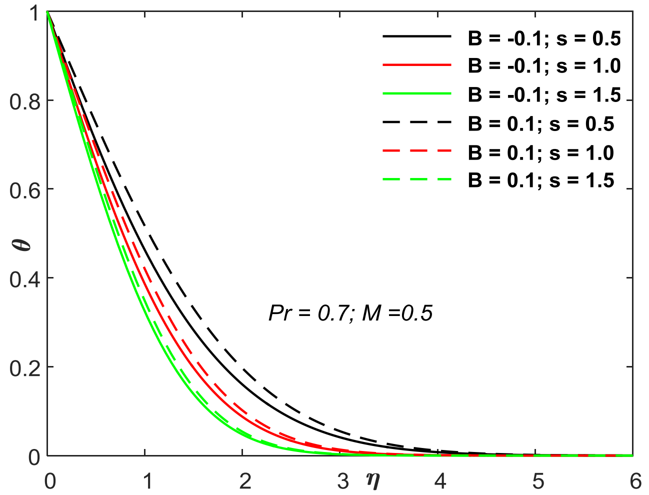

Fig. 6. Variations of the parameters *(M, s)* on the θ profile.

For entire values of $'s'$ expanding Pr diminishes the thermal boundary layer thickness. Temperature diminishes while increasing $'s'$ and its impact is progressively obvious for the minor Pr. Figure 6 displays the temperature distribution for altered estimates of $'s'$ B and. The temperature rises with the increase in B and the boundary layer width. The impact of B temperature is increasingly expressed for the minor. The numerical calculations of nondimensional heat transfer rate and shear stress at the wall for a fixed Pr and B are presented in Tables 1 and 2 values M. For smaller M, shear stress at the For different estimates of $'s'$ and M the wall shear stress increments with an increase of $'s'$ for entire wall falls with an increase in M however enhancing M more builds it and is important to observe the inversion of the indication of $f''(0)$ for all M for $s<1$. Table 2 demonstrates that for all M, an increasing $'s'$ or M the result increments in $-\theta'(0)$. values $'s'$. In any case, the impact of $'s'$ temperature curves is progressively obvious for greater B

The impact of s $f''(0)$ on and $-\theta'(0)$ is progressively evident for smaller values of M. For $s<1$, heat transfer rate increases with an increase of M; be that as it may, for $s<1$, rate of heat transfer falls with enhancing of M. Table 3 introduce the influence of s $-\theta'(0)$ on, for different estimations of Pr for fixed M & B. With an increase of $'s'$ there is an increment $-\theta'(0)$ for entire Pr and its outcome is progressively expressed for higher Pr. Heat transfer rate $-\theta'(0)$ enhances with an increase in Pr for whole values of $'s'$ and its effect is increasingly evident for higher values of $'s'$ the influence of the parameters s B and on heat transfer rate ,for fixed M & Pr as shown in Table 4. For all values of B, increasing $'s'$ raises $-\theta'(0)$, yet expanding B diminishes $-\theta'(0)$, for all $'s'$.

Table 1 Fixed $\Pr = 0.7; B = 0.0$ **the variation in skin friction** $f''(0)$

M	s = 0.1	s = 0.2	s = 0.5	s = 1.0	s = 1.1	s = 1.2	s = 1.5
0	-0.96944	-0.9181	-0.66726	0	0.16429	0.337739	0.90953
1	-1.32111	-1.2156	-0.83213	0	0.192014	0.391892	1.03644
2	-1.59812	-1.4546	-0.97010	0	0.216321	0.439629	1.14987
3	-1.83394	-1.6598	-1.09102	0	0.238212	0.482768	1.2533

Table 2 Fixed $\Pr = 0.7; B = 0.0$ **the variation in** $-\theta'(0)$

M	s = 0.1	s = 0.2	s = 0.5	s = 1.0	s = 1.1	s = 1.2	s = 1.5
0	0.481521	0.50322	0.56914	0.667559	0.685631	0.703251	0.753695
1	0.440061	0.4739	0.55834	0.667558	0.68673	0.705267	0.757695
2	0.414573	0.45509	0.55078	0.667558	0.687577	0.706838	0.760901
3	0.396855	0.44165	0.54508	0.667559	0.688259	0.708115	0.763559

Table 3 Fixed $M = 1.0; B = 0.0$ **the variation in** $-\theta'(0)$

Pr	s = 0.1	s = 0.2	s = 0.5	s = 1.0	s = 1.1	s = 1.2	s = 1.5
0.05	0.184100	0.187412	0.198132	0.217500	0.221499	0.225523	0.237695
0.1	0.202232	0.208942	0.230379	0.267786	0.275271	0.282717	0.304715
0.5	0.360501	0.389162	0.464647	0.564202	0.581574	0.598336	0.645568
1	0.552417	0.589207	0.679290	0.797885	0.818975	0.83943	0.897551

Table 4	Fixed $M = 0.5; \Pr = 0.7$ the variation in Nusselt number - $\theta'(0)$						
B	s = 0.1	s = 0.2	s = 0.5	s = 1.0	s = 1.1	s = 1.2	s = 1.5
-0.01	0.465890	0.493946	0.568995	0.672174	0.690678	0.708644	0.759777
0	0.457877	0.486692	0.563190	0.667558	0.686220	0.704329	0.755816
0.1	0.369285	0.408119	0.502339	0.620096	0.640475	0.660122	0.715409

V. CONCLUSION

The 2-D stagnation point flow is analyzed with heat generation/absorption in the porous medium of viscous incompressible fluid imposed on a permeable stretching surface. The calculation of flow and heat transmission assets for various nondimensional parameter estimates is obtained through numerical consequences for the governing equations. The outcomes present study is as follow:

- The boundary layer thickness diminishes while increasing the stretching sheet velocity increases.
- Then again, through increasing extending velocity, both temperature and decreases the thermal boundary layer thickness. For smaller estimates of the porosity parameter, the impact of the stretching factor on the velocity and temperature is progressive.
- The velocity factors depend on the size of the stretching velocity just as heat transfer rates at walls with porosity parameters. The indication of the wall shear stress seemed to rely upon the extended velocity. The impact on the heat transfer rate on the wall of generation/absorption parameter ' B ' is more and more apparent in smaller's '.

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AUTHORS PROFILE

Dr.B. Shankar Goud has received a Ph.D. degree from JNTU Hyderabad and presently working as an Assistant Professor, Department of Mathematics, JNTUniversity Hyderabad College of Engineering Hyderabad, India. he has 10 years of wide experience in teaching various disciplines like B. Tech, M.Sc, M.Tech, etc. He published twenty-four research papers and presented four papers international and four papers national conferences. His interested areas are computational fluid dynamics, heat & mass transfer, nanofluids, etc.

Mr.G. Narender is pursuing a Ph.D. in Flow and Heat transfer of Nanofluid on Boundary Layer (Registered in 2008), JNT University Hyderabad. From 2014 to till date he is working as Assistant Professor in the Department of Humanities & Sciences (Mathematics), CVR College of Engineering, Vasthunagar, Mangalpalli (V), Ibrahimpatnam (M), Rangareddy (Dist.)-501510, Telangana State, India. He has published more than 9 journals in peer-reviewed journals. His research has also been presented at over 7 conferences. He is currently engaged in different non-Newtonian, Casson, Maxwell fluids over different curved bodies.

Dr. E. Ranjit Kumar has received Ph.D. degree from Rayalaseema University, Kurnool, Andhra Pradesh, India and presently working as an Assistant Professor in the Department of Mathematics, Kakatiya Institute of Technology and Sciences, Warangal. He has a total of 20 years of teaching experience in various disciplines such as B.Tech.,B.Pharm. His research areas are computational fluid dynamics, heat and mass transfer.