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Transpiration effects on stagnation flow towards a stretching sheet with induced magnetic field

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Abstract
In this study, we analyzed the effect of suction/injection on stagnation-point flow towards a stretching sheet with heat source/sink and induced magnetic field. The nonlinear partial differential equations are transformed into a set of nonlinear ordinary differential equations using self-suitable transformations, which are then solved numerically using bvp4c Matlab package. The effects of various physical parameters like magnetic field parameter B, heat source/sink parameter Q_H and stretching ratio a/c etc. on velocity, induced magnetic field and temperature profiles are presented and discussed with the help of graphs. It is found that rising values of heat source/sink parameter declines the temperature filed.
Key words: Induced magnetic field, suction/injection, heat source/sink, stretching sheet.

1. Introduction

The study of stagnation flow towards a stretching sheet has gained much interest in recent days, due to its wonderful industrial application like metallurgy, extrusion of plastic sheets, spinning of fibers, cooling of elastic sheets, polymer processing and chemical engineering plants. Hiemenz (1911) discussed the flow in the neighbourhood of a stagnation point in a plane. Initially, the flow of stagnation point was studied by Pai (1956). Later, the flow over a stretching sheet and obtaining similarity solution in closed analytical form was investigated by Crane (1970). Chen et al.(1990) studied the non-newtonian flow of a temperature field over a stretching plate. The electrical conducting fluid on a heat transfer over a stretching surface was explained by Vajravelu and Rollins (1992).

The hydromagnetic flow on heat and mass transfer of a visco-elastic fluid over a stretching sheet was analysed by Char (1988). The MHD non-Newtonian fluid over a stretching sheet with internal heat absorption/generation was explained by Prasad et al. (2009). The effects of heat source/sink and variable thermal conductivity of a viscous fluid in the presence of magnetic field over stretching sheet was analysed by Sharma and Singh (2009) and conclude that increasing the value of Hartmann number and decreases the velocity profile. The effects of radiation on the boundary flow of a nanofluid over a permeable stretching sheet was analysed by Murshed et al. (2015). Aziz (2015) investigated the variable surface heat flux and non-uniform heat source/sink in a stagnation point flow towards a stretching heat and thereby concluding the increased velocity ratio and magnetics field parameters. Rosca and Pop (2014) discussed the Eyring Powell fluid on a heat transfer in a parallel free stream over a shrinking surface. The effect of magnetic field and radiation on an unsteady mixed convection flow with suction/injection over a stretching/shrinking surface was analysed by Sandeep et al. (2015).

The homogeneous-heterogeneous reaction and magnetic field effects on stagnation flow of a Casson fluid have been explained by Raju et al. (2015) and found that increasing the value of non-uniform heat source/sink parameter enhances the temperature profiles. The researchers (Ramana Reddy et al. 2014, Mohan Krishna et al. 2014, Sandeep et al. 2013, Sugunamma et al., 2011, Raju et al. 2015, Sulochana et al. 2015) are discussed the heat transfer characteristics on MHD flows through different channels. (Sandeep et al., 2012) analyzed the effect of radiation and chemical reaction on transient MHD free convective flow over a vertical plate through porous media. The effect of thermal radiation and magnetic field on heat transfer and stagnation flow of nanofluid over a shrinking surface has been studied by Samir kumar Nandy and Ioan Pop (2014). Pal and Mandal (2015) discussed the effects of thermal radiation of convection flow towards stagnation-point flow over shrinking sheet in porous medium with viscous dissipation and heat generation. The results concluded an increasing value of Eckert number and decrease the Nusselt number of Cu-water for stretching sheet. Prasad et al (2010) analysed the MHD viscoelastic fluid flow and heat transfer with the effects of variable viscosity over a stretching sheet and found that Prandtl number increases with decreases the boundary layer thickness.

The heat transfer and stagnation point flow over a nonlinear shrinking sheet with slip effects was explained by Fauzi et al. (2016). The effect of variable viscosity on heat transfer along a vertical moving surface was explained by Ali (2006). The boundary layer flow and its effect of partial slip past a permeable stretching sheet in the presence of thermal radiation was explained by Mukhopadhyay and Gorla (2012). Mahapatra and Gupta (2002) explained the heat transfer in a stagnation-point flow over a stretching sheet. The heat transfer and viscoelastic fluid flow over a stretching sheet with the effects of viscous dissipation, non-uniform heat source and thermal radiation have been studied by Bataller (2007). Anwar et al. (2014) investigated the effect of radiation and MHD on stagnation point flow towards a nonlinear stretching sheet. The unsteady stagnation point flow of nanofluid over a stretching sheet was explained by Malvandi et al. (2014). Very recently, the researchers Ananth et al. (2015), Jayachandra Babu et al. (2015, 2016), Ramana Reddy et al. (2016), Raju and Sandeep (2016) analyzed the heat and mass transfer characteristics of various flows.

In this study, we analyzed the effect of suction/injection on stagnation-point flow towards a stretching sheet with heat source/sink and induced magnetic field. The nonlinear partial differential equations are transformed into a set of nonlinear ordinary differential equations using self-suitable transformations, which are then solved numerically using bvp4c Matlab package. The effects of various physical parameters like magnetic field parameter B, heat source/sink parameter Q_H and stretching ratio a/c etc. on velocity, induced magnetic field and temperature profiles are presented and discussed with the help of graphs.

2. Mathematical Formulation

Consider a steady, incompressible, electrically conducting stagnation-point flow towards a stretching sheet in the presence of induced magnetic field. The stretching sheet is considered along the $x-$axis and $y-$axis is normal to it. It is assumed that the applied magnetic field is of uniform strength H_0. It is also assumed that induced magnetic field is applied in $y-$direction and the parallel component H_1 approaches the value $H_e = H_0$ in the free stream flow and normal component of the induced magnetic field H_2 vanishes near the wall. Heat source/sink is taken into account. Under the above assumptions the governing boundary layer equations are given by

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

$$\frac{\partial H_1}{\partial x}+\frac{\partial H_2}{\partial y}=0, \tag{2}$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu\frac{\partial^2 u}{\partial y^2}+u_e(x)\frac{\partial u_e(x)}{\partial x}+\frac{\mu}{4\pi}\left(H_1\frac{\partial H_1}{\partial x}+H_2\frac{\partial H_1}{\partial y}-H_e\frac{\partial H_e}{\partial x}\right), \tag{3}$$

$$u\frac{\partial H_1}{\partial x}+v\frac{\partial H_1}{\partial y}=H_1\frac{\partial u}{\partial x}+H_2\frac{\partial u}{\partial y}+\alpha_1\frac{\partial^2 H_1}{\partial y^2}, \tag{4}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\frac{Q}{\rho c_p}(T-T_\infty), \tag{5}$$

Subject to the boundary conditions

$$\left.\begin{aligned} &u=u_w(x)=cx, v=v_w, \frac{\partial H_1}{\partial y}=H_2=0, T=T_w \quad \text{at } y=0,\\ &u=u_e(x)=ax, H_1=H_e(x)=H_0x, T=T_\infty, \quad \text{as } y\to\infty, \end{aligned}\right\} \tag{6}$$

where u,v are the velocity components of the fluid in x,y directions, H_1,H_2 are the magnetic components in x,y directions, ρ and μ are the fluid density and dynamic viscosity respectively, σ is the electrical conductivity, ρc_p is the specific heat capacitance, T is the fluid temperature, k is the effective thermal conductivity, v_w is the suction/injection velocity, α_1 is the magnetic diffusivity of the nanofluid, which is given by $\alpha_1=1/4\pi\sigma$.

To convert the governing equations into set of nonlinear ordinary differential equations, we now introduce the following similarity transformation.

$$\left.\begin{aligned} &u=cxf'(\eta), v=-\upsilon^{1/2}c^{1/2}f(\eta), \eta=\upsilon^{-1/2}c^{1/2}y, T=T_\infty(1+(\theta_w-1)\theta)\\ &H_1=H_0xg'(\eta), H_2=-H_0\upsilon^{1/2}c^{-1/2}g(\eta), \theta(\eta)=(T-T_\infty)/(T_w-T_\infty), \end{aligned}\right\} \tag{7}$$

Using eq. (7), eqs. (1) to (5) transformed as

$$f'''-\left(f'^2-ff''\right)+B\left(g'^2-gg''-1\right)+\left(\frac{a}{c}\right)^2=0, \tag{8}$$

$$\lambda g'''+fg''-f''g=0, \tag{9}$$

$$\theta''+\Pr f\theta'-\Pr Q_H\theta=0, \tag{10}$$

With the transformed boundary conditions

$$\left.\begin{aligned} &f=S, f'=1, g=0, g''=0, \theta=1, \quad \text{at } \eta=0,\\ &f'=a/c, g'=1, \theta=0, \quad \text{as } \eta\to\infty, \end{aligned}\right\} \tag{11}$$

where S is the suction/injection parameter, a,c are constants, B is the magnetic parameter, λ is the reciprocal magnetic Prandtl number, $\Pr$ the Prandtl number, Q_H is the heat source/sink parameter, which are represented below.

$$B = \frac{\mu H_0^2}{4\pi\rho c^2}, \lambda = \frac{1}{4\pi\sigma\upsilon}, \Pr = \frac{v}{\alpha}, \qquad (12)$$

3. Results and Discussion

The system of nonlinear ordinary differential equations (8) – (10) with the boundary conditions (11) has been solved numerically using bvp4c Matlab package. Further the effects of various physical parameters like magnetic field parameter B, heat source/sink parameter Q_H and stretching ratio a/c etc. on velocity, induced magnetic field and temperature profiles are presented through graphs. For numerical results we considered $a/c = 0.5$, $Q_H = 0.5, B = 1, \lambda = 1, \Pr = 0.71$. These values are kept as common in entire study except the varied values as displayed in the respective figures.

Figs. 1 and 2 exhibits effect of magnetic field parameter on velocity and induced magnetic field profiles for both suction/injection cases. It is evident that an increase in magnetic field parameter increases the velocity and decreases the induced magnetic profiles. Generally, increasing in magnetic field generates the opposite force to the flow, called Lorentz force. But induced magnetic field acts opposite to this force. Due to this reason we have seen rise in velocity field.

Figs. 3-5 depict the effect of stretching ratio parameter on velocity, induced magnetic field and temperature fields. It is clear that rising values of stretching ratio parameter hikes the velocity field and declines the induced magnetic field along with temperature fields. This agrees the general physical behaviour of stretching ratio parameter. It is also observed that the momentum and thermal boundary layers are highly effective in injection case when compared with suction case.

Figs. 6-8 display the influence of reciprocal magnetic Prandtl number on velocity, induced magnetic field and temperature fields for both suction/injection cases. It is observed that increasing values of magnetic Prandtl number depreciates the velocity field and increases the induced magnetic field and temperature fields. Figs. 9 and 10 illustrate the effect of heat source/sink parameter and Prandtl number on temperature filed. It is clear that rising values of heat source/sink parameter and Prandtl number depreciates the temperature field, this leads to enhance the heat transfer rate.

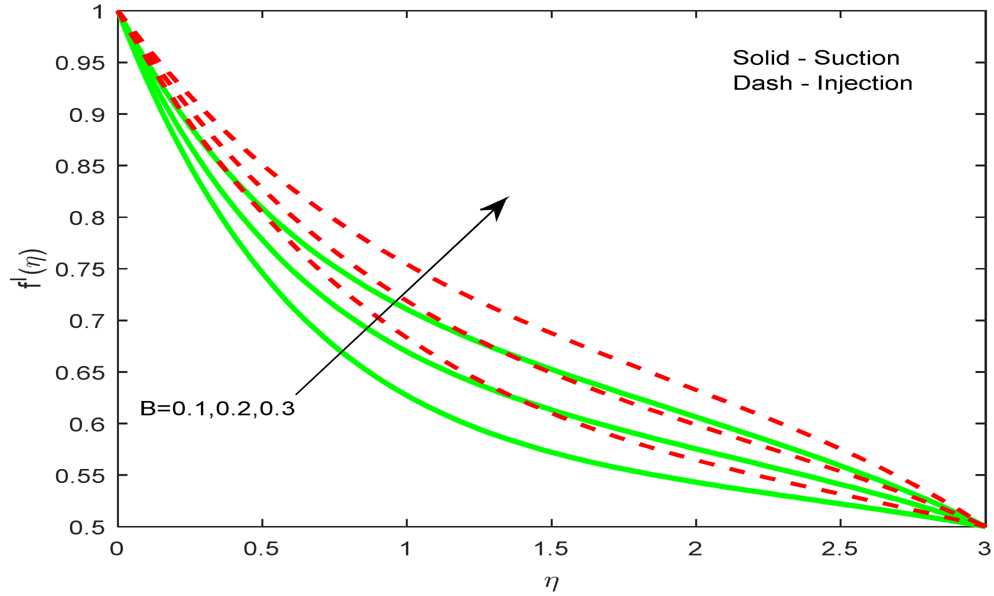

Fig.1 Velocity field for different values of magnetic field parameter

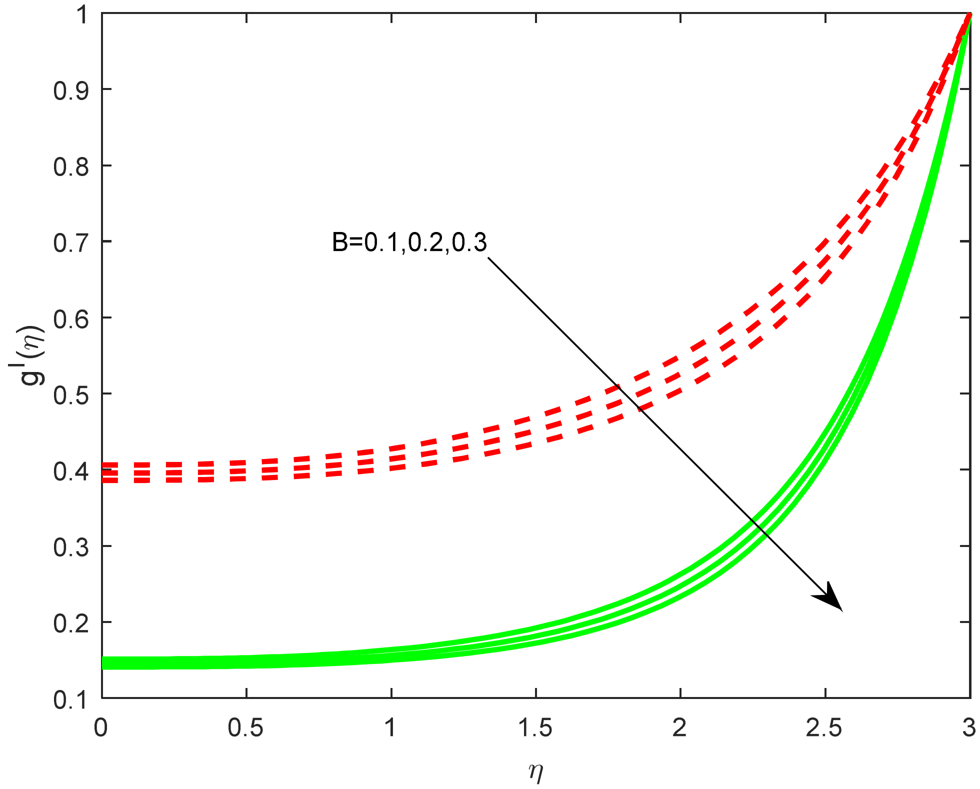

Fig.2 Induced magnetic field for different values of magnetic field parameter

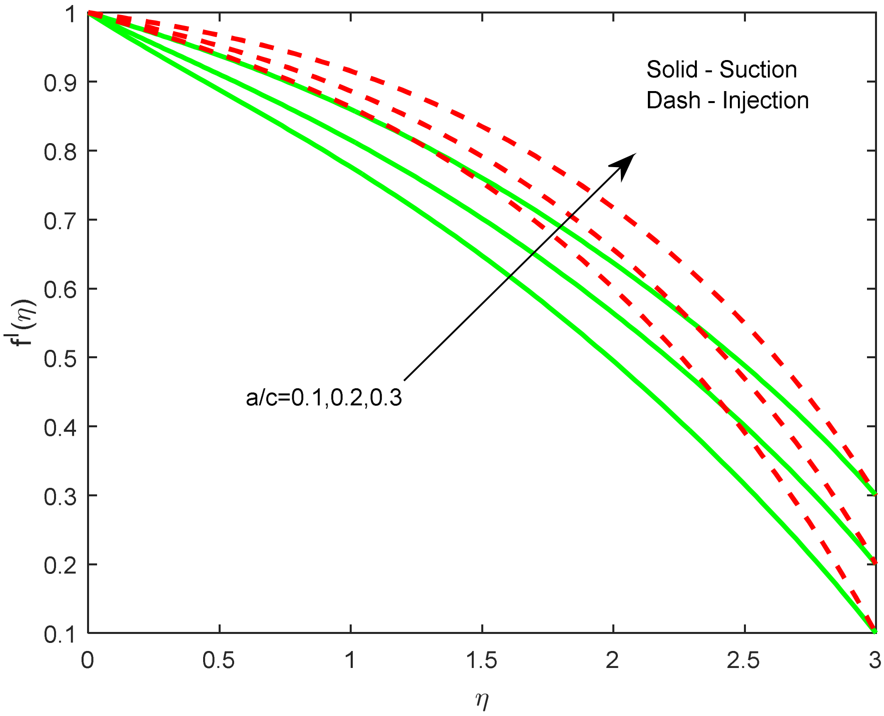

Fig.3 Velocity field for different values of stretching ratio parameter

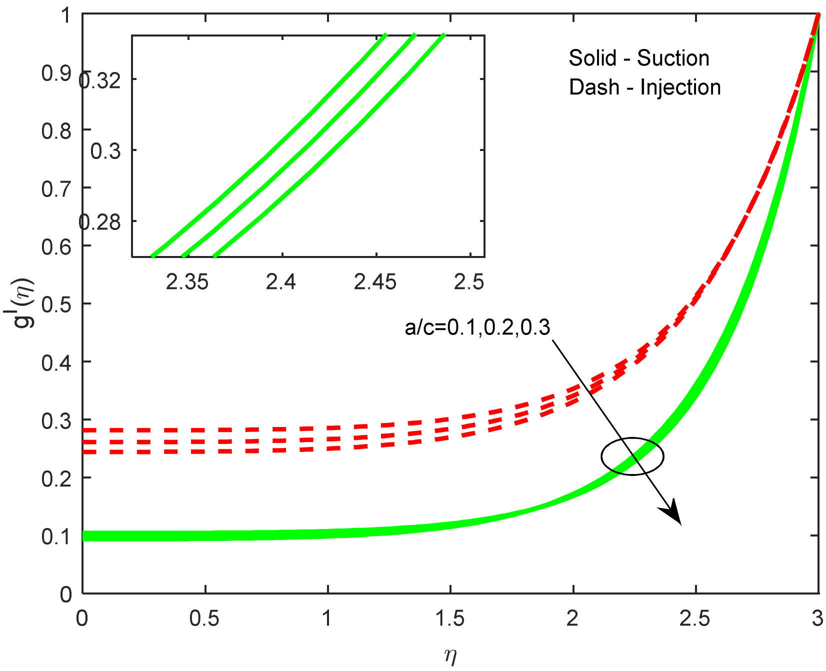

Fig.4 Induced Magnetic field for different values of stretching ratio parameter

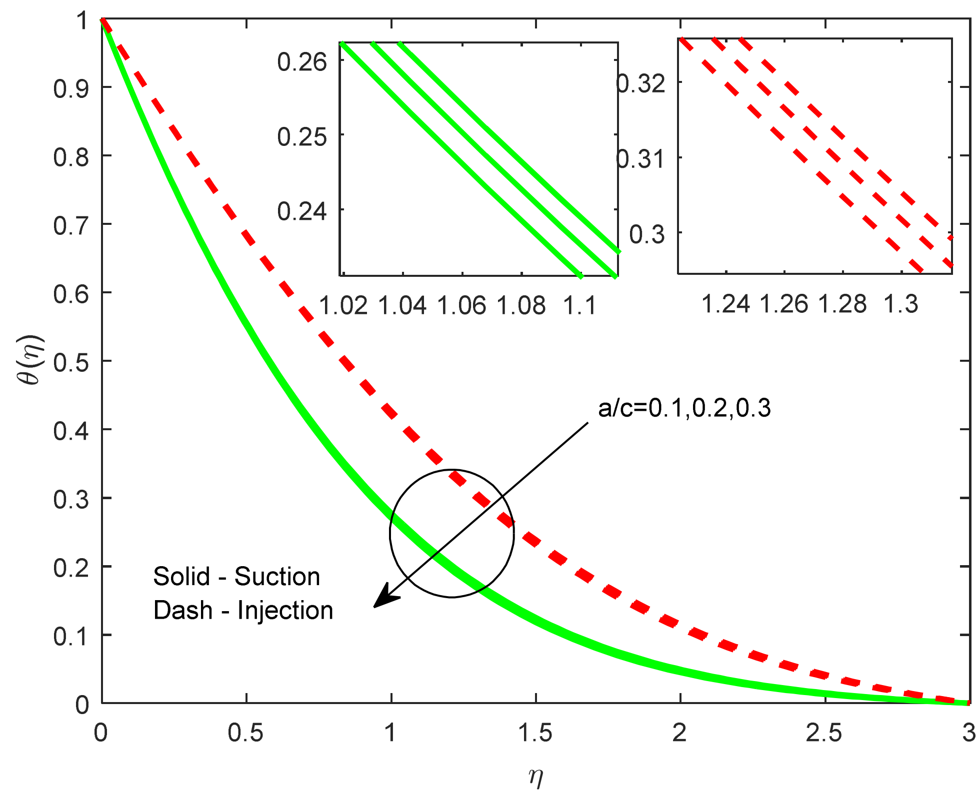

Fig.5 Temperature field for different values of stretching ratio parameter

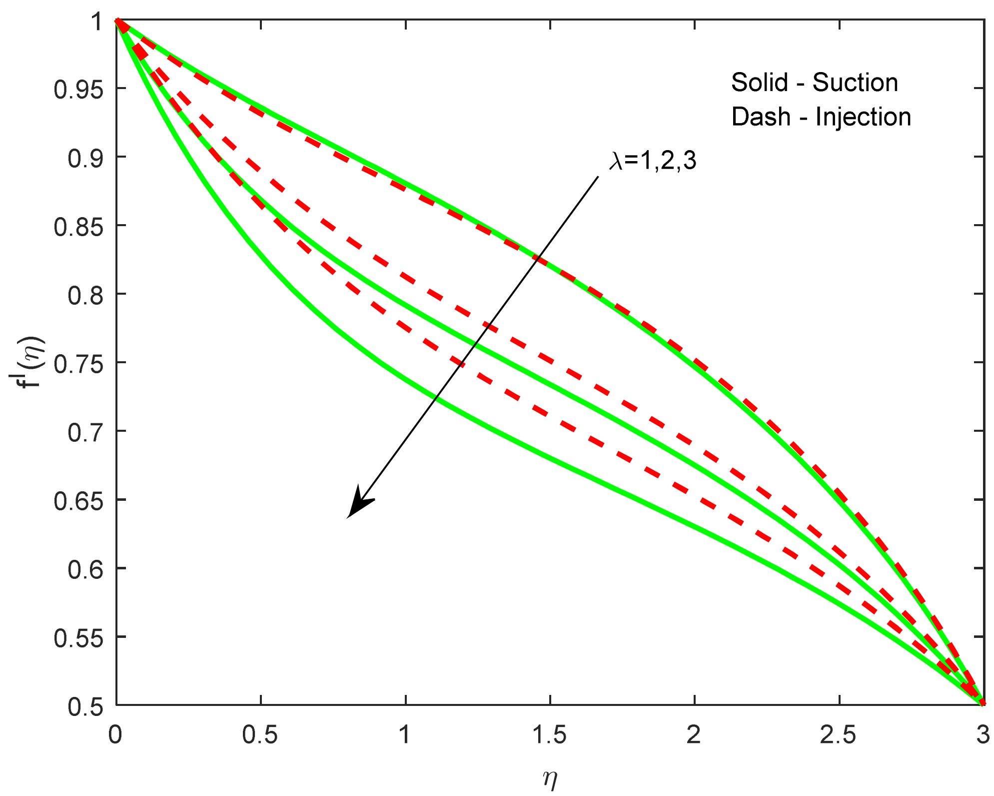

Fig.6 Velocity field for different values of reciprocal magnetic Prandtl number

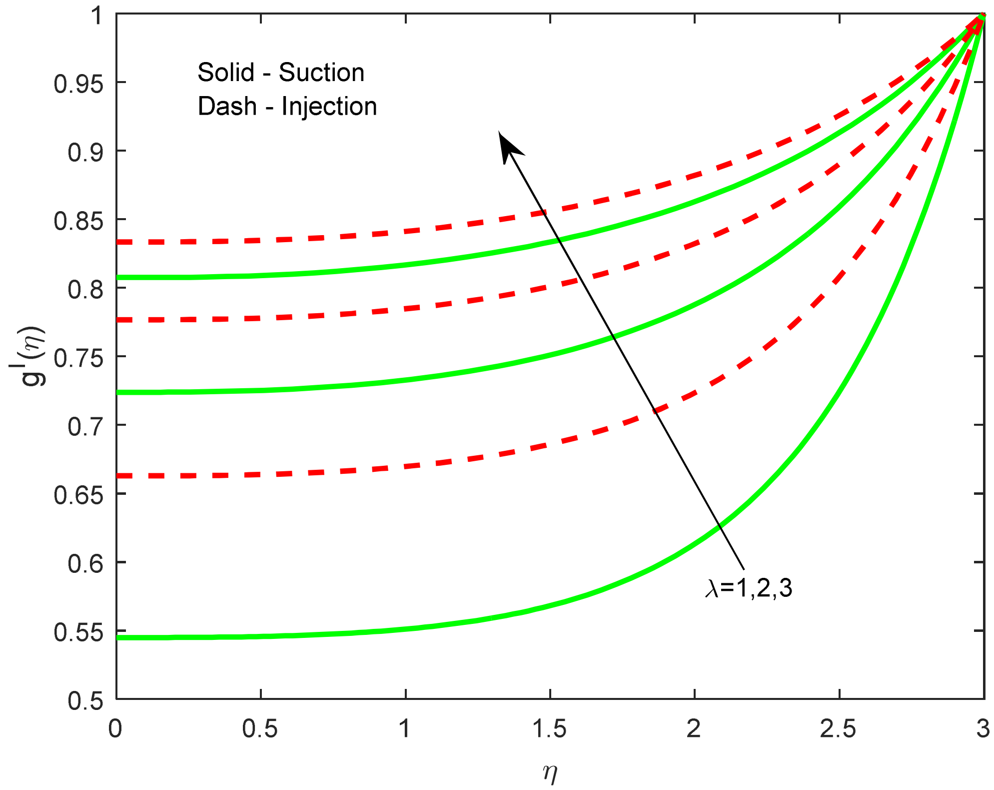

Fig.7 Induced magnetic field for different values of reciprocal magnetic Prandtl number

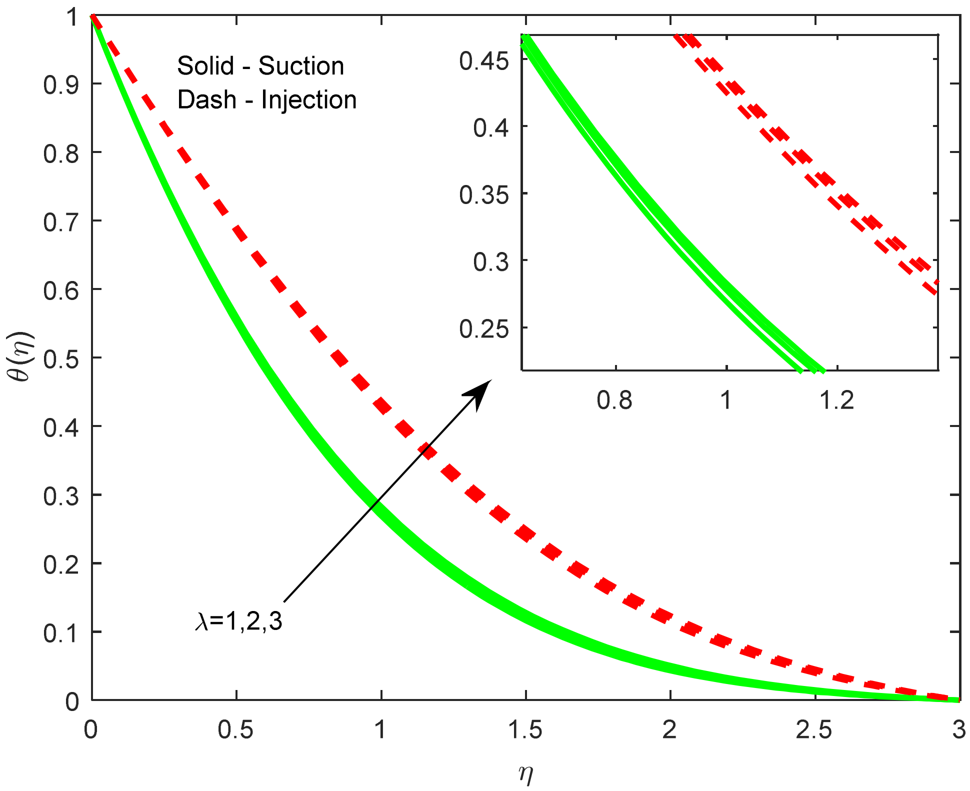

Fig.8 Temperature field for different values of reciprocal magnetic Prandtl number

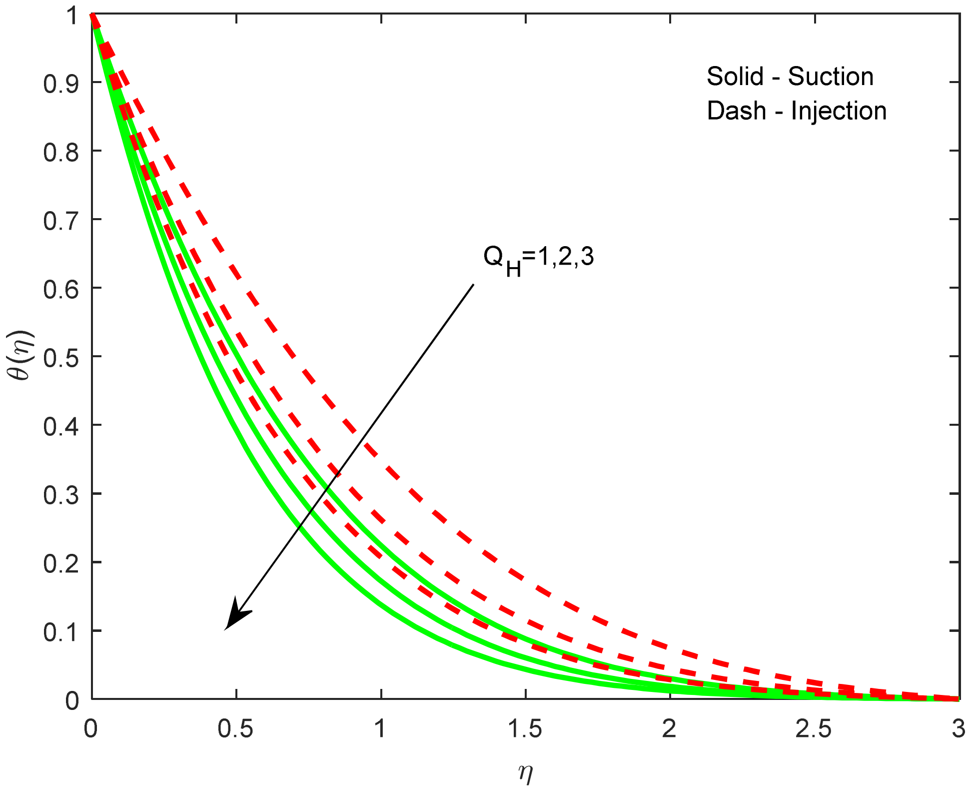

Fig.9 Temperature field for different values of heat source/sink parameter

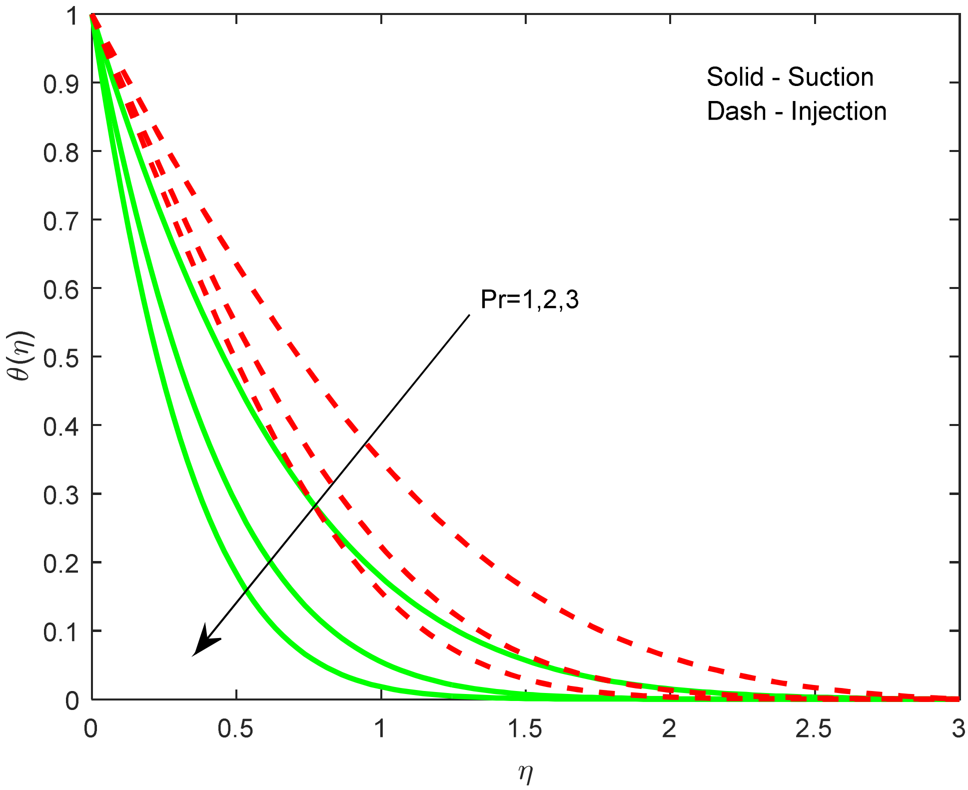

Fig.9 Temperature field for different values of Prandtl number

4. Conclusion

Suction/injection effect on stagnation-point flow towards a stretching sheet with heat source/sink and induced magnetic field was analyzed numerically. The nonlinear partial differential equations are transformed into a set of nonlinear ordinary differential equations using self-suitable transformations, which are then solved numerically using bvp4c Matlab package. Findings of the present study are as follows:

- Heat source/sink parameter and Prandtl number have tendency to reduce the temperature filed.
- Magnetic field parameter have tendency to enhance the momentum boundary layer thickness.
- Rising values of reciprocal magnetic Prandtl number enhances the induced magnetic field.
- Momentum and heat transfer is high in injection case when compared with suction case.

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