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Entropy Generation for MHD Flow of viscous fluid on a Stretching Sheet with Variable viscosity

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Abstract

This research explores the combined effects of magnetic field and viscous dissipation on the heat field and discusses the second law study (generation of entropy) in an electrically conducting fluid under the influence of wall mass transfer over a continuous, variable viscosity spread non-isothermal surface. It is considered that the viscosity of the fluid is an inverse linear temperature property. The theory of approximation of boundary layers is used to model the governing equations of momentum, energy and concentration. To transfer the governing partial differential equations into ordinary ones, appropriate similarity transformations are used and numerical results are obtained by using the shooting technique. To measure the entropy generation and the Bejan number in the flow region, velocity, temperature and concentration distribution are obtained and used. The effect on velocity, temperature, concentration, entropy production, and Bejan number of the vector viscosity, Schmidt number, Hartman and Reynolds number are are studied and discussed. It is found that presences of the variable viscosity parameter reduces the fluid friction in the region close to the surface. This in turn results in low irreversibility (i.e. entropy) with increasing Schmidt number Sc and viscous dissipation parameter Ec inside the boundary layer. Further, the Bejan number for the variable viscosity case is lower than that for uniform viscosity when there is a variation in the values of group parameter $Br\Omega^{-1}$ and Hartman number Ha.

Keywords: Entropy generation; heat and mass transfer; Stretching sheet; variable viscosity; non-Newtonian fluid

1. INTRODUCTION

Fluid flow over a stretching sheet is important in many practical applications such as extrusion of plastic sheets, paper production, glass blowing, metal spinning, polymers in metal spring processes, the continuous casting of metals, drawing plastic films and spinning of fibers, all involve some aspects of flow over a stretching sheet or cylindrical fiber (Paullet and Weidman [1]). The quality of the final product depends on the rate of heat transfer at the stretching surface. Literature survey shows that interest in the flows over a stretched surface has grown during the past decades. The problem of stretching surface with constant surface temperature was analyzed by Crane [2]. Later, the stretching sheet flow has been studied by several researchers to examine the sole effects of rotation, velocity and thermal slip conditions, heat and mass transfer, chemical reaction, MHD, suction/injection, different non-Newtonian fluids or possible combinations effects ([3-8]). Elbashbeshy and Basziz [9] studied the effect of variable viscosity and internal heat generation on heat transfer over a continuous moving surface. Salem [10] Studied the problem of flow and heat transfer of an electrically conducting viscoelastic fluid having a temperature-dependent viscosity over a continuously stretching sheet. Salem [11] has further studied the problem of steady laminar free-convection boundary-layer flow along a vertical wedge with the effect of temperature-dependent viscosity immersed in electrically fluid-saturated porous medium in the presence of internal heat generation or absorption. Entropy generation is associated with thermodynamic irreversibility, which is common in all types of heat transfer processes. Different mechanisms are responsible for the generation of entropy such as transfer across finite temperature gradient, magnetic effect, viscous dissipation effects, etc. Sahin [12] introduced the second law analysis to a viscous fluid in circular duct with isothermal boundary layer conditions. Also, Sahin [13] presented the effect of variable viscosity on the entropy generation rate through a duct subjected to constant heat flux. The study of entropy generation in a falling liquid film along an inclined heated plate was carried out by Saouli and Aiboud-Saouil [14]. Makinde [15-18] studied the entropy generation analysis for variable viscosity channel flow with non-uniform wall temperature , also Thermodynamic second law analysis for a gravity driven variable viscosity liquid film along an inclined heated plate with convective cooling and studied Second law analysis for variable viscosity hydromagnetic boundary layer flow with thermal radiation and Newtonian heating. Naseem and Khan [19] examined boundary layer flow past a stretching plate with suction, heat and mass transfer and with variable conductivity. Cortell [20] also found the flow and heat transfer of a fluid through porous medium over a stretching surface with internal heat generation. Combined effects of magnetic field and partial slip on obliquely striking rheological fluid over a stretching surface have been investigated by Nadeem et al. [21]. Akbar et al. [22] have studied the numerical analysis of magnetic field effects on Eyring-Powell fluid flow towards a stretching sheet. Heat transfer and entropy generation analysis of non-Newtonoan fluid flow through vertical microchannel with convective boundary condition has been investigated by Madhu et al [23]. Recently, Entropy generation for the flow and heat transfer of Sisko-fluid over an exponentially stretching surface have been studied by Abdel-Aziz et al. [24]. Here, we examine the effects of temperature dependent fluid viscosity in an electrically fluid on the flow, thermal and entropy generation features over a linear stretching sheet in the presence of a constant transfer magnetic field with blowing at the sheet. We derive velocity, concentration and temperature distribution and use them to compute the entropy generation and the Bejan number in the flow field. We also study and examine the effect of variable viscosity, Hartman and Reynolds number on velocity, temperature and concentration.

2. FORMULATION OF THE PROBLEM

We consider an steady two-dimensional boundary layer flow with heat and mass transfer of an incompressible viscous and electrically conducting fluid over a surface which is permeable but stretches linearly with coordinates (x; y) having corresponding velocity components as (u; v) see (Fig. 1). The sheet stretches with velocity u=cx where $c > 0$ and mass transfer velocity at the surface equal to v_w . Magnetic field B_0 is applied externally perpendicular to the flow direction. The magnetic Reynolds number is sufficiently small to negate the induced magnetic field produced by the motion of the conducting fluid. Joule heating and Hall current effects are also ignored [Jalilpour, Jafarmadar, Ganji, Shotorban and Taghavifar (2014)]. Under the above assumption and using the Boussinesq approximation, the continuity, momentum, energy and concentration boundary layer equations are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1).$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{1}{\rho_\infty}\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) - \frac{\sigma B_0^2}{\rho_\infty}u \ , \qquad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = k\frac{\partial^2 T}{\partial y^2} + \frac{\mu}{\rho_\infty c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{\sigma B_0^2}{\rho_\infty c_p}u^2 + \frac{Q}{\rho_\infty c_p}(T - T_\infty) \ , \qquad (3)$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} \ , \qquad (4)$$

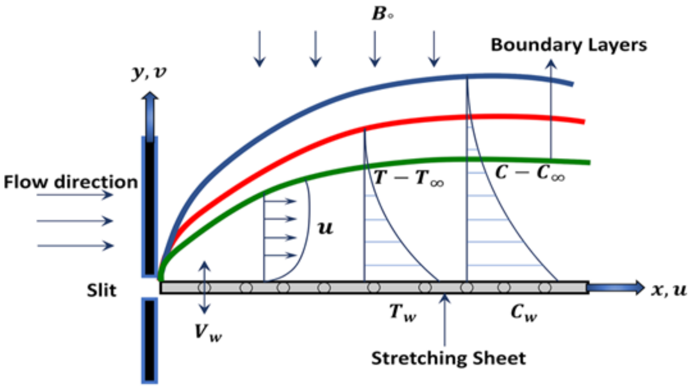

Figure 1. Problem schematic and coordinate system.

The boundary conditions are given by

$$u = cx \ , \ v = -v_w \ ,$$
$$T = T_w(x) = T_\infty + A\left(\frac{x}{L}\right)^2, \quad C = C_w + B\left(\frac{x}{L}\right)^2, \quad \text{at } y = 0$$
$$u \to 0 \ , \ T \to T_\infty, \ C \to C_\infty \ \text{ as } y \to \infty \qquad (5)$$

where ρ_∞ and c_p are the density and specific heat at constant pressure, Q is the volumetric heat generation or absorption, σ is the electric conductivity, B_0 is the magnetic induction , K is the thermal conductivity, T is the temperature ,C is concentration of the fluid, D is the molecular diffusivity, T_w, C_w are the variable wall temperature and concentration, l is a characteristic length, c is constant and v_w represents suction velocity across the stretching sheet, the viscosity is considered to be of the form:

$$\frac{1}{\mu} = \frac{1}{\mu_\infty}[1 + \delta(T - T_\infty)] \text{ or } \frac{1}{\mu} = a(T - T_r), \ a = \delta/\mu_\infty \ ,$$
$$T_r = T_\infty - 1/\delta \qquad (6)$$

where μ_∞ and T_∞ are the fluid free stream dynamic viscosity and fluid free stream temperature; a and T_r are constants and their values depend on the reference state and thermal property of the fluid, i.e. δ. In general, $a > 0$ for fluids such as liquids and $a < 0$ for gases.

The governing Eqs. (1)-(4) can be expressed in a simpler form by introducing the following similarity transformation:

$$\eta = \sqrt{\frac{c}{\nu_\infty}}y, \ \psi = \sqrt{c\nu_\infty}\,xf(\eta), \ \theta = \frac{T - T_\infty}{T_w - T_\infty},$$
$$\varphi = \frac{C - C_\infty}{C_w - C_\infty} \qquad (7)$$

Substituting Eq. (7) into Eqs. (1)-(4) produces the following ordinary differential equations

$$f''' - \left(\frac{\theta}{\theta_r} - 1\right)(f'^2 - ff'' + Mf') - \frac{1}{\theta - \theta_r}\theta' f'' = 0 \qquad (8)$$

$$\theta'' - \Pr(2\ f'\theta - f\ \theta' - \alpha\theta - EcMf'^2 + Ec\frac{\theta}{\theta-\theta_r}f''^2) = 0 \quad (9)$$

$$\varphi'' + Sc\ f\ \varphi' - 2Sc\ f'\varphi = 0 \quad (10)$$

where the prime denote the differentiation with respect to similarity variable η. Boundary conditions are:

$$f(\eta) = F_w,\ f'(\eta) = 1,\ \theta(\eta) = 1 \quad \varphi'(\eta) = -1 \text{ at } \eta = 0 \quad (11)$$

$$f'(\eta) \to 1,\ \theta(\eta) \to 0,\ \varphi(\eta) \to 0 \text{ as } \eta \to \infty \quad (12)$$

where $\theta_r = -\frac{1}{\delta(T_w - T_\infty)}$ is the variable viscosity parameter, $M = \frac{\sigma B_0^2}{\rho_\infty c}$ is the magnetic field, $\Pr = (1-\frac{\theta}{\theta_r})^{-1}\Pr_\infty$ is the Prandtl number with $\Pr_\infty = \frac{\mu_\infty c_p}{k}$ being the ambient Prandtl number, $\alpha = \frac{Q}{\rho_\infty c C_p}$ is the heat source or sink parameter, $Ec = \frac{c^2L^2}{C_pA}$ is the Eckert number, $Sc = \frac{D}{\nu_\infty}$ is the Schmidt number+ and $F_w = -\frac{v_w}{\sqrt{\nu_\infty c}}$ is the dimensionless wall mass transfer coefficient.

2. ENTROPY GENERATION ANALYSIS

The local volumetric rate of entropy generation in the presence of magnetic field is given by:

$$S_G = \frac{k}{T_\infty^2}[(\frac{\partial T}{\partial x})^2 + (\frac{\partial T}{\partial y})^2] + \frac{\mu}{T_\infty}(\frac{\partial u}{\partial y})^2 + \frac{\sigma B_0^2}{T_\infty}u^2 + \frac{D}{C_\infty}[(\frac{\partial C}{\partial x})^2 + (\frac{\partial C}{\partial y})^2] + \frac{D}{T_\infty}[\frac{\partial T}{\partial x}\frac{\partial C}{\partial x} + \frac{\partial T}{\partial y}\frac{\partial C}{\partial y}] \quad (13)$$

The first term on the right side of Eq.(13) is the generation of entropy due to heat transfer over a finite temperature difference, the second term is the generation of local entropy due to viscous dissipation, the third term is the generation of local entropy due to the magnetic field effect, and the Lorentz force is responsible for the final terms. The Amount of Entropy Generation is

$$N_s = \frac{L^2T_\infty^2S_G}{k\,\Delta T^2} \quad (14)$$

where k is the thermal conductivity and L is the characteristic length scale. Using the similarity variables defined in Eq.(7), we obtain the entropy generation number as

$$N_s = N_H + N_F + N_J + N_M$$

where N_H, N_F, N_J and N_M are respectively the dimensionless local entropy generation rate due to heat transfer, fluid friction, joule heating, and concentration defined as

$$N_H = \frac{4}{X^2}\theta^2(\eta) + Re_L\theta'^2(\eta),$$

$$N_F = Re_L\frac{Br}{\Omega}\frac{\theta_r}{\theta_r - \theta}f''^2(\eta),\ N_J = Ha^2\frac{Br}{\Omega}f'^2(\eta),$$

$$N_M = \frac{4}{X^2}\lambda_1\varphi^2 + Re_L\lambda_2\varphi'^2 + \lambda_3[\frac{4}{X^2}\theta\varphi + Re_L\theta'\varphi'] \quad (15)$$

where Re_L is the number of Renold, Br is the number of Brinkman, Ω is the difference in dimensionless temperature, and Ha is the number of Hartman. Such parameters are given by

$$Re_L = \frac{Lu_L}{\nu_\infty},\ Br = \frac{\mu_\infty u_w^2}{k\,\Delta T},\ \Omega = \frac{\Delta T}{T_\infty},\ Ha = B_0L\sqrt{\frac{\sigma}{\mu_\infty}},$$

dimensionless terms denoted $\lambda_i(1 \le i \le 3)$, and called irreversibility distribution ratios, are given by

$$\lambda_1 = \frac{DT_\infty}{KC_\infty}(\frac{\Delta C}{\Delta T})^2,\quad \lambda_2 = \frac{DT_\infty^2}{KC_\infty}(\frac{\Delta C}{\Delta T})^2,\quad \lambda_3 = \frac{DT_\infty}{K}(\frac{\Delta C}{\Delta T}) \quad (16)$$

The local Bejan number, which can be calculated as the entropy generation ratio due to heat transfer N_H to the total generation of entropy N_s, is also important to define, i.e.

$$Be = \frac{N_H}{Ns} \quad (17)$$

3. NUMERICAL METHOD FOR SOLUTION

The nonlinear system of differential Eqs. (8), (9) and (10) with the boundary conditions (11) and (12) are solved using shooting method, by converting into an initial value problem

(IVP). In this method we have to choose a finite value of the boundary $\eta \to \infty$, say η_∞. We construct the following first order differential equations by assuming

$(f, f', f'', \theta, \theta', \varphi, \varphi') = (z_1, z_2, z_3, z_4, z_5, z_6, z_7)$, as

$$z_1' = z_2,\ z_2' = z_3,\ z_3' = (\frac{z_4}{\theta_r} - 1)(z_2^2 - z_1 z_2 + M z_3) - \frac{1}{z_4 - \theta_r} \quad (18)$$

$$z_4' = z_5,\ z_5' = 2z_2 z_4 - z_1 z_5 - \alpha z_4 - Ec(M z_2^2 + \frac{z_4}{z_4 - \theta_r} z_3^2) \quad (19)$$

$$z_6' = z_7,\ z_7' = Sc(2z_2 z_6 - z_1 z_7) \quad (20)$$

with the boundary conditions

$$z_1'(0) = F_w,\ z_2'(0) = 1,\ z_4(0) = 1,\ z_7(0) = -1 \quad (21)$$

In order to solve (18), (19) and (20) with (21) as IVP the values for $z_3'(0)$ i.e. $f''(0)$, $z_5'(0)$ i.e. $\theta'(0)$, $z_6'(0)$ i.e. $\varphi(0)$ are required and no such values are given, therefore, we chose initial values for $z_3'(0)$, $z_5'(0)$ and $z_6(0)$, are satisfied with appropriate domain length η_∞ and improve chosen values iteratively by Runge-Kutta and shooting method (see pal et. al. [26]. The step-size is taken as $\Delta\eta = 0.001$. The process is repeated until the results are correct up to desired accuracy at 10^{-6} level.

4. FINDINGS AND DISCUSSION

In the present section we will discuss the behavior of velocity, temperature and concentration profiles along with entropy generation rate and Bejan number for a linear stretching sheet for bundry values of the fluid viscosity parameter θ_r, the magnetic field parameter M, the Ekeart number E_c, the heat source or sink parameter α, the Schmidt number S_c and the dimensionless wall mass transfer F_w.

Figures 2-4 are graphical representation of dimensionless velocity, temperature and concentration profiles for different values of magnetic field parameter M in the absent and presence of temperature dependent viscosity θ_r throughout the boundary layer. It is found that as M increases, the fluid velocity decreases; this is due to presence of transfer magnetic fields which causes the emergency of drag force opposing the motion of the field and as a result it retards the flow velocity. This is accompanied with slight increase in the fluid temperature and concentration within the boundary layer. In addition, the velocity in the case of variable viscosity (plotted as dotted lines) is higher than that constant viscosity (plotted as solid lines) for all values of magnetic field parameter M and reverse trend is seen for temperature and concentration profiles. The rise in concentration and temperature profiles may be attributed to resistance offered by Lorentz force.

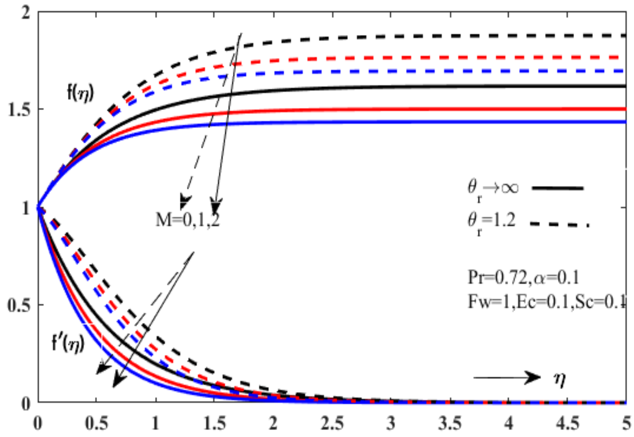

Figure 2. The velocity distribution for different values of M and θ_r.

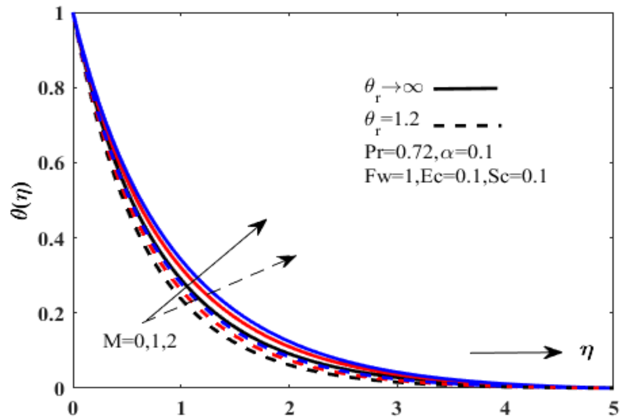

Figure 3. The temperature distribution for different values of M and θ_r.

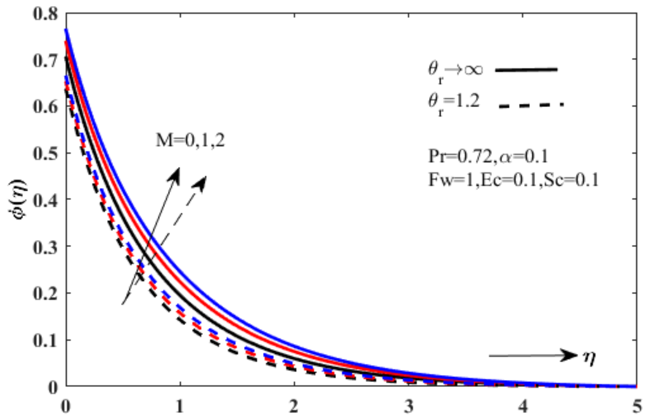

Figure 4. The concentration distribution for different values of M and θ_r.

Figures.(5-10) display the influence of the Eckert number Ec and heat generation parameter α on the velocity, temperature and concentration profiles in the absence and presence of θ_r. The velocity and concentration are almost not affected with increase of E_c *and* α in the absence of the variable viscosity θ_r inside the boundary layer. From figures 5 and 7 one sees that the viscous dissipation and heat generation has negligible effect on the velocity and concentration in the case of constant viscosity since the viscous dissipation and heat generation are associated basically with energy equation. However, in the presence of variable viscosity, the momentum and energy equations are coupled, therefore, changes in values of viscous dissipation and heat generation causes change in the velocity profiles which are plotted as dotted lines. In the presence and absence of variable viscosity, the effect of viscous dissipation and heat generation increase temperature inside the thermal boundary layer. Physically, when the frication on plate increases due to fluid viscosity, more heat is generated and as a result the fluid temperature increases.

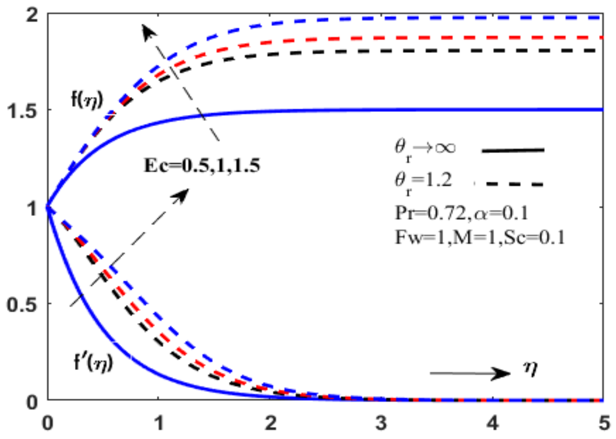

Figure 5. The velocity distribution for different values of Ec and θ_r.

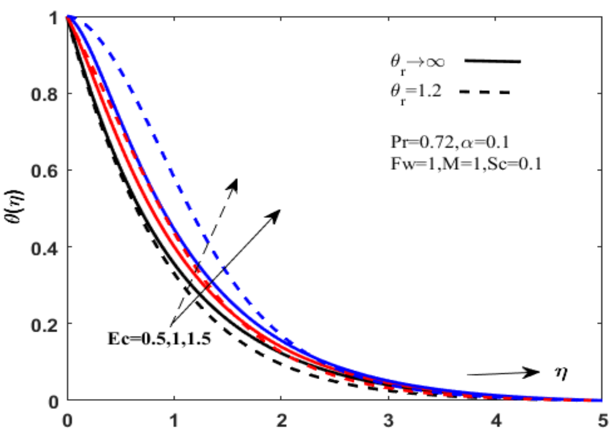

Figure 6. The temperature distribution for different values of Ec and θ_r.

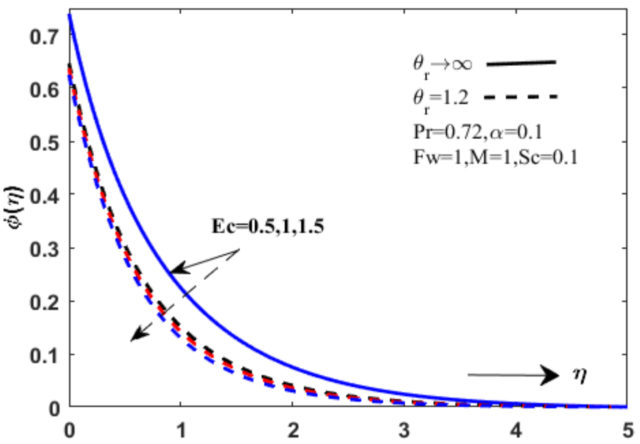

Figure 7. The conteration distribution for different values of Ec and θ_r.

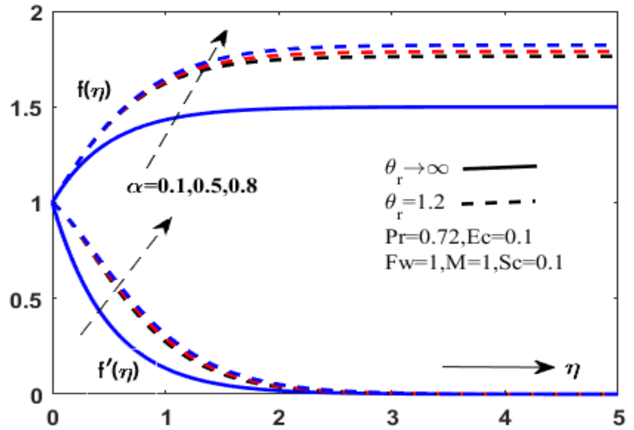

Figure 8. The velocity distribution for different values of α and θ_r.

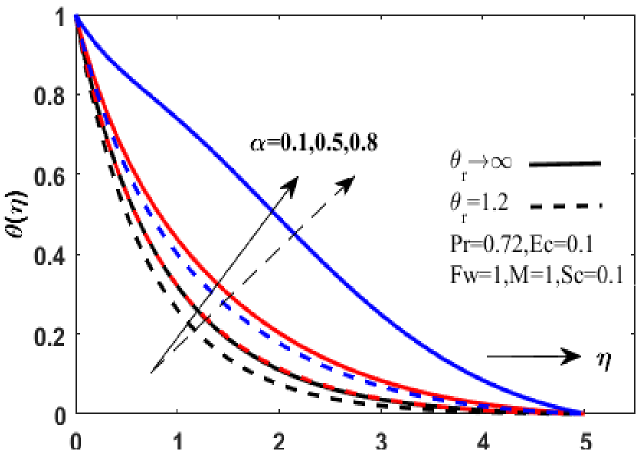

Figure 9. The temperature distribution for different values of α and θ_r.

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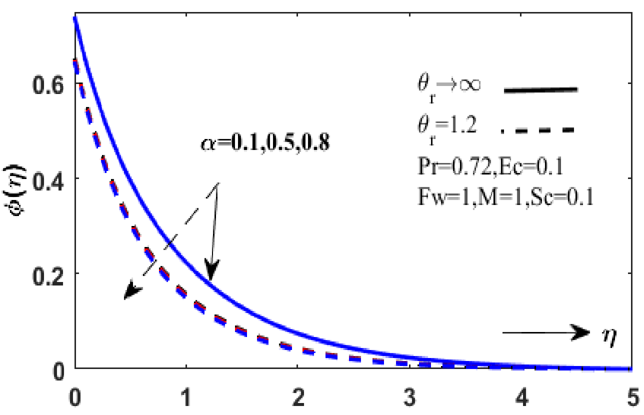

Figure 10. The concentration distribution for different values of α and θ_r .

Figures 11-13 show the effect of Schmidt number Sc on the velocity, temperature and concentration in the absence and presence of variable viscosity θ_r . It is seen in Figures 11 and 13 that the variation of Schmidt number does not have much effect on velocity and temperature profiles. However, as it is seen in Figure 12, the effect of increasing the values Sc is to decrease concentration distribution inside the flow region. Physically, the increase of Sc means decrease of molecular diffusivity. Hence, the concentration of species is higher for small values of Sc and lower for large values of Sc. Also it is observed that the concentration in the case of variable viscosity is lower than that of uniform viscosity for all values of Schmidit number Sc.

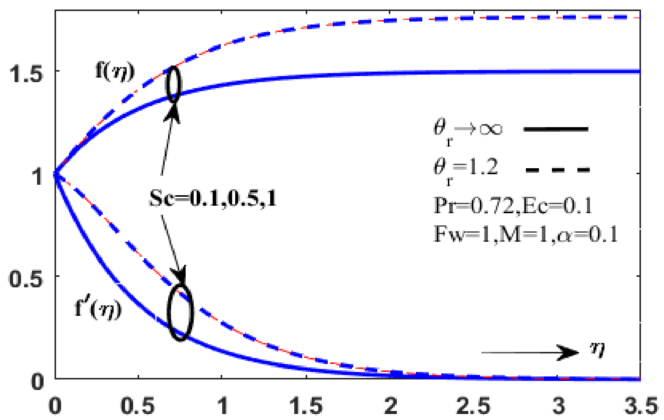

Figure 11. The velocity distribution for different values of Sc and θ_r .

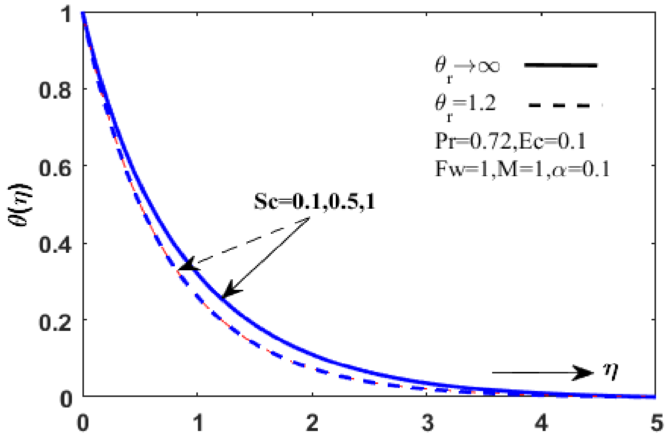

Figure 12. The temperature distribution for different values of Sc and θ_r .

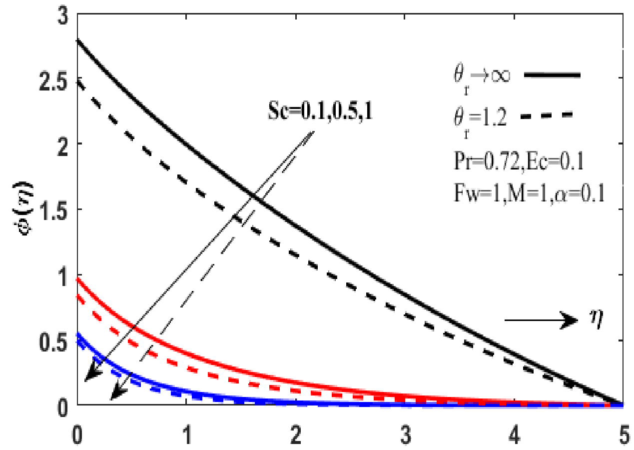

Figure 13. The concentration distribution for different values of Sc and θ_r .

In Figures 14, 15 and 16, the dimensionless velocity, temperature and concentration profiles are plotted for different values of suction parameter F_w in the absence and presence of variable viscosity parameter θ_r throughout the boundary layer. For M=1, $\alpha = 0.1$, Ec=0.1 and Pr=0.72, we observe that both profiles of horizontal velocity, temperature and concentration decrease with the increase of suction parameter. The same observation is made by Kandasamy et al. [27] which is " the presence of wall suction decreases the velocity boundary layer thicknesses but decreases the thermal and solute boundary layer thickness, i.e. thin out the thermal and solute boundary layers". In addition, the velocities in the case of variable viscosity are higher than that of constant viscosity for all values of suction parameter and reverse trend is seen for temperature and concentration inside the boundary layer.

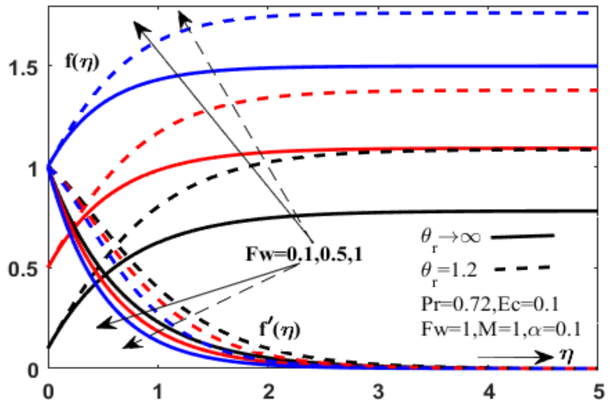

Figure 14. The velocity distribution for different values of Fw and θ_r

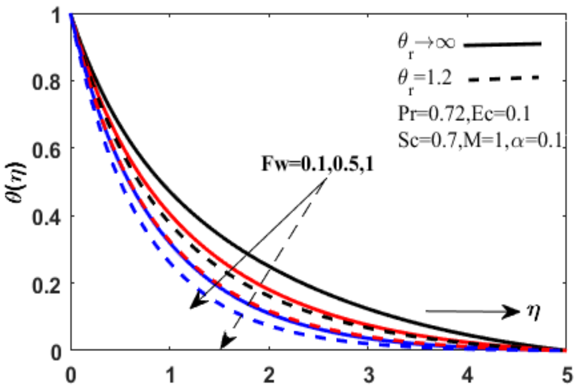

Figure 15. The temperature distribution for different values of Fw and θ_r.

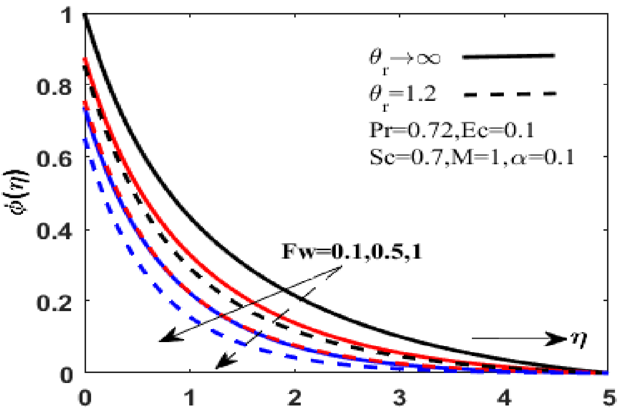

Figure 16. The concentration distribution for different values of Fw and θ_r.

5. ENTROPY GENERATION RATE

Figures 17-22 show entropy generation number profiles $Ns(\eta)$ for different values of magnetic field parameter M, viscous dissipation parameter Ec, heat generation parameter α, suction parameter F_w, Schmidt number Sc, Hartmann number Ha and group parameter $Br\Omega^{-1}$ in the presence and absence of variable viscosity parameter θ_r. As it is observed in Figures 17, 18 and 19, the entropy generation decreases across the boundary layer with increase of M, Ec and α, while the reverse trend is observed outside the boundary layer. However an increase in suction parameter F_w ,generates the opposite effect to magnetic field parameter M as shown in Figure 20. According to Figure 21, the increase of Schmidt number Sc could highly diminish the entropy generation number profiles throughout the boundary layer. In the presence of temperature-dependent viscosity, the effect of Schmidt number is to decrease the entropy generation number profiles throughout the boundary layer more than that the case of fluid with uniform viscosity for lower and higher values of Sc, i.e. variable viscosity with large values of Schmidt number causes a decrease in the entropy generation throughout the boundary layer. The effect of Hartmann number Ha causes the entropy generation number to slightly increase throughout the boundary layer, as it is observed in Figure 22.

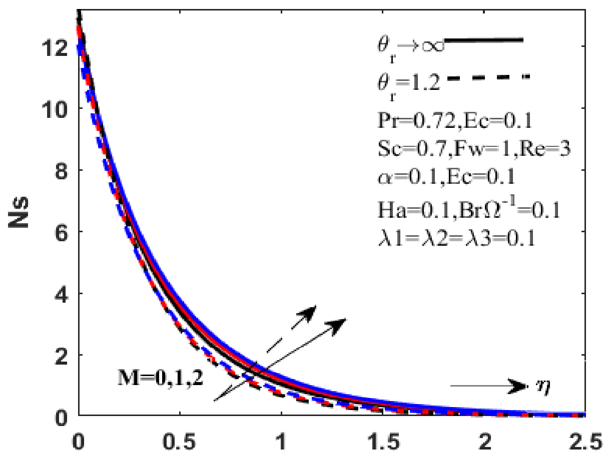

Figure 17. The Entropy generation for different values of M and θ_r.

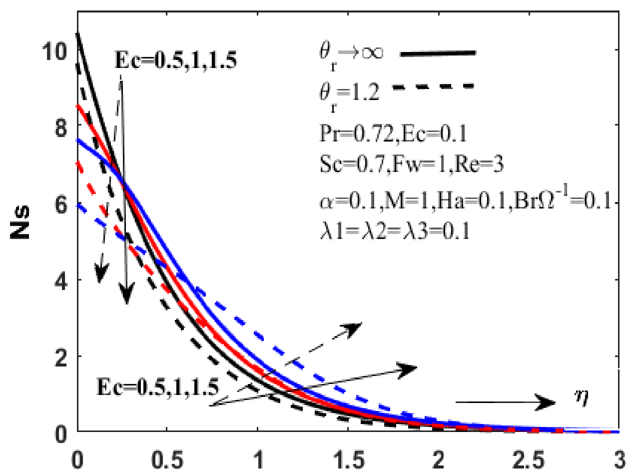

Figure 18. The Entropy generation for different values of Ec and θ_r.

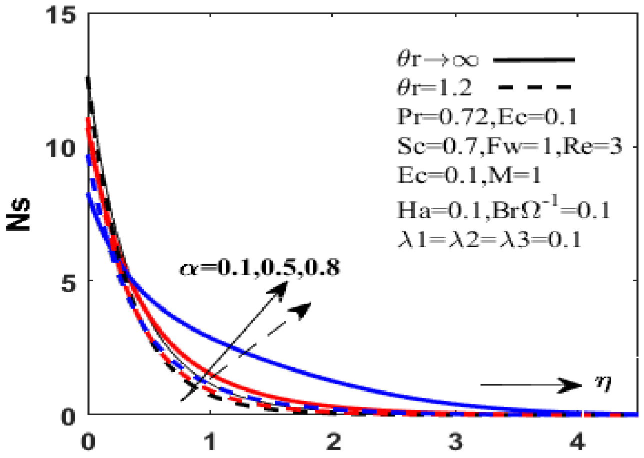

Figure 19. The Entropy generation for different values of α and θ_r.

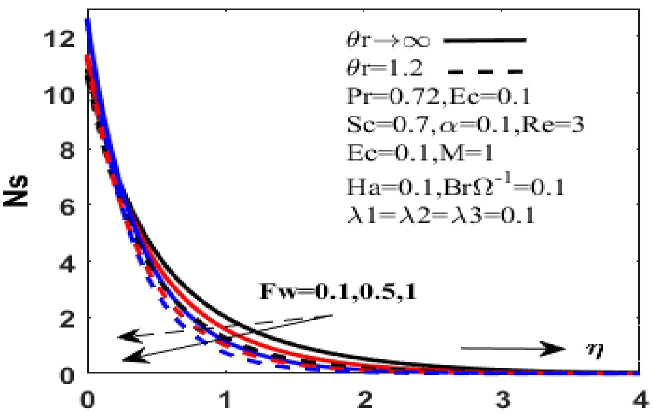

Figure 20. The Entropy generation for different values of Fw and θ_r.

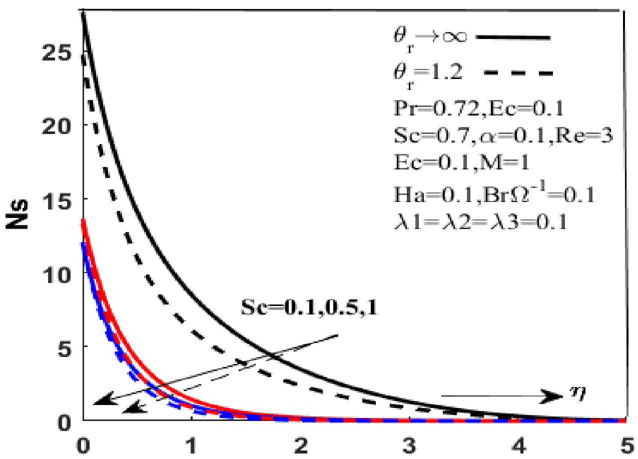

Figure 21. The Entropy generation for different values of Sc and θ_r.

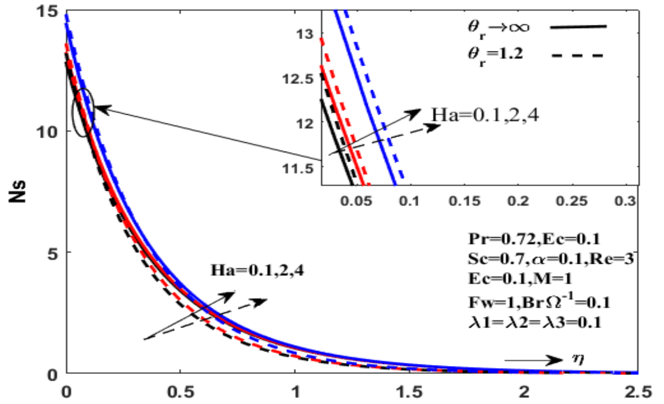

Figure 22. The Entropy generation for different values of Ha and θ_r.

6. BEJAN NUMBER

Figure 23 shows how the Bejan number profiles $Be(\eta)$ vary with the Hartman number. The Bejan number profiles increase due to increase in the Hartman number within the boundary layer in the absence as well as in the presence of temperature dependent fluid viscosity. In addition, the Bejan number of the fluid with constant viscosity is greater than that for the fluid with variable viscosity for all values of Hartman number. The effect of Brinkman group $Br\Omega^{-1}$ on Bejan number for three different values of Hartman number, namely, Ha=0, 0.5 and 1.5, is presented in Figure 24 in the absence and presence of variable viscosity parameter. The Bejan number increases due to an increase in the group parameter $Br\Omega^{-1}$ for $Ha > 0$ within the boundary layer. This increase in Bejan number is much at large values of Ha.

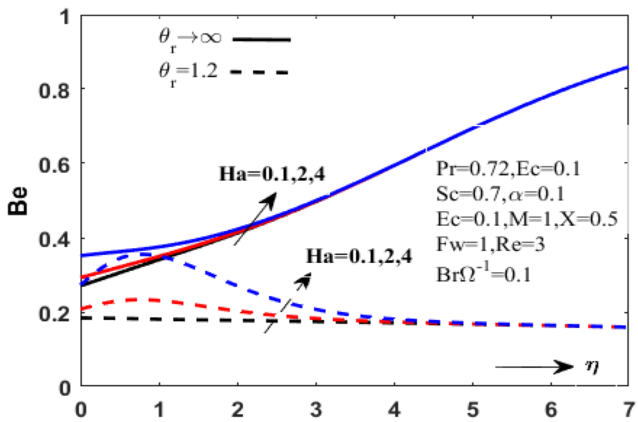

Figure 23. The Began number for different values of Ha and θ_r.

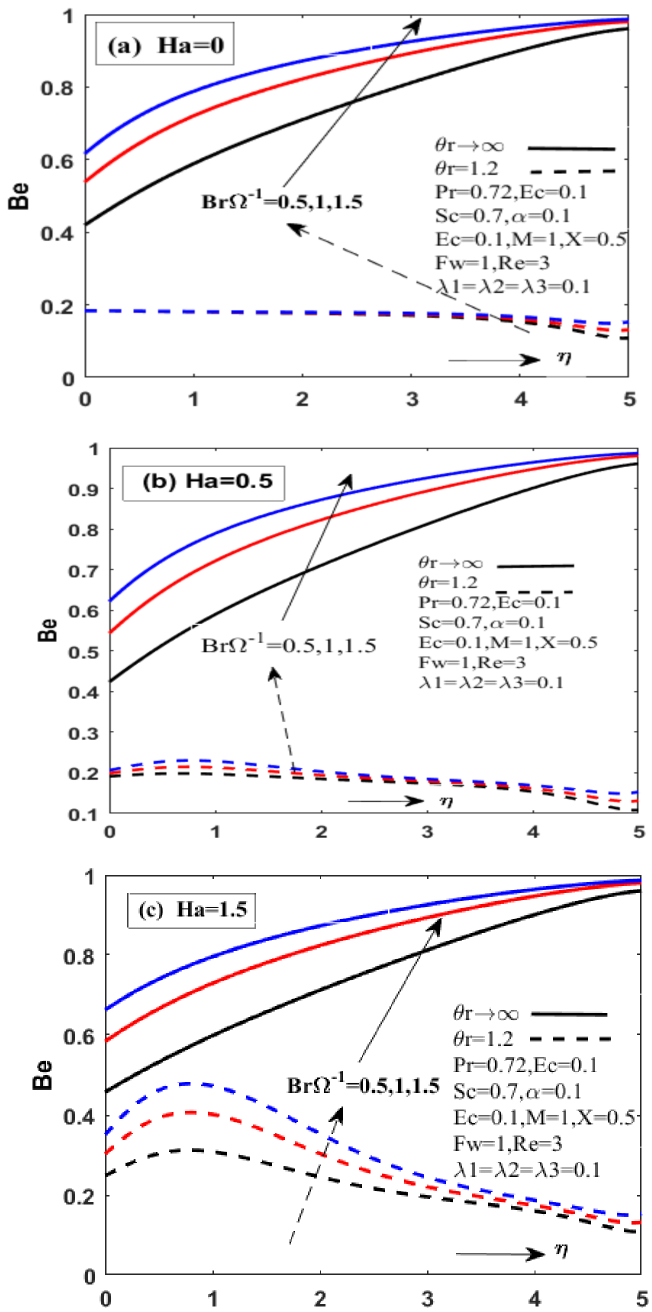

Figure 24. (a) The Began number for different values of $Br\Omega^{-1}$ and θ_r and Ha=0, (b) The Began number for different values of $Br\Omega^{-1}$ and θ_r and Ha=0, (c) The Began number for different values of $Br\Omega^{-1}$ and θ_r and Ha=0,

7. CONCLUSION

Entropy analysis for the steady two dimensional laminar flow, heat and mass transfer of an incompressible fluid over a non-isothermal permeable stretching sheet in the presence magnetic field, variable viscosity, and heat generation is examined. The governing boundary layer equations are transferred using suitable similarity transformations three nonlinear coupled ordinary differential equations, which are then solved by using Rung-Kutta method with shooting technique. The effect of variable physical parameters on the velocity, temperature, concentration, entropy generation number, and Bejan number are analyzed. The results indicate that, increasing the magnetic field parameter tends to decrease the velocity profile but increases the temperature and concentration profiles. In addition, when the temperature dependent fluid viscosity is included, a considerable rise in the velocity and considerable reduction in the temperature and concentration profiles throughout the boundary layer are observed. Also it has been noticed that the increasing of Schmidt number Sc corresponds to lower concentration field $\varphi(\eta)$ for both constant and variable viscosity. The entropy generation inside the boundary layer slightly decreases with increase of magnetic field, Eckert number and heat generation but the opposite behavior is noticed outside the boundary layer. Moreover, by increasing the Schmidt number, the entropy generation is found to be smaller for the flow of variable fluid viscosity than that for the flow of constant fluid viscosity. The present study assures that the Schmidt number and temperature dependent fluid viscosity parameter may be taken as the dominant variables for entropy generation since their variations could considerably alter the entropy generation inside the boundary layer.

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