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Effect of Heat Source/Sink on Unsteady Free Convective Mhd Flow Past A Linearly Accelerated Vertical Plate With Mass Diffusion

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ABSTRACT:

The Effect of Heat source/sink on unsteady free-convective flow past an accelerated infinite vertical plate with mass diffusion in the presence of transverse magnetic field is investigated. Laplace transformation technique is used to find the exact solution of the problem. The profiles of concentration, temperature and velocity are shown graphically for magnetic field parameter(M), Prandtl number(Pr), Heat source/sink parameter(H), Thermal Grashof number(Gr), Mass Grashof number(Gm), Schmidt number(Sc) and Soret number(So). Variations of Skin-friction, Nusselt number and Sherwood number are also discussed with the help of tables and graphs. It is shown that mass diffusivity, time, viscosity and mass buoyancy forces increases the fluid motion whereas magnetic field parameter, thermal buoyancy forces , heat absorption parameter decreases the fluid motion. It is also shown that mass diffusion decreases the species concentration and temperature increases with time. The results are represented in terms of exponential and complementary error functions.

KEYWORDS: Free-convection, MHD, Vertical plate, Heat Source/Sink, Transverse magnetic field, Mass diffusion.

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INTRODUCTION

The study of MHD free convection flow is very important because of its wide range of applications in the field of engineering, science, technology, astrophysics, space dynamics etc. Free convection in the fluid arises when change in temperature cause variation in density which leads to buoyancy forces acting on the fluid elements. This study has many engineering applications as in MHD bearings, MHD pumps etc. The investigation on MHD free convective flow is applied to study the solar and stellar composition in astrophysics and geophysics. The magnetic field effect on free convective flow is studied because of its importance in ionized gases, liquid metals and electrolytes etc. The study of radiative flows is important in numerous industrial and environment processes such as evaporation process from water reservoirs, fossil fuel combustion energy processes, heating and cooling chambers, astrophysical flows, space vehicle re-entry and solar power technology etc.

Many researchers have made contribution in solving problems of free convective flows under different boundary conditions. Soundalgekar et al.[1, 2] studied the effects of transversely applied magnetic field on the impulsively started vertical infinite plate with variable temperature and an electrically conducting fluid past an impulsively started infinite isothermal vertical plate. Rajput and Sahu[3] studied the on the unsteady transient free convection flow of an incompressible viscous fluid between two vertical infinite parallel plates with constant temperature and uniform transverse magnetic field. Sandeep and Sugunamma[4] investigated on unsteady free convective flow of a dissipative fluid past a vertical plate with inclined magnetic field. The thermal radiation effects of a optically thin gray gas bounded by a stationary vertical plate were investigated by England and Emery[5]. Radiation effect on mixed convection along a isothermal vertical plate were studied by Hossain and Takhar[6]. Das et al.[7] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. Recently Garg et al.[8] have investigated on mixed convective MHD flow in hot vertical channel through porous medium with spanwise co sinusoidal temperature and thermal radiations. Very recently Garg et al.[9, 10] have investigated on unsteady free convective flow in vertical channel through porous medium under different boundary conditions with thermal radiations. Chamkha[11] studied the effect of thermal radiation and buoyancy forces with heat source or sink on hydro-magnetic flow over an accelerating permeable surface. Kandasamy et al.[12] studied the heat and mass transfer and chemical reaction effects with heat source on MHD flow over a vertical stretching surface. Effects of radiations on MHD flow past a moving isothermal vertical plate with variable mass diffusion were studied by Muthucumaraswamy and Janakiraman[13]. Rajesh et al.[14] and Kumar et al.[15] investigated on the effects of thermal diffusion and radiation on MHD flow past a vertical plate with and mass diffusion and variable temperature. Saxena and Dubey[16] carried out the study of effects of heat generation and thermal diffusion on unsteady MHD convective flow of a polar fluid which past a vertical moving plate in a porous medium with heat and mass transfer. Very recently, Garg and Shipra[17, 18] studied the heat source/sink effects on MHD flow past an impulsively started vertical plate with variable heat and mass transfer

The present study considers the effects of heat source/sink on unsteady free-convective flow past a linearly accelerated vertical plate with mass diffusion. The dimensionless governing equations of the flow are solved using Laplace transformation technique and solutions are expressed in terms of exponential and complementary error functions. The results of velocity, temperature are shown with the help of graphs and tables.

MATHEMATICAL ANALYSIS

We are considering flow of a incompressible viscous fluid past a linearly accelerated vertical plate .The x'-axis is chosen along the plate in vertically up direction and y'-axis is chosen perpendicular to it. At time $t' \leq 0$, the fluid and plate are kept at equal temperature in stationary condition. At time $t' > 0$, the plate is linearly accelerated with velocity $u = u_o t'$. The temperature and concentration of plate is slightly raised to T_w' and C_w' . A uniform magnetic field is applied normal to the plate. The flow field is governed by the set of equations:

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty) - \frac{\sigma B_0^2 u'}{\rho} + \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta^*(C' - C'_\infty) \tag{1}$$

$$\rho c_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} + Q^*(T' - T'_\infty) \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} + D_1\frac{\partial^2 T'}{\partial y'^2} \tag{3}$$

The initial and boundary conditions are

$$\left.\begin{array}{l} u' = 0, T' = T'_\infty, C' = C'_\infty \ \forall\ y',\ t' \leq 0 \\ \left.\begin{array}{r} u' = u_o t' \\ T' = T'_\infty + (T'_w - T_\infty)At' \\ C' = C'_\infty + (C'_w - C_\infty)At' \end{array}\right\} at\ y' = 0,\ t' > 0 \\ u' \to 0, T' \to T'_\infty, C' \to C'_\infty\ as\ y' \to \infty\ , t' > 0 \end{array}\right] \tag{4}$$

Where A = $\frac{u_o^2}{\nu}$.

Here u' is velocity in x' direction, t' is time, g is acceleration due to gravity, T' is temperature of the fluid, T'_w is the plate temperature, T'_∞ is temperature of fluid far away from plate, C' is species concentration, C'_w is the species concentration near the wall, C'_∞ is species concentration in the fluid far away from the plate, β is the coefficient of volume expansion, β^* is the coefficient of thermal expansion with concentration, σ is electrical conductivity of the fluid, ν is the kinematic viscosity, ρ is the density, B_o is electromagnetic induction, c_p is specific heat at constant pressure, k is thermal conductivity, Q^* is heat source/sink, D is chemical molecular diffusivity and D_1 is coefficient of thermal diffusivity .

Introducing the following non- dimensional quantities:

$$u = \frac{u'}{u_o} \quad y = \frac{y'}{\nu}u_o \quad t = \frac{t'u_o^2}{\nu} \quad H = \frac{Q^*\nu^2}{ku_o^2}$$

$$\theta = \frac{(T'-T'_\infty)}{(T'_w-T'_\infty)} \quad C = \frac{(C'-C'_\infty)}{(C'_w-C'_\infty)} \quad G_r = \frac{\nu g\beta(T'_w-T'_\infty)}{u_o^3}, G_m = \frac{\nu g\beta^*(C'_w-C'_\infty)}{u_o^3} \tag{5}$$

$$M = \frac{\sigma B_o^2\nu}{\rho u_o^3} \quad P_r = \frac{\nu\rho c_p}{k} \quad S_c = \frac{\nu}{D} \quad S_o = \frac{D_1(T'_w - T'_\infty)}{\nu(C'_w - C'_\infty)}$$

Where H, M, θ, G_r , G_m, Pr , Sc and S_o are the heat source parameter, the magnetic field parameter, the dimensionless temperature, thermal Grashof number, mass Grashof number, the Prandtl number, Schmidt number and Soret number respectively.

Then in view of (5), equations (1), (2) and (3) reduce to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m C - Mu$$

(6)

$$P_r\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - H\theta$$

(7)

$$S_c\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} + S_o S_c\frac{\partial^2 \theta}{\partial y^2}$$

(8)

The corresponding initial and boundary conditions becomes

$u(y,t) = 0,\ ,\theta(y,t) = 0,\ C(y,t) = 0\ \forall\ y$ and $t \le 0$

$u(y,t) = t,,\theta(y,t) = t, C(y,t) = t$ for $y = 0\ and\ t > 0$

(9)

$u(y,t) \to 0,\ ,\theta(y,t) \to 0,\ C(y,t) \to 0$ as $y \to \infty$ and $t > 0$

The system of equations of flow (6)-(8), under the boundary conditions (9) consist of the effect of heat source on unsteady free convective flow with transverse magnetic field and mass diffusion past a linearly accelerated vertical plate .

SOLUTION OF THE PROBLEM

To find the solution of the equations of flow (6)-(8), under the boundary conditions (9), we have used Laplace Transformation method. The solution of given problem is given by

$$\theta(y,t) = C_4 exp(\alpha_6)erfc(\beta_{13}) + C_5 exp(-\alpha_6)erfc(\beta_{14}) \tag{10}$$

$$C(y,t) = (1+b)\left[C_3 erfc(\beta_5) - \alpha_{10}\exp\left(-\beta_5^2\right)\right] + merfc(\beta_5)$$
$$-\frac{1}{2}mexp(-\gamma_1)[exp(\alpha_3)erfc(\beta_{21}) + exp(-\alpha_3)erfc(\beta_{22})]$$
$$-b[C_4 exp(\alpha_6)erfc(\beta_{13}) + C_5 exp(-\alpha_6)erfc(\beta_{14})]$$
$$+\frac{1}{2}mexp(-\gamma_1)[exp(\alpha_7)erfc(\beta_{15}) + exp(-\alpha_7)erfc(\beta_{16})]$$
$$-\tfrac{1}{2}m[exp(\alpha_6)erfc(\beta_{13}) + exp(-\alpha_6)erfc(\beta_{14})] \qquad (11)$$

$$u(y,t) = A_1[C_1 exp(\alpha_1)erfc(\beta_1) + C_2 exp(-\alpha_1)erfc(\beta_2)] - \frac{A_2}{2}exp(-\gamma_1)[exp(\alpha_2)erfc(\beta_3)$$
$$+ exp(-\alpha_2)erfc(\beta_4)] + \frac{A_3}{2}[exp(\alpha_1)erfc(\beta_1) + exp(-\alpha_1)erfc(\beta_2)]$$
$$- B_1\left[C_3 erfc(\beta_5) - \beta_6\exp\left(-\beta_5^2\right)\right] - \frac{B_2}{2}exp(-\gamma_1)[exp(\alpha_3)erfc(\beta_7)$$
$$+ exp(-\alpha_3)erfc(\beta_8)] + \frac{B_3}{2}exp(\gamma_2)[exp(\alpha_4)erfc(\beta_9) + exp(-\alpha_4)erfc(\beta_{10})]$$
$$- \frac{B_3}{2}exp(\gamma_2)[exp(\alpha_5)erfc(\beta_{11}) + exp(-\alpha_5)erfc(\beta_{12})] - B_4 erfc(\beta_5)$$
$$+ B_5[C_4 exp(\alpha_6)erfc(\beta_{13}) + C_5 exp(-\alpha_6)erfc(\beta_{14})] + \frac{B_6}{2}exp(-\gamma_1)[exp(\alpha_7)erfc(\beta_{15})$$
$$+ exp(-\alpha_7)erfc(\beta_{16})] - \frac{B_7}{2}exp(-\gamma_3)[exp(\alpha_8)erfc(\beta_{17}) + exp(-\alpha_8)erfc(\beta_{18})]$$
$$+ \frac{B_7}{2}exp(-\gamma_3)[exp(\alpha_9)erfc(\beta_{19}) + exp(-\alpha_9)erfc(\beta_{20})] + \frac{B_8}{2}[exp(\alpha_6)erfc(\beta_{13})$$
$$+ exp(-\alpha_6)erfc(\beta_{14})]$$

NUSSELT NUMBER

The Nusselt number is derived from temperature field and it is the measure of heat transfer rate. In dimensionless form, Nusselt number is given by

$$N_u = -\left(\frac{\partial\theta(y,t)}{\partial t}\right)_{y=0}$$
$$= \left(t\sqrt{H} + \frac{P_r}{2\sqrt{H}}\right) erf\sqrt{\frac{H}{P_r}t} + \sqrt{\frac{tP_r}{\pi}}\, e^{-\frac{H}{P_r}t}.$$

SHERWOOD NUMBER

The Sherwood number is derived from Concentration field and it is the measure of mass transfer rate at plate. In dimensionless form, Sherwood number is given by

$$S_h = -\left(\frac{\partial C(y,t)}{\partial t}\right)_{y=0} = 2(1+b)\sqrt{\frac{tS_c}{\pi}} - me^{-ct}\sqrt{-cS_c}erf\sqrt{-ct} - b\left[\left(t\sqrt{H} + \frac{P_r}{2\sqrt{H}}\right) erf\sqrt{\frac{H}{P_r}t} + \sqrt{\frac{tP_r}{\pi}}\, e^{-\frac{H}{P_r}t}\right] + m\left[\sqrt{H-cP_r}erf\sqrt{\left(\frac{H}{P_r}-c\right)t} + \sqrt{\frac{P_r}{\pi t}}\, e^{-\left(\frac{H}{P_r}-c\right)t}\right] - m\left[\sqrt{H}erf\sqrt{\frac{H}{P_r}t} + \sqrt{\frac{P_r}{\pi t}}\, e^{-\frac{H}{P_r}t}\right]$$

SKIN FRICTION

Skin Friction is derived from velocity field. The effect of t, H, M, Sc and Pr on Skin Friction coefficient in the dimensionless form is given by

$$\tau = -\left(\frac{\partial u(y,t)}{\partial t}\right)_{y=0}$$

$$= U_1 erf\sqrt{Mt} + U_2\sqrt{\frac{1}{\pi t}}\, e^{-Mt} - U_3\sqrt{\frac{S_c}{\pi t}} + U_4 erf\sqrt{\frac{H}{P_r}t} + U_5 e^{-\frac{H}{Pr}t}$$

$$+e^{-ct}\left[A_2\sqrt{M-c}\, erf\sqrt{(M-c)t} - B_2\sqrt{-cS_c} erf\sqrt{-ct} + B_6\sqrt{H-cP_r} erf\sqrt{\left(\frac{H}{P_r}-c\right)t}\right]$$

$$+B_3 e^{kt}\left[\sqrt{kS_c} erf\sqrt{kt} - \sqrt{M+k}\, erf\sqrt{(M+k)t}\right] - B_7 e^{-lt}\left[\sqrt{H-cl} erf\sqrt{\left(\frac{H}{P_r}-l\right)t} - \sqrt{M-l}\, erf\sqrt{(M-l)t}\right].$$

RESULTS AND DISCUSSIONS

To understand the physical meaning of the problem, numerical calculations are carried out to demonstrate the effect of different parameters upon the nature of flow. The numerical values of concentration, temperature, velocity, Nusselt number, Sherwood number and Skin friction coefficient are computed at different parameters like Prandtl number Pr, Schmidt number Sc, thermal Grashof number Gr, mass Grashof number Gm , Magnetic field parameter M, Heat source/sink parameter H and time t. The numerical results are shown graphically by Figs. (1)-(12) and Tables- (1)-(3).

Fig. 1 demonstrates the concentration profile for different values of heat source/sink parameter H. The values of H are taken as 2, 4, 6 and 8. The graph of concentration shows that concentration of plate increases with increasing value of heat source/sink parameter but after some time it becomes constant.

Fig. 2 depicts the concentration profile at different time. The values of t are taken as 0.1, 0.2 0.3 and 0.4. The graph of concentration shows that concentration of plate increases when time is increased .Here other parameters such as H, Pr, Sc and So are kept constant.

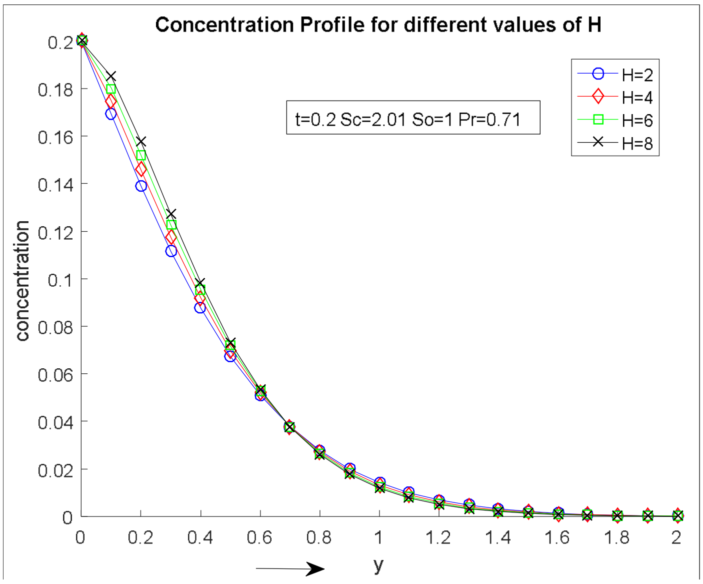


Figure (1): Concentration profile for different values of Heat Source/Sink Parameter

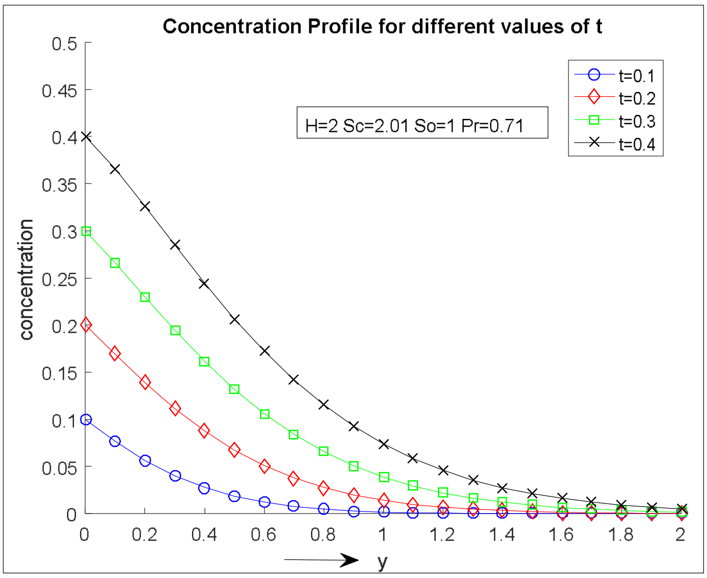


Figure (2): Concentration profile for different values time

Fig. 3 demonstrates the concentration profile for different values of Soret number (So) , Schmidt number (Sc) and Prandtl number (Pr). The values of Schmidt number are taken as 2.01, 3 and 4 keeping other numbers as constants. The graph of concentration shows that concentration of plate slow down with increasing value of Schmidt number. The graph also shows that concentration of plate raises with rising values of Soret number. The same graphs also describe the effect of Prandtl number on concentration. It is shown that concentration increases with increase in Prandtl number.

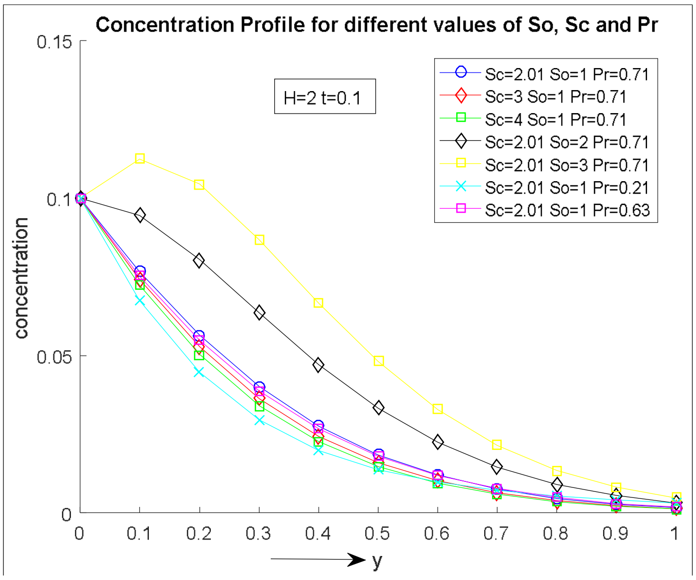


Figure (3): Concentration profile for different values of Soret Number, Schmidt Number and Prandtl Number

Variations in temperature profile with Heat source/sink parameter, time and Prandtl number are shown in Fig.4. Here different values of heat source/sink parameter are chosen as H = 2, H = 4 and H =6 to show the effect of it on temperature .The value of Prandtl number is taken as 0.71 and time is chosen as 0.2. It is observed from the graph that increases in heat source/sink parameter results in decrease in temperature when other parameters are kept constant. The effect of time on temperature profile is shown by taking values of t as 0.2, 0.4 and 0.6. Here heat source/sink parameter is taken as H=2 and Prandtl number is taken as t = 0.4. From the graph, it is observed that temperature increases with increasing values of time while heat source/sink parameter and Prandtl number are kept constant

The effect of Prandtl number on temperature is shown by choosing the values of Pr 0.21, 0.71 and 7. Here heat source/sink parameter is taken as H=2 and time is taken as t = 0.2. From the graph, it is observed that temperature reduces when Prandtl number increases. It is also noticed that temperature for water (Pr=7) is low as compared to temperature for air (Pr=0.71).

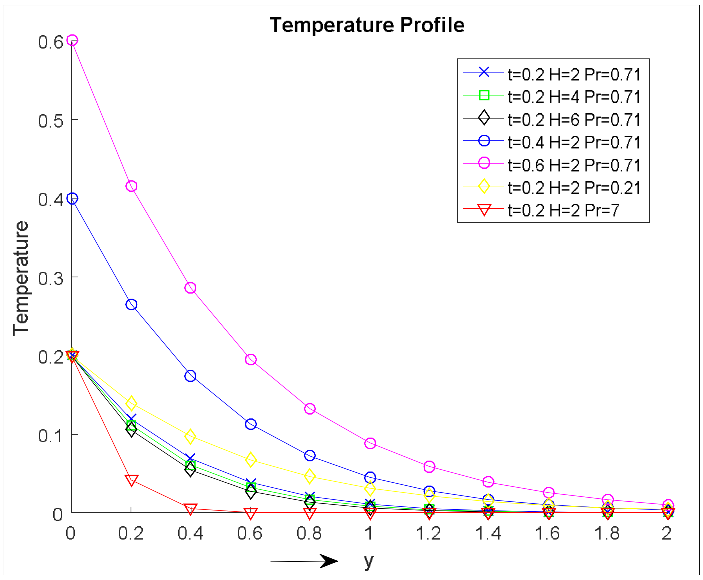


Figure (4): Temperature profile for different values of time, Heat Source/Sink Parameter and Prandtl Number

Fig.5 depicts the effect of Heat Source/Sink parameter (H) and Magnetic field parameter (M) on velocity Profile. The values of H are chosen as 4, 6 and 8. Other parameters (Pr=0.71, t=0.1, M=1, Gr = 1, Gm=1, Sc=2.01, So =1) are kept constant. The graph depicts that increasing value of H accelerate the fluid flow. The values of M are chosen as 1, 1.2 and 1.4. Other parameters (H=4, Pr=0.71, t=0.1, M=1, Gr = 1, Gm=1, Sc=2.01, So =1) are kept constant. It is shown that transverse magnetic field retards the fluid flow.

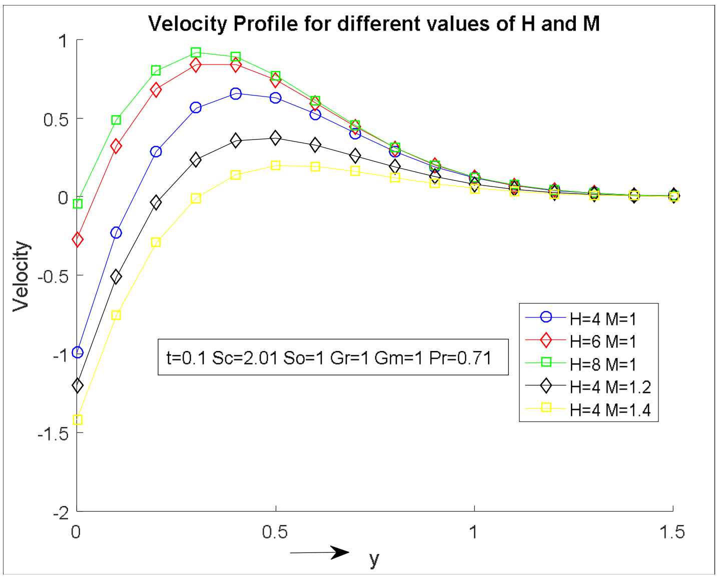


Figure (5): Effect of Heat Source/Sink Parameter and Magnetic Field Parameter on Velocity Profile

Fig.6 represents the effect of time on velocity Profile. The values of t are chosen as 0.1, 0.2, 0.3 and 0.4. Other parameters (H=4, M=1, Sc=2.01, So=1, Pr=0.71, Gm=1, Gr = 1) are kept constant. The graph depicts that velocity decreases with increasing value of t.

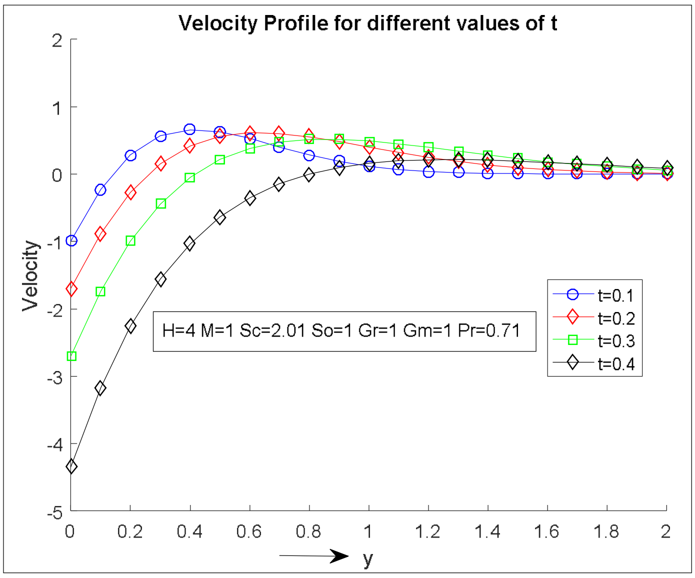
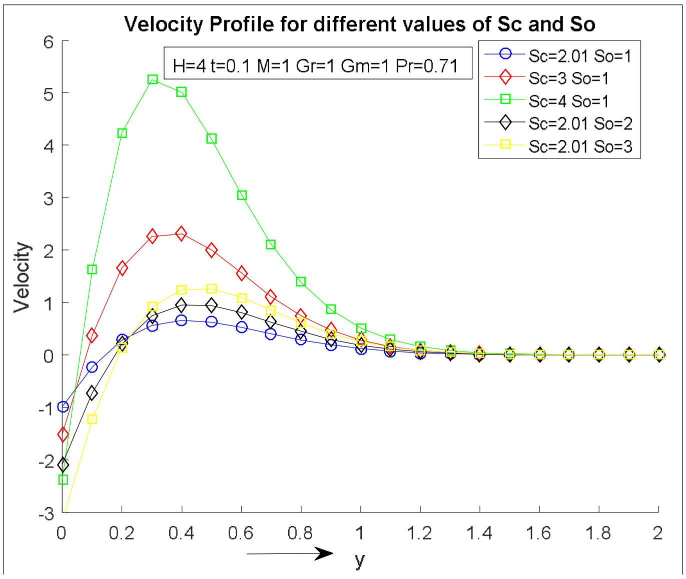


Figure (6): Effect of Time on Velocity Profile

The Effects of Schmidt number and Soret number on velocity profile are shown by Fig. 7. The graph shows that velocity increases with increasing values of Schmidt number. The same graph also shows that initially velocity of fluid decreases but after some value y (distance from the plate) it starts increasing with increasing values of Soret number.



Figure(7): Effect of Schmidt Number and Soret Number on Velocity Profile

The Effects of Thermal Grashof number, Mass Grashof number and Prandtl number on velocity profile are shown by Fig. 8 & 9. Fig. 8 clearly depicts that velocity profile rises with increasing values of thermal Grashof number and mass Grashof number. Fig. 9 shows variations in velocity profile at different values Prandtl number. The graph shows that velocity increases with increasing values of Prandtl number.

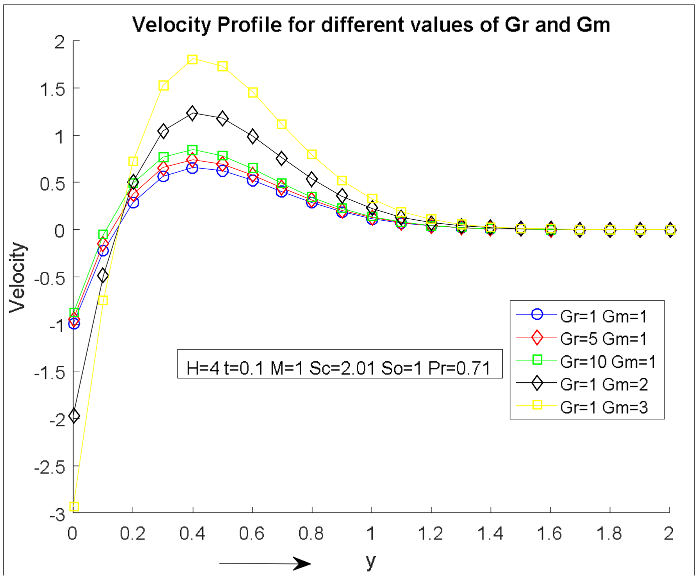


Figure (8): Effect of Thermal Grashof Number and Mass Grash of Number on Velocity Profile

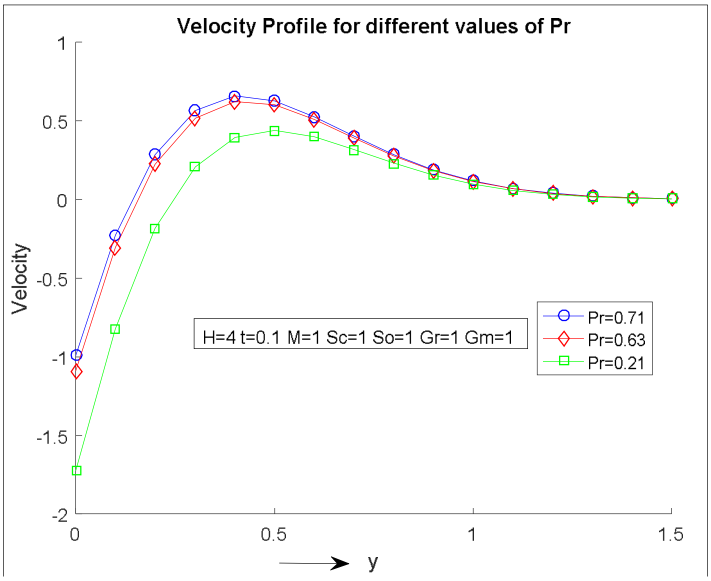


Figure (9): Effect of Prandtl Number on Velocity Profile

The effect of t, H and Pr on Nusselt number is depicted by Table-(1). Table indicates that heat transfer rate is higher by increasing values of time, heat source parameter and Prandtl Number. These effects are presented graphically by Fig. 10.

Table-1: Variations of Nusselt Number

Time(t)	Heat Source/Sink(H)	Prandtl Number(Pr)	Nusselt Number(Nu)
0.1	2	0.71	0.3281
0.2	2	0.71	0.5009
0.3	2	0.71	0.6564
0.1	4	0.71	0.3542
0.1	6	0.71	0.3790
0.1	2	0.21	0.2111
0.1	2	0.16	0.1959

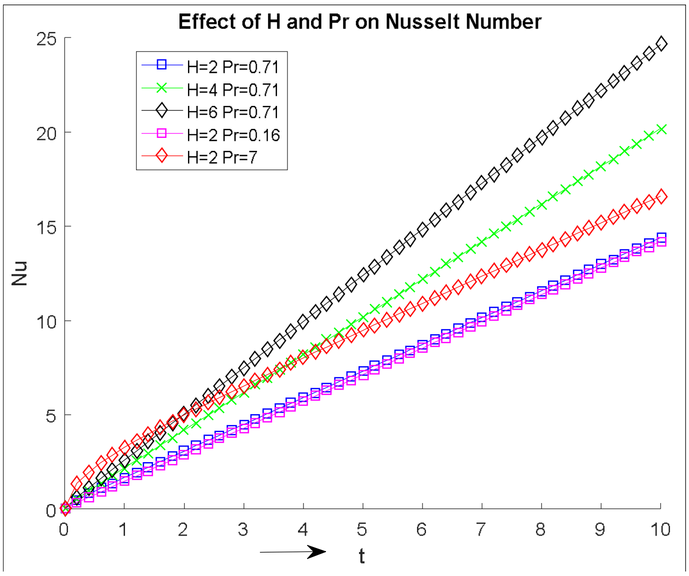


Figure (10) Effect of Heat Source/Sink Parameter and Prandtl Number on Nusselt Number

Sherwood number variations at different values of Schmidt number, Heat source/sink parameter, Prandtl number and Soret number with time are shown by Table-(2) and Fig. 11.The graph shows that increasing values of Schmidt number rises the Sherwood number. From Table-(2), it is noticed that initially Sherwood number decreases slightly with increasing values of Schmidt number but after some time it starts increasing with Schmidt number. Also it is observed that increasing values of Heat source/sink parameter, Prandtl number and Soret number reduce the Sherwood number. It means rate of mass transfer decreases with increase in time, Heat source/sink parameter, Prandtl number and Soret number.

Table-2: Variations of Sherwood Number

Time ↓	**H=2 So=1 Pr=0.71**			**Sc=2.01 So=1Pr=0.71**		**Sc=2.01 H=2 So=1**		**Sc=2.01 H=2 Pr=0.71**	
	Sc=2.01	**Sc=3**	**Sc=4**	**H=4**	**H=6**	**Pr=0.68**	**Pr=0.21**	**So=2**	**So=3**
0.1	-0.4637	-0.5551	-0.6974	-0.7511	-1.0546	-0.4280	0.0118	-1.4332	-2.4028
0.2	-1.0623	-1.1860	-1.4295	-1.9512	-2.9948	-0.9984	-0.2738	-2.8400	-4.6177
0.3	-1.8267	-1.9432	-2.2822	-3.6679	-6.1357	-1.7286	-0.6723	-4.5295	-7.2324
0.4	-2.7594	-2.8155	-3.2408	-6.0306	-11.0979	-2.6187	-1.1596	-6.5305	-10.3017
0.5	-3.8729	-3.7985	-4.2965	-9.2427	-18.9078	-3.6790	-1.7298	-8.8770	-13.8812
0.6	-5.1871	-4.8922	-5.4446	-13.5920	-31.2100	-4.9269	-2.3833	-11.6134	-18.0397
0.7	-6.7282	-6.0994	-6.6833	-19.4764	-50.6213	-6.3857	-3.1240	-14.7949	-22.8615
0.8	-8.5286	-7.4251	-8.0123	-27.4398	-81.2976	-8.0844	-3.9579	-18.4880	-28.4474
0.9	-10.6274	-8.8761	-9.4331	-38.2243	-129.8348	-10.0581	-4.8926	-22.7724	-34.9174
1	-13.0711	-10.4608	-10.9480	-52.8407	-206.6997	-12.3483	-5.9374	-27.7419	-42.4128

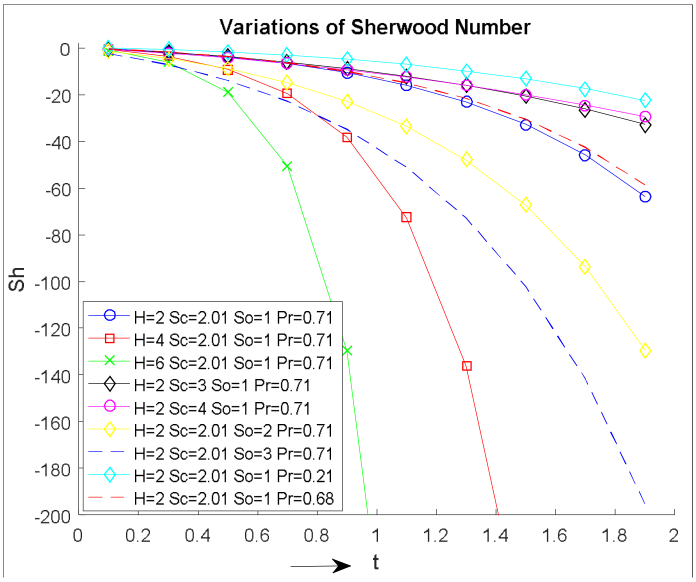


Figure (11): Effect of Different Parameters on Sherwood Number

Table-3: Variations of Parameters on Skin Friction

Time (t)	**Heat Source /Sink Parameter (H)**	**Magnetic Field Parameter (M)**	**Schmidt Number (Sc)**	**Soret Number (So)**	**Thermal Grashof Number (Gr)**	**Mass Grashof Number (Gm)**	**Prandtl Number (Pr)**	**Skin-Friction (τ)**
0.2	**4**	**1**	**2.01**	**1**	**5**	**1**	**0.71**	6.2135
0.3	4	1	2.01	1	5	1	0.71	7.5998
0.4	4	1	2.01	1	5	1	0.71	8.2295
0.2	**8**	1	2.01	1	5	1	0.71	6.2671
0.2	**10**	1	2.01	1	5	1	0.71	6.0760
0.2	4	**1.5**	2.01	1	5	1	0.71	3.9808
0.2	4	**2**	2.01	1	5	1	0.71	2.5834
0.2	4	1	**3**	1	5	1	**0.71**	12.4068
0.2	4	1	**4**	1	5	1	**0.71**	20.5309
0.2	4	1	2.01	**2**	5	1	0.71	9.8376
0.2	4	1	2.01	**3**	5	1	0.71	13.4617
0.2	4	1	2.01	1	**10**	1	0.71	6.0574
0.2	4	1	2.01	1	**15**	1	0.71	5.9013
0.2	4	1	2.01	1	5	**2**	0.71	12.0455
0.2	4	1	2.01	1	5	**3**	0.71	17.8774
0.2	4	1	2.01	1	5	1	**0.21**	5.7694
0.2	4	1	2.01	1	5	1	**0.16**	5.6995

Skin-Friction variations at different parameters are shown by Table-(3) and Figs. 12 & 13. An increment in skin-friction is observed with increasing values of t, Sc, So and Pr. Also an increase in values of H, M and Gr shows reduction in the value of skin friction. It is also observed that value of Skin-Friction increase initially with growing values of Gm but it starts decreasing with time.

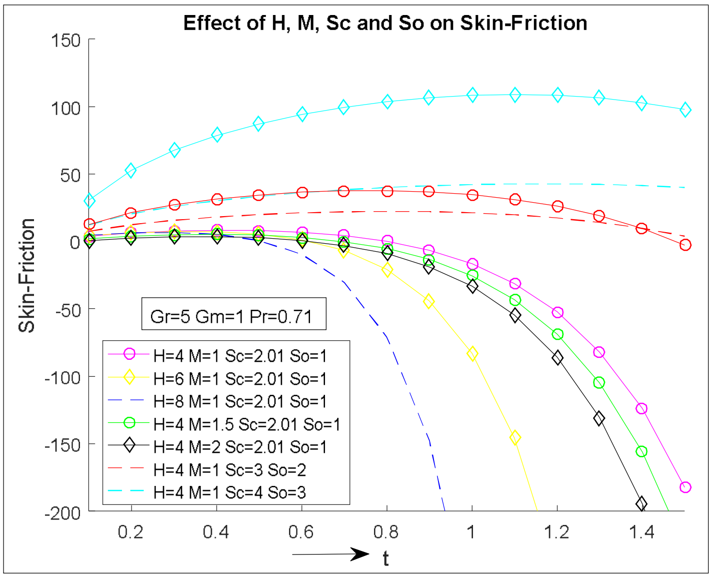


Figure (12): Effect of Heat Source/Sink Parameter, Magnetic Field Parameter, Schmidt Number and Soret Number on Skin-Friction

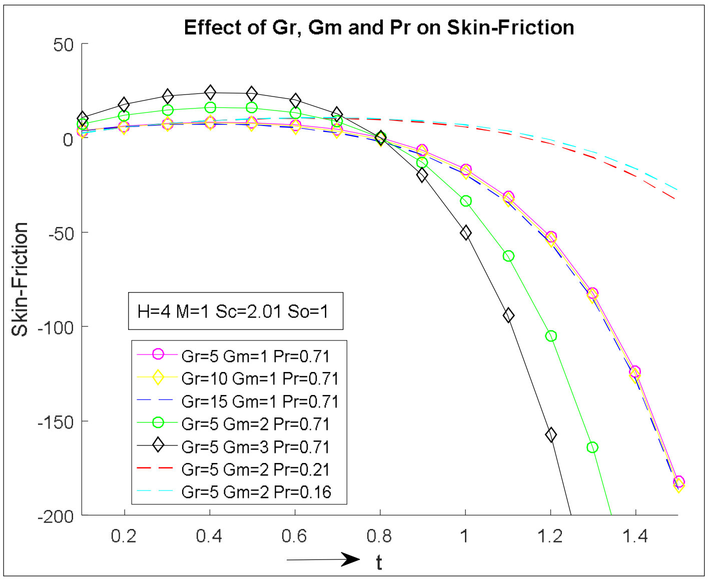


Figure (13): Effect of Thermal and Mass Grash of Number and Prandtl Number on Skin-Friction

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CONCLUSIONS

The study of the heat source/sink effects on unsteady free convective flow with transverse magnetic field and mass diffusion past a linearly accelerated vertical plate can be concluded as:

(i) Progression in time, heat absorption and viscosity increases the species concentration whereas mass diffusivity decreases it.

(ii) Viscosity and heat source parameter reduces the fluid temperature whereas increasing time increases the fluid temperature.

(iii) Mass diffusivity, time, viscosity and mass buoyancy forces accelerate the fluid motion whereas magnetic field, thermal buoyancy force, heat absorption parameter tends to retard the fluid motion.

(iv) The heat transfer rate is increased with progression in time, viscosity and heat source parameter.

(v) Rate of mass transfer decreases with increment in time, viscosity and heat absorption parameter whereas it increases with mass diffusivity.

(vi) Shear stress increases with increment in time, viscosity, mass diffusivity and Soret effect whereas heat absorption parameter, magnetic field parameter, thermal buoyancy forces and mass buoyancy forces decrease it.

APPENDIX

$$a = bc\,,\quad b = S_o S_c\,,\quad c = \frac{H}{P_r - S_c}\,,\quad d = \frac{bP_r}{P_r - S_c}\,,\quad k = \frac{M}{S_c - 1}\,,\quad l = \frac{H - M}{P_r - 1}$$

$$B_1 = \frac{G_m(a + c)}{Mc}\,,\quad B_2 = \frac{bS_cG_m}{H(S_c - 1)(k + c)}\,,\quad B_3 = \frac{G_m(S_c - 1)[M(H + bcP_r) + Hc(S_c - 1)(1 + b)]}{M^2H(S_c - 1)(k + c)}$$

$$B_4 = \frac{G_m[H(S_c - 1)(1 + b) + MbS_c]}{M^2H}\,,\quad B_5 = \frac{bG_m - G_r}{H - M}\,,\quad B_6 = \frac{bG_m(cP_r - H)}{cH(cP_r - H - c + M)}$$

$$B_7 = \frac{(1-P_r)[bcG_m(MP_r-H)-HG_r(cP_r-H-c+M)]}{H(H-M)^2(cP_r-H-c+M)}\,,\quad B_8 = \frac{cH(G_r-bG_m)(P_r-1)+bG_m(P_r-H)(H-M)}{cH(H-M)^2}$$

$$A_1 = 1 + B_1 - B_5\,,\quad A_2 = B_2 + B_6\,,\quad A_3 = B_3 - B_7\,,\quad A_4 = B_4 - B_8$$

$$C_1 = \frac{t}{2} + \frac{y}{4\sqrt{M}}\,,\quad C_2 = \frac{t}{2} - \frac{y}{4\sqrt{M}}\,,\quad C_3 = t + \frac{y^2}{2}S_c\,,\quad C_4 = \frac{t}{2} + \frac{y}{4\sqrt{H}}P_r\,,\quad C_5 = \frac{t}{2} - \frac{y}{4\sqrt{H}}P_r$$

$$U_1 = A_1\left(\frac{1}{2\sqrt{M}} + t\sqrt{M}\right) + A_3\sqrt{M}\,,\quad U_2 = A_1t - A_2 - A_3 + A_4\,,\quad U_3 = 2B_1t + B_2 - B_3 + B_4$$

$$U_4 = B_5\left(\frac{P_r}{2\sqrt{H}} + t\sqrt{H}\right) + B_8\sqrt{H}\,,\quad U_5 = B_5t + B_6 - B_7 + B_8$$

$$\alpha_1 = y\sqrt{M}\,,\quad \alpha_2 = y\sqrt{M - c}\,,\quad \alpha_3 = y\sqrt{-cS_c}\,,\quad \alpha_4 = y\sqrt{kS_c}\,,\quad \alpha_5 = y\sqrt{M + k}$$

$$\alpha_6 = y\sqrt{H}\,,\quad \alpha_7 = y\sqrt{H - cP_r}\,,\quad \alpha_8 = y\sqrt{H - lP_r}\,,\quad \alpha_9 = y\sqrt{M - l}\,,\ ,\quad \alpha_{10} = y\beta_6$$

$\beta_1 = \frac{y}{2\sqrt{t}} + \sqrt{Mt}$, $\beta_2 = \frac{y}{2\sqrt{t}} - \sqrt{Mt}$,

$\beta_3 = \frac{y}{2\sqrt{t}} + \sqrt{(M-c)t}$, $\beta_4 = \frac{y}{2\sqrt{t}} - \sqrt{(M-c)t}$

$\beta_5 = \frac{y}{2\sqrt{t}}\sqrt{S_c}$, $\beta_6 = \sqrt{\frac{tS_c}{\pi}}$,

$\beta_7 = \frac{y}{2\sqrt{t}} + \sqrt{-ct}$, $\beta_8 = \frac{y}{2\sqrt{t}} - \sqrt{-ct}$

$\beta_9 = \frac{y}{2\sqrt{t}}\sqrt{S_c} + \sqrt{kt}$, $\beta_{10} = \frac{y}{2\sqrt{t}}\sqrt{S_c} - \sqrt{kt}$

$\beta_{11} = \frac{y}{2\sqrt{t}} + \sqrt{(M+k)t}$, $\beta_{12} = \frac{y}{2\sqrt{t}} + \sqrt{(M+k)t}$

$\beta_{13} = \frac{y}{2\sqrt{t}}\sqrt{P_r} + \sqrt{\frac{H}{P_r}t}$, $\beta_{14} = \frac{y}{2\sqrt{t}}\sqrt{P_r} - \sqrt{\frac{H}{P_r}t}$,

$\beta_{15} = \frac{y}{2\sqrt{t}}\sqrt{P_r} + \sqrt{\left(\frac{H}{P_r} - c\right)t}$, $\beta_{16} = \frac{y}{2\sqrt{t}}\sqrt{P_r} - \sqrt{\left(\frac{H}{P_r} - c\right)t}$

$\beta_{17} = \frac{y}{2\sqrt{t}}\sqrt{P_r} + \sqrt{\left(\frac{H}{P_r} - l\right)t}$, $\beta_{18} = \frac{y}{2\sqrt{t}}\sqrt{P_r} - \sqrt{\left(\frac{H}{P_r} - l\right)t}$

$\beta_{19} = \frac{y}{2\sqrt{t}} + \sqrt{(M-l)t}$, $\beta_{20} = \frac{y}{2\sqrt{t}} - \sqrt{(M-l)t}$,

$\beta_9 = \frac{y}{2\sqrt{t}}\sqrt{S_c} + \sqrt{-ct}$, $\beta_{10} = \frac{y}{2\sqrt{t}}\sqrt{S_c} - \sqrt{-ct}$

$\gamma_1 = ct$, $\gamma_2 = kt$, $\gamma_3 = lt$

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