Global and Stochastic Analysis
Special Issue: *25th International Conference of*
Forum for Interdisciplinary Mathematics

MUK PUBLICATIONS
Open Access Publisher

SORET AND DUFOUR EFFECTS ON MHD FLUID FLOW DUE TO MOVING PERMEABLE CYLINDER WITH RADIATION

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Abstract: In this study heat transfer and MHD fluid flow due to moving permeable cylinder with suction or injection, radiation, and the Soret and Dufour effects are investigated. A similarity transformation is used to reduce the governing partial differentials into ordinary partial differentials. These non-dimensional differential equations are solved numerically by using Runge-Kutta fourth order method with shooting techniques. The main aim of this study is to deeply investigate the effects of governing parameters such as curvature parameter, suction/injection parameters, Soret and Dufour parameter and Radiation parameter etc. on the velocity and temperature profiles. The numerical results which are obtained by non-dimensional equations are displayed through graphically showing the effects of various parameters.

1. Introduction

Study of heat, momentum and mass transfer on moving permeable cylinderplays an important role in many engineering and industrial processes. Firstly,in 1961 Sakiadis [1, 2] gave a note on boundary-layer behavior on continuous solid surfaces: I. boundary-layer equations for two-dimensional and axisymmetric flow and boundary-layer behavior on continuous solid surfaces: II. The boundary-layer on a continuous flat surface. Crane [3] extended the Sakiadis problem and examined boundary layer flow past a stretching sheet. Lakshmisha et. al., [4] investigated the three dimensional unsteady flow with heat and mass transfer over a continuous stretching surface. Mahapatra and Gupta [5] studied heat transfer in stagnation-point flow towards a stretching sheet.

Boundary layer flow due to stretching/shrinking cylinder has many applications in fluid dynamics and attracted several researchers.Wang [6] examined boundary layer fluid flow due to a stretching cylinder. Combined heat and mass transfer along a vertical moving cylinder with a free stream investigated by Chamkha et. al., [7]. Wang [8] extended his own problem and numerically investigated natural convection in a vertical stretching cylinder.Erickson et. al., [9] discussed heat and mass transfer on a moving continuous flat plate with suction or injection. In continuity Ali [10] gave a note on thermal boundary layer on a power-law stretched surface with suction or injection. Uniform suction/blowing effect on flow and heat transfer due to a stretching cylinder investigated by Ishak et. al., [11]

Keyword. Stretching cylinder, Soret-Dufour effects, MHD, Radiation, Suction/Injection.

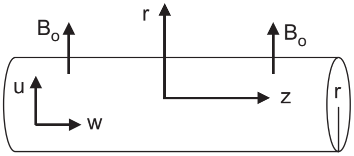
Chauhan and Vyas [12] examined heat transfer in MHD viscous flow due to stretching of a boundary in the presence of a naturally permeable bed. Amkandi and Azzouzi [13] gave a view on a similarity solution of MHD boundary layer flow over a moving vertical cylinder. Ishak et. al., [14] extended this problem and examined magneto hydrodynamic (MHD) flow and heat transfer due to a stretching cylinder. Chauhan and Agrawal [15] investigated MHD flow and heat transfer in a channel bounded by a shrinking sheet and a plate with a porous substrate. Ganesan and Loganathan [16] studied radiation and mass transfer effects on flow of an incompressible viscous fluid past a moving vertical cylinder. Chauhan et. al., [17] discussed magneto hydrodynamic flow and heat transfer in a porous medium along a stretching cylinder with radiation: Homotopy Analysis Method. Pop et. al., [18] examined radiation effect on the flow near the stagnation point of a stretching sheet. Makanda et. al., [19] studied effects of radiation on MHD free convection of a Casson fluid from a horizontal circular cylinder with partial slip in non-Darcy porous medium with viscous dissipation. Jain and Choudhary [20] discussed effects of MHD on boundary layer flow in porous medium due to exponentially shrinking sheet with slip Alao et. al., [21] investigated effects of thermal radiation, Soret and Dufour on an unsteady heat and mass transfer flow of a chemically reacting fluid past a semi-infinite vertical plate with viscous dissipation. Recently Jain and Bohra [22] studied radiation effects in flow through porous medium over a rotating disk with variable fluid properties.

Adrian [23] gave the influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Alam et. al., [24] studied Dufour and Soret effects on steady free convection and mass transfer flow past a semi-infinite vertical porous plate in a porous medium. Mahdy [25-26] investigated MHD flow of non-Darcian free convection from a vertical wavy surface embedded in porous media in the presence of Soret and Dufour effect also he studied Soret and Dufour effect on double diffusion mixed convection from a vertical surface in a porous medium saturated with a non-Newtonian fluid. Mixed convection heat and mass transfer in a non-Darcy micropolar fluid with Soret and Dufour effects were examined by Srinivasacharya and RamReddy [27]. Several researchers have done a lot of work in this area such as Rao et. al., [28], Zaib and Shafie [29], Omowaye et. al., [30], Srinivasacharya et. al., [31] and Vedavathi et. al., [32]. Recently Ramzan et. al., [33] studied three dimensional boundary layer flow of a viscoelastic nanofluid with Soret and Dufour effects. Sravanthi [34] investigated homotopy analysis solution of MHD slip flow past an exponentially stretching inclined sheet with Soret-Dufour effects. Hayat et. al., [35] discussed Soret and Dufour effects in MHD peristalsis of pseudoplastic nanofluid with chemical reaction. Zaidi and Mohyud-Din [36] investigated numerically analysis of wall jet flow for Soret, Dufour and chemical reaction effects in the presence of MHD with uniform suction/injection.

In this particular study we have investigated Soret and Dufour effects with radiative MHD boundary layer flow and heat transfer with suction/injection over a stretching moving cylinder. The numerical studied carried out with graphs.

2. Mathematical Formulation

Let we consider a laminar two-dimensional MHD boundary layer flow near the stagnation point flow and heat transfer in an electrically conducting fluid caused by vertical permeable cylinder moving with linear velocity, suction/injection and Soret and Dufour effects with radiation.



Schematic model of the problem

Under the Boussinesq approximation the continuity, momentum, energy and concentration equations are given as follows:

$$\frac{\partial}{\partial z}(rw) + \frac{\partial}{\partial r}(ru) = 0 \tag{1}$$

$$w\frac{\partial w}{\partial z} + u\frac{\partial w}{\partial r} = \nu\left(\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r}\right) + w_e(z)\frac{dw_e(z)}{dz} - \frac{\sigma B_0^2}{\rho}[w_e(z) - w] \tag{2}$$

$$w\frac{\partial T}{\partial z} + u\frac{\partial T}{\partial r} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + \frac{D_k}{c_p c_s}\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r}\right) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial r} \tag{3}$$

$$w\frac{\partial C}{\partial z} + u\frac{\partial C}{\partial r} = D\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r}\right) + \frac{D_k}{T_m}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) \tag{4}$$

where, z is the axial distance and r is the radial distance. w and u are the z-component and r-component respectively. T and T_∞ are the fluid temperature and ambient fluid temperature. C and C_∞ are the concentration and ambient concentration respectively. Here B_0 is uniform magnetic field, σ is electrical conductivity of the fluid, ρ is density, ν is kinematic viscosity, C_p is specific heat at constant pressure, α is thermal diffusivity, D_k is the diffusion coefficient, c_p is the specific heat, c_s is the concentration susceptibility, q_r is the radiative heat flux, D is the mass diffusion and T_m is the fluid mean temperature. Also here $w_e(z)$ is the free stream velocity.

The radiative heat flux followed by Rosseland approximation is

$$q_r = -\frac{4\sigma_1}{3k_1}\frac{\partial T^4}{\partial z}$$

where, σ_1 is the is the Stephan-Boltzmann constant and k_1 is the mean absorption constant.

T^4 may be expressed in terms of T is as follows

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4.$$

The boundary condition for this particular problem are

at $\quad r = R,\ u = -u_w,\ w = w_w z,\ T = T_w,\ C = C_w$

at $\quad r \to \infty,\ w = w_e(z) = w_\infty z,\ T = T_\infty,\ C = C_\infty \qquad (5)$

where, w_w (constant) u_w are the suction (> 0) or injection (< 0) velocity, T_w and C_w are the wall temperature and wall concentration respectively.

To get a similarity solution of this problem, we introduces following non-dimensional variables:

$$\eta = \sqrt{\frac{w_w}{2\nu}}\left(\frac{r^2 - \mathrm{R}^2}{\mathrm{R}}\right),\ \psi = \sqrt{\frac{\nu w_w}{2}}\ \mathrm{R}z\, f(\eta),\ \theta(\eta) = \frac{\mathrm{T} - \mathrm{T}_\infty}{\mathrm{T}_w - \mathrm{T}_\infty}$$

$$\mathrm{C}(\eta) = \frac{\mathrm{C} - \mathrm{C}_\infty}{\mathrm{C}_w - \mathrm{C}_\infty},\ w = \frac{1}{r}\frac{\partial\psi}{\partial r},\ u = -\frac{1}{r}\frac{\partial\psi}{\partial z} \tag{6}$$

where, η, $f(\eta)$, $\theta(\eta)$ and $\mathrm{C}(\eta)$ are the similarity variable, dimensionless velocity, dimensionless temperature and dimensionless concentration, respectively.

Eq. (1) identically satisfied by given similarity transformations. Substituting Eq. (6) into Eqs. (2), (3) and (4), then we obtain ordinary differential equations are as follows:

$$2(\mathrm{K}\eta + 1)f''' + (2\mathrm{K} + f)f'' - f'^2 - \mathrm{Ha}^2(\lambda - f') + \lambda^2 = 0 \tag{7}$$

$$\left[2(\mathrm{K}\eta + 1) - \mathrm{N}\right]\theta'' + \left(2\mathrm{K} + \mathrm{Pr}\, f - \mathrm{NK}\right)\theta' + \mathrm{Pr}\,\mathrm{D}f\left[2\mathrm{K}\phi' + 2(\mathrm{K}\eta + 1)\phi''\right] = 0 \tag{8}$$

$$2(\mathrm{K}\eta + 1)\phi'' + \left(2\mathrm{K} + \mathrm{S}cf\right)\phi' + \mathrm{S}c\mathrm{S}r\left[2\mathrm{K}\theta' + 2(\mathrm{K}\eta + 1)\theta''\right] = 0 \tag{9}$$

where, $$\mathrm{K} = \frac{1}{\mathrm{R}}\sqrt{\frac{2\nu}{w_w}},\ \mathrm{Ha}^2 = \frac{\sigma \mathrm{B}_0^2}{\rho w_w},\ \lambda = \frac{w_\infty}{w_w},\ \mathrm{N} = \frac{16\sigma_1 \mathrm{T}_\infty^3}{3k_1 K},\ \mathrm{Pr} = \frac{\nu}{\alpha},$$

$$\mathrm{D}f = \frac{\mathrm{D}_k}{c_p c_s \nu}\frac{(\mathrm{C}_w - \mathrm{C}_\infty)}{(\mathrm{T}_w - \mathrm{T}_\infty)},\ \mathrm{Sr} = \frac{\mathrm{D}_k}{\mathrm{T}_m \nu}\frac{(\mathrm{T}_w - \mathrm{T}_\infty)}{(\mathrm{C}_w - \mathrm{C}_\infty)},\ \mathrm{Sc} = \frac{\nu}{\mathrm{D}}.$$

Here, K is the curvature parameter, Ha^2 is the Hartmann number, λ is the ratio of the free stream to cylinder stretching velocity, N is the radiation parameter, Pr is the Prandtl number, Df is the Dufour parameter, Sr is the Soret parameter and Sc is the Schmidt number.

The transformed dimensionless boundary conditions are as follows:

$$f'(0) = 1,\ f(0) = f_0,\ \theta(0) = 1,\ \mathrm{C}(0) = 1,\ f'(\infty) = \lambda,\ \theta(\infty) = 0,\ \mathrm{C}(\infty) = 0,$$

where, $f_0 = u_w\sqrt{\frac{2}{\nu w_w}}$ is the dimensionless suction ($f_0 > 0$) or injection ($f_0 > 0$) velocity.

3. Numerical Solution

Using similarity transformation, the governing Eqs. (2), (3) and (4) are converted into a system of nonlinear, coupled ordinary differential equations (7), (8) and (9). These equations are solved numerically by using Runge-Kutta fourth order with shooting technique for various parameters such as curvature parameter, Hartmann number, suction/injection parameter, Soret and Dufour parameters, radiation parameter and Prandtl number.

After applying some transformations we converted the boundary layer problem into the initial value problems and reduced these system of equation in system or first order equations. For Runge-Kutta method with shooting technique we have applied suitable initial guesses for $f''(0)$, $\theta'(0)$ and $\phi'(0)$. We assumed that r_1, r_2 and r_3 are the initial guesses for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ respectively. We know that the physical domain of considered problem is unbounded, but the computational domain for this problem needs to be finite, in all numerical computations we have used the value of $\eta_{\max} = 10$. For this particular problem the step size and convergence criteria are preferred to be 0.001 and 10^{-6}.

4. Results and Discussion

In this problem many numerical results were obtained and these results shown graphically with the help of figures. Figure 2 represents velocity profile for different values of the velocity ratio λ for suction and injection. Increasing the value of λ shows that free stream velocity increases with cylinder velocity. This is due to increasing in velocity ratio, causes enhancement in pressure with straining motion near stagnation point, so velocity shows increment. It is also noted that when $\lambda < 1$ the velocity profile decreases with η on the other hand when $\lambda > 1$ the velocity profile increases. Figure 3 depicts the effects of the curvature parameter K on velocity profiles for two different values of λ for suction ($f_0 > 0$) and injection ($f_0 < 0$). When $\lambda = 0.5$ velocity increases as K increases while at $\lambda = 1.5$ velocity decreases with the increasing values of K. In both the cases when K increases boundary layer thickness increases.

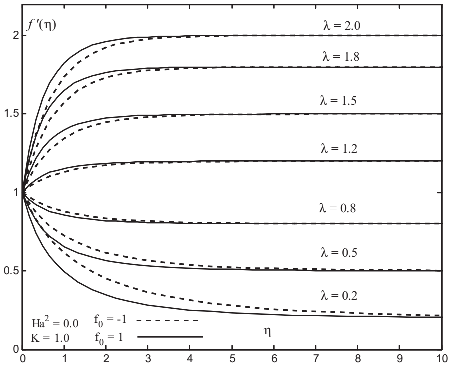


Figure 2. Effects of λ on velocity profile

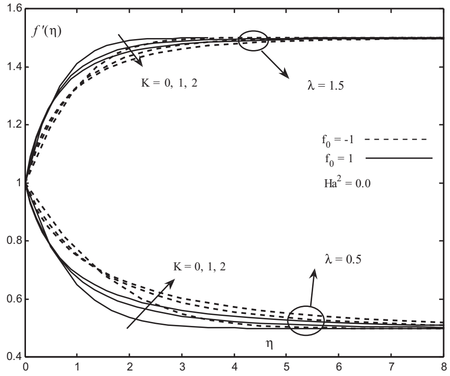


Figure 3. Effects of K on velocity profile

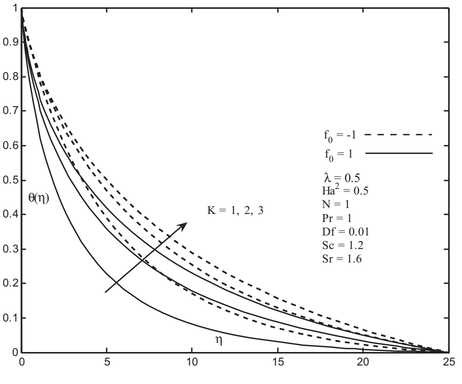


Figure 4. Effects of K on temperature profile

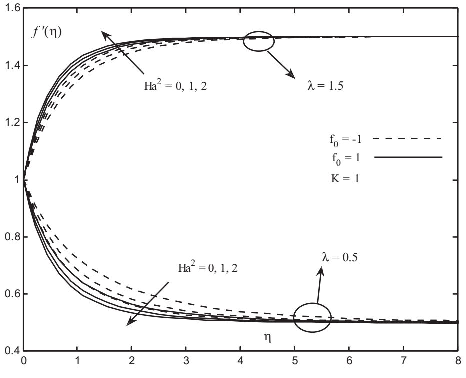


Figure 5. Effects of Ha^2 on velocity profile

Figure 5 shows the effects of Hartmann number Ha^2 on velocity profile for two different values of λ for suction ($f_0 > 0$) and injection ($f_0 < 0$). When $\lambda = 0.5$ increase in Hartmann number causes decrease in velocity profile. Transverse magnetic field normal to the flow direction provides growth to a resistive force, which is called Lorentz force. In other words when we the strength of magnetic field increased, velocity profiles shows reduction in boundary layer thickness. Exactly opposite results shown when $\lambda = 1.5$.

Figure 6 illustrate the effects of suction/injection parameter on velocity profiles for two different values of λ. When $\lambda = 0.5$, increasing in suction/injection parameter f_0 the velocity profile decreases. It is due to when $\lambda < 1$, the imposition of fluid suction at cylinder boundary decreases, hence velocity profile decreases, whereas injection provides opposite effects, leads to velocity profile increases. Exactly opposite results shown for $\lambda = 1.5$.

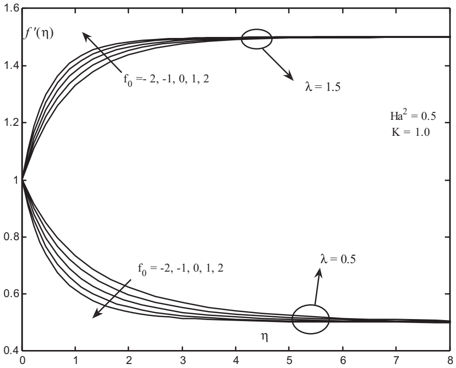


Figure 6. Effects of f_0 on velocity profile

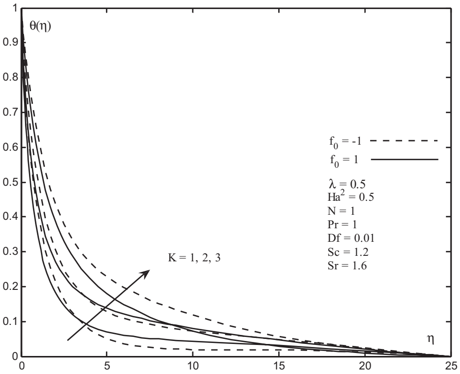


Figure 7. Effects of K on concentration profile

Figure 4 and 7 shows effects of curvature parameter K on temperature profiles and concentration profiles for suction and injection applied. It is noted that both profiles increases as we increase curvature parameter K. When we increase K for both values of λ, thermal boundary layer thickness increases.

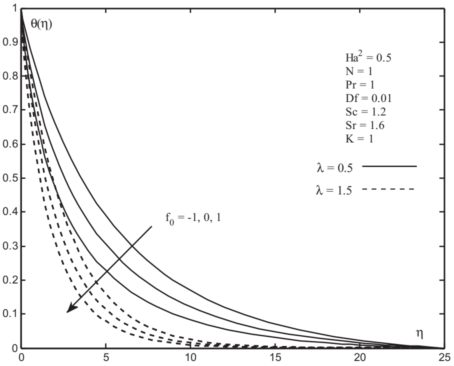


Figure 8. Effects of f_0 on temperature profile

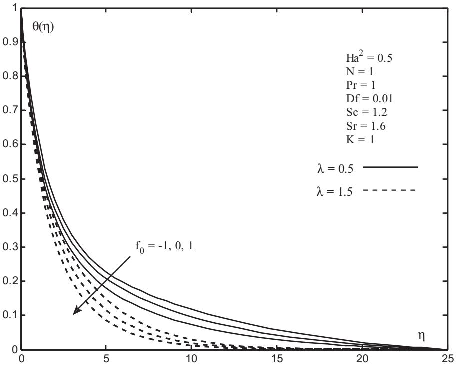


Figure 9. Effects of f_0 on concentration profile

Figures 8 and 9 depicts the effects of suction/injection parameter f_0 on temperature profiles and concentration profile for $\lambda = 0.5$ and $\lambda = 1.5$. It is clearly seen that for every increasing values of f_0 boundary layer thickness decreases for both profiles.

It is due to imposition of fluid suction ($f_0 > 0$) shrinks thermal and concentration boundary layer nearer to the cylinder surface, exactly opposite results have shown when injection ($f_0 < 0$).

Figures 10 and 11 displays the effects of Dufour and Soret effects on temperature profiles and concentration profiles for both suction and injection. When we increases Dufour parameter, causes enhancement in temperature profile due to increasing influence of concentration gradient in temperature profile which causes thermal diffusion. On the other hand increase in Soret number causes increment in concentration profile, physically increase in Soret number causes enhance the influence of temperature gradient in concentration profile, which causes concentration diffusion. In both cases temperature profile and concentration profile increases as we increase Dufour parameter Df and Soret Parameter Sr.

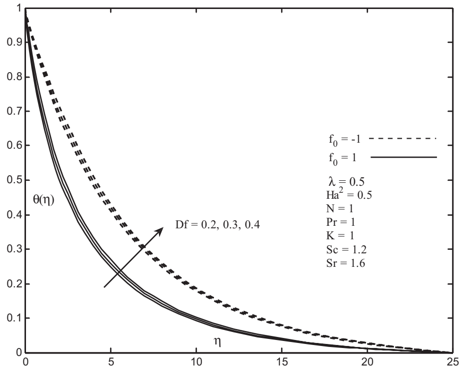


Figure 10. Effects of Dufour parameter on temperature profile

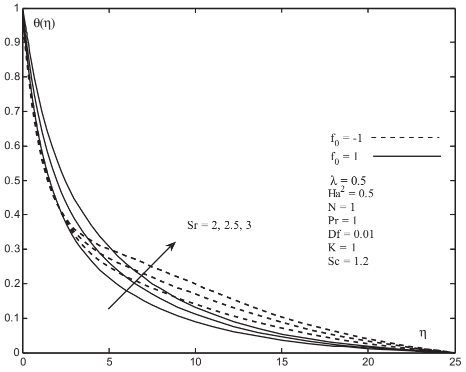


Figure 11. Effects of Soret parameter on concentration profile

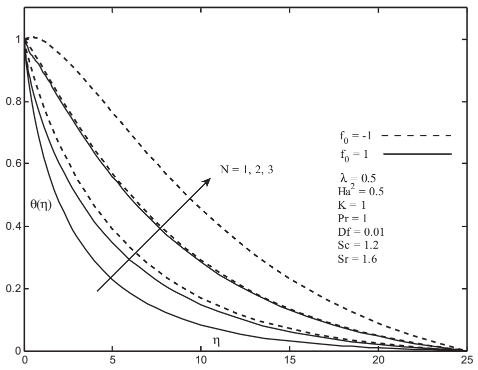


Figure 12. Effects of N on temperature profile

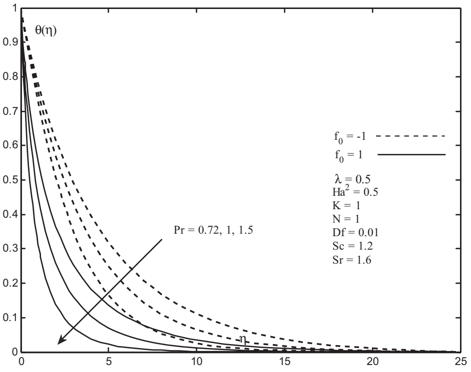


Figure 13. Effects of Pr on temperature profile

Figures 12 and 13 presents the effects of radiation parameter N and Prandtl number Pr on temperature profiles for both suction and injection. Prandtl number is used to increases the cooling rate in viscous fluids. If the fluid have lower Prandtl number then it have high thermal conductivity and temperature. Hence increasing Prandtl number always reduces the fluid temperature.

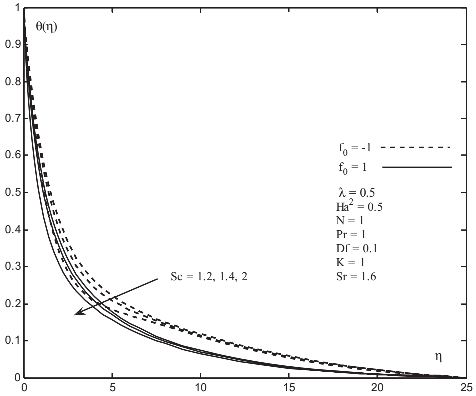


Figure 14. Effects of Sc on concentration profile

In figure 12 temperature profile increases as we increase radiation parameter N, we know that higher values of radiation parameter produces more heat on viscous fluid. Hence enhancement in radiation parameter leads to increases of thermal boundary layer thickness.

Figure 14 displays the effects of Schmidt number (Sc) on concentration profile for suction and injection. It is clearly seen that for increasing values of Sc concentration profiles shows reduction for both suction and injection. This is due to the concentration buoyancy effects which leads to reduce the concentration profile thickness.

5. Conclusion

We have investigated Soret and Dufour effects with radiative MHD boundary layer flow and heat transfer with suction/injection over a stretching moving cylinder.It is observed that:

- Velocity profile increases, when ratio parameter (λ) increases.
- Velocity profile decreases with increasing values of Hartmann number (Ha^2).
- Higher Prandtl number (Pr) gives reduction in temperature profile.
- Permeability parameter (K), radiation parameter (N) and Dufour number (Df) gives rise in temperature profile.
- Concentration profile increases with Soret parameter (Sr), while decreases with Schmidt number (Sc).

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