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CHARACTERISTICS FEATURES OF HEAT AND MASS TRANSFER UNSTEADY FLUID FLOW OVER A SEMI INFINITE POROUS SURFACE

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Abstract

Study of heat transfer in a laminar flow of Newtonian viscous and electrically conducting fluid with a problem that causes heat and absorbs heat was the focus of this research. To the best analytical solution possible, the non-dimensional form of the governing equations is analyzed. Whenever we go further away from a plate with a certain Schmidt number, the concentration drops dramatically. We can also see that concentration rises as time goes on and falls as we go farther from the boundary. Lower temperatures are noticed when the prandtl number is increased as well as lower speeds. Velocity may be affected by the porosity factor, and as the prandtl number varies.

“Keywords: MHD, Chemical reaction, Porous medium, Radiation absorption.*”*

Nomenclature:

B_o :“Applied Transverse Magnetic Field

N : Applied Magnetic Field

g^* : Acceleration due to gravity

V_o : Constant velocity along y-axis

U_o : Constant velocity

C'_∞ : Concentration of the fluid far away from the plate

C'_w : Concentration of the fluid at that wall

C' : Concentration of the fluid”

K'_r : Chemical reaction parameter

n' : Constant

Q'_o	:	Concentration diffusion
K'	:	Dimensional porosity of the Fluid bed
ρ	:	Density
σ	:	Electrical conductivity of the fluid
ω	:	Frequency of excitation
φ	:	Heat source parameter
υ	:	Kinematic viscosity
G_m	:	Modified Grashoff number
D	:	Molecular diffusivity
G_c	:	Modified Grashoff concentration number
u^*	:	Non dimensional velocity along x-axis
K	:	Porosity of the fluid in the dimensional form
P_r	:	Prandtl number
S_c	:	Schmidt number
A	:	Suction coefficient
Q_o	:	Temperature diffusion
G_r	:	Thermal Grashoff number
k	:	Thermal diffusivity
t'	:	Time in the dimension form
T'_∞	:	Thermal conductivity at ∞
T'	:	Temperature of the fluid
U'_∞	:	The free stream velocity
β	:	Thermal conductivity in the dimensional form
β^*	:	Thermal diffusivity in the dimensional form
ν	:	Velocity along y-axis
T'_w	:	Wall temperature

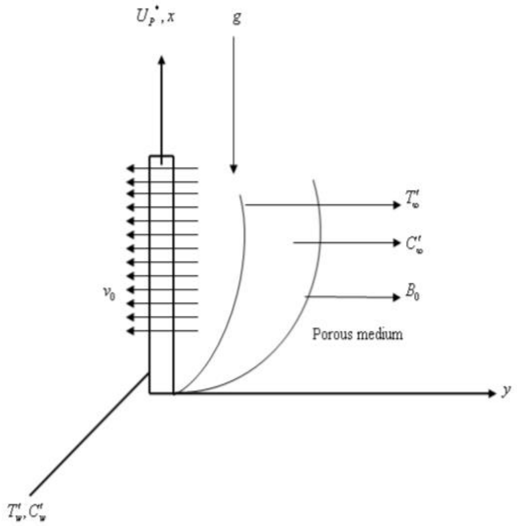
Introduction

Heat and mass transport play a critical part in a number of chemical engineering challenges, including chemical formulations. It has therefore been studied in recent years the relevance of a governing equation parameter that occurs in the participation parameter. When electrical energy is created directly from a flowing conducting fluid, many technical applications might be imagined.In several chemical reactions, chemical factors the rate of diffusion in concentration and temperature influences the reaction rate more significantly. Pilot studies have been conducted to examine the relevance of numerous participating characteristics, including Schmidt (Sc), Prandtl (Pr), and the porosity (K) of the bonding surface.

The findings of Chandrasekhar [1] reveal that a large number of factors in a field entity contribute to its overall performance, which is a practical consideration. Chambre and Young investigated a chemical reaction near a horizontal plate [2]. "MHD Convective Flow over a vertical surface via a porous medium has shown remarkable findings, according to Dhanalakshmi and Jayarami Reddy [3]. Gregantopoulos et al [4]. subsequently conducted research on two-dimensionally unstable free convective and mass transfer flow through infinite vertical porous plates. Afterwards, Gribben [5] conducted a study of a semi-infinite plate with an applied magnetic field in the presence of pressure gradients. In the study of casson fluid flow and heat transfer through an exponentially porous stretched surface, the influence of porosity and thermal radiation was emphasized by Hymavathi and Sridhar [6]. Incredibly impressive results have been accomplished by these people. Because of its importance in plasma physics and its high temperature, the effect of radiation on mixed convection across a vertical plate by Hossian and Takhar

[7] was stable. As Raja Kumari [8] established in a comparable scenario, the porosity and radiation of a viscous fluid played a crucial role in convective heat and mass transmission.Muthucumaraswamy et al [9]. investigated the effect of a chemical reaction on a vertical oscillating plate with varying temperature and mass diffusion. This method was then employed by Muthuraj and Srinivas [10] to examine the fully developed MHD flow of a micro-polar and viscous fluid [10]. To take into account the findings of the aforementioned study, Ramana Reddy [11] recently brought attention to the Soret and its effect on MHD micropolar fluid flow. While investigating the MHD Mixed Convection Oscillatory Flow over a Vertical Surface in a Porous Medium with Chemical Reaction and Thermal Radiation, Ramana Reddy et al [12] uncovered astounding findings regarding skin friction. An MHD fluid embedded in a porous medium was investigated by Ramachandra Prasad and colleagues [13]. Some fascinating results came from an indepth analysis by Rajakumari [14] of a wide range of variables. Saddeek [15] studied the effects of chemical reaction, thermophoresis, changing viscosity, and hydro magnetic flow on a flat plate. Suction variation in the presence of a homogeneous magnetic field was examined by Sudheer Babu and Satyanarayana [16]. Sreenivasan and Ramana Reddy et al [17] investigated the effect of critical parameters on MHD flow. Reddy" [18] investigated a wide range of parameters when researching heat and mass transmission through very porous media with radiation and other impacts. As a follow-up to his previous studies, Vijaya [19] recently presented fascinating findings while investigating the influence of radiation in an unstable flow situation using casson fluid. By Vedavathi [20] with regard to the issue of heat transfer and MHD nanofluid flow, it has now been thoroughly examined

Specifically, we are looking at the effects of various input factors on the field's corresponding concentration, temperature, and velocity characteristics. A magnetic field is assumed to move a plate at a constant velocity since it is assumed to be embedded in a homogeneous porous medium. Continuous, momentum, energy and diffusion equations have been solved to the best resolution possible.



“**Figure – 1: Physical model and coordinate system of the problem when held horizontal**

Mathematical Formulation

We examine a two-dimensional flow of a laminar, viscous, electrically conducting, and heat-absorbing fluid through a semi-infinite vertical permeable moving plate submerged in a uniform porous material and subjected to a uniform transverse magnetic field. A small number of species are expected to be found outside the wall. Consequently, the Soret and Dufour effects are considered so modest that they may be neglected. All thermophysical parameters are assumed to be constant while chemical reactions take place inside the flow. Semi-infinite planar surfaces mean that flow variables must be described as functions of y and time. Under these suppositions, we may derive physical equations:

$$\frac{\partial v'}{\partial y'} = 0 \quad (1)$$

$$\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} = -\frac{1}{p}\frac{\partial p'}{\partial x'} + v\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - v\frac{u'}{K'} - \frac{\sigma}{\rho}B_o^2 u' \quad (2)$$

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=-\frac{1}{pc_p}\left[k\frac{\partial^2 T'}{\partial y'^2}\right]-Q_o(T'-T'_\infty)+ \quad (3)$$
$$+Q'_1(C'-C'_\infty)$$

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}-K'_r(C'-C'_\infty) \quad (4)$$

On the right-hand side of the equation (2), the third and fourth components represent the heat and concentration buoyancy effects. Consequently, the last component on the right side of the energy equation (3) represents the radiated heat flow.

Temperatures, concentrations, and velocities form the limits of these three fields

$$u'=u'_p, T'=T'_\infty+\varepsilon\left(T'_w+T'_\infty\right)e^{n't'},$$
$$C'=C'_\infty+\varepsilon\left(C'_w+C'_\infty\right)e^{n't'} \qquad \text{at } y'=0$$

$$u'=U'_\infty=U_o+\varepsilon\left(1+\varepsilon e^{n't'}\right), T'\to T'_\infty, C'\to C'_\infty \text{ as } y'\to\infty \quad (5)$$

Equation 1 shows that the plate's suction velocity is either constant or a function of time. Hence the suction velocity normal to the plate is assumed to possess the structure as

$$v'=-V_o\left(1+\varepsilon Ae^{n't'}\right) \quad (6)$$

Positive constants A and € meet the condition for a non-zero scale of suction velocity. The negative symbol indicates that the suction is aimed towards the plate.

In this case, equation (2) yields a solution.

$$-\frac{1}{p}\frac{\partial p'}{\partial x'}=v\frac{dU_\infty{}'}{\partial t'}+\frac{v}{K'}U'_\infty+\frac{\sigma}{\rho}B_o^2U_\infty{}' \quad (7)$$

These non-dimensional values are included in the governing equations and boundary conditions in order to eliminate the need for dimensions.

$$G_r=\frac{v\beta g(T'_w-T'_\infty)}{U_oV_o^2}, \Pr=\frac{v\rho C_p}{k}=\frac{v}{\alpha},$$

$$M=\frac{\sigma B_o^2 v}{\rho V_o^2}, u=\frac{u'}{U_o}, v=\frac{v'}{V_o},$$

$$y=\frac{V_o y'}{v}, U_\infty=\frac{U'_\infty}{U_o}, U_p=\frac{u'_p}{U_o}, t=\frac{t'V_o^2}{v}\text{,,}$$

$$\theta=\frac{T'-T'_\infty}{T'_w-T'_\infty}, C=\frac{C'-C'_\infty}{C'_w-C'_\infty},$$

$$n=\frac{vu'}{V_o^2}, K=\frac{K'V_o^2}{v^2}, Sc=\frac{v}{D},$$

$$G_m=\frac{v\beta^* g(C'_w-C'_\infty)}{U_oV_o^2}, K_r=\frac{K'_r v}{V_o^2} \quad (8)$$

In view of equations (6)-(8), Equations (2)-(4) are reduced to this dimensional form.

$$\frac{\partial u}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial u}{\partial y}=\frac{\partial U_\infty}{\partial t}+\frac{\partial^2 u}{\partial y^2}+G_r\theta+$$
$$G_m C+G\sin\alpha+Mu+\frac{u}{k} \tag{9}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial \theta}{\partial y}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2}-\phi\theta+Q_1 C \tag{10}$$

$$\frac{\partial C}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial C}{\partial y}=\frac{1}{S_c}\frac{\partial^2 C}{\partial y^2}-K_r C \tag{11}$$

Where α is the angle of inclination to the horizontal plane

The corresponding boundary conditions are as follows:

$$u=U_p,\theta=1+\varepsilon e^{nt},C=1+\varepsilon e^{nt} \text{ at } y=0$$
$$U\to U_\infty=1+\varepsilon e^{ny},\theta\to 0,C\to 0 \text{ as } y\to\infty \tag{12}$$

Methodology for solution

They cannot be solved in closed form since they are connected and non-linear, hence it is impossible.As a result of this reduction, these equations may be solved analytically using ordinary differential equations. An example of this would be to show velocities, temperatures, and concentrations of fluid near the plate as a function of distance.

$$\left.\begin{aligned}u&=u_o(y)+\varepsilon e^{nt}u_1(y)+o(\varepsilon^2)+......\\ \theta&=\theta_o(y)+\varepsilon e^{nt}\theta_1(y)+o(\varepsilon^2)+......\\ C&=C_o(y)+\varepsilon e^{nt}C_1(y)+o(\varepsilon^2)+......\end{aligned}\right\} \tag{13}$$

Substituting (13) in Equations (9) – (11) and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of o(ε^2) , we obtain

$$u_o''+u_o'=-G_r\theta_o-G_m C_o-G\sin\alpha-Mu_o-\frac{1}{k}u_o \tag{14}$$

$$u_1''+u_1'-(n-M)u_1=-n-Au_o'-G_r\theta_1-G_m C_1-\frac{1}{k}u_1 \tag{15}$$

$$\theta_o''+P_r\theta_o'-P_r\phi\theta_o=-P_rQ_1C_o \tag{16}$$

$$\theta_1''+P_r\theta_1'-P_r\theta_1(n+\phi)=-P_rA\theta_o'-P_rQ_1C_1 \tag{17}$$

$$C_o''+S_cC_o'-S_cK_rC_o=0 \tag{18}$$

$$C_1''+S_cC_1'-S_cC_1(n+K_r)=-S_cAC_o' \tag{19}$$

Where prime denotes ordinary differentiation w.r.t y

These are the non-dimensional boundary equations for the related two-dimensional equations:

$$\left.\begin{aligned}&\text{“}u_o=U_p,u_1=0,\theta_o=1,\theta_1=1,C_o=1,C_1=1 \text{ at } y=0\\ &u_o\to 1,u_1\to 1,\theta_o\to 0,\theta_1\to 0,C_o\to 0,C_1\to 0 \text{ as } y\to\infty\end{aligned}\right\} \tag{20}$$

The velocity, temperature, and concentration of the boundary layer may be determined using Equations (14) – (19) and the boundary conditions (20)”

$$C(y,t) = e^{m_2 y} + \varepsilon e^{nt}\left(A_4 e^{m_4 y} + A_{14} e^{m_2 y}\right) \quad (21)$$

$$\theta(y,t) = A_6 e^{m_6 y} - A_{16} e^{m_2 y} + \varepsilon e^{nt}\left(A_8 e^{m_8 y} + A_{18} e^{m_6 y} + A_{20} e^{m_2 y} + A_{22} e^{m_4 y} + A_{24} e^{m_2 y}\right) \quad (22)$$

$$u(y,t) = \begin{pmatrix} A_9 e^{m_9 y} + A_{10} e^{m_{10} y} + \\ A_{26} e^{m_6 y} + A_{28} e^{m_2 y} + \\ A_{30} e^{m_2 y} + A_{31} \end{pmatrix} + \varepsilon e^{nt} \begin{bmatrix} \left(1 - A_{32} + A_{33} + A_{37} - A_{39}\right) e^{m_{11} y} + \\ \begin{pmatrix} -1 + A_{34} - A_{36} + A_{38} - A_{40} - \\ A_{43} + A_{45} + A_{47} + A_{49} + \\ A_{51} + A_{53} + A_{55} \end{pmatrix} e^{m_{12} y} \\ + A_{32} - A_{33} e^{m_9 y} - A_{37} e^{m_1 y} + \\ A_{39} e^{m_1 y} - A_{34} e^{m_{10} y} + A_{36} e^{m_6 y} - \\ A_{38} e^{m_2 y} + A_{40} e^{m_2 y} + \\ A_{43} e^{m_8 y} - A_{45} e^{m_6 y} - A_{47} e^{m_2 y} \\ - A_{49} e^{m_4 y} - A_{51} e^{m_2 y} - \\ A_{53} e^{m_4 y} - A_{55} e^{m_2 y} \end{bmatrix} \quad (23)$$

Where

$$m_1 = \frac{-S_c + \sqrt{S_c^2 + 4S_c K_r}}{2}, m_2 = \frac{-S_c - \sqrt{S_c^2 + 4S_c K_r}}{2}$$

$$m_3 = \frac{-S_c + \sqrt{S_c^2 + 4S_c (n + K_r)}}{2} \quad m_4 = \frac{-S_c - \sqrt{S_c^2 + 4S_c (n + K_r)}}{2}$$

$$m_5 = \frac{-P_r + \sqrt{P_r^2 + 4P_r \phi}}{2}, m_6 = \frac{-P_r - \sqrt{P_r^2 + 4P_r \phi}}{2}$$

$$m_7 = \frac{-P_r + \sqrt{P_r^2 + 4P_r (n + \phi)}}{2}, m_8 = \frac{-P_r - \sqrt{P_r^2 + 4P_r (n + \phi)}}{2}$$

$$m_9 = \frac{-\sqrt{k} + \sqrt{k - 4(Mk + 1)}}{2\sqrt{k}}, m_{10} = \frac{-\sqrt{k} - \sqrt{k - 4(Mk + 1)}}{2\sqrt{k}}$$

"$$m_{11} = \frac{-1 + \sqrt{1 - 4(M - n + \frac{1}{k})}}{2}, m_{12} = \frac{-1 - \sqrt{1 - 4(M - n + \frac{1}{k})}}{2}$$

$$\left.\begin{array}{l} A_1 = A_3 = A_5 = A_7 = A_{13} = A_{15} = A_{17} \\ = A_{19} = A_{21} = A_{23} = A_{25} = A_{27} = A_{29} \\ = A_{35} = A_{41} = A_{42} = A_{44} = A_{46} = A_{48} \\ = A_{50} = A_{52} = A_{54} = 0 \end{array}\right\}$$

"

$$A_2 = 1, A_4 = 1 - \frac{Am_2}{n}, A_6 = 1 + \frac{P_r Q_1}{m_2^2 + P_r m_2 - P_r \phi},$$

$$A_8 = 1 - A_{18} - A_{20} + A_{22} + A_{24}, A_9 = 1 + \frac{G \sin\alpha}{M + \frac{1}{k}},$$

$$A_{10} = U_p + A_{26} + A_{28} + A_{30} - 1,$$

“ $A_{11} = 1 - A_{32} + A_{33} + A_{37} - A_{39}$

$$A_{12} = A_{34} - A_{36} + A_{38} - A_{40} - A_{43} - A_{45} - A_{47} + A_{49} + A_{51} + A_{53} + A_{55} - 1$$ ”

$$A_{14} = \frac{AA_2 m_2}{n}, A_{16} = \frac{-P_r Q_1 A_2}{m_2^2 + P_r m_2 - P_r \phi}, A_{18} = \frac{AA_6 m_6}{n},$$

$$A_{20} = \frac{P_r^2 Q_1 A m_2}{\left(m_2^2 + P_r m_2 - P_r (n + \phi)\right)\left(m_2^2 + P_r m_2 - P_r \phi\right)},$$

$$A_{22} = \frac{-P_r Q_1 A_4}{m_4^2 + P_r m_4 - P_r (n + \phi)}, A_{24} = \frac{-P_r Q_1 A m_2}{n(m_2^2 + P_r m_2 - P_r (n + \phi))}$$

$$A_{26} = \frac{GA_6}{m_6^2 + m_6 + (M + \frac{1}{k})},$$

$$A_{28} = \frac{-GP_r Q_1 A_2}{\left(m_2^2 + m_2 + (M + \frac{1}{k})\right)\left(m_2^2 + P_r m_2 - P_r \phi\right)}$$

$$A_{30} = \frac{G_m A_2}{m_2^2 + m_2 + (M + \frac{1}{k})}, A_{31} = \frac{-G \sin\alpha}{M + \frac{1}{k}}, A_{32} = \frac{n}{M - n + \frac{1}{k}}$$

$$A_{33} = \frac{AA_9 m_9}{m_9^2 + m_9 + (M - n + \frac{1}{k})}, A_{34} = \frac{AA_{10} m_{10}}{m_{10}^2 + m_{10} + (M - n + \frac{1}{k})},$$

$$A_{36} = \frac{AA_{30} m_6}{m_6^2 + m_6 + (M - n + \frac{1}{k})}, A_{37} = \frac{AA_{31} m_1}{m_1^2 + m_1 + (M - n + \frac{1}{k})},$$

$$A_{38} = \frac{AA_{32} m_2}{m_2^2 + m_2 + (M - n + \frac{1}{k})}, A_{39} = \frac{AA_{33} m_1}{m_1^2 + m_1 + (M - n + \frac{1}{k})},$$

$$A_{40} = \frac{AA_{34} m_2}{m_2^2 + m_2 + (M - n + \frac{1}{k})}, A_{43} = \frac{G_r A_8}{m_8^2 + m_8 + (M - n + \frac{1}{k})},$$

$$A_{45} = \frac{G_r A_8}{m_6^2 + m_6 + (M - n + \frac{1}{k})}, A_{47} = \frac{G_r A_{20}}{m_2^2 + m_2 + (M - n + \frac{1}{k})},$$

$$A_{49} = \frac{G_r A_{22}}{m_4^2 + m_4 + (M - n + \frac{1}{k})}, A_{51} = \frac{G_r A_{24}}{m_2^2 + m_2 + (M - n + \frac{1}{k})},$$

$$A_{53} = \frac{G_m A_4}{m_4^2 + m_4 + (M - n + \frac{1}{k})}, A_{55} = \frac{G_m A_{14}}{m_2^2 + m_2 + (M - n + \frac{1}{k})}$$

Results and conclusions:

1. The Figure3,Figure4 and Figure5 illustrates the concentration profiles for Sc=0.75, 0.50 and 0.25. In each of these profiles, the concentration falls as we move away from the boundary. A further observation shows that as t increases, the concentration in the fluid increases.
2. Figure2 and Figure15 demonstrate two distinct temperature distributions for various prandtl numbers. As we move away from the boundary, the temperature decreases.Furthermore, when the prandtl number rises, the temperature decreases.
3. Figure6 depicts the velocity profiles as a function of prandtl number. When the bounding surface's porosity is 0.25. As we drive away from the boundary, we see that our velocity rises. In addition to the above, it is observed that the Prandtl number and velocities are proportional to each other.
4. Figure8 and Figure13, illustrates the nature of velocity profiles for a constant Sc=0.25 and k=0.09, 0.05 it is noticed that as we move far away from the boundary. The profiles appear to be parabolic in nature. Further it is noticed that as the Prandtl number increases the velocity decreases.
5. Velocity profiles for Sc=0.39 and porosity factors k=0.05, 0.25-0.09 are shown in Figure10; Figure12; and Figure14. Speed profiles are linear in the case of k=0.25, whereas the velocity profiles are parabolic in the case of the other two values: k=0.05 and k=0.09.
6. This suggests that the porosity factor significantly contributes on the velocity. In each of these cases it is seen that as the prandtl no. increases the velocity decreases.
7. Prandtl number influences the velocity profiles which can be seen in Figures 7 9 and 11 for Sc=0.49 and porosity factor k=0.05 to 0.25. Velocity profiles are linear in the case of k=0.25, whereas the velocity profiles are parabolic in the case of the other two values: k=0.05 and k=0.09.There is a strong correlation between the velocity and the porosity of the material. In each of these scenarios, the velocity falls as the prandtl number grows.

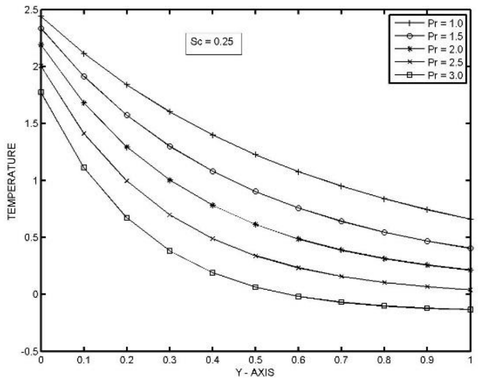


Figure 2: "Variation of temperature with respect to prandtl number"

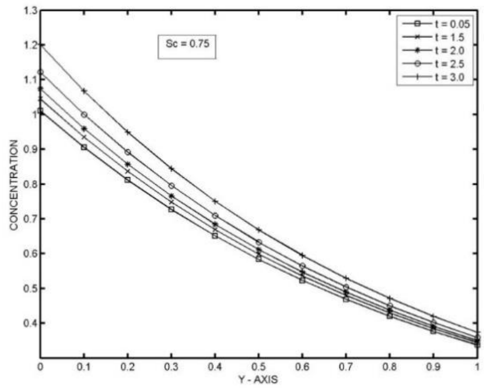


Figure 3: Variation of velocity profiles with respect to time

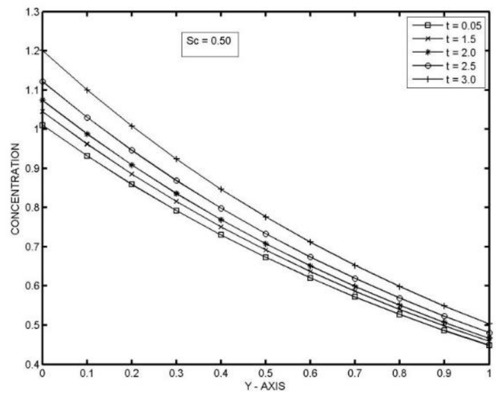


Figure 4:Nature of concentration with respect to time

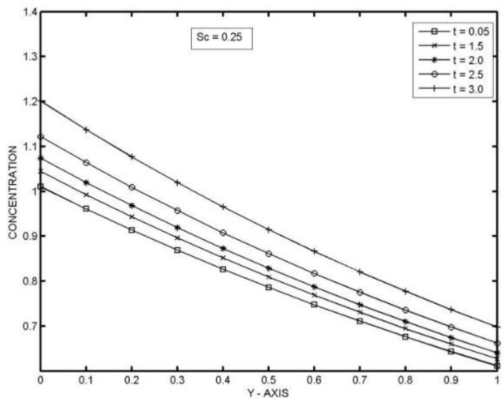


Figure 5: **Concentration profiles for Sc=0.25**

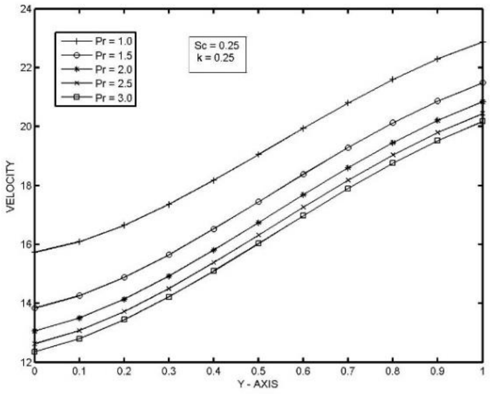


Figure 6: Nature of velocity profiles for k=0.25

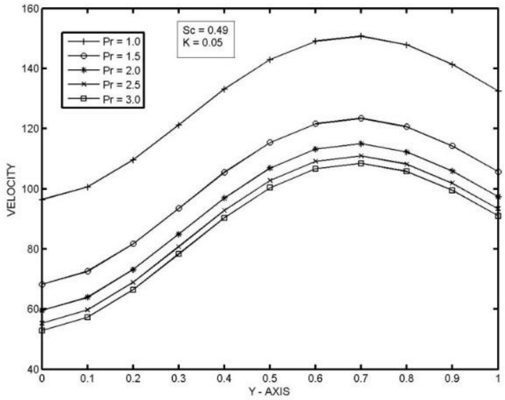


Figure 7:Distribution of velocityprofiles with respect to prandtl number.

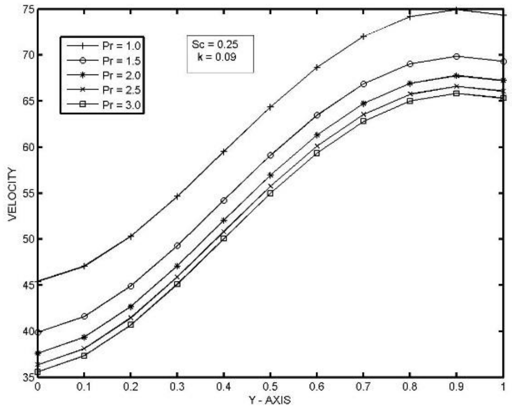


Figure 8:Variation in velocity for k=0.09

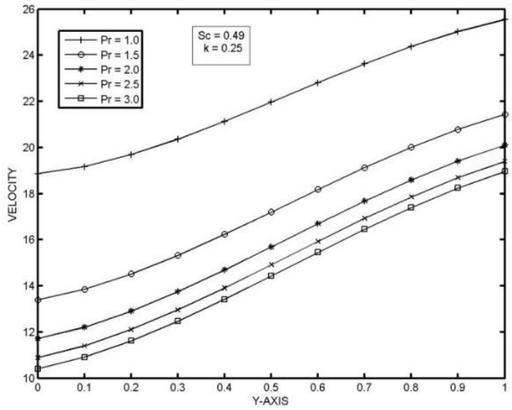


Figure 9:"The variation of velocity with respect to the prandtl number

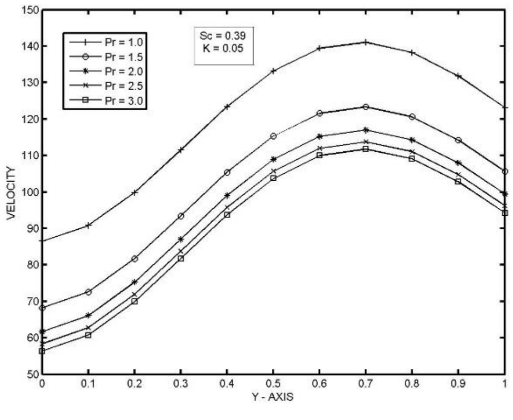


Figure 10:The nature of velocity distribution with respect to prandtl number

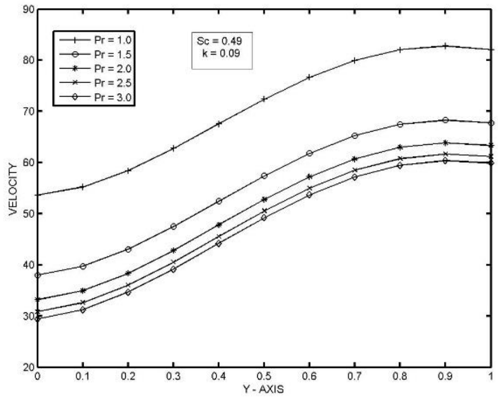


Figure 11: Variation in velocity with respect toSc and k

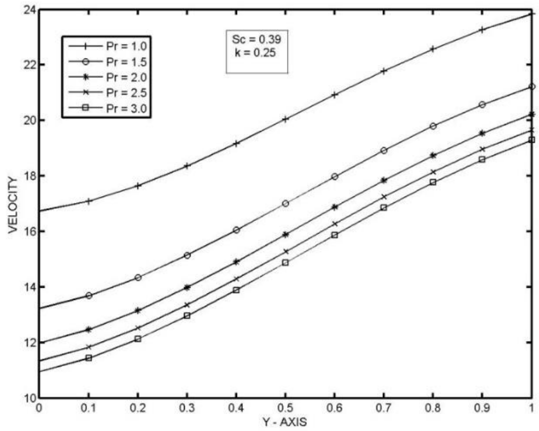


Figure 12:The nature of velocity profiles for Sc=0.39

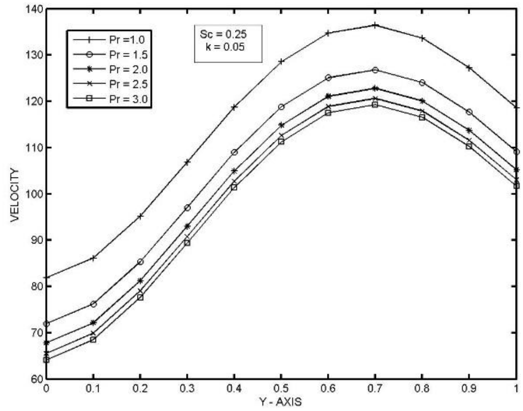


Figure 13:Velocity profiles for Sc=0.25

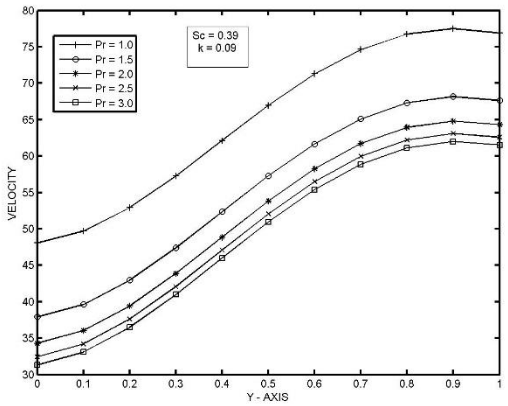


Figure 14: The nature of velocity field for Sc=0.39

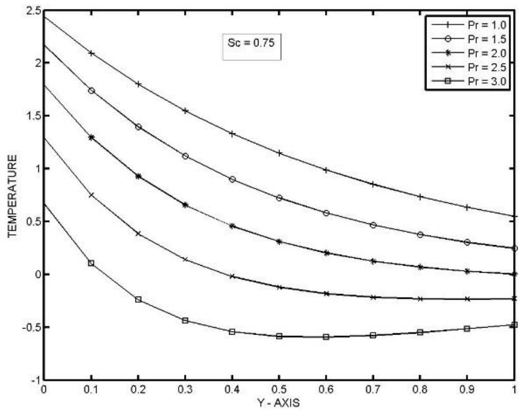


Figure 15: Variation of temperature for Sc=0.75

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