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INFLUENCE OF THERMAL RADIATION ON MOVING INFINITE VERTICAL PLATE

D. Vijay Kumar and Ch. V. Ramana Murthy
Lakireddy Bali Reddy College of Engineering, Mylavaram-521230 (Andhra Pradesh) India

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ABSTRACT

The present analysis aims at the free convective flow past an impulsively started vertical plate with constant heat flux in the presence of thermal radiation. The analytical expressions for the velocity and temperature are obtained in the best possible closed form and are analyzed graphically in detail with respect to various parameters. The influence of all such parameters are examined and discussed qualitatively. It is seen that, as the prandtl number increases, the fluid velocity increases and also as the pore size is increased, the fluid velocity decreases marginally. Also, the velocity profiles are found to be oscillatory in their behavior and the amplitude of such sinusoidal motion is found to be decreasing as we move far away from the boundary. Further, as the radiation parameter increases, the velocity of the fluid is found to be decreasing, and of course with the diminishing amplitude. For a fixed Prandtl number, the influence of the Grashoff number when examined, it is seen that, the velocity profiles are oscillatory in its nature. It is observed that, increase in Prandtl number contributes to the increase in skin friction while increase in Grashoff number causes skin friction to decrease. Not much of apparent change in skin friction is observed even for the significant change in the radiation parameter.

Key words: *Thermal radiation, constant heat flux, impulsive motion.*

NOMENCLATURE:

A	:	Constant	C_p	:	Specific heat and constant pressure
g	:	Acceleration due to gravity	G_r	:	Thermal Grashoff number
k	:	Thermal conductivity of the fluid	P_r	:	Prandtl number
p	:	Pressure	q_r	:	Radiative heat flux in the y-direction
N	:	Radiation parameter	T	:	Temperature of the fluid near the plate
T_ω	:	Temperature of the plate	T_∞	:	Temperature of the fluid far away from the plate
t	:	Time	u	:	Velocity of the fluid in x-direction
u_0	:	Velocity of the plate	U	:	Dimensionless velocity
y	:	Coordinate axes normal to the plate	y'	:	Dimensionless Coordinate axes normal to the plate
k^*	:	Mean absorption coefficient			

GREEK SYMBOLS:

α	:	Thermal diffusivity	β	:	Volumetric coefficient of thermal expansion
ν	:	Kinematic viscosity	ρ	:	Density
θ	:	Dimensional temperature	σ	:	Stefen-Boltzmann constant

INTRODUCTION

In several Situations where heat and mass transfer occurs the effect of thermal radiation and its associated parameters plays significant role in understanding the fluid behavior and the friction offered by the fluid on the bounding surface. The problem assumes greater significance in the areas of granular insulation, cooling and heating of reaction chamber, combustion in internal combustion engines, energy process and several other associated applications. The concept of thermal radiation is most important component in the precious and accurate design and installation of equipment mainly in chemical engineering, pharmaceutical and metallurgical equipment. The exhaustive application is found in literature by Somess [2]. More such application were discussed and reviewed by Hussian and Takhar [8].

Brinkman [1] was the first to examine the viscous force imparted by a flowing fluid in a dense swarm of particles. Later, Das *et al* [3] analysed the radiation effects over an isothermal vertical plate. Thereafter, the boundary layer growth on a flat plate with suction or injection at one of the boundaries was presented in detail by Hassmoto [4]. Later, the thermal radiation effects of a optically thin gray gas bounded by a stationary vertical plate was examined and analysed by England and Elbarbary [5].

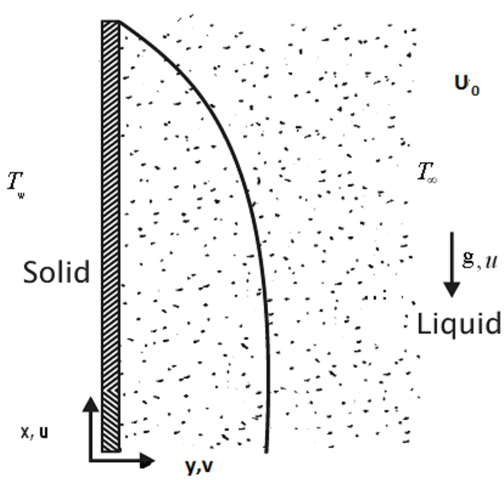
***Corresponding Author: Ch. V. Ramana Murthy**
E-mail: drchvr@gmail.com*

Subsequently, the radiative free convective flow of a thin gray gas past a semi infinite vertical plate was examined by soundalgekar and Takhar [6]. The free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with time dependent temperature and concentration was presented by Sattar [7]. Subsequently, Hussain and Takhar [8] examined the radiation effect on a mixed convection along an isothermal vertical plate. The effects of thermal radiation and free convection flow past a moving infinite vertical plate was presented by Raptis and prediks [9].

Subsequently, Chowdary and Das [10] investigated the magneto hydro dynamic boundary layer flow of a non Newtonian fluid past a flat plate. At high operating temperature the radiation effect were found to be quite significant and all such effects to some extent were reported by Ghaly and Elbarbary [11]. Recently. The effects of radiation on moving infinite vertical plate with variable temperature were examined by Muthucumaraswamy and Ganesan [12]. To be more realistic and appropriate it would be reasonable to include all those parameters that are connected with thermal radiation and also to explore the impact of magnetic field on thermal transport system such a problem was re examined by Chien [13]. Of late, Das *et al* [14] obtained numerical approximations for the mass transfer effects of an unsteady flow past an accelerated vertical porous plate.

MATHEMATICAL FORMULATION:

The flow of an incompressible viscous radiating fluid past an impulsively started infinite vertical plate with uniform heat flux is examined in the present note. The x-axis is taken along the plate in vertical direction and the y- axis is taken normal to plate. Initially, the plate and fluid are at the same temperature in a stationary condition. At time t > 0, the plate is given an impulsive motion in the vertical direction against the gravitational field with constant velocity u_0 .At the same time, the heat is supplied from the plate to the fluid at uniform rate. The fluid is considered here is a gray, absorbing-emitting radiation but a non-scattering medium. Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.



$$\frac{\partial u}{\partial t'} = g\beta(T - T_\infty) + \nu \frac{\partial^2 u}{\partial y^2} \tag{1}$$

$$\rho C_p \frac{\partial T}{\partial t'} = k \frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} \tag{2}$$

Where the Rosseland approximation (Brewster [1]) is used, which leads to

$$q_r = -\frac{4\sigma}{3k^*}\frac{\partial T^4}{\partial y} \tag{3}$$

The initial and boundary conditions are as follows

$t' \le 0: \quad u = o, T = T_\infty$ For all y' $t' > 0$;

$$u = u_0, \frac{\partial T}{\partial y} = -\frac{q}{k} \text{ at } y' = 0 \tag{4}$$

$$u = 0, \quad T \to T_\infty \text{ as } y' \to \infty$$

Where $A = \dfrac{u_0^2}{\nu}$

We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher order terms, thus

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \tag{5}$$

By using equations (4) and (5), equation (2) reduces to

$$\rho C_p \frac{\partial T}{\partial t'} = k \frac{\partial^2 T}{\partial y^2} + \frac{16\sigma T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2} \tag{6}$$

Introducing the following non-dimensional quantities as:

$$U = \frac{u}{u_0}, t = \frac{t' u_0^2}{\nu}, y = \frac{y' u_0}{\nu}, \theta = \frac{T - T_\infty}{T_\omega - T_\infty}, \tag{7}$$

$$G_r = \frac{g\beta\nu(T_\omega - T_\infty)}{u_0^3}, P_r = \frac{uC_p}{k}, N = \frac{k^* k}{4\sigma T_\infty^3}$$

Eqns (1) to (6), leads to

$$\frac{\partial u}{\partial t} = G_r\theta + \frac{\partial^2 u}{\partial y^2} + \frac{u}{k} \tag{8}$$

$$3NP_r \frac{\partial \theta}{\partial t} = (3N + P_r)\frac{\partial^2 \theta}{\partial y^2} \tag{9}$$

The initial and boundary conditions in non - dimensional form are

$$u = 0, \theta = 0 \text{ for all } y, t \le 0$$
$$t > 0: u = 1, \frac{\partial \theta}{\partial y} = -1 \text{ at } y = 0 \quad (10)$$
$$u = 0, \theta \to 0, \text{ as } y \to \infty$$

METHODOLOGY FOR SOLUTION:

Assuming that the trail solutions for the governing equations are in the following form:

$$u(y,t) = u_0(y)e^{i\omega t} \quad (11)$$
$$\theta(y,t) = \theta_0(y)e^{i\omega t} \quad (12)$$

With the modified boundary conditions:

$$u_o = 0, \theta_0 = 0, \text{ for all } y, t \le 0$$
$$t > 0: u_0 = e^{-i\omega t}, \frac{\partial \theta_0}{\partial y} = -e^{-i\omega t}, \quad \text{at } y = 0 \quad (13)$$
$$u_0 = 0, \theta_0 = 0, \text{ as } y \to \infty$$

Using Eqns (11), (12) and (13) in Eqns (8),(9)

$$u(y,t) = \exp(-m_2 y) + \frac{G_r}{R_1}[\exp(-m_2 y) - \exp(-m_1 y)] \quad (14)$$

$$\theta(y,t) = \frac{1}{m_1}\exp(-m_1 y) \quad (15)$$

Where $m_1 = \sqrt{\frac{3NP_r i\omega}{3N + P_r}}$, $m_2 = \sqrt{i\omega - \frac{1}{k}}$ and

$$R_1 = m_1(m_1^2 + \frac{1}{k} - i\omega)$$

The Skin Friction is as follows

$$\left(\frac{\partial \mu}{\partial t}\right)_{(0,0)} = -m_2 + \frac{G_r}{R_1}\left[m_1 - m_2\right] \quad (16)$$

RESULTS AND CONCLUSIONS:-

1. The effect of prandtl number on the velocity profiles has been illustrated in figure-1 and figure – 2. In both cases when the porosity of the fluid bed is held constant, it is seen that, as the prandtl number increases the fluid velocity increases. However, as we move far away from the boundary it is notice that the prandtl number loses its significance and not much of significance change in the velocity is observed. Further, it is also noticed that as the pore size increases the fluid velocity decreases marginally while all other features remains constant.

2. Figure-3 and Figure-4 depicts the influence of porosity on the fluid velocity. As the pore size of the fluid bed increases the velocity profiles are found to be oscillatory in its behavior. From the illustrations it is seen that, the prandtl number contributes significantly for such a phenomena in the both cases.

3. For a constant radiation parameter, the influence of porosity on the velocity profiles is illustrated in figure-5 and fgure-6. For a fixed porosity value, the fluid velocity is found to be sinusoidal and the amplitude of such sinusoidal motion is found to be decreasing as we move far away from the boundary. In both the cases, it is observed that, initially a backward flow is observed and such a backward flow can be attributed due to the porosity of the fluid bed.

4. The plot in figure - 7 and figure - 8 shows the effect of radiation parameter on the velocity field. In general it is observed that, the increase in radiation parameter contributes to the decreae in the velocity of the fluid. Even in such a case, the amplitude decreases gradually. Such a pattern is noticed even for a slight change in the porosity, However, the dispersion in the velocity field is found to be marginally small.

5. The influence of the Grashoff number for a fixed Prandtl number is illustrated in figure 9, figure - 10 and figure - 11. In all such illustrations the velocity profiles are observed to be oscillatory in its nature. Initially a backward flow is noticed and subsequently the velocity filed is found to be in the forward direction. Even a slight change in the Prandtl number, does not contribute much in the velocity field.

6. Illustrations given in figure - 12 and figure 13 shows the influence of the Prandtl number when Grashoff values are held constant. In each of these cases as the Prandtl number increases, the velocity increases and in general, it is seen that the pattern of the velocity moment is sinusoidal and the amplitude of such sinusoidal motion increases as we move far away from the bounding surface. Though the Prandl number is held constant and Grashoff number is modified marginally, not much of appreciable change is noticed in the velocity profiles.

7. Figure - 14, figure - 15, figures - 16 and figure - 17 depicts the influence of the Prandtl number on Skin friction. It is seen that, as the Prandtl number increases, the skin friction also increases. Further, for a constant Prandtl number, increase in Grashoff number contributes for the decrease in skin friction. Inspite of change in the radiation parameter not much of significant change is observed in the Phenomena. Therefore, it can be concluded that the Skin friction apears to be independent of radiation parameter.

8. The influnce of Grashoff number with respect to prandtl number has been illustrated in Figure - 18, Figure - 19, Figure - 20, and Figure - 21. It is noticed that as the Grashoff number increases, the skin friction decreases. However, for a constant Grashoff number, increase in prandtl number contributes to the raise in Skin friction. In all these situations though the radiation parameter is changed not much of significant change is observed.Therefore,the phenomena is found to be independent of radiation parameter.

9. The consolidated effect of radiation parameter with respect to Grashoff number is illustrated in Figure - 22, figure -

23, figure - 24 and figure – 25 for prandtl number 1.5 and 2.5 respectively. For a constant radiation parameter as Grashoff number is increased,the skin friction is found to be decreasing. Further, when the Grashof number is held constant and as the radiation parameter increases the skin friction decreases. It is also observed that the prandtl number contributes in skin friction as prandtl number increases it is seen that the skin friction increases.

10. The consolidated effect of Grashoff number with respect to the radiation parameter for a constant prandtl number is illustrated in figure - 26, figure - 27, figure-28,and Figure-29. When the radiation parameter is held constant and as Grashoff number increases the kin friction decreases. Not much of apparent change is observed even the radiation parameter is increased. Further, it is seen that as the prandtl number is increased the Skin friction is found to be increasing.

11. The effect of radiation parameter with respect to prandtl number is illustrated in figure -30, figure - 31, figure - 32 and figure-33. In all these illustrations it is observed that as the radiation parameter increases the skin friction if found to be increasing. The situation is examined for Grashoff numbers 0.25, 0.50, 0.75 and 1.00. It is noticed that,even for slight change in Grashoff number a marginal change in the skin friction is noticed. As Grassoff number increases the skin friction is observed to be decreasing. In each of these situations for a constant radiation parameter and Grashoff number, increase in prandtl number contributes to raise in skin friction.

12. The consolidated influence of prandtl number with respect to radiation parameter is illustrated in figure - 34, figure - 35, figure - 36 and figure - 37. In each of these cases increase in prandtl number contibutes to increase in Skin friction. For a constant prandtl number, increase in the radiation parameter also contributes to the increase in Skin friction. Further, as Grashoff number increases in general. It is found that the Skin friction decreases for similar values of prandtl numbers.

ILLUSTRATIONS:

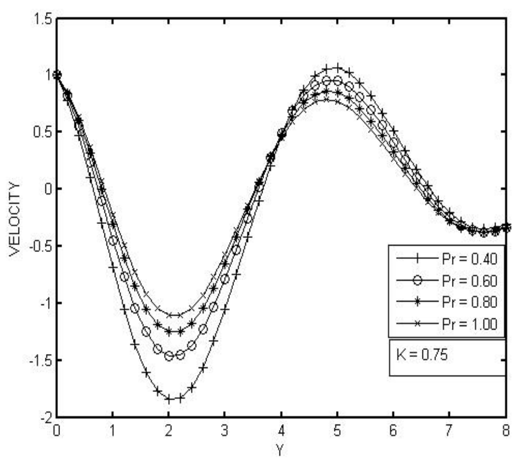


Figure 1:- The influence of Prandtl number on velocity profiles

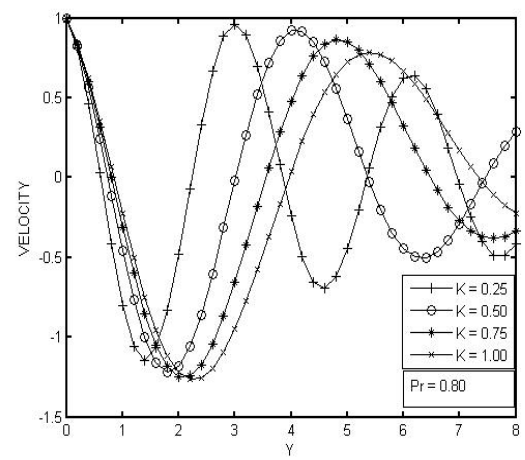


Figure 3:- The influence of porosity on velocity profiles

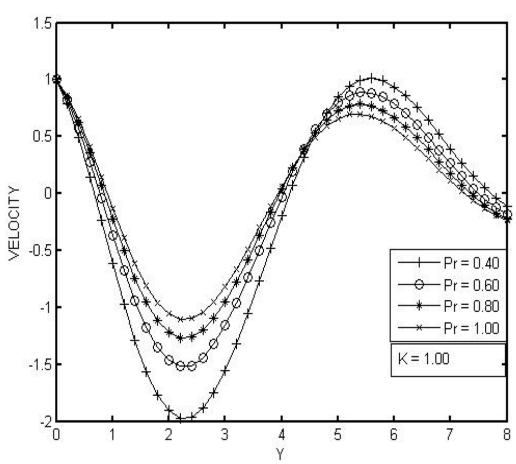


Figure 2:- The effect of Prandtl number on velocity profiles

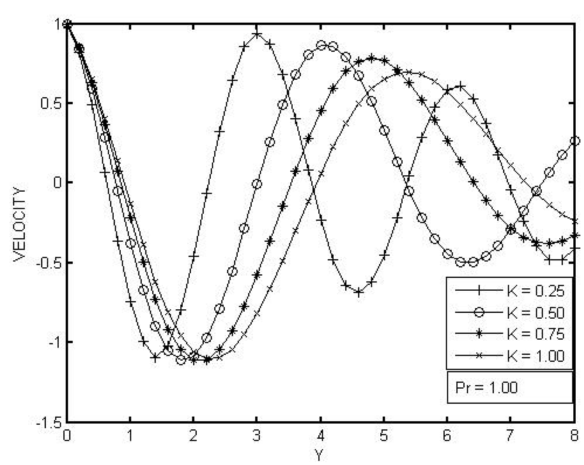


Figure 4:- The effect of K on velocity profiles

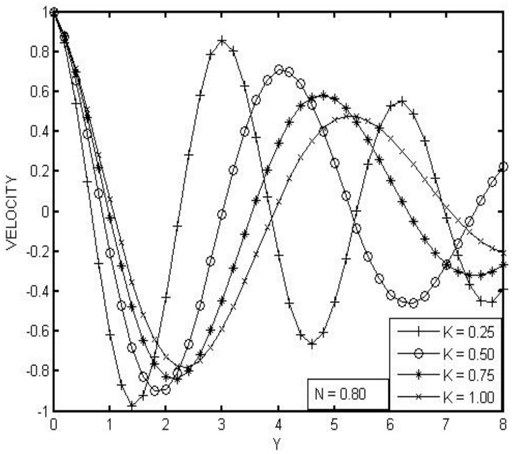


Figure 5:- The influence of porosity on velocity profiles

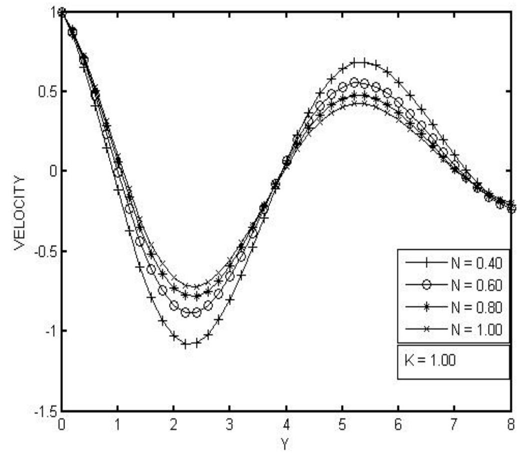


Figure 8:- The effect of radiation parameter on velocity profiles

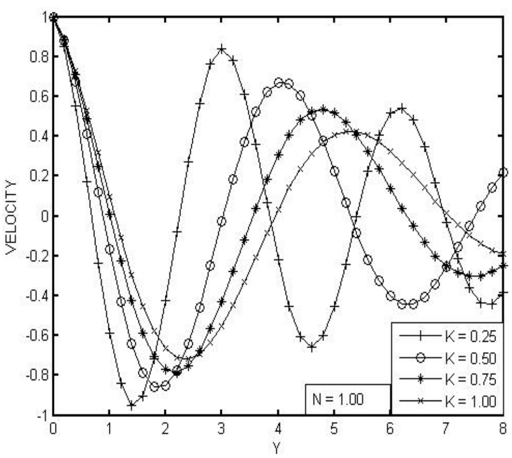


Figure 6:- Variation in velocity with respect to porosity.

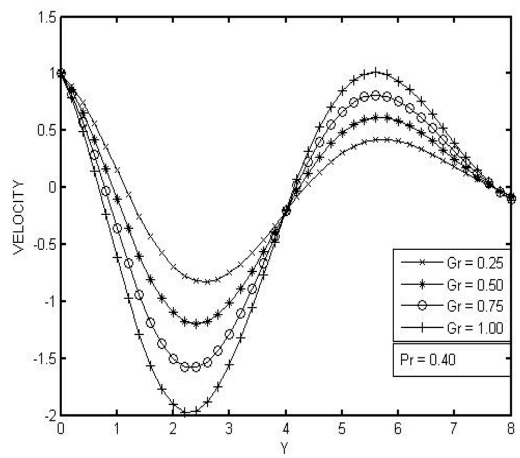


Figure 9:- The effect of Grashoff number on velocity profiles

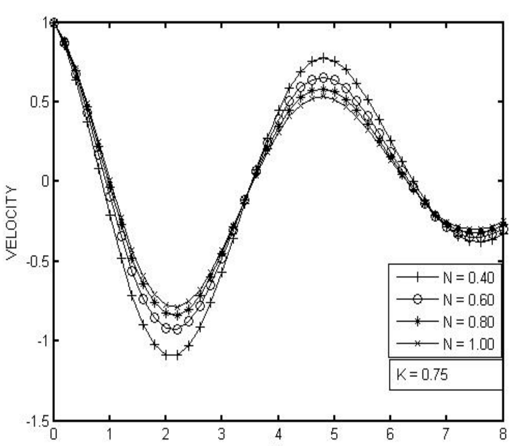


Figure 7:- The influence of radiation parameter on velocity profiles

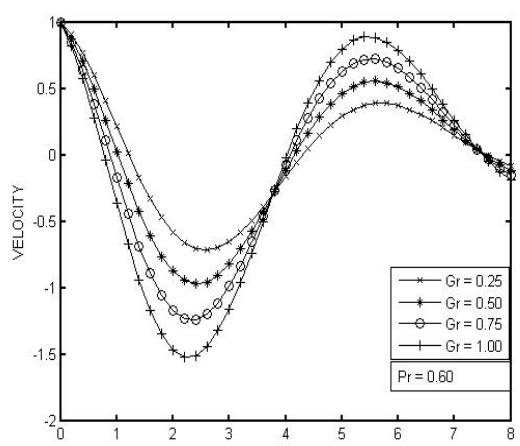


Figure 10:- The influence of Grashoff number on velocity profiles

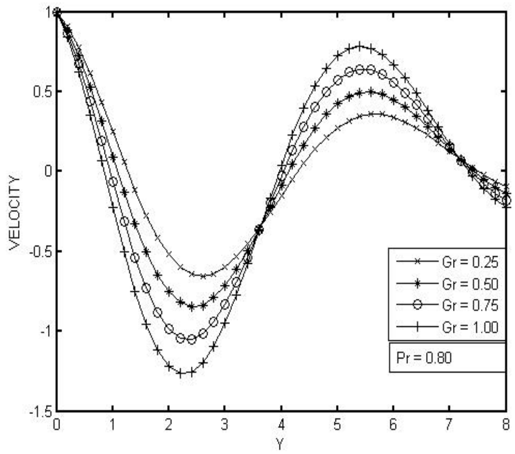


Figure 11:- The effect of Grashoff number on velocityprofiles

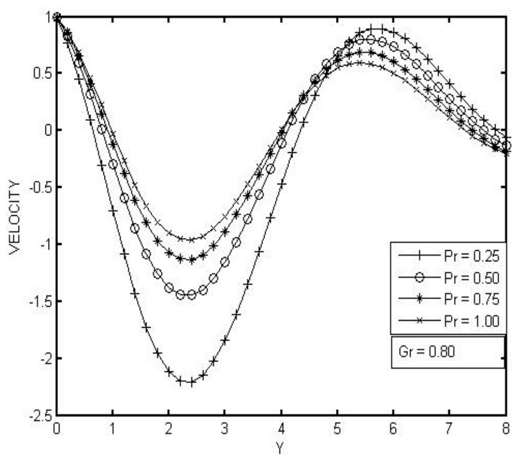


Figure 12:- Variation of velocity with respect to Prandtl number on velocity profiles

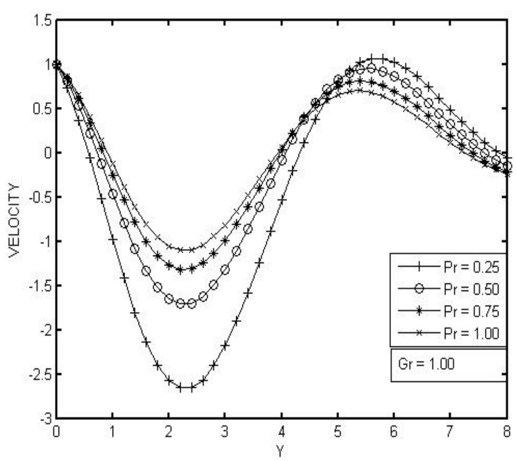


Figure 13:- The effect of Prandtl number on velocity profiles

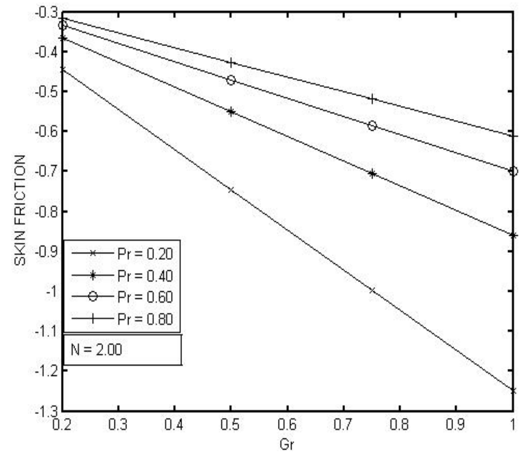


Figure 14:- The effect of Prandtl number on Skin friction profiles

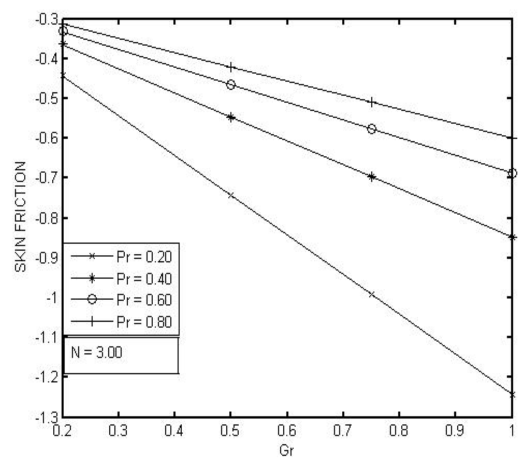


Figure 15:- The effect of Prandtl number on Skin friction profiles

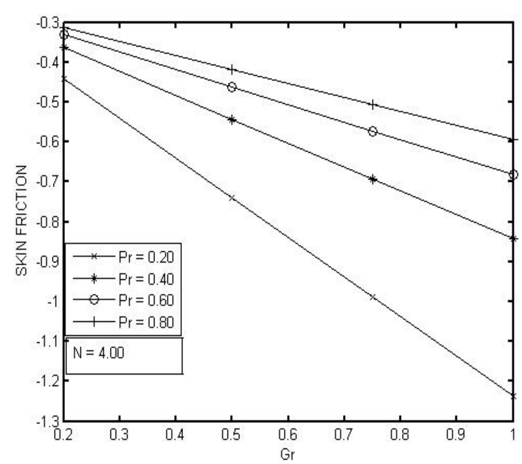


Figure 16:- The effect of Prandtl number on Skin friction profiles

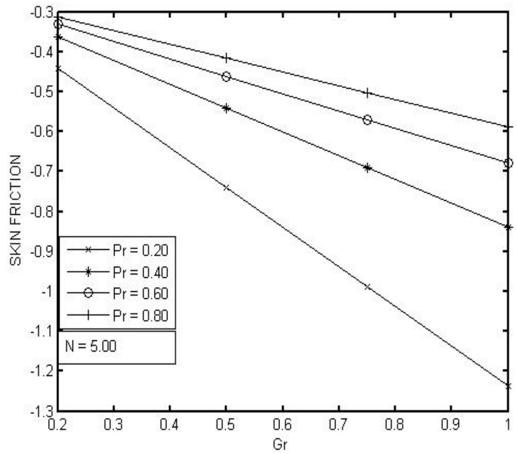


Figure 17:- The effect of Prandtl number on Skin friction profiles

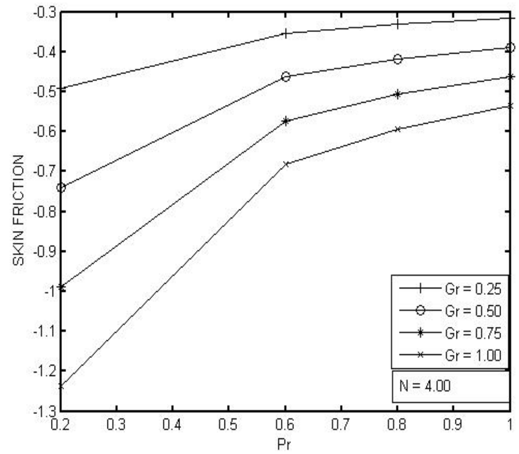


Figure 20:- The effect of Grashoff number on Skin Friction profiles

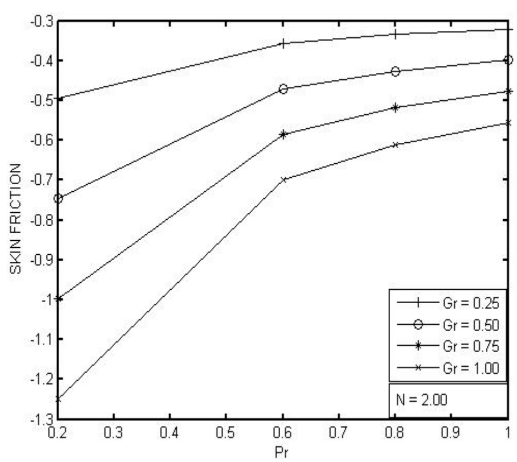


Figure 18:- The effect of Grashoff number on Skin Friction profiles

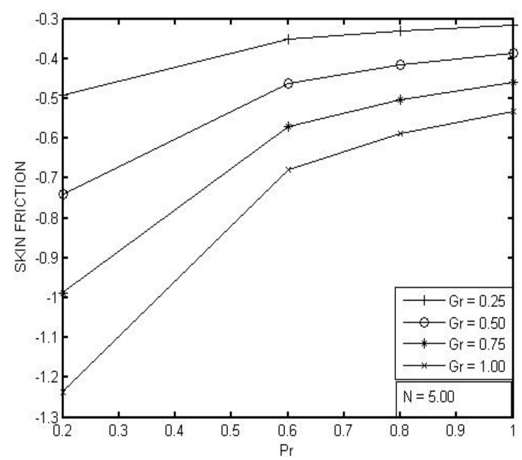


Figure 21:- The effect of Grashoff number on Skin Friction profiles

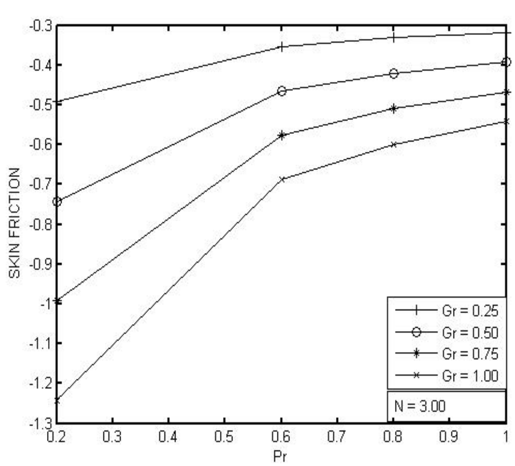


Figure 19:- The effect of Grashoff number on Skin Friction profiles

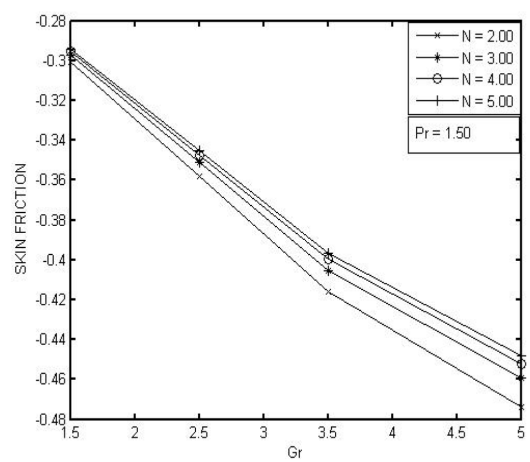


Figure 22:- The effect of N on Skin Friction profiles

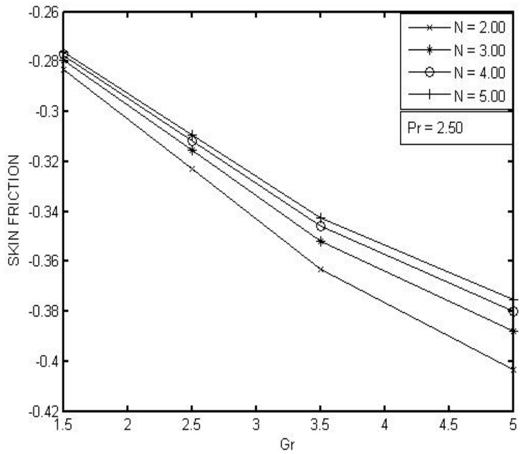


Figure 23:- The effect of N on Skin Friction profiles

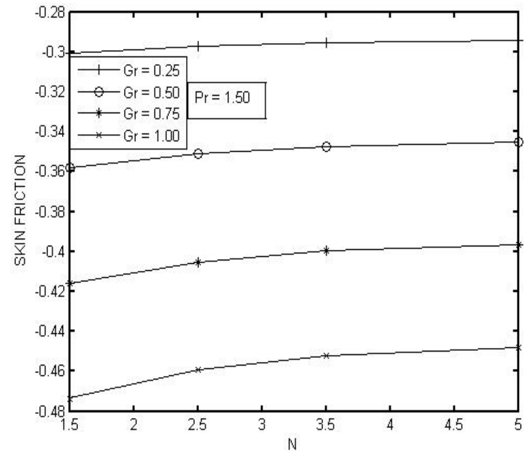


Figure 26:- The effect of Grashoff number on Skin Friction profiles

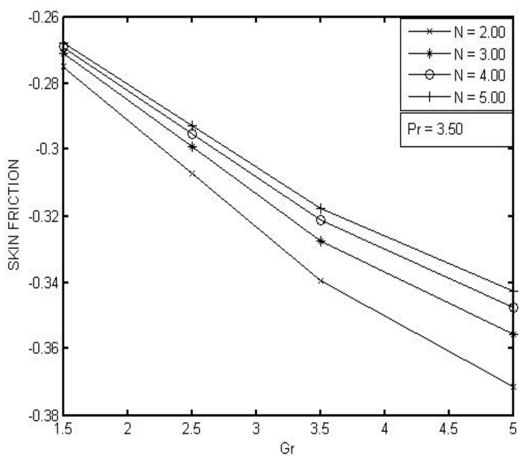


Figure 24:- The effect of N on Skin Friction profiles

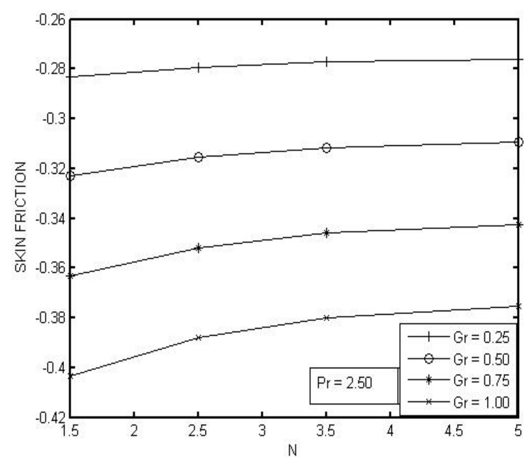


Figure 27:- The effect of Grashoff number on Skin Friction profiles

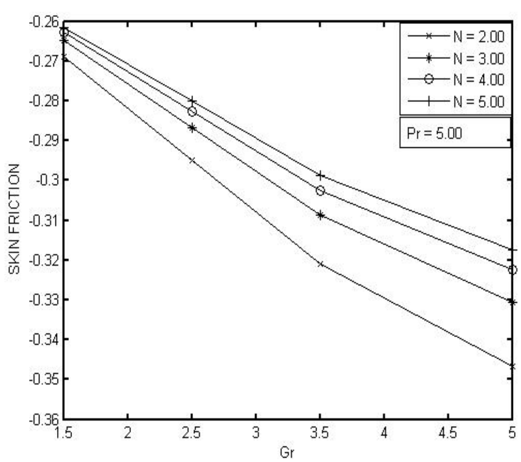


Figure 25:- The effect of N on Skin Friction profiles

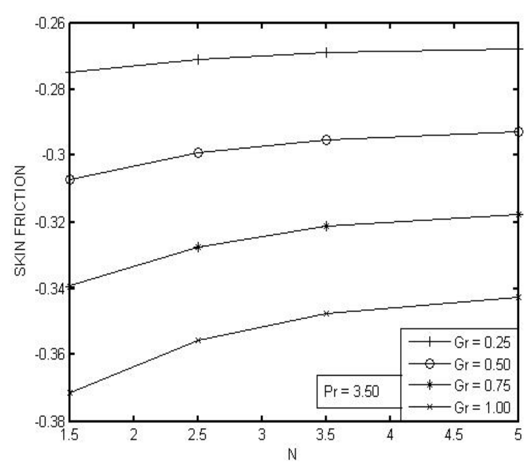


Figure 28:- The effect of Grashoff number on Skin Friction profiles

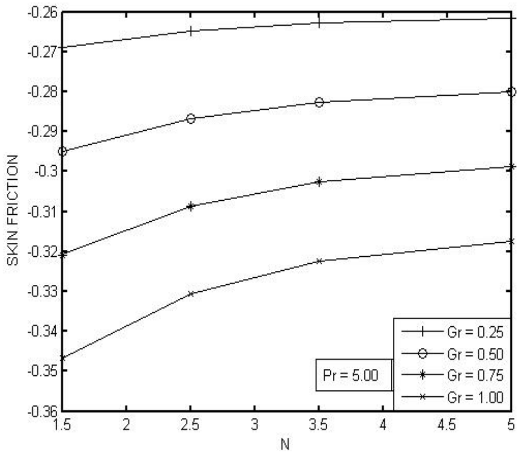


Figure 29:- The effect of Grashoff number on Skin Friction profiles

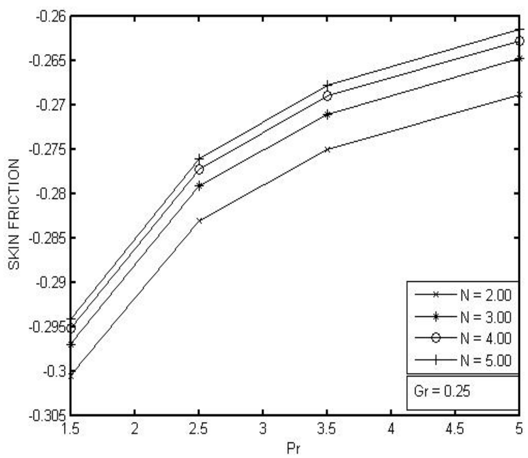


Figure 30:- The effect of N on Skin Friction profiles

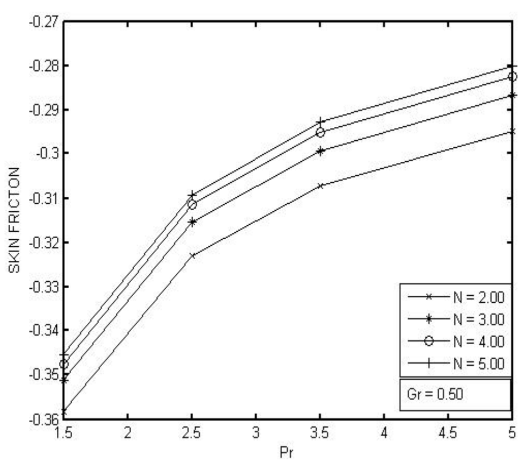


Figure 31:- The effect of N on Skin Friction profiles

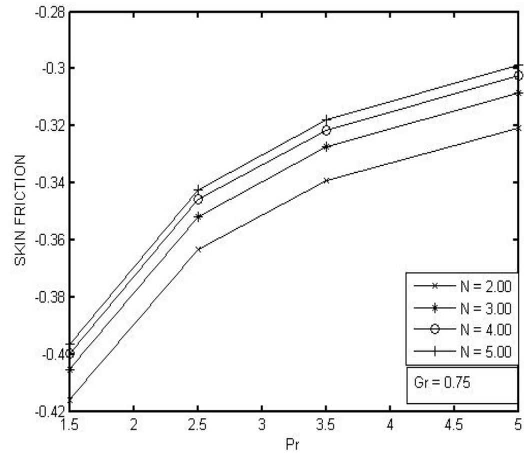


Figure 32:- The effect of N on Skin Friction profiles

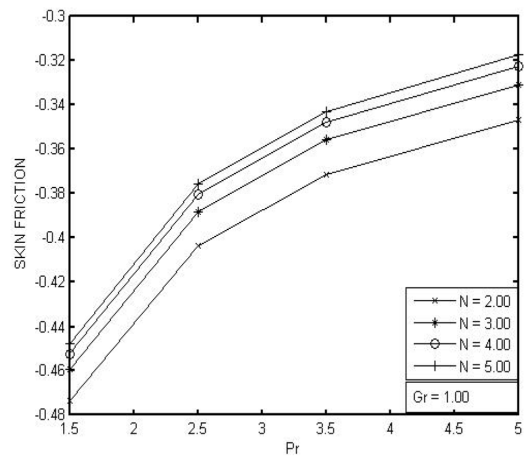


Figure 33:- The effect of N on Skin Friction profiles

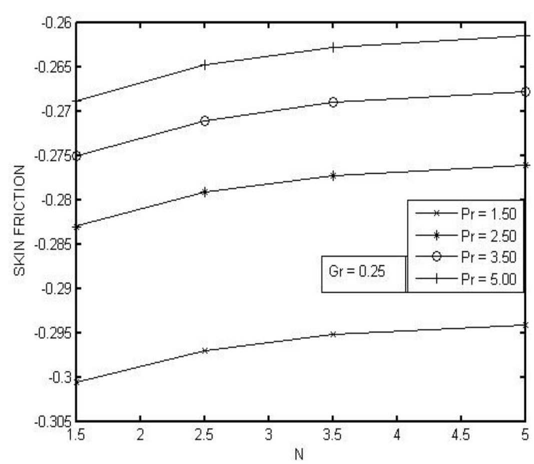


Figure 34:- The effect of Prandtl number on velocity profiles

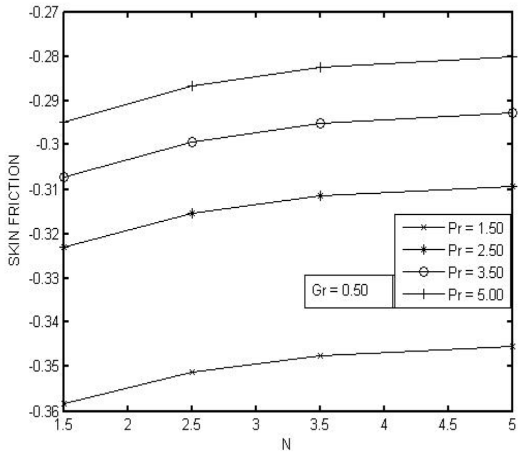


Figure 35:- The effect of Prandtl number on velocity profiles

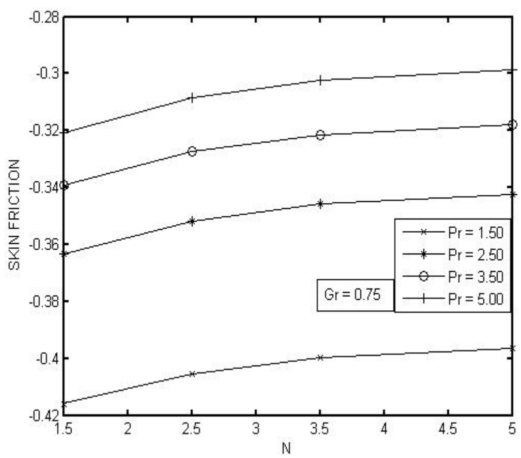


Figure 36:- The effect of Prandtl number on velocity profiles

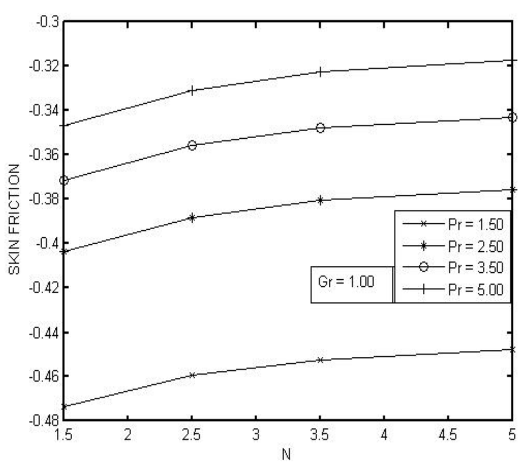


Figure 37:- The effect of Prandtl number on velocity profile

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