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RADIATION EFFECT ON NATURAL CONVECTION FLOW PAST AN IMPULSIVELY STARTED INFINITE VERTICAL PLATE THROUGH POROUS MEDIUM IN THE PRESENCE OF MAGNETIC FIELD AND FIRST ORDER CHEMICAL REACTION

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ABSTRACT

In this paper, the effect of thermal radiative past an impulsively started infinite vertical plate through porous medium under the influence of transverse magnetic field has been discussed. The fluid is assumed to be gray, emitting – absorbing but non-scattering medium and the optically thick radiation limit is considered. The dimensionless governing equations are solved using Laplace transformation technique. The velocity and temperature profiles are shown graphically. The variation of skin – friction and Nusselt number are also shown in the table.

KEYWORDS: First Order Chemical Reaction, Heat and Mass Transfer, MHD, Natural Convection, Porous Medium

1. INTRODUCTION

In recent year, the subject of magneto-hydrodynamics has attracted the attention of many authors in view not only of its own interest, but also of its application to problems in geophysics, astrophysics and engineering. At the high temperatures attained in some engineering devices, gas, for example, can be ionized and so becomes an electrical conductor. The ionized gas or plasma can be made to interact with the magnetic field and alter heat transfer and friction characteristic. Since some fluid can also emit and absorb thermal radiation, it is of interest to study the effect of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing thermal radiation. This is of interest because heat transfer by thermal radiation is becoming of greater importance when we are concerned with space application and higher operating temperature.

In this paper, we consider one of the simplest problem of this type in which an electrically conducting, radiation, viscous incompressible fluid past an impulsively started infinite vertical plate through porous medium under the action of a constant pressure gradient is subjected to an external magnetic field of constant strength in the direction perpendicular to the plate and to the direction of flow.

Several investigations have been carried out on problem of heat transfer by radiation as an important application of space and temperature related problems. Greif et al. [1] obtained an exact solution for the problem of laminar convective flow in a vertical heated channel in the optically thin limit. In the optically thin limit, the fluid does not absorb its own emitted radiation which means that there is no self absorption but the fluid does absorb radiation emitted by the boundaries. Soundal gekar and Takhar [2] studied that effect of radiation on the natural convection flow of a gas past a semi infinite using the Cogly-Vincentine-Gilles equilibrium modal (Cogly et al. [3]).

Hossain and Takhar [4] analyzed the effect of radiation using the Rosseland diffusion approximation which leads to non-similar solution for the forced and free convection of an optically dense viscous incompressible fluid past a heated vertical plate with uniform free stream and uniform surface temperature, while Hossaion et al. [5] studies the effect of radiation on free convection from a porous vertical plates. Muthucumaraswamy and Kumar [6] studied the thermal radiation effects on moving infinite vertical plate in the presence of variable temperature and mass diffusion.

Gorla et al. [7] solved the non-similar problem of free convective heat transfer from a vertical plate embedded in a saturated porous medium with an arbitrarily varying surface temperature. Sattar and Alam [8] presented unsteady free convection and mass transfer flow of a viscous, incompressible, and electrically conducting fluid past a moving infinite vertical porous plate with thermal diffusion effect. Effect of porosity on the free convection flow along a vertical plate embedded in a porous medium was investigated by Beithou et al. [9]. Their results show that as the porosity is increased the temperature variation becomes steeper, that is, the heat transfer rate is increased. Kumari et al. [10] investigated the mixed convection flow over a vertical wedge embedded in a porous medium. They found that the heat transfer is increased with the Prandtl number and the effect of permeability on the heat transfer is very small. Chen [11] studied the natural convection flow over a permeable inclined surface with variable wall temperature and concentration. The results show that the velocity is decreased in the presence of a magnetic field. Increasing the angle of inclination decreases the effect of buoyancy force. Heat transfer rate is increased when the Prandtl number is increased. A comprehensive review of the literature concerning natural convection in fluid-saturated porous media may be found in the books by Nield and Bejan [12], Vafai [13]. Mazumdar and Deka [14] considered an electrically radiating, viscous incompressible fluid past an impulsively stated infinite vertical plate under the action of a constant pressure gradient in the presence of magnetic field. The influence of thermal radiation on the boundary layer flow due to an exponentially stretching sheet is studied by Sajid and Hayat [15]. El-Aziz [16] considered the thermal radiation effect on an unsteady flow. Singh and Kumar [17] observed the effects of chemical reactions on unsteady MHD free convection and mass transfer for flow past a hot vertical porous plate with heat generation/absorption through porous medium. Rao and Shivaiah [18] studied the chemical reaction effects on unsteady MHD flow past semi-infinite vertical porous plate with viscous dissipation. Radiation effects on MHD flow past an exponentially accelerated isothermal vertical plate with uniform mass diffusion in the presence of a heat source was studied by Reddy et al. [19]. Prakash et al. [20] analysed the diffusion-thermo and radiation effects on unsteady MHD flow through porous medium past an impulsively started infinite vertical plate with variable temperature and mass diffusion.

In this paper, our objective is to examine quantitatively the effect of magnetic field of an optically thin viscous incompressible fluid from an impulsively started vertical plate through porous medium in the presence of thermal radiation. The results of Mazumdar and Deka [14] have been extended by using porosity parameter. We have also compared the previous results Mazumdar and Deka [14] in the presence of porosity parameter. The temperature and velocity distribution are evaluated numerically for some values the radiation parameter, magnetic parameter, porosity parameter, Prandtl number and time.

2. MATHEMATICAL FORMULATION

We consider an electrically conducting, radiation, viscous, incompressible fluid past an impulsively started infinite vertical plate through porous medium. initially, the plate and the surrounding gas are at the same temperature $T'_\infty > 0$. At time $t' > 0$, the plate temperature is slightly increased to $T'_w - T'_\infty > 0$ and the magnetic field of strength B_0 is assumed to be applied in a direction perpendicular to the vertical plate, so that there exists free convection current in the vicinity of the plate when the plate is given an impulsive motion with a velocity u_0. The x'-axis is taken along the plate in the vertically upward direction and the y'-axis is taken normal to the plate, in the direction of the applied magnetic field. Then the fully developed flow of a radiating gas is governed by the following set of equations:

$$\frac{\partial u'}{\partial t'} = \upsilon \frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) - \frac{\sigma B_0^2 u'}{\rho} - \frac{\upsilon u'}{K'} \tag{2.1}$$

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} \tag{2.2}$$

With the following initial and boundary condition

$$\left.\begin{array}{ll} t' \le 0, & u' = 0, T' = T'_\infty \quad \text{for all } y' \\ t' > 0, & \begin{cases} u' = u_0, & T' = T'_w, \quad at \quad y' = 0 \\ u' \to 0, & T' \to T'_\infty \quad as \quad y' \to \infty \end{cases} \end{array}\right\} \tag{2.3}$$

In the optically thick limit, the fluid does not absorb its own emitted radiation that is there is no self absorption, but it does absorb radiation emitted by the boundaries. It has been shown by Cogly et al. [3], that in the optically thick limit for a non-gray gas near equilibrium, that

$$\frac{\partial q_r}{\partial y'} = 4(T' - T'_\infty)\int_0^\infty K_{\lambda w}\left(\frac{de_{b\lambda}}{dT'}\right)_w d\lambda = 4I_1(T' - T'_\infty) \tag{2.4}$$

Where,

$K_{\lambda w}$ is the absorption coefficient $e_{b\lambda}$ is the Planck function and the subscript w refers to values at the wall.

On introducing the following non-dimensional quantities

$$u = \frac{u'}{v_0},\quad y = \frac{\sqrt{G_r}\, y' u_0}{\upsilon},\quad t = \frac{G_r t' u_0^2}{\upsilon},\quad \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},$$

$$M = \frac{\sigma B_0^2 \upsilon}{\rho u_0^2},\quad P_r = \frac{\mu C_p}{\kappa},\quad G_r = \frac{g\beta\upsilon(T'_w - T'_\infty)}{u_0^3},\quad F = \frac{4I_1\upsilon}{\kappa u_0^2 G_r} \tag{2.5}$$

In the equations (2.2.1) to (2.2.4) leads to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + \theta - (M + \frac{1}{K})u \tag{2.6}$$

$$P_r \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - F\theta \tag{2.7}$$

The initial and boundary condition in non-dimensional quantities are

$$t \le 0, \quad u=0, \quad \theta=0 \quad for\ all\ y$$
$$t>0, \quad \begin{cases} u=1, \quad \theta=1, \quad at\ y=0 \\ u\to 0, \ \theta\to 0, \quad as\ y\to\infty \end{cases} \tag{2.8}$$

3. SOLUTION OF THE PROBLEM

Using Laplace transform technique, solution of equation (2.6) is given by

$$u=\frac{1}{2}\begin{bmatrix} e^{2\eta\sqrt{a_1 t}}erfc(\eta+\sqrt{a_1 t}) \\ +e^{-2\eta\sqrt{a_1 t}}erfc(\eta-\sqrt{a_1 t}) \end{bmatrix}+\frac{1}{2(a-\frac{1}{\kappa})}\begin{bmatrix} e^{2\eta\sqrt{a_1 t}}erfc(\eta+\sqrt{a_1 t}) \\ +e^{-2\eta\sqrt{a_1 t}}erfc(\eta-\sqrt{a_1 t}) \end{bmatrix}$$
$$-\frac{1}{2(a-\frac{1}{\kappa})}\begin{bmatrix} e^{2\eta\sqrt{Ft}}erfc(\eta\sqrt{\Pr}+\sqrt{\frac{F\,t}{\Pr}}) \\ +e^{-2\eta\sqrt{Ft}}erfc(\eta\sqrt{\Pr}-\sqrt{\frac{F\,t}{\Pr}}) \end{bmatrix}-\frac{1}{2(a-\frac{1}{\kappa})}\begin{bmatrix} e^{2\eta\sqrt{(a_1+a_2)t}}erfc(\eta+\sqrt{(a_1+a_2)t}) \\ +e^{-2\eta\sqrt{(a_1+a_2)t}}erfc(\eta-\sqrt{(a_1+a_2)t}) \end{bmatrix}$$
$$+\frac{1}{2(a-\frac{1}{\kappa})}\begin{bmatrix} e^{2\eta\sqrt{(F+a_2\Pr)t}}erfc(\eta\sqrt{\Pr}+\sqrt{(\frac{F}{\Pr}+a_2)t}) \\ +e^{-2\eta\sqrt{(F+a_2\Pr)t}}erfc(\eta\sqrt{\Pr}-\sqrt{(\frac{F}{\Pr}+a_2)t}) \end{bmatrix} \tag{3.1}$$

Skin-Friction

Knowing the velocity field, we now study the changes in the skin-frication, which is given in non-dimensional form as

$$\tau=-\left(\frac{\partial u}{\partial y}\right)_{y=0}=-\frac{1}{2\sqrt{t}}\left(\frac{\partial u}{\partial \eta}\right)_{\eta=0}$$

Then from equation (3.1), we have

$$\tau=(1+\frac{1}{(a-\frac{1}{\kappa})})\left[\sqrt{a_1}erf(\sqrt{a_1 t})+\frac{1}{\sqrt{\pi t}}e^{-a_1 t}\right]-\frac{1}{(a-\frac{1}{\kappa})}\left[\sqrt{F}erf(\sqrt{\frac{F\,t}{\Pr}})+\sqrt{\frac{\Pr}{\pi t}}e^{\frac{F}{\Pr}t}\right]$$
$$-\frac{1}{(a-\frac{1}{\kappa})}\left[\sqrt{(a_1+a_2)}erf(\sqrt{(a_1+a_2)t})+\frac{1}{\sqrt{\pi t}}e^{-(a_1+a_2)t}\right]$$
$$+\frac{1}{(a-\frac{1}{\kappa})}\left[\sqrt{(F+a_2\Pr)}erf(\sqrt{(\frac{F}{\Pr}+a_2)t})+\sqrt{\frac{\Pr}{\pi t}}e^{-(\frac{F}{\Pr}+a_2)t}\right] \tag{3.2}$$

Solution of equation (2.7) by using Laplace Transform is

$$\theta=\frac{1}{2}\left[e^{2\eta\sqrt{Ft}}erfc(\eta\sqrt{\Pr}+\sqrt{\frac{F\,t}{\Pr}})+e^{-2\eta\sqrt{Ft}}erfc(\eta\sqrt{\Pr}-\sqrt{\frac{F\,t}{\Pr}})\right] \tag{3.3}$$

Nusselt Number

The rate of heat transfer

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = -\frac{1}{2\sqrt{t}}\left(\frac{\partial\theta}{\partial\eta}\right)_{\eta=0}$$

$$Nu = \sqrt{F}erf(\sqrt{\frac{F\,t}{\Pr}}) + \sqrt{\frac{\Pr}{\pi t}}e^{-\sqrt{\frac{F\,t}{\Pr}}} \tag{3.4}$$

4. RESULTS AND DISCUSSIONS

Figure 1 shows the velocity profiles for various values of the magnetic parameters M. It is observed that the fluid velocity decreases exponentially as increasing η and also concluded that the fluid velocity decays with increasing magnetic parameter M as shown in Figure 1.

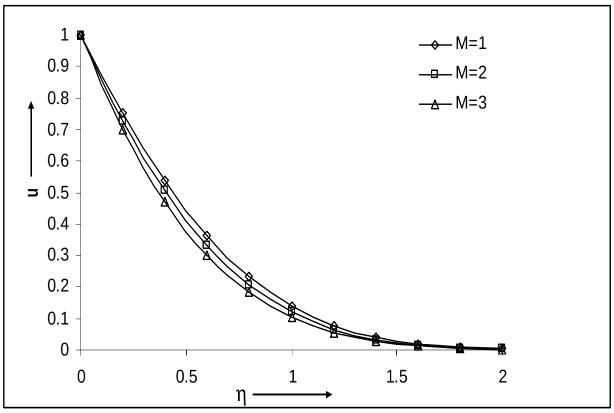

Figure 1: Velocity Distribution for Various Values of the M, Taking t=0.2, F=5, Pr=0.71, K=2

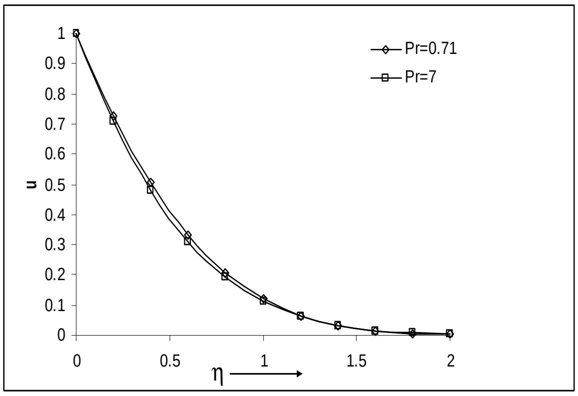

Figure 2: Velocity Distribution for Various Values of the Prandtl Number Pr, taking t=0.2, F=5, K=2, M=2

Figure 2 and 3 had shown the effect of Pr on the velocity and temperature profiles. From Figure 2, it is concluded that the fluid velocity decreases with increasing Pr. From Figure 3, it is observed that an increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer, the reason is that smaller value of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Pr. Hence in the case of smaller Prandtl numbers as thermal the boundary layer is thicker and the heat transfer is reduced.

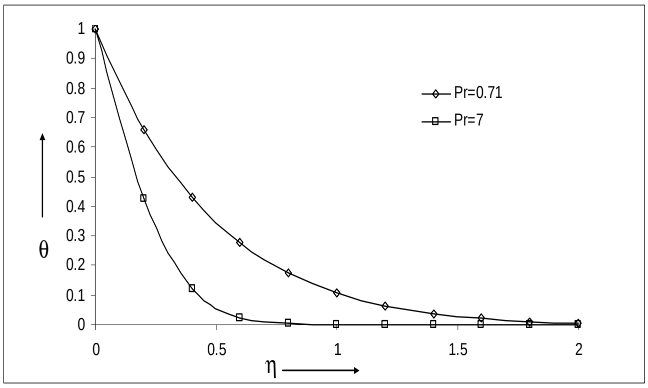

Figure 3: Temperature Dist. for Various Values of the Prandtl Number P_r, Taking t=0.2, F=5, K=2, M=2

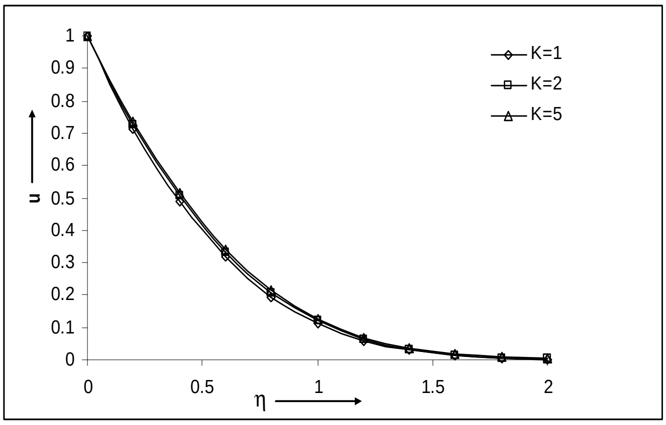

Figure 4: Velocity Distribution for Various Values of the Porosity Parameter K, Taking t=0.2, F=5, Pr=0.71, M=2

`Figure 4, shows the effects of the porosity parameter (K) on velocity profiles against η. It is observed that velocity increases with increasing K. Since the presence of a porous medium increases the resistance to flow resulting in decrease in the flow velocity. This behavior is depicted by the decrease in the velocity as K decreases as shown in Figure 4.

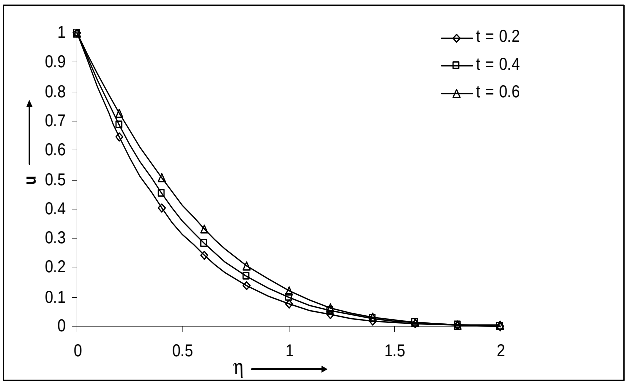

Figure 5: Velocity Distribution for Various Values of the Time t, Taking t=0.2, F=5, Pr=0.71, K=2

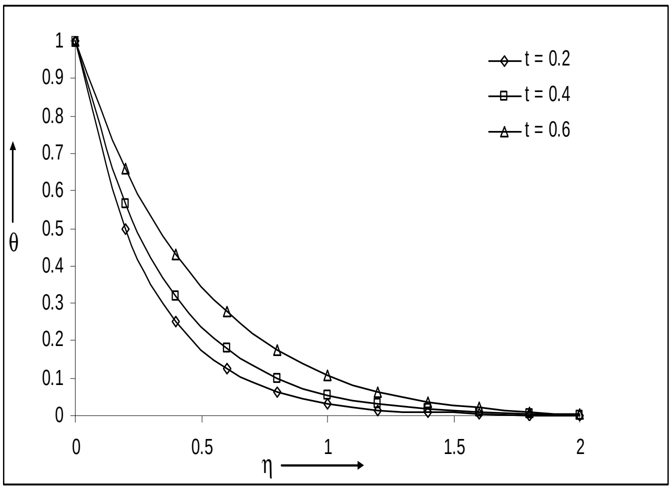

Figure 6: Temperature Distribution for Various Values of the Time t, Taking F=5, Pr=0.71, K=2, M=2

Figure 5 and 6 reveal the velocity and temperature profiles against y for different values of t respectively. In both Figures, the magnitude of velocity and temperature are greatest at the plate and then decays to zero asymptotically. In both Figures, the velocity and temperature profiles increase with increasing t.

Figure 7 and 8 show the velocity and temperature profiles against y for different values of F respectively. In both Figures, the magnitude of velocity and temperature are greatest at the plate and then decays to zero exponentially. An increase in F causes a significant decrease in the velocity. We also note that with increasing values of F the time taken to attain the steady state is reduced. Thermal radiation flux therefore has a de-stabilizing effect on the transient flow regime. This is important in polymeric and industrial flow process, since it shows that the presence of thermal radiation while decreasing temperature, will affect flow control from the plate surface into the boundary regime. As expected, temperature values are also significantly reduced with an increase in F as there F is a progressive decrease in thermal radiation contribution accompanying this.

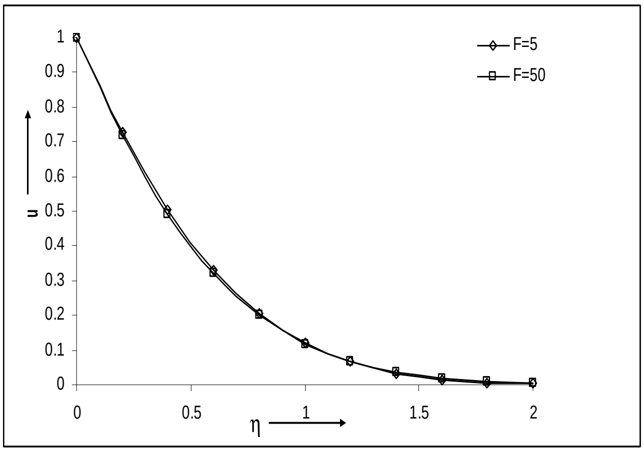

Figure 7: Velocity Distribution for Various Values of the Radiation Parameter F, Taking t=0.2, Pr=0.71, K=2, M=2

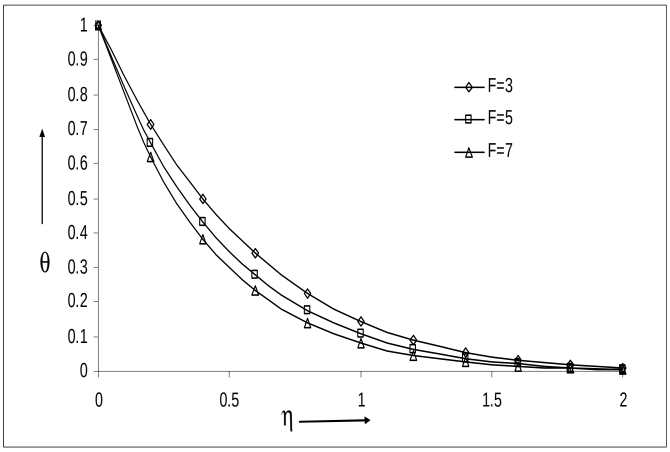

Figure 8: Temperature Distribution for Various Values of the Radiation Parameter F, Taking t=0.2, Pr=0.71, K=2, M=2

The numerical values of skin-friction and Nusselt number are presented in table 1 & table 2 respectively for different values of radiation parameter F, magnetic parameter M, Prandtl number Pr, porosity parameter K and time t.

Table 1

T	M	F	K	Pr	τ
0.2	2	3	2	0.71	1.680508
0.2	**2**	5	2	0.71	1.661427
0.2	**2**	7	2	0.71	1.660503
0.2	3	5	2	0.71	1.558516
0.2	4	5	2	0.71	1.421356
0.2	2	5	5	0.71	1.593168
0.2	2	5	10	0.71	1.570173
0.2	2	5	2	7	1.773236
0.4	2	5	2	0.71	1.427777
0.6	2	5	2	0.71	1.361989
0.8	2	5	2	0.71	1.337882

Table 2

T	Pr	F	Nu
0.2	0.71	3	1.853258
0.2	0.71	5	2.287374
0.2	7	5	3.802999
0.2	0.71	10	3.170112
0.4	0.71	5	2.241608
0.6	0.71	5	2.23688
0.8	0.71	5	2.236204

5. CONCLUSIONS

In this paper, our objective is to examine quantitatively the effect of magnetic field of an optically thin viscous incompressible fluid from an impulsively started vertical plate through porous medium in the presence of thermal radiation. The non-dimensional equations are solved using Laplace-transform technique. The temperature and velocity distribution are evaluated numerically and shown graphically for some values the radiation parameter, magnetic parameter, porosity parameter, Prandtl number and time. Effect of different parameters on skin-friction and Nusselt number are also shown in tables.

Nomenclature

C_p - Specific heat at constant pressure, $J.Kg^{-1}.K^{-1}$, G_r - The thermal Grashof number

g - Acceleration due to gravity, $m.s^{-1}$, k - Thermal conductivity, $Wm^{-1}K^{-1}$

K' - The porosity parameter, K - Dimensionless porosity parameter, B_0 – Electromagnetic induction

M - The magnetic parameter, F – The dimensionless radiation parameter, Nu – the Nusselt number

P_r - Prandtl number, T' - Temperature of the fluid near the plate, K, t' - Time, s, t - Dimensionless time

u' - Velocity of the fluid in the x' - direction, $m.s^{-1}$, u_0 - Velocity of the plate, $m.s^{-1}$,

u - Dimensionless velocity, y' - Coordinate axis normal to the plate, m

y - Dimensionless coordinate axis normal to the plate

Greek Symbols

β - Volumetric coefficient of thermal expansion, K^{-1}, μ - Coefficient of viscosity, Pa.s

υ - Kinematic viscosity, $m^2.s^{-1}$, ρ - Density of the fluid, $Kg.m^{-3}$, σ – Conductivity of the fluid

τ - Dimensionless skin-friction, θ - Dimensionless temperature,

$erfc$ - Complementary error function, erf - Error function

Subscripts

w - Conditions at the wall, ∞ - Conditions in the free stream

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