International Journal of Engineering, Science and Mathematics
Vol. 7 Issue 8, August 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

VARIABLE HEAT AND MASS TRANSFER VISCOUS FLOW ALONG WITH ACCELERATED PLATE EMBEDDED IN POROUS MEDIUM WITH RADIATION

GOVIND PATHAK

Associate Professor, Department of Mathematics, M. B. Govt. P. G. College, Haldwani Nainital – 263 139 (Uttarakhand)

ABSTRACT

The effect of radiation on the unsteady free convection flow with variable heat and mass transfer along with accelerated motion of a vertical plate embedded in porous medium is considered. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. The non-linear partial differential equations with boundary conditions have been transformed into set of coupled ordinary differential equations with the help of similarity transformations and then solved by Runge-Kutta method with shooting technique. Perturbation solutions in terms of the magnetic interaction parameter areobtained to a desired order of approximations. Theresulting ordinary differential equations have been solved numerically and by repeated integrals of complementaryerror functions. Thevelocity, skin-friction and temperature profiles, fordifferentvaluesof theparameters, have been drawn and discussed.

Keywords: Viscous Flow, Accelerated Plate, Porous medium, Radiation

1. INTRODUCTION

The study of heat and mass convective flow along a vertical porous plate is receiving considerable attention of many researchers because of its wide applications. In nature and industrial application many transport processes exist where the transfer of heat and mass takes place simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. The problem of free convection flows past an accelerated vertical plate has many practical applications in manufacturing processes in industry. Free convection flow of viscous fluids through porous medium have attracted the attention of many authors in view of its application to geophysics, astrophysics, meteorology, aerodynamics, boundary layer control and so on. In addition, convective flow through porous medium has application in the field of chemical engineering for filtration and purification processes. Radiation effect and heat transfer plays an important role in nuclear power plants, gas turbines and various propulsion devices for aircraft. If the temperature of the surrounding fluid is high, radiation effects play an important role.Raptis[1] studied the unsteady two-dimensional flow of viscous fluid through a porous medium bounded by infinite porous plate with constant suction and variable temperature. Raptis and Perdikis[2] then study the same problem when the temperature of porous plate oscillates in time about a constant mean. Dave et al.[3] and Tak and Pathak[4] have studied the unsteady free convection flow past an impulsively started infinite hot accelerated plate in presenceof transversemagnetic field fixed relative to fluid. A study of an unsteady free convection flow past an infinite hot vertical porous plate with constant suction and temperature of the plate to be varying span-wise sinusoidal fluctuating with time has been generalized by Singh[5].An analysis of unsteady free convective flow past a vertical porous plate with variable temperature has been done by Singh and Chand[6].Takhar et al.[7] considered the effect of radiation on free convective flow along semi-infinitevertical plate in presence of transverse magnetic field. Dass et al.[8]alsoinvestigated the numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Taking an impulsively started infinite vertical plateGaneshan et al.[9]and Muthucumaraswamy and Vijayalakshmi[10]have studied radiation effects in free convection flow.Radiation and mass transfer effects on transient freeconvection flow of a dissipative fluid past semi-infinitevertical plate with uniform heat and mass flux is studied by Vasu et al.[11]. MHD free convective chemically reactive flow of a dissipative fluid with thermal diffusion, fluctuating wall temperature and concentrations in velocity slip regime is studied by Sengupta and Ahmad[12].

The main objective of this paper is tostudy radiation effects on free convection flow through porous medium bounded by an accelerated vertical plate with variable heat and mass transfer. The solutions of governing equations have been obtained in terms of *repeated integrals of complementary error functions.*

2. MATHEMATICAL FORMULATIONAND ANALYSIS

Consider anunsteady free convection flow of an incompressible viscous radiating fluid, through aporous medium bounded by an accelerated heated vertical plate of infinite extent in a uniform magnetic field with variable heat and mass transfer.At time $t^* \leq 0$, the temperature at the plate and the fluid is assumed to be $T_\infty{}^*$ and $C_\infty{}^*$. For $t^*> 0$, theplate temperature and species concentration temperature at the plate are instantaneously raised. The plate is assumed to be suddenly accelerated in the upward direction with uniform acceleration u_0^{*3}/ν . The x^* axis is taken along the vertical plate in upward direction and y^* axis normal to it (see Fig. 1).Since the motion is two-dimensional and length of the plate is large, therefore, all the physical variables are independent of x^* only. Then, under the usual Bousinesq's approximations, the governing equations can be written as:

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = \upsilon\,\frac{\partial^2 u^*}{\partial y^{*2}} + g\,\beta(T^* - T_\infty{}^*) + g\,\beta^*(C^* - C_\infty{}^*) - \frac{\upsilon}{K^*}u^* - \frac{\sigma B_0^2}{\rho}u^* \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \frac{\kappa}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho c_p}\frac{\partial q_r{}^*}{\partial y^*} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + v^*\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - K_1 C^*. \tag{4}$$

where u^* and v^* are components of velocity along x^* and y^* directions, g theacceleration due to gravity, β the coefficient of volume expansion , β^* the coefficient of species concentration expansion, T^* the temperature,C^* the concentration, υ the kinematic viscosity, ρ the density, κ the thermal conductivity, c_p the specific heat at constant pressure, σ the electrical conductivity, B_0 is magnetic field,D the coefficient of mass diffusion,K_1 the rate of chemical reaction,$K*$ and q_r* are permeability and heat flux respectively.

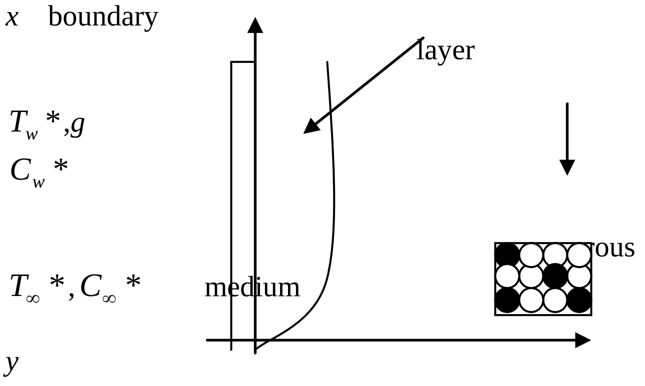

Fig. 1 Physical model of the Problem

The radiative heat flux q_r* is given byCogley et al.[13]:

$$\frac{\partial q_r*}{\partial y*} = 4\,(T*-T_\infty*)\ I* \tag{5}$$

where $I* = \int_0^\infty K_{\lambda w} . \frac{\partial e_{b\lambda}}{\partial T*} d\lambda$, $K_{\lambda w}$ is the absorptioncoefficient at the wall and $e_{b\lambda}$ is plank function

The initial and boundary conditions are as follows:

$$\left.\begin{aligned} &t* \le 0 : u* = 0,\ T* = T_\infty*,\ C* = C_\infty*\ \ \forall\, y* \\ &t* > 0\ : u* = \frac{u_0^{*3}}{v} t^*,\ T* = T_\infty* + (T_w* - T_\infty*)\,At*,\ C* = C_\infty* + (C_w* - C_\infty*)At*\ \ at\ \ y* = 0 \\ &\qquad u* = 0\ ,\ T* = T_\infty*\ ,\ C* = C_\infty*\ \ as\ \ y* \to \infty \end{aligned}\right\}$$

where $A = u_0^{*2} / v$. (6)

Introducing the following non-dimensional quantities:

$$y = \frac{y* u_0*}{\upsilon},\quad t = \frac{t* u_0*^2}{\upsilon},\quad u = \frac{u*}{u_0*},\quad v = \frac{v*}{u_0*},\quad \theta = \frac{(T*-T_\infty*)}{(T_w*-T_\infty*)},\quad C = \frac{(C*-C_\infty*)}{(C_w*-C_\infty*)}$$

in the equations (1) to (6),leads to

$$\frac{\partial v}{\partial y} = 0 \tag{7}$$

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\cdot\theta + Gc\cdot C - \frac{u}{K_0} - mu \tag{8}$$

$$\frac{\partial \theta}{\partial t} + v\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - F.\theta \tag{9}$$

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - K\cdot C \tag{10}$$

The initial and boundary conditions in non-dimensional form are

$$\left.\begin{array}{l} t \le 0 : u = 0,\ \theta = 0,\ C = 0 \quad \forall\, y \\ t > 0 : u = t,\ \theta = t,\ C = t \quad at\ y = 0 \\ \qquad u = 0,\ \theta = 0,\ C = 0 \quad as\ \ y \to \infty \end{array}\right\} \tag{11}$$

where

$$Gr = \frac{\upsilon g \beta (T_w{}^* - T_\infty{}^*)}{u_0{}^{*3}}\ (Grashof\ number),\ \ K_0 = \frac{u_0{}^{*2} K^*}{\upsilon^2}\ (Permeability\ parameter),$$

$$Gc = \frac{\upsilon g \beta^* (C_w{}^* - C_\infty{}^*)}{u_0{}^{*3}}\ (Modified\ Grashof\ number),\ \ Pr = \frac{\mu\, c_p}{\kappa}\ (Prandtl\ number),$$

$$F = \frac{4\upsilon I^*}{\rho c_P u_0{}^{*2}}\ (Radiation\ parameter),\ \ m = \frac{\sigma B_0{}^2 \upsilon}{\rho u_0{}^{*2}}\ (Magnetic\ parameter),$$

$$Sc = \frac{v}{D}(Schmidt\ number),\ \ K = \frac{K_1 \upsilon}{u_0^{*2}}\ (Chemical\ reaction\ parameter).$$

Integrating equation (7), we obtain

$$v = -\frac{a}{\sqrt{t}} \tag{12}$$

where a is suction/injection parameter. It may be noted that for suction $a > 0$, for injection $a < 0$ and for impermeable plate $a = 0$.

For solution of momentum equation (8), energy equation (9) and concentration equation (10), the similar solution is not feasible and therefore we see a series solution by expanding u,$\theta$and $c$in terms of power series (Mt), called magnetic interaction parameter, which is considered to be small i.e. $Mt \ll 1$ [Dave et al.[3]]:

$$\left.\begin{aligned} u(y,t) &= t\cdot\sum_{i=0}^{\infty}(Mt)^i f_i(\eta), \\ \theta(y,t) &= t\cdot\sum_{i=0}^{\infty}(Mt)^i\theta_i(\eta) \\ C(y,t) &= t\cdot\sum_{i=0}^{\infty}(Mt)^i C_i(\eta) \end{aligned}\right\} \text{ and } \quad \eta=\frac{y}{2\sqrt{t}} \tag{13}$$

then equating the like powers of (Mt) equations (7) to (11) are reduced to the following set of ordinary differential equations

$$Sc^{-1}.C_0'' + 2(a+\eta)C_0' = 0, \tag{14}$$

$$Pr^{-1}.\theta_0'' + 2(a+\eta)\theta_0' - 4\theta_0 = 0, \tag{15}$$

$$f_0'' + 2(a+\eta)f_0' - 4f_0 = 0, \tag{16}$$

$$Pr^{-1}\theta_1'' + 2(a+\eta)\theta_1' - 8\theta_1 - \frac{4\cdot F}{m}\theta_0 = 0, \tag{17}$$

$$Sc^{-1}c_1'' + 2(a+\eta)c_1' - 4c_1 - \frac{4K}{m}c_0 = 0 \tag{18}$$

$$f_1'' + 2(a+\eta)f_1' - 8f_1 + \frac{4\cdot Gr}{m}\theta_0 + \frac{4\cdot Gc}{m}C_0 - 4\left(1+\frac{1}{mK_0}\right)f_0 = 0, \tag{19}$$

$$Pr^{-1}\theta_i'' + 2(a+\eta)\theta_i' - 4\cdot(i+1)\cdot\theta_i - \frac{4\cdot F}{m}\theta_{i-1} = 0, \quad i\ge 2 \tag{20}$$

$$Sc^{-1}c_i'' + 2(a+\eta)c_i' - 4i\,c_i - \frac{4K}{m}c_{i-1} = 0, \quad i\ge 1 \tag{21}$$

$$f_i'' + 2(a+\eta)f_i' - 4\cdot(i+1)\cdot f_i + \frac{4\cdot Gr}{m}\theta_{i-1} + \frac{4\cdot Gc}{m}C_{i-1} - 4\left(1+\frac{1}{mK_0}\right)f_{i-1} = 0, \quad i\ge 2 \tag{22}$$

with the initial conditions

$$\left.\begin{aligned} &\eta=0 \quad : C_0=1,\ C_i=0,\ \theta_0=1,\ \theta_i=0,\ f_0=1,\ f_i=0, \quad \forall\ i\ge 1 \\ &\eta\to\infty : C_i=0,\ \theta_i=0,\ f_i=0,\ \forall\ i\ge 0 \end{aligned}\right\} \tag{23}$$

3. SOLUTION OF THE PROBLEM

The homogenous parts of the above system of differential equation admit solutions in terms of repeated integrals of complementary error functions (Abramowitz and Stegun[14]).The equations (14) to (22), subject to the boundary conditions (23) are derived as follows:

$$C_0 = \frac{i^0 .erf_c(\sqrt{Sc}.\xi)}{i^0 erf_c(\sqrt{Sc}.a)}, \qquad \xi = \eta + a$$

$$\theta_0 = \frac{i^2 .erf_c(\sqrt{Pr}.\xi)}{i^2 erf_c(\sqrt{Pr}.a)},$$

$$f_0(\xi) = \frac{i^2 erf_c(\xi)}{i^2 erf_c(a)},$$

$$\theta_1 = \frac{F}{m}\left(\frac{i^4 erf_c(\sqrt{Pr}\cdot\xi)}{i^4 erf_c(\sqrt{Pr}\cdot a)} - \frac{i^2 erf_c(\sqrt{Pr}\cdot\xi)}{i^2 erf_c(\sqrt{Pr}\cdot a)}\right),$$

$$C_1 = \frac{K}{m}\left(\frac{i^2 erf_c(\sqrt{Sc}.\xi)}{i^2 erf_c(\sqrt{Sc}.a)} - \frac{i^0 erf_c(\sqrt{Sc}.\xi)}{i^0 erf_c(\sqrt{Sc}.a)}\right),$$

$$f_1 = Ai^4 erf_c(\xi) - \left(1 + \frac{1}{mK_0}\right)\frac{i^2 erf_c(\xi)}{i^2 erf_c(a)} - \frac{4\cdot Gr\cdot i^4 erf_c(\sqrt{Pr}.\xi)}{m(Pr-1)\, i^2 erf_c(\sqrt{Pr}.a)} - \frac{4\cdot Gc\cdot i^2 erf_c(\sqrt{Sc}.\xi)}{m(Sc-1)\, i^0 erf_c(\sqrt{Sc}.a)},$$

where

$$A = \frac{4\cdot Gr\cdot i^4 erf_c(\sqrt{Pr}.a)}{m(Pr-1)\, i^2 erf_c(\sqrt{Pr}.a)\, i^4 erf_c(a)} + \frac{4\cdot Gc\cdot i^2 erf_c(\sqrt{Sc}.a)}{m(Sc-1)\, i^0 erf_c(\sqrt{Sc}.a)\, i^4 erf_c(a)} + \left(1 + \frac{1}{mK_0}\right)\frac{1}{i^4 erf_c(a)}$$

The function $i^n erf_c(\xi)$ is the repeated integral of complementary error function defined as:

$$i^n erf_c(\xi) = \frac{2}{\sqrt{\pi}}\int_{\xi}^{\infty}\frac{(t-\xi)^n}{n!}\, e^{-t^2}\, dt, \;\; n = 0,1,2......$$

$$= \sum_{K=0}^{\infty}\frac{(-1)^K \xi^K}{2^{n-K} K!\,\Gamma\left(1 + \frac{n-K}{2}\right)}$$

$$i^{-1} erf_c(\xi) = \frac{2}{\sqrt{\pi}} e^{-\xi^2}, i^n erf_c(\xi) = erf_c(\xi), \quad \frac{\partial}{\partial\xi} i^n erf_c(\xi) = -i^{n-1} erf_c(\xi)$$

and the recurrence relation is

$$i^{n-2} erf_c(\xi) - 2\xi\, i^{n-1} erf_c(\xi) - 2n i^n erf_c(\xi) = 0$$

4. RESULTS AND DISCUSSION

To discuss the physical importance of the problem like velocity, temperature and skin-friction coefficient we have chosen the different values of the parameter. The value of magnetic field parameter *m*and time parameter *t* isconsider as a fixed quantityi.e. 0.5 and 0.2 in all cases.For the numerical solution ofall equations, the unknown initial values are identified by the Runge-Kutta method with shooting technique, with a step size of 0.01. The numerical solution is then compared with exact solution, which is obtained by repeated integrals of complementary error function, and the comparison is clearly shown in Table 1. We see that the results obtained by both the method are in a good agreement.

Table 2 represents the numerical values of wall shear stress function $f_i^{'}(0)$ and surface heat transfer function $\theta_i^{'}(0)$ for $K = 0$ and $i = 0$ to 2 obtained by numerical solution for $m = 0.5$; $Pr = 0.72$, 1.0, 3.0; $a = -0.5$, 0, 0.5; $K_0 = 0.2$, 0.4, 2.0 and $F = 0.4$, 2.0, 10.0. It is observed from this table, that an increase in the radiation parameter F leads to fall in the value of the velocity and temperature both.

Knowing the velocity, temperature and concentration fields, we can determine the skin friction, heat transfer rate and concentration rate at the plate. The dimensionless values of skin friction, Nusselt and Sherwood numbers are determined by the following relations:

$$C_f = \sqrt{t}\sum_{i=0}^{\infty}(Mt)^i\ f_i'(0)\ , \quad Nu = -\sqrt{t}\cdot\theta'(0) \quad \text{and} \quad Sh = -\sqrt{t}\sum_{i=0}^{\infty}(Mt)^i c_i'(0)$$

Fig. 2 and Fig. 3 shows the skin-friction coefficient C_f profiles for different values of suction/injection parameter a, Prandtl number Pr, permeability parameter K_0, Chemical reaction parameter $K$and radiation parameter $F$and taking other parameters fixed. It is observed that C_f increases with K_0 and decreases with increase in the radiation parameter F or Prandtl number Pror parameter a. It is observed that the curve of the function C_f increases with decreasing radiation parameter and that become asymptotic as t approaches 0.7.

The dimensionless rate of heat transfer in terms of Nusselt number profile for different values of Prandtl number are shown in Fig. 4. The rate of heat transfer increases with increasing Prandtl number.

Fig. 5 represents the dimensionless rate of mass transfer in terms of Sherwood number for different values of chemical reaction parameter and Schmidt number. It is observed that the rate of mass transfer of the fluid increases with increase of chemical reaction parameter. Sherwood number increases with increasing Schmidt number. This trend is just opposite in Sherwood number with respect to Schmidt number, because, the concentration profiles decreases with increasing value of Sc, near the plate.

In Fig. 6 the temperature function θ is plotted against the variable $\eta$for different values of suction/injection parameter$a$and Prandtl number Prtaking other parameter fixed. It may be noted that the temperature decreases as $a$or Princreases.

The effect of radiation parameter is important in temperature profiles. Fig. 7 shows that the temperature increases with decreasing radiation parameter. This shows that the heat transfer decreases in the presence of thermal radiation.

In Fig. 8, the velocity function u is plotted against η for different values of K_0 and a, taking other parameters fixed. It is observed that velocity increases as permeability K_0 increases whereas it decreases as suction / injection parameter a increases.

In Fig. 9, the velocity function u is plotted against $\eta$for different values ofPrandtl number Pr and radiation parameter F taking other parametersfixed. It is observed that velocity decreases as Prandtl number Pr or radiation parameter Fincreases.

5. CONCLUSIONS

1. Since the graph of C_f becomes asymptotic for $t \geq 0.7$ in all the cases, it may be concluded that the flow is reduced to steadiness after time t = 0.7.
2. The skin-friction increases with decreasing radiation parameter.
3. The effect of radiation F is to decrease the velocity and temperature in the free convective boundary layer.
4. With the increase in permeability parameter K_0, the velocity increases in the boundary layer.
5. Thermal boundary layer thickness decreases as Prandtl number or suction / injection parameter increases.
6. Concentration in boundary layers decreases as the Schmidt number increases.
7. The rate of mass transfer (in terms of Sherwood number) of the fluid increases with increase of chemical reaction parameter. Sherwood number increases with increasing Schmidt number.
8. When the plate moves upward the fluid near the plate moves with greater velocity due to convection.

ACKNOWLEDGEMENT

The author is very much thankful to University Grant Commission, New Delhi for providing the financial support under the Minor Research Project Scheme.

REFERENCES

[1] Raptis, A., 1983. Unsteady free convective flow through a porous medium, Int. J. Engg.Sci., Vol 21,345-348.

[2]Raptis, A. and Perdikis, C.P., 1985. Oscillatory flow through a porous medium by the presence of free convective flow, Int. J. Engg. Sci., Vol 23, 51-55.

[3] Dave, Abha, Bansal, J.L andJat, R.N., 1990.Heat, mass and momentum transfer in unsteady hydromagnetic free convection flow past an accelerated vertical plate, Proc. Natn. Acad. Sci. India, Vol 50(A), No II, 211-226.

[4]Tak, S.S. and Pathak, Govind, 2002. Unsteady free convection along a hot vertical plate suddenlyset in motion in presence of transverse magnetic field, Far East J.Appl. Math,Vol. 8(3), 169-182.

[5] Singh, K. D., 1992. Unsteady free convection flow past a vertical porous plate with variable temperature. Proc. Indian Natn. Sci. Acad. 58, 537-544.

[6] Singh, K. D. and Chand, Khem, 2000. Unsteady free convective MHD flow past a vertical porous plate with variable temperature. Proc. Nat. Acad. Sci. India. 70(A), I, 49-58.

[7] Takhar, H.S., Gorla, R.S.R. and Soundalgekar, V.M., 1996. Radiation effects on MHD free convection flow of a gas past a semi-infinite vertical plate, Int. J. Num. Methods for Heat and Fluid Flow, Vol 2, No. 6, 77-83.

[8] Das, S. S., Sahoo, S. K. and Dash, G. C., 2006. Numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Bull.Malays. Math.

Sci. Soc. 29, 33-42.

[9] Ganesan, P., Loganathan, P. and Soundalgekar, V.M., 2001. Radiation effects on flow past an impulsively started infinite vertical plate, Int. J. of Applied Mechanics and Engineering,Vol. 6, No.3,719-730.

[10]Muthucumaraswamy, R. and Vijayalakshmi, A., 2005. Radiation effects on flow past an impulsively started vertical plate with variable temperature and mass flux, Theoret. Appl. Mech., Vol. 32, No. 3, 223-234.

[11] Vasu, B., Ramachandra Prasad, V. and Bhaskar Reddy, N., 2011. Radiation and mass transfer effects on transient free convection flow of a dissipative fluid past semi-infinite verticalplate with uniform heat and mass flux, Journal of Applied Fluid Mechanics, Vol. 4, No. 1, 15-26.

[12] Sengupta, S. and Ahmad, N., 2014. MHD free convective chemically reactive flow of a dissipative fluid with thermal diffusion, fluctuating wall temperature and concentrations in velocity slip regime, Int. J. of Appl. Math and Mech. 10 (4), 27-54.

[13]Cogley, A.C., Vinceti ,W.G. and Gilles, S.E., 1968. Differential approximation forradiation transferin a non-grey gas near equilibrium, AIAA J., Vol 6, 551-553.

[14] Abramowitz, M. andStegun, I.A., 1972.Hand Book of Mathematical Functions with Formulas,Graph and Mathematical Tables, Dover Publications, Inc. New York,Tenth Edition.

Table 1: Comparison of results obtain by numerical solution and exact solution for m = 0.5, K = 0, Gr =5.0 and a = 0.0

Pr	K_0	F	$f_0'(0)$ Numerical Solution	$f_0'(0)$ Exact Solution	$f_1'(0)$ Numerical Solution	$f_1'(0)$ Exact Solution	$\theta_0'(0)$ Numerical Solution	$\theta_0'(0)$ Exact Solution	$\theta_1'(0)$ Numerical Solution	$\theta_1'(0)$ Exact Solution
1.0	0.4	0.4	-2.25675	-2.25675	3.0090	3.0084	-2.25675	-2.25673	-0.60180	-0.60168
1.0	0.4	2.0	-2.25675	-2.25675	3.0090	3.0084	-2.25675	-2.25673	-3.00904	-3.0084
1.0	0.2	0.4	-2.25675	-2.25675	-0.7522	-0.7521	-2.25675	-2.25673	-0.60180	-0.60168

International Journal of Engineering, Science and Mathematics
Vol. 7 Issue 8, August 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Table 2: Numerical values of wall shear stress function $f_i^{'}(0)$ and surface heat transfer function $\theta_i^{'}(0)$ for K = 0 and i = 0, 1, 2.

Pr	a	F	K_0	$\theta_0^{'}(0)$	$f_0^{'}(0)$	$\theta_1^{'}(0)$	$f_1^{'}(0)$	$\theta_2^{'}(0)$	$f_2^{'}(0)$
0.72	0.5	2.0	0.4	-2.33930	-2.85346	-2.47141	3.73250	0.934088	-5.44235
0.72	0.5	0.4	0.2	-2.33930	-2.85346	-0.49428	0.12026	0.037362	-1.61795
1.0	0.0	2.0	0.4	-2.25675	-2.25675	-3.00904	3.00904	1.20365	-4.81461
0.72	0.5	0.4	0.4	-2.33930	-2.85346	-0.49428	3.73250	0.037362	-3.16304
1.0	0.5	0.4	0.4	-2.85346	-2.85346	-0.57795	2.88978	0.043125	-2.15625
3.0	0.5	0.4	0.4	-5.79897	-2.85346	-0.95695	0.22579	0.066390	0.411983
0.72	-0.5	0.4	0.4	-1.55425	-1.76409	-0.51569	3.43042	0.042312	-2.97302

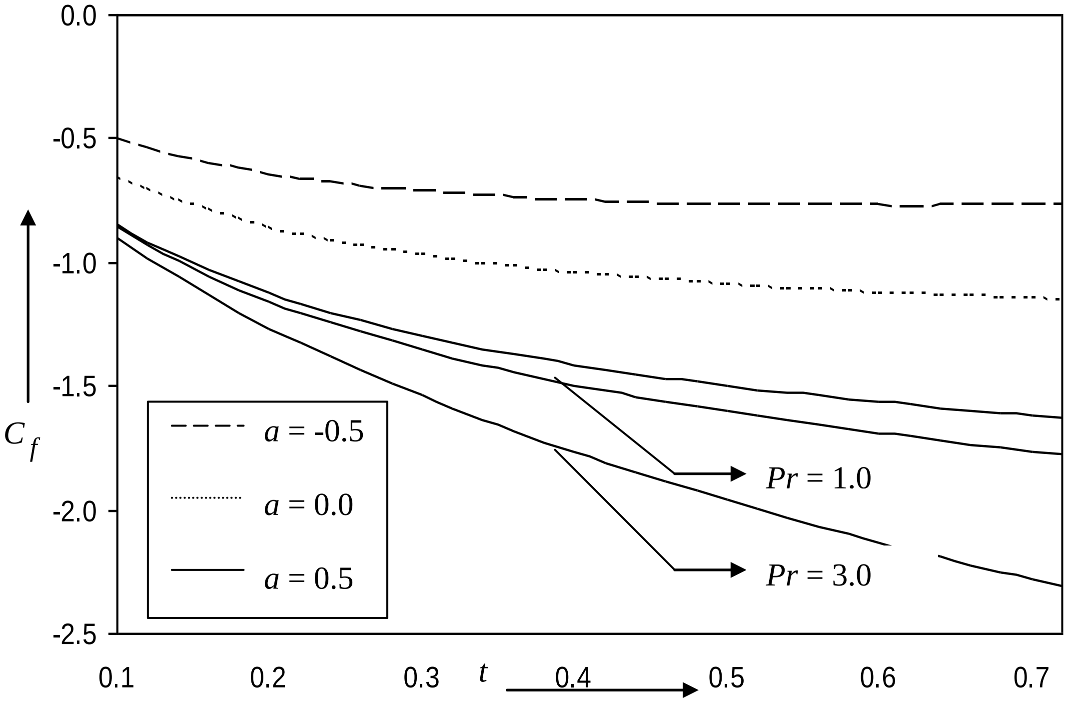

Fig. 2 Variation of skin - friction coefficient with time at fixed values of Gr = 5.0, F = 0.4 and K_0 = 0.4

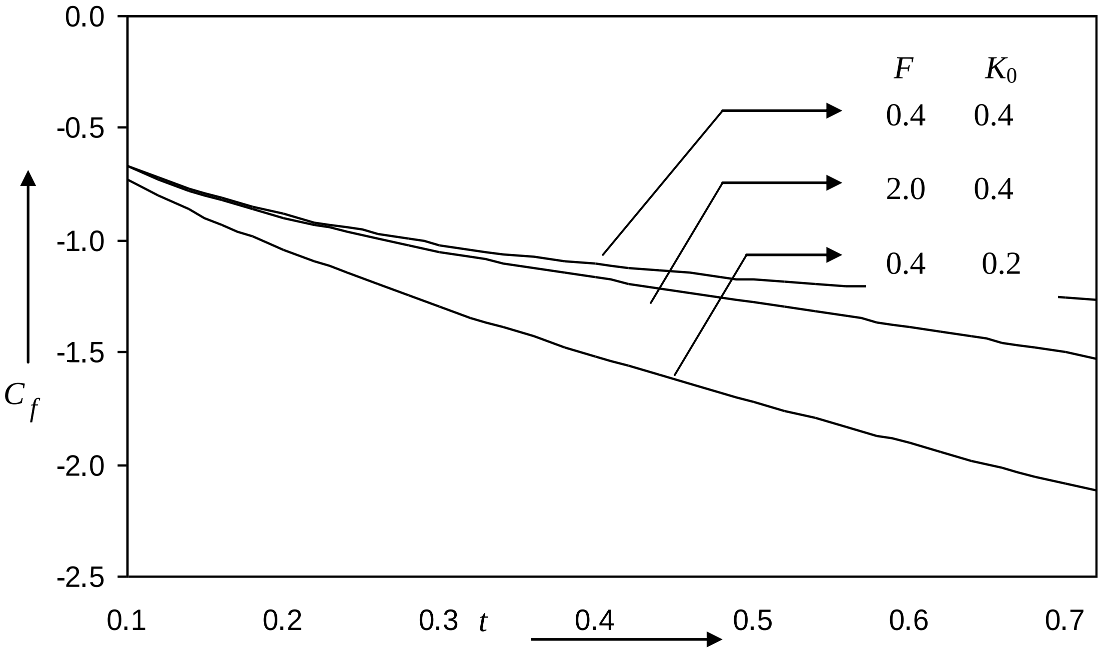

Fig. 3 Variation of skin - friction coefficient with time at fixed values of Pr = 1.0, Gr = 5.0 and a = 0.0

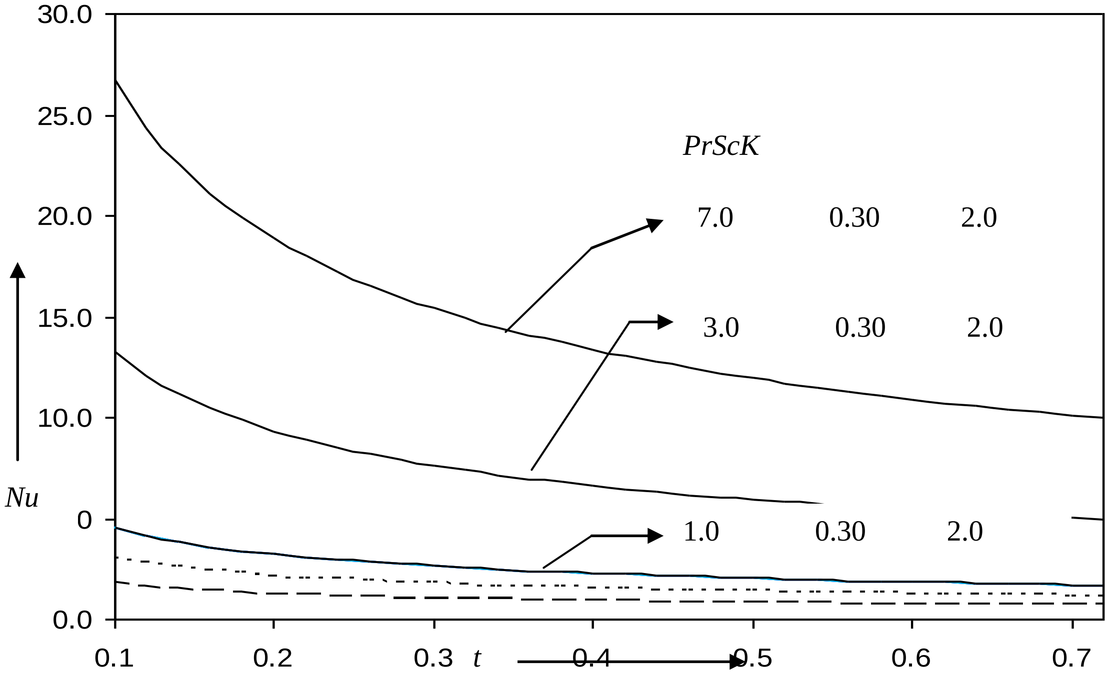

Fig. 4 Variation of surface heat transfer function with time at fixed values of m = 0.5, Gr = 5.0 and Gc = 2.0

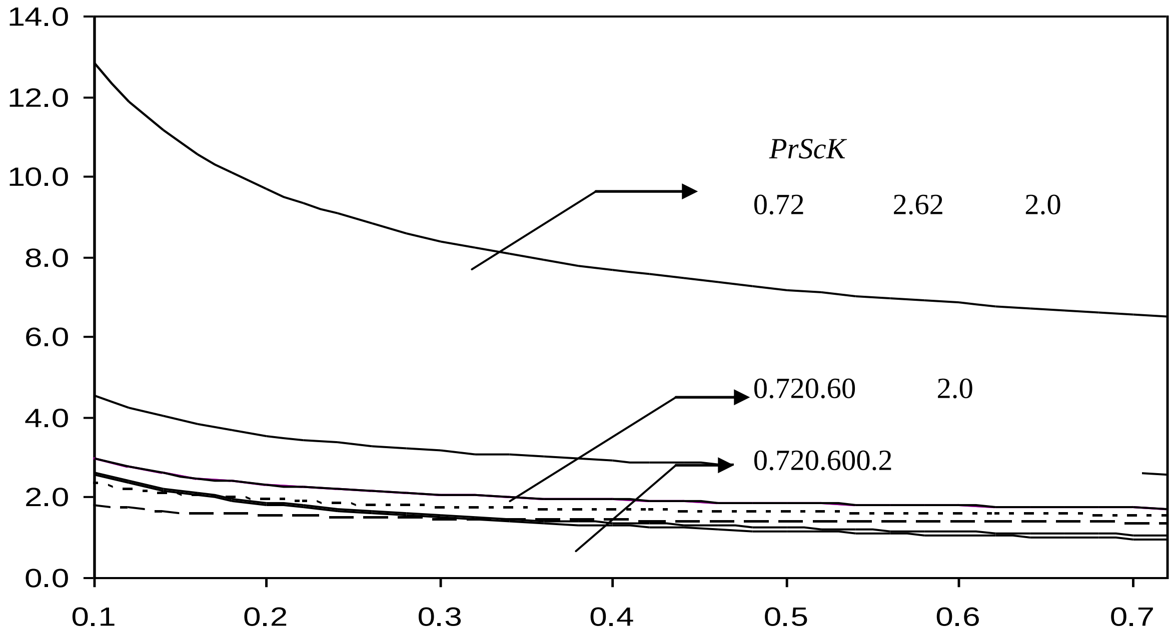

Fig. 5 Variation of Sherwood number with time at fixed values of m = 0.5, Gr = 5.0 and Gc = 2.0

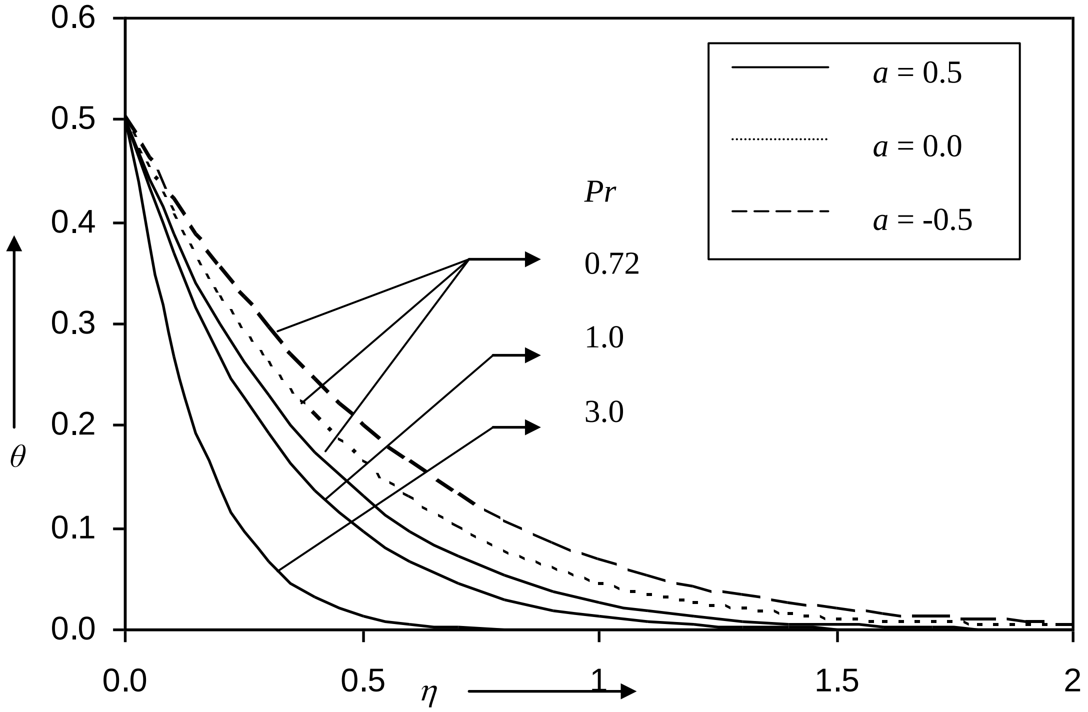

Fig. 6 Temperature profiles at fixed values of Gr = 5.0, F = 0.4 and K_0 = 0.4

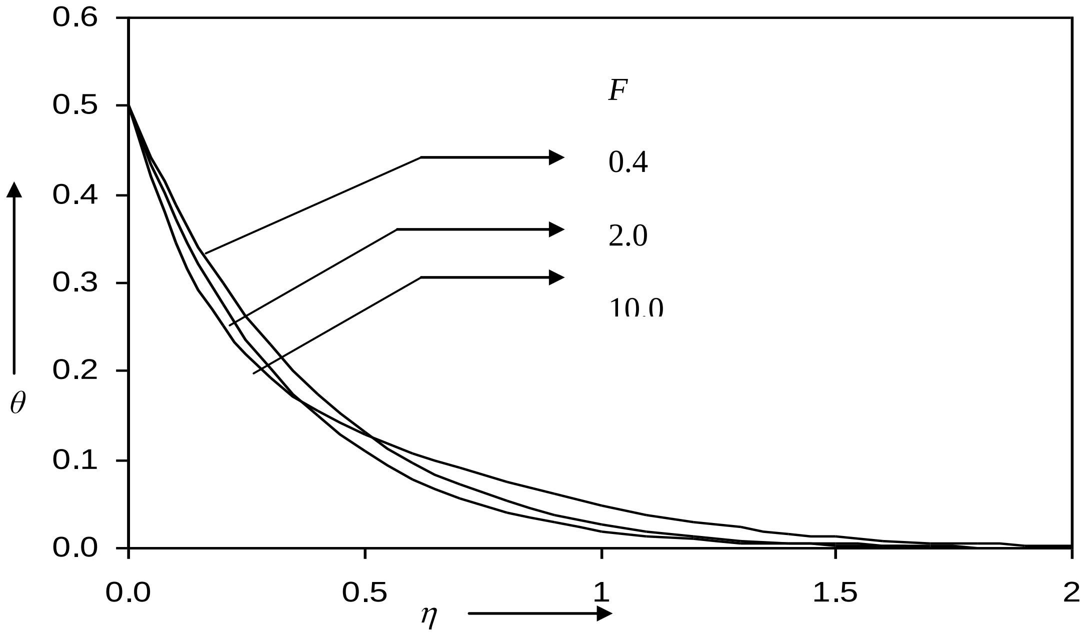

Fig. 7 Temperature profiles at fixed values of Pr = 0.72, a = 0.5 and Gr = 5.0

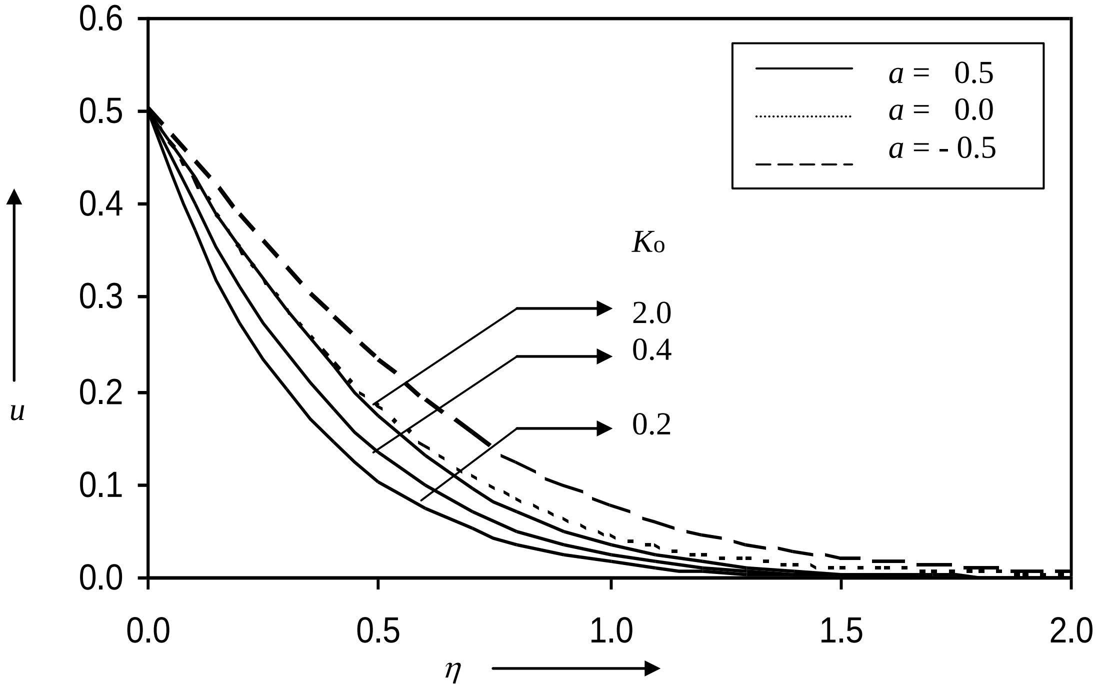

Fig. 8 Velocity profiles at fixed values of Gr = 5.0, Pr = 0.72 and F = 0.4

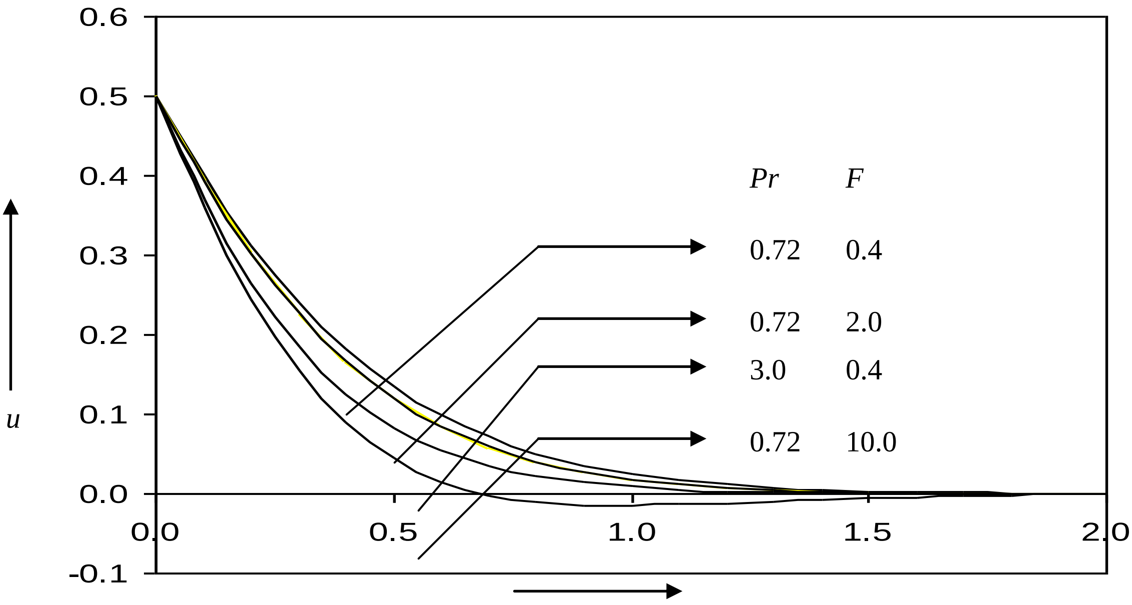

Fig. 9 Velocity profile[illegible]ed values of Gr = 5.0, a = 0.5 and K_0 = 0.4