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EFFECT OF RADIATION ON NATURAL CONVECTION FLOW FROM A POROUS VERTICAL PLATE IN PRESENCE OF HEAT GENERATION

Amena Ferdousi[1*], M. Mostafizur Rahman[2], Mohammad Salek Parvez[3], M. A. Alim[4]

[1]Faculty of EEE, Eastern University, Dhaka, Bangladesh
[2]Department of CSE and CIS, Daffodil International University, Dhaka, Bangladesh
[3]Department of Natural Sciences, Daffodil International University, Dhaka, Bangladesh
[4]Dpartment of Mathematics, Bangladesh University of Engineering and Technology, Dhaka

*Corresponding Author: amena@easternuni.edu.bd

ABSTRACT

The effects of Radiation on Natural Convection Flow from a Porous Vertical Plate in Presence of Heat Generation have been presented here. The governing boundary layer equations are first transformed into a non-dimensional form and the resulting nonlinear system of partial differential equations are then solved numerically using finite difference method together with Keller-Box scheme. The numerical results of the surface shear stress in terms of skin friction coefficient and the rate of heat transfer in terms of local Nusselt number, velocity as well as temperature profiles are shown graphically and tabular form for a selection of parameters set of consisting of heat generation parameter Q, radiation effect Rd, Prandtl number Pr.

Keywords: Radiation effect, Porous plate, Heat generation, Natural convection.

1. INTRODUCTION

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Possible heat generation effects may alter the temperature distribution; consequently the particle deposition rate in nuclear reactors, electronic chips and semiconductor waters.

The effect of radiation on free convection has been drawn forth not only for its fundamental aspects but also for its significance in the contexts of space technology and processes involving high temperature. In the presence of heat generation, natural convection boundary layer flow from a porous vertical plateof a steady two dimensional viscous incompressible fluid and the radiated heat transfer has been investigated. In this analysis consideration had been given to grey gases that emit and absorb but do not scatter thermal radiation. Over the work it is assumed that the surface temperature of the porous vertical plate T_w, is constant, where$T_w > T_\infty$. Here $T_\infty$is the ambient temperature of the fluid, T is the temperature of the fluid in the boundary layer, g is the acceleration due to gravity, the fluid is assumed to be a grey emitting and absorbing, but non scattering medium. In the present work following assumptions are made:

- Variations in fluid properties are limited only to those density variations which affect the buoyancy terms.

- The radiative heat flux in the x-direction is considered negligible in comparison with that in the y direction, where the physical coordinates (u, v) are velocity components along the (x, y) axes.

Vajravelu and Hadjinicolaou[1] studied the heat transfer in a viscous fluid over a stretching sheet with viscous dissipation and internal heat generation. In this study, they considered that the volumetric rate of heat generation $q^m[W/m^3]$ should be:

$$q^{m} = \begin{cases} Q_0 (T - T_\infty) & for\ T \geq T_\infty \\ 0 & for\ \ T < T_\infty \end{cases}$$

where Q_0 is the heat generation constant. The above relation explained is valid as an approximation of the state of some exothermic process and having T_∞as the onset temperature. When the inlet temperature is not less than T_∞ they used $Q_0(T- T_\infty)$.

Merkin[2] studied free convection with blowing and suction. Lin and Yu[3] studied free convection on a horizontal plate with blowing and suction. Hossain et al[4] studied the effect of radiation on free convection flow with variable viscosity from a porous vertical plate. Hossain et a[5]l studied flow of viscous incompressible fluid with temperature dependent viscosity and thermal conductivity past a permeable wedge with variable heat flux. Hossain and Takhar[6] studied radiation effect on mixed convection along a vertical plate with uniform surface temperature. Molla et al.[7] studied natural convection flow along a vertical wavy surface with uniform surface temperature in presence of heat generation/absorption. Akhter[8] studied the effect of radiations on free convection flow on sphere with isothermal surface and uniform heat flux. Ali[9] studied the effect of radiation on free convection flow on sphere with heat generation. Makinde and Moitsheki [10] studied on non-perturbative techniques for thermal radiation effect on natural convection past a vertical plate embedded in a saturated porous medium. Makinde and Ogulu[11] studied the effect of thermal radiation on the heat and mass transfer flow of a variable viscosity fluid past a vertical porous plate permeated by a transverse magnetic field. Ogulu and Makinde [12] studied unsteady hydromagnetic free convection flow of a dissipative and radiating fluid past a vertical plate with constant heat flux. Hossain et al. [13] studied the effect of radiation on free convection flow from a porous vertical plate. They [4] analyzed a full numerical solution and found, an increase in Radiation parameter R_d causes to thin the boundary layer and an increase in surface temperature parameter causes to thicken the boundary layer. The presence of suction ensures that its ultimate fate if vertically increased is a layer of constant thickness.

None of the aforementioned studies, considered the heat generation effects on laminar boundary layer flow of the fluids along porous plate with radiation heat loss.

The present study deals with effects of radiation on natural convection flow from a porous vertical plate in presence of heat generation. The results will be obtained for different values of relevant physical parameters and will be shown in graphs as well as in tables.

The governing partial differential equations are reduced to locally non-similar partial differential forms by adopting some appropriate transformations. The transformed boundary layer equations are solved numerically using implicit finite difference scheme together with the Keller box technique[14] . Here, we have focused our attention on the evolution of the surface shear stress in terms of local skin friction and the rate of heat transfer in terms of local Nusselt number, velocity profiles as well as temperature profiles for selected values of parameters consisting of heat generation parameter Q, Prandtl number Pr and the radiation parameter R_d. In order to check the accuracy of our numerical results the present results are compared with[13].

2. FORMULATION OF THE PROBLEM

We have investigated the effects of radiation on natural convection flow from a porous plate in presence of heat generation. The fluid is assumed to be a grey, emitting and absorbing but non scattering medium. Over the work it is assumed that the surface temperature of the porous vertical plate, T_w, is constant, where $T_w > T$. The physical configuration considered is as shown in Fig.1.

The conservation equations for the flow characterized with steady, laminar and two dimensional boundary layers; under the usual Boussinesq approximation, the continuity, momentum and energy equations can be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu\frac{\partial^2 u}{\partial y^2}+\rho g\beta(T-T_\infty)-\sigma_0\beta_0^2 u \tag{2}$$

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y} \tag{3}$$

With the boundary conditions

$$\begin{aligned} &x=0,\, y>0,\, u=0,\, T=T_\infty. \\ &y=0,x>0,u=0,v=-V,\ T=T_W \qquad (4) \\ &y\to\infty,\, x>0,\, u=0,\, T=T_\infty \end{aligned}$$

where ρ is the density, β_0 is the strength of magnetic field, σ_0 is the electrical conduction, k is the thermal conductivity, β is the coefficient of thermal expansion, ν is the reference kinematic viscosity ν = μ/ρ , μ is the viscosity of the fluid, C_p is the specific heat due to constant pressure and q_r is the radiative heat flux in the y direction.

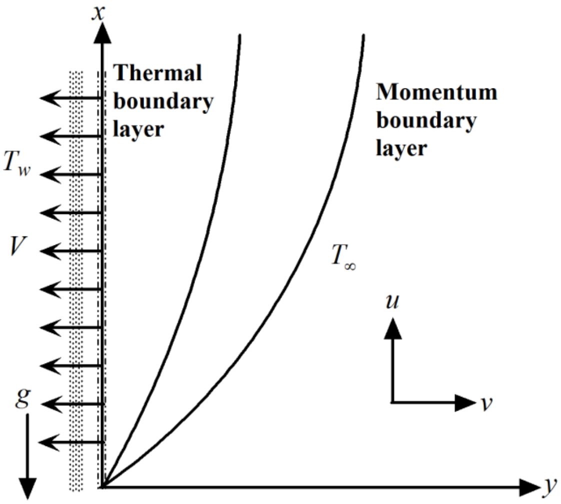


Figure1.The coordinate system and the physical model

In order to reduce the complexity of the problem and to provide a means of comparison with future studies that will employ a more detail representation for the radiative heat flux; we will consider the optically thick radiation limit. Thus radiation heat flux term is simplified by the Rosseland diffusion approximation [13] and is given by

$$q_r=-\frac{4\sigma}{3\left(a_r+\sigma_s\right)}\frac{\partial T^4}{\partial y} \qquad (5)$$

In Equation (5) a_r is the Rosseland mean absorption co-efficient, σ_s is the scattering co-efficient and σ is the Stephan-Boltzman constant.

Now introduce the following non-dimensional variables:

$$\eta=\frac{Vy}{\nu\xi},\ \xi=V\left\{\frac{4x}{\nu^2 g\beta\Delta T}\right\}^{\frac{1}{4}}$$

$$\psi=V^{-3}\nu^2 g\beta\Delta T\xi^3\left\{f+\frac{\xi}{4}\right\},\ \theta=\frac{T-T_\infty}{T_W-T_\infty} \qquad (6)$$

$$\theta_W=\frac{T_W}{T_\infty},\quad \Delta=\theta_W-1=\frac{T_W}{T_\infty}-1=\frac{T_W-T_\infty}{T_\infty},\ Rd=\frac{4\sigma T_\infty^3}{k(a+\sigma_S)}$$

Where, θ is the non-dimensional temperature function, $\theta_w$is the surface temperature parameter and $R_d$is the radiation parameter.

Substituting (6) into Equations (1, 2, 3) leads to the following non-dimensional equations

$$\begin{aligned} &f'''+\theta-2f'^2+3ff''+\xi f'' \\ &=\xi\left(f'\frac{\partial f'}{\partial\xi}f''\frac{\partial f'}{\partial\xi}\right)-\frac{\sigma_0\beta_0{}^2}{\rho}\nu^{-2}\xi^2 f' \end{aligned} \qquad (7)$$

$$\begin{aligned} &\frac{1}{pr}\frac{\partial}{\partial\eta}\left[\left\{1+\frac{4}{3}Rd\left(1+\left(\theta_W-1\right)\theta\right)^3\right\}\frac{\partial\theta}{\partial\eta}\right]^2+3f\theta'+\xi\theta' \\ &=\xi\left(f'\frac{\partial\theta}{\partial\xi}-\frac{\partial f}{\partial\xi}\theta'\right) \end{aligned} \qquad (8)$$

Where $Pr=\nu C_p/k$ is the Prandtl number is the heat generation parameter and $M=\beta_0{}^2\sigma_0/\nu\rho$ is the magneto hydrodynamic parameter.

The boundary conditions (4) become

$$\begin{aligned} &f=0,\, f'=0,\ \theta=1 \ \text{ at } \ \eta=0 \\ &f'=0,\ \theta=0 \ \text{ as } \ \eta\to\infty \end{aligned} \qquad (9)$$

The solution of equations (6), (8) enable us to calculate the non dimensional velocity components $\bar{u}$, $\bar{v}$ from the following expressions

$$\begin{aligned} &\bar{u}=\frac{\nu^2}{Vg\beta(T_W-T_\infty)}u=\xi^2 f'(\xi,\eta) \\ &\bar{v}=\frac{v}{V}=\xi^{-1}\left(3f+\xi-\eta f'+\xi\frac{\partial f}{\partial\xi}\right) \end{aligned} \qquad (10)$$

In practical applications, the physical quantities of principle interest are the shearing stress τ_w and the rate of heat transfer in terms of the skin-friction coefficients C_{fx} and Nusselt number Nu_x respectively, which can be written as

$$Nu_x=\frac{\nu}{V\Delta T}(q_c+q_r)_{\eta=0},C_{fx}=\frac{V}{g\beta\Delta T}(\tau)_{\eta=0} \qquad (11)$$

where $\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{\eta=0}$ and $q_c = -k\left(\frac{\partial T}{\partial y}\right)_{\eta=0}$ (12)

q_c is the conduction heat flux.

Using the Equations (6) and the boundary condition (9) into (11 and 12), we get

$$C_{fx} = \xi f''(x,0)$$
$$Nu_x = -\xi^{-1}\left(1+\frac{4}{3}Rd\theta_w^3\right)\theta'(x,0) \qquad (13)$$

The values of the velocity and temperature distribution are calculated respectively from the following relations:

$$\bar{u}=\xi^2 f'(\xi,\eta), \quad \theta=\theta(x,y)$$

3. METHOD OF SOLUTION

Solutions of the local non similar partial differential equation (7) to (8) subjected to the boundary condition (9) are obtained by using implicite finite difference method with Keller-Box Scheme[14], which has been described in details by Cebeci[15] .

4. RESULTS AND DISCUSSION

In this exertion the effects of radiation on natural convection flow on a porous vertical plate in presence of heat generation is investigated. Numerical values of local rate of heat transfer are calculated in terms of Nusselt number Nu_x for the surface of the porous vertical plate from lower stagnation point to upper stagnation point,for different values of the aforementioned parameters and these are shown in tabular form in Table:1 and Table:2 and graphically in Fiqure 6-9. The effect for different values of heat generation parameter Q on local skin friction coefficient C_{fx} and the local Nusselt number Nu_x, as well as velocity and temperature profiles are displayed in Fig.2 and 6.The aim of these figures are to display how the profiles vary in ξ, the selected streetwise co-ordinate.

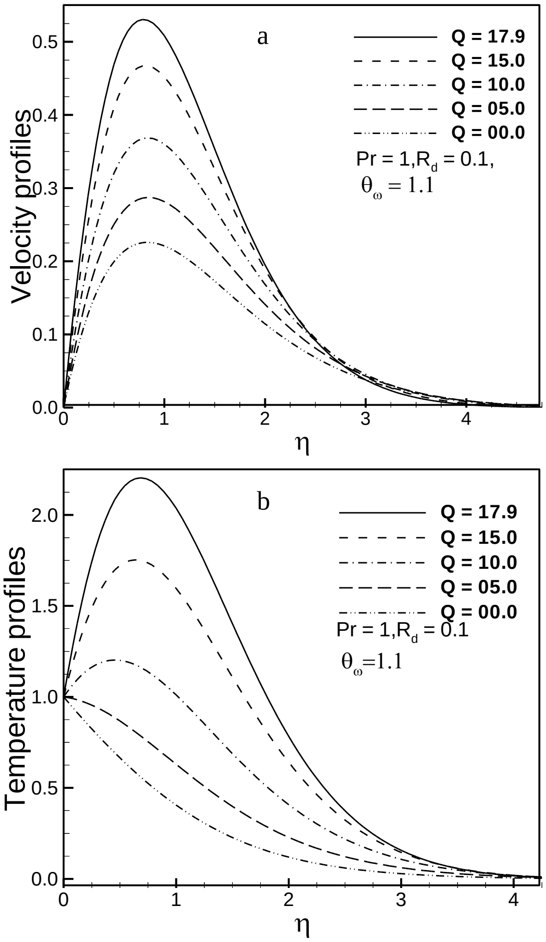


Figure 2. (a) Velocity and (b) temperature profiles for different values of heat generation parameter Q with others fixed parameters.

Figures 2(a)-2(b) display results for the velocity and temperature profiles, for different values of heat generation parameter Q with Prandtl number Pr = 1.0, radiation parameter R_d =0.1 and surface temperature parameter θ_w = 1.1. It has been seen from Figures 2(a) and 2(b) that as the heat generation parameter Q increases, the velocity and the temperature profiles increase. The changes of velocity profiles in the η direction reveals the typical velocity profile for natural convection boundary layer flow, i.e., the velocity is zero at the boundary wall then the velocity increases to the peak value as η increases and finally the velocity approaches to zero (the asymptotic value). The maximum values of velocity are recorded to be 0.22590, 0.28724, 0.36866 and 0.46717 for Q=00.0, 5.0, 10.0, 15.0 respectively which occur at the same point η=0.83530 and for Q=17.9, the maximum values of velocity are recorded to be 0.53057. Here, it is observed that at η= 0.97931, the velocity increases by 106.8%as the heat generation parameter Q changes from 0.0 to 15.0. The changes of temperature profiles in the η direction also shows the typical temperature profile for natural convection boundary layer flow that is the value of temperature profile is 1.0 (one) at the boundary wall then the temperature profile decreases gradually along η direction for the value Q less then 1.0 to the asymptotic value. But for Q ≥ 1.0 the temperature profile increases (at η = 0.68459 temperature is 2.20416 for Q = 17.9) and again it decreases gradually along η direction to the asymptotic value.

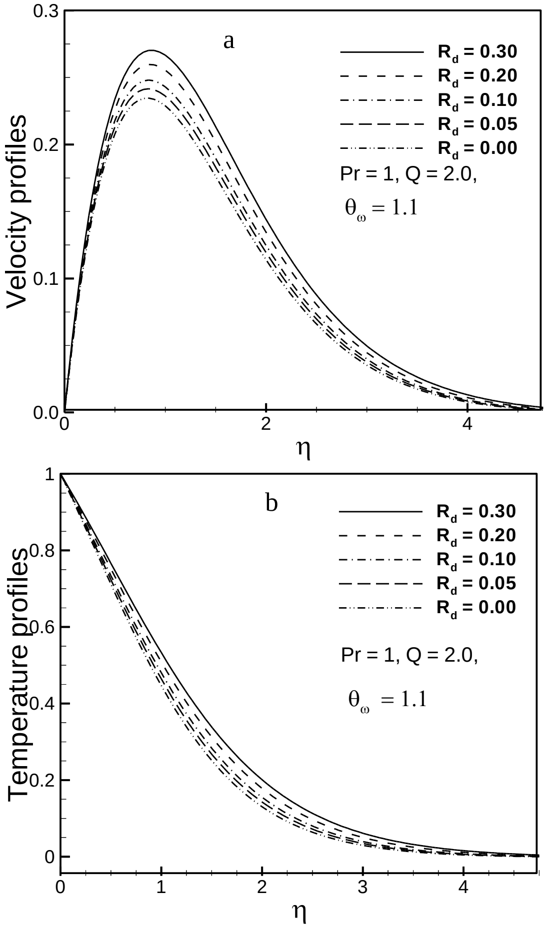


Figure 3. (a) Velocity and (b) temperature profiles for different values of radiation parameter R_d with others fixed parameters.

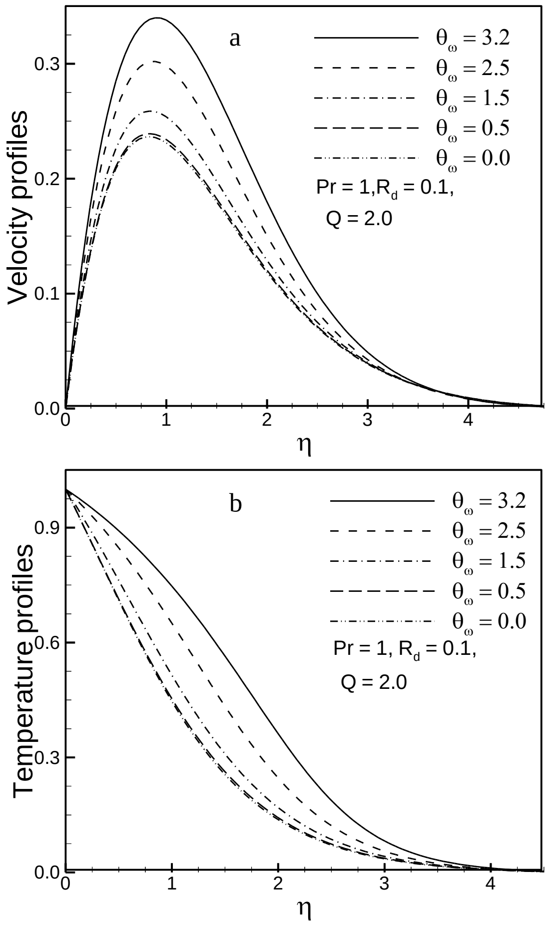


Figure 4. (a) Velocity and (b) temperature profiles for different values of heat flux parameter θw with others fixed parameters

The effect for different values of radiation parameter R_d the velocity and temperature profiles in case of Prandtl number Pr = 1.0, heat generation parameter Q = 2.0 and surface temperature parameter θ_w = 1.1 are shown in Figures 3(a)-3(b). Here, as the radiation parameter R_d increases, the velocity profile increases and the temperature profile increases slightly such that there exists a local maximum of the velocity within the boundary layer, but velocity increases near the surface of the vertical porous plate and then temperature decreases and finally approaches to zero.

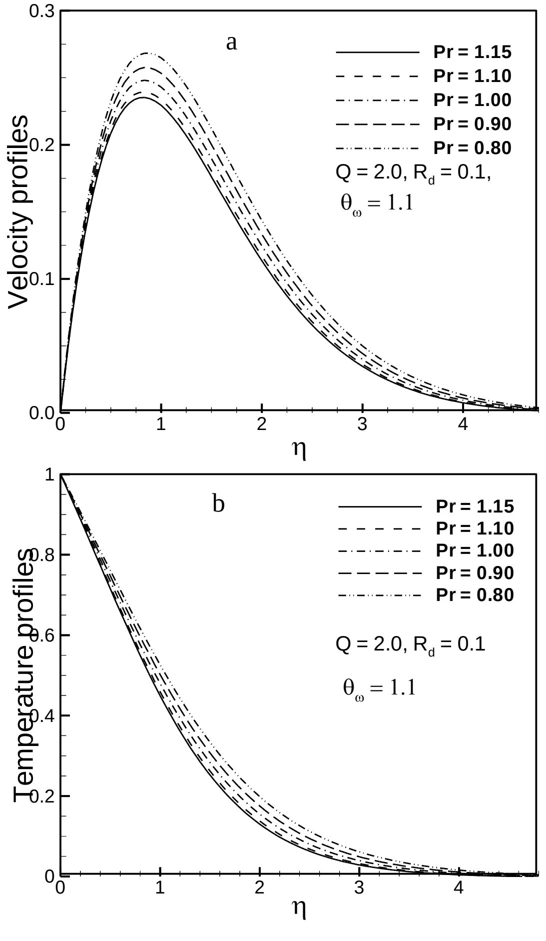


Figure 5. (a) Velocity and (b) temperature profiles for different values of prandtl number *Pr* with others fixed parameters

The effect of different values of surface temperature parameter θ_w, the velocity and temperature profiles while Prandtl number $Pr = 1.0$, heat generation parameter $Q = 2.0$ and radiation parameter R_d=0.1 are shown in Figures 4(a)-4(b). Here, as surface temperature parameter θ_w increases, the velocity profile increases and the temperature profile increases such that there exists a local maximum of the velocity within the boundary layer, but velocity increases near the surface of the vertical porous plate and then temperature decreases and finally approaches to zero.

However, in Figures 5(a)-5(b), it is shown that when the Prandtl number *Pr* increases with θ_w = 1.1, R_d =0.1 and Q = 2.0, both the velocity and temperature profiles decrease.

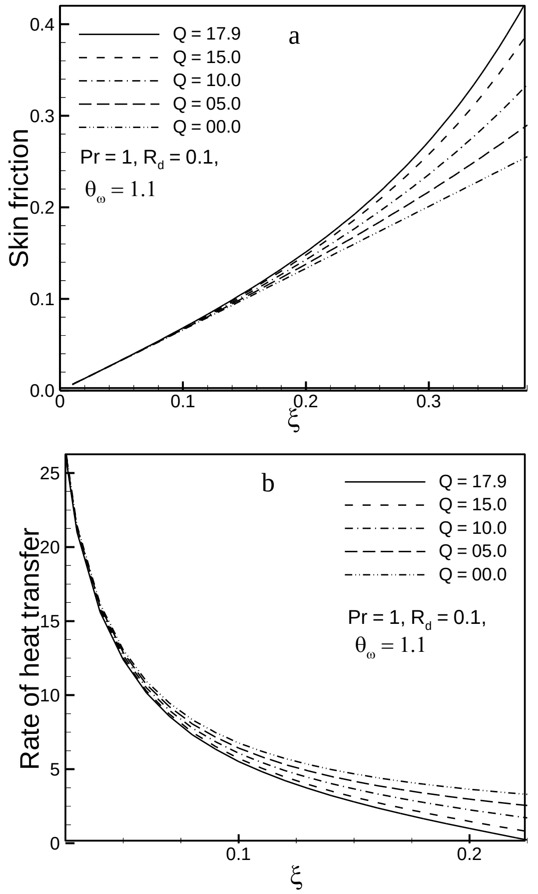


Figure 6. (a) Skin friction and (b) rate of heat transfer for different values of heat generation parameter Q with others fixed parameters.

Figures 6(a)-6(b) show that skin friction coefficient C_{fx}increases and heat transfer coefficient *Nu* decrease respectively for increasing values of heat generation parameter Q. in case of Prandtl number Pr = 1.0, radiation parameter R_d =0.1 and surface temperature parameter θ_w = 1.1. The values of skin friction coefficient $C_{fx}$and Nusselt number Nu_x are recorded to be 0.18218, 0.17690, 0.16844, 0.16072, 0.15370 and 0.06579, 0.66612, 1.61572, 2.46974, 3.24161 for Q =17.9, 15.0, 10.0, 05.0 and 00.0 respectively which occur at the same point ξ = 0.23. Here, it is observed that at ξ = 0.23, the skin friction increases by 18.52% and Nusselt number *Nu* decreases by 97.336% as the heat generation parameter Q changes from 17.9 to 00.0.

The effect of different values of radiation parameter R_d on the skin friction coefficient and the local rate of heat transfer while Prandtl number *Pr* = 1.0, heat generation parameter Q = 2.0 and surface temperature parameter θ_w = 1.1 are shown in the figures 7(a)-7(b). Here, as the radiation parameter R_d increases, the skin friction coefficient and heat transfer coefficient increase.

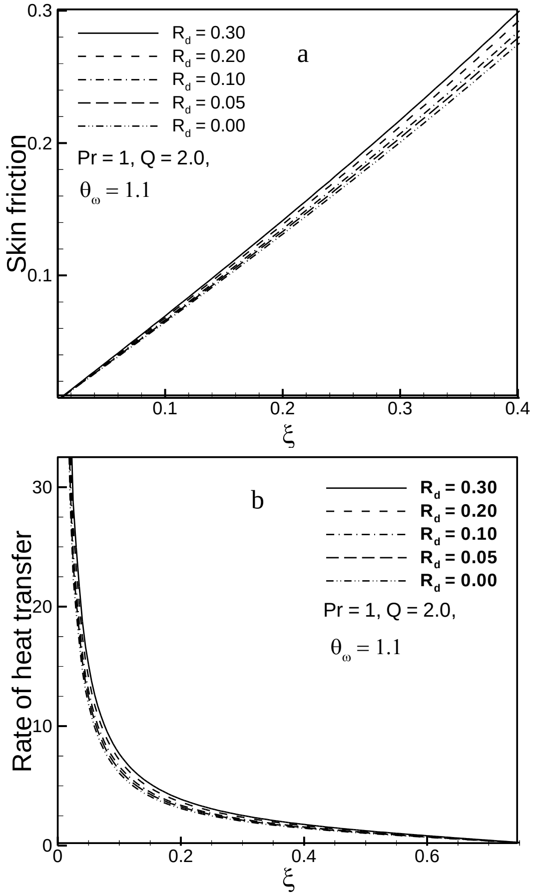
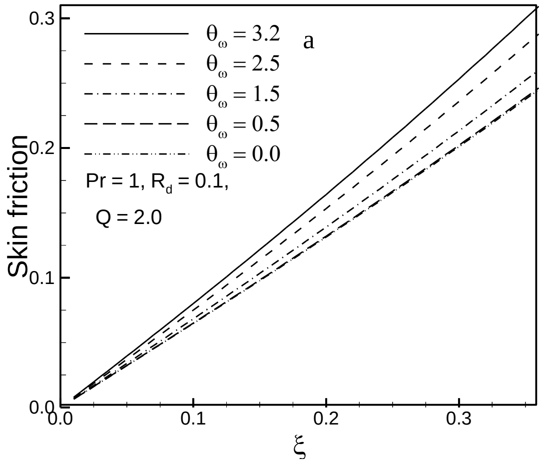


Figure 7.(a) Skin friction and (b) rate of heat transfer for different values of radiation parameter Rd with others fixed parameters



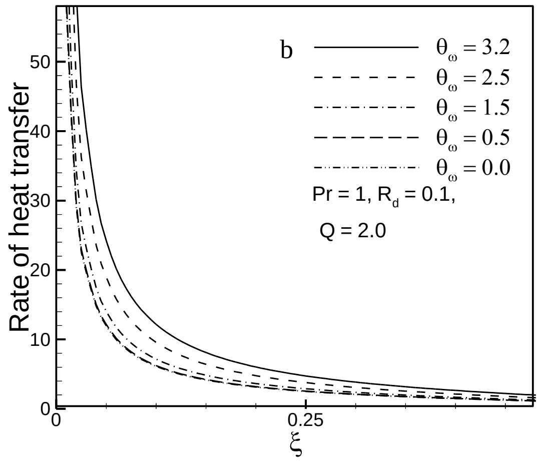


Figure 8. (a) Skin friction and (b) rate of heat transfer for different values of heat flux parameter θ_w with others fixed parameters

From Figures 8(a)-8(b), it can also easily be seen that an increase in the surface temperature parameter θ_w leads to increase in the local skin friction coefficient C_{fx} and the local rate of heat transferNu_xwhile Prandtl number Pr = 1.0, heat generation parameter Q = 2.0 and radiation parameter R_d=0.1. It is also observed that at any position of ξ, the skin friction coefficient C_{fx} increases and the local Nusselt number Nu_x increase as θ_w increases from 0.0 to 3.2. This phenomenon can easily be understood from the fact that when the surface temperature parameter θ_w increases, the temperature of the fluid rises and the thickness of the velocity boundary layer grow, i.e., the thermal boundary layer become thinner than the velocity boundary layer.

The variation of the local skin friction coefficient C_{fx} and local rate of heat transfer$Nu_x$for different values of Prandtl number Pr for θ_w = 1.1, Rd =0.1 and Q = 2.0 are shown in Figures 9(a)-9(b). We can observe from these figures that as the Prandtl number Pr increases, the skin friction coefficientdecreasesand rate of heat transfer increase.

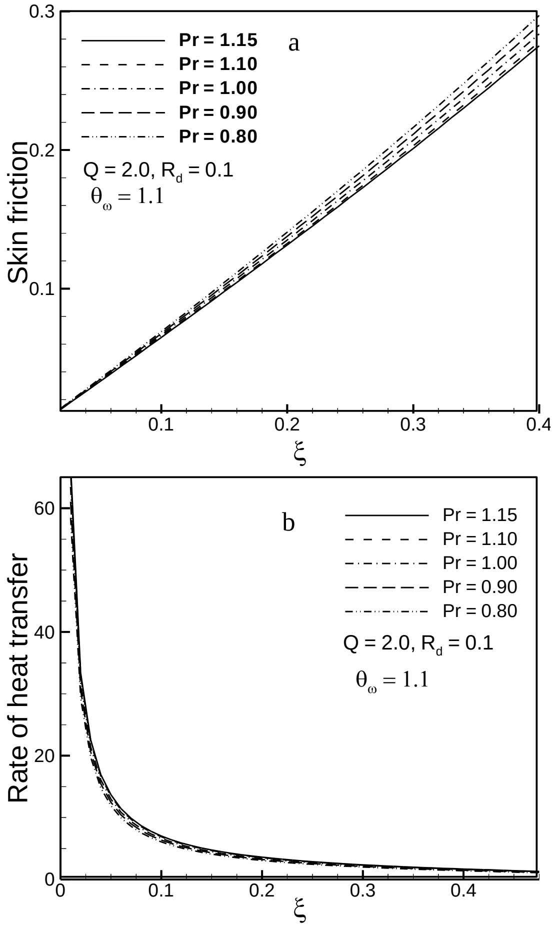


Figure 9. (a) Skin friction and (b) rate of heat transfer for different values of Prandtl number parameter *Pr* with others fixed parameters.

Numerical results of skin friction and rate of heat transfer are calculated from equation (13) for the surface of the porous plate from lower stagnation point to upper stagnation point at ξ= 0.01 to ξ=0.23. Numerical values of C_{fx}andNu_x are depicted in Table .1.

Here in the below table the values of skin friction coefficient $C_{fx}$and Nusselt number Nu_x are recorded to be 0.18218, 0.17690, 0.16072, 0.15370 and 0.06579, 0.66612, 2.46974, 3.24161 for Q=17.9, 15.0, 10.0, 05.0 and 00.0 respectively which occur at the same point ξ = 0.23. Here, it is observed that at ξ = 0.23, the skin friction increases by 18.52% and Nusselt number Nu_x decreases by 97.336% as the heat generation parameter Q changes from 17.9 to 00.0.

Table:1 Skin friction coefficient and rate of heat transfer against x for different values of heat generation parameter Q with other controlling parametersPr = 1.0, R_d = 0.1, θ_w =1.1.

ξ	Q=00.00		Q=05.00	
	C_{fx}	Nu_x		C_{fx}
0.01	0.00658	63.48390	0.00659	63.41941
0.03	0.01980	21.45338	0.01982	21.32936
0.05	0.03305	13.06291	0.03313	12.87776
0.07	0.04633	9.47057	0.04654	9.22375
0.09	0.05965	7.47655	0.06007	7.16749
0.11	0.07300	6.20876	0.07377	5.83677
0.13	0.08639	5.33190	0.08764	4.89618
0.15	0.09980	4.68956	0.10172	4.18914
0.17	0.11324	4.19896	0.11604	3.63276
0.19	0.12671	3.81216	0.13062	3.17888
0.21	0.14020	3.49949	0.14550	2.79773
0.23	0.15370	3.24161	0.16072	2.46974
ξ	Q=15.00		Q=17.90	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.01	0.00659	63.29037	0.00659	63.25294
0.03	0.01986	21.08118	0.01987	21.00816
0.05	0.03328	12.50441	0.03333	12.39560
0.07	0.04695	8.72285	0.04707	8.57579
0.09	0.06094	6.53465	0.06120	6.34736
0.11	0.07535	5.06650	0.07582	4.83626
0.13	0.09026	3.98158	0.09106	3.70489
0.15	0.10580	3.12176	0.10705	2.79424
0.17	0.12208	2.40231	0.12396	2.01846
0.19	0.13925	1.77308	0.14197	1.32608
0.21	0.15746	1.20180	0.16129	0.68326
0.23	0.17690	0.66612	0.18218	0.06579

5. COMPARISON OF THE RESULTS

ξ	θw= 1.1			
	Hossain		Present	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.1	0.0655	6.4627	0.06535	6.48306
0.2	0.1316	3.4928	0.13138	3.50282
0.4	0.2647	2.0229	0.26408	2.03018
0.6	0.3963	1.5439	0.39519	1.55522
0.8	0.5235	1.3247	0.52166	1.32959
1.0	0.6429	1.1995	0.64024	1.20347
1.5	0.8874	1.0574	0.88192	1.06109
ξ	θw = 2.5			
	Hossain		Present	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.1	0.0709	8.0844	0.07078	8.10360
0.2	0.1433	4.2858	0.14313	4.29682
0.4	0.2917	2.4003	0.29120	2.40669
0.6	0.4423	1.7863	0.44145	1.78912
0.8	0.5922	1.4860	0.59080	1.48991
1.0	0.7379	1.1098	0.73590	1.31822
1.5	1.0613	1.1098	1.05693	1.11262

In order to verify the accuracy of the present work, the values of Nusselt number and skin friction for Q = 0, R_d = 0.05.Pr = 1.0 and various surface temperature θ_w=1.1, θ_w=2.5 at different position of ξ are compared with Hossain et al. [13] as presented in Table 2. The results are found to be in excellent agreement.

6. CONCLUSION

The effect of radiation on natural convection flow on a porous vertical plate in presence of heat generation has been investigated for different values of relevant physical parameters including Prandtl number Pr, and surface temperature parameter θ_w.

Significant effects of heat generation parameter Q on velocity and temperature profiles as well as on skin friction and the rate of heat transfer have been found in this investigation but the effect of heat generation parameter Q on rate of heat transfer is more significant. An increase in the values of heat generation parameter Q leads to increase both the velocity and the temperature profiles, the local skin friction coefficient C_{fx} increases at different position of η and the local rate of heat transfer Nu_x decreases at different position of ξ for ξ< 0.1 and decrease asymptotically when Pr=1.0.

The increase in the values of radiation parameter R_d leads to increase in the velocity profile, the temperature profile, the local skin friction coefficient C_{fx} and the local rate of heat transfer Nu_x.

All the velocity profile, temperature profile, the local skin friction coefficient C_{fx} and the local rate of heat transfer Nu_xincreases significantly when the values of surface temperature parameter θ_w increase.

The increase in Prandtl number Pr leads to decrease in all the velocity profile, the temperature profile, the local skin friction coefficient C_{fx} but the local rate of heat transfer Nu_xincrease.

Nomenclatures

a_r	Rosseland mean absorption co-efficient
C_f	Local skin friction coefficient
C_p	Specific heat at constant pressure
f	Dimensionless stream function
g	Acceleration due to gravity
k	Thermal conductivity
Nu_x	Local Nusselt number
Pr	Prandtl number
Q	Heat generation parameter
q_w	Heat flux at the surface
q_c	Conduction heat flux
q_r	Radiation heat flux
R_d	Radiation parameter
T	Temperature of the fluid in theboundary layer
T_∞	Temperature of the ambient fluid
T_w	Temperature at the surface
(u,v)	Dimensionless velocity components along the (x,y) axes
V	Wall suction velocity
(x, y)	Axis in the direction along and normal to the surface respectively

Greek symbols

α	Equal to $\frac{4}{3}R_d$
β	Coefficient of thermal expansion
Δ	Equal to $\theta_w - 1$
ΔT	Equal to $T_w - T_\infty$
η	Similarity variable
θ	Dimensionless temperature function
θ_w	Surface temperature parameter
μ	Viscosity of the fluid
ν	Kinematic viscosity
ξ	Similarity variable
ρ	Density of the fluid
σ	Stephman-Boltzman constant
σ_s	Scattering co-efficient
μ_f	AbsoluteViscosity at the film temperature
τ	Coefficient of skin friction
τ_w	Shearing stress
ψ	Non-dimensional stream function

Subscripts

w	wall conditions
∞	Ambient temperature

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