

Radiation Effect on MHD Mixed Convection Flow Along an Isothermal Vertical Wedge Embedded in a Porous Medium with Heat Generation

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Abstract

This paper study the effect of radiation on a steady mixed convection flow of a viscous incompressible electrically conducting and radiating fluid over an isothermal vertical wedge embedded in a porous medium. The governing nonlinear partial differential equations and their boundary conditions are transformed into a nonsimilar form by using a suitable dimensionless variables. The system of nonsimilar equations is solved numerically using a finite difference method. The present results of local Nusselt number are compared with previously published work for the case of Darcy solution. The comparison is found to be in excellent agreement. The present results showed that as the wedge angle parameter increases the local Nusselt number increases. Increasing in the value of the square of the Hartmann number leads to decreasing the value of the local Nusselt number. Increasing in the value of the radiation parameter leads to an increase in the value of the local Nusselt number. Increasing in the value of the heat generation parameter leads to decreasing the value of the local Nusselt number. Increasing in the value of the radiation parameter in the presence of the square of the Hartmann number and the heat generation parameter has a similar effect on the local Nusselt number presented above but with less values.

Keywords: Porous medium, Mixed convection, Wedge, Nonsimilarity solutions, Thermal radiation, Heat generation.

تأثير الإشعاع على جريان الحمل المختلط الهيدروديناميكي المغناطيسي على طول حافة عمودية ثابتة درجة الحرارة مغمورة في وسط مسامي مع توليد الحرارة

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الخلاصة

هذا البحث يدرس تأثير الإشعاع على جريان الحمل المختلط المستقر لمانع لزج غير قابل للانضغاط موصل للتيار الكهربائي ومشع فوق حافة عمودية ثابتة درجة الحرارة مغمورة في وسط مسامي. لقد تم تحويل المعادلات الاشتقاقية الجزئية اللاخطية المتحكممة وشروطها الحدية إلى شكل لامتماثل بواسطة استعمال متغيرات لابعدية مناسبة. إن نظام المعادلات اللامتماثل تم حله عددياً باستخدام طريقة الفروق المحددة. إن النتائج الحالية لعدد نسلت الموقعي قد تمت مقارنتها مع نتائج عمل سابق مطبوع لحالة الحل الدارسي. لقد أظهرت المقارنة تطابق ممتاز بين الحلين. إن النتائج الحالية قد بينت انه بزيادة معلمة زاوية الحافة فان عدد نسلت الموقعي سيزداد. الزيادة في قيمة مربع عدد هارتمان يؤدي إلى النقصان في قيمة عدد نسلت الموقعي. إن الزيادة في قيمة معلمة الإشعاع الحراري يؤدي إلى زيادة في قيمة عدد نسلت الموقعي. الزيادة في قيمة معلمة التوليد الحراري تؤدي إلى النقصان في قيمة عدد نسلت الموقعي. الزيادة في معلمة الإشعاع الحراري بوجود مربع عدد هارتمان ومعلمة التوليد الحراري له تأثير مشابه على عدد نسلت الموقعي الموضح أعلاه لكن مع قيم أقل.

Nomenclature

B	Constant, equation (8).	T	Temperature (K).
c_p	Specific heat of the fluid ($J/kg.K$).	u,v	Velocity components in the x and y direction (m/s).
f	Dimensionless stream function.	U_∞	Free stream velocity (m/s).
g	Gravitational acceleration (m/s^2).	x,y	Axial and normal coordinate (m).
h	Local heat transfer coefficient ($W/m^2.K$).	α	Thermal diffusivity of the fluid (m^2/s).
i	Index of mesh points in the ζ -direction.	β	Thermal expansion coefficient of the fluid ($1/K$).
j	Index of mesh points in the η -direction.	β_0	Magnetic induction ($(Volt.s)/m^2$).
k	Thermal conductivity of fluid ($W/m.K$).	γ	Half wedge angle.
k^*	Mean absorption coefficient ($1/m$).	$\Delta\zeta, \Delta\eta$	Subintervals in the ζ and η direction.
K	Permeability of the porous medium (m^2).	ζ	Nonsimilarity parameter.
M	Square of the Hartmann number.	η	Pseudosimilarity variable.
Nu_x	Local Nusselt number.	θ	Dimensionless temperature.
N_ζ, N_η	Integer numbers greater than zero.	λ	Wedge angle parameter.
P	Pressure of the fluid (N/m^2).	μ	Dynamic viscosity of the fluid ($kg/(s.m)$).
Pe_x	Local Peclet number.	ρ	Density of the fluid (kg/m^3).
q_r	Radiation heat flux (W/m^2).	Σ	Prefix indicating summation.
q_w	Local surface heat flux (W/m^2).	ψ	Stream function.
Q	Heat generation parameter.	σ	Electrical conductivity of the fluid ($1/(ohm.m)$).
Q_0	Heat generation constant ($W/m^3.K$).	σ^{*}	Stefan-Boltzmann constant ($W/(m^2.K^4)$).
R	Radiation parameter.	ϕ	Porosity
Ra_x	Local Rayleigh number.		

Subscript

max	Sufficiently large value.
na	Assumed value not affected by the first convergence criterion.
new	New value.
old	Old value.
w	Surface conditions.
∞	Conditions far away from surface.

Introduction

The study of mixed convection boundary layer flow along surfaces embedded in fluid saturated porous media has received considerable interest recently. Interest in such studies was inspired by energy applications such as in geothermal operations, petroleum industries, thermal exchangers, chemical catalytic reactors, and many others.

In this field of study, Yih [1] analyzed the problem of coupled heat and mass transfer in mixed convection about a wedge embedded in saturated porous media by nonsimilar solutions for the case of variable heat and mass fluxes. Ibrahim and Hassanien [2] studied mixed convection along a vertical nonisothermal wedge embedded in saturated porous media incorporating the variation of permeability and thermal conductivity. Kumari et al. [3] investigated the steady mixed convection flow over a vertical wedge with a magnetic field embedded in porous medium. The effects of the permeability, surface mass transfer and viscous dissipation have been included in the analysis. Yih [4] presented numerical solutions for the effect of radiation on mixed convection flow of optically dense viscous fluids about an isothermal wedge embedded in a saturated porous medium. Kandasamy et al. [5] are carried out an analysis to study the variable viscosity and chemical reaction effects in a viscous fluid over a porous wedge in the presence of heat radiation. The wall of the wedge is embedded in a uniform Darcian porous medium in order to allow for possible fluid wall suction or injection. The above references are considered Newtonian fluids. Previous works that considered non-Newtonian fluids are found in references [6-8].

Previous works in this field that considered Newtonian fluids don't take into consideration the radiation effects on magnetohydrodynamic mixed convection flow with heat generation. Therefore, the aim of the present work is to study the effect of radiation on a steady mixed convection flow of a viscous incompressible electrically conducting and radiating fluid over an isothermal vertical wedge embedded in a porous medium with heat generation.

Mathematical Formulation

Consider a two-dimensional steady mixed convection flow of a viscous incompressible electrically conducting and radiating fluid over an isothermal vertical wedge embedded in a porous medium. The coordinate system is shown in Figure (1). A temperature dependent heat source is assumed to be present in the flow. The fluid is assumed to be gray, emitting and absorbing radiation but non-scattering medium. A magnetic field of uniform strength is applied transversely to the direction of the flow. The transverse applied magnetic field is assumed to be very small, so that the induced magnetic field is negligible.

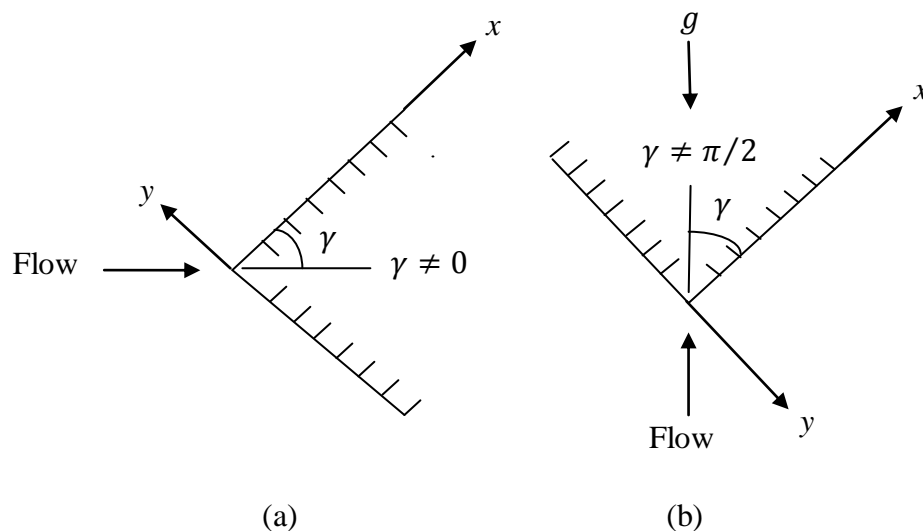


Figure (1): Flow model and physical coordinate system.

The surface of the wedge is maintained at a uniform constant temperature T_w , which is higher than the corresponding value T_∞ , sufficiently far away from the wedge surface. Also the fluid is assumed to have constant properties except the density in the buoyancy term of the balance of the momentum equation that is approximated according to the Boussinesq approximation. In the absence of an input electric field, the governing boundary layer equations are:

1- Continuity equation.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

where u and v are the velocity components in the x and y directions respectively.

2- Momentum equation [9,11]

a- in the x -direction

$$u = -\frac{K}{\mu} \left(\frac{\partial P}{\partial x} + \rho g_x + \frac{\sigma \beta_0^2 u}{\phi} \right) \quad (2)$$

b- in the y -direction

$$v = -\frac{K}{\mu} \left(\frac{\partial P}{\partial y} - \rho g_y + \frac{\sigma \beta_0^2 v}{\phi} \right) \quad (3)$$

Where $g_x = g \cos \gamma$, $g_y = g \sin \gamma$, P , ρ , and μ are the pressure, density and dynamic viscosity of the fluid respectively; K is the permeability of the porous medium; ϕ is porosity; g is gravitational acceleration; σ and β_0 are the electrical conductivity of the fluid and the magnetic induction respectively.

Differentiate equation (2) with respect to y and equation (3) with respect to x , after that eliminate pressure term from these equations. Then by invoking the Boussinesq approximation $\rho = \rho_\infty [1 - \beta(T - T_\infty)]$ [9] and under the assumptions that (1) within the boundary layer ($v \ll u$, $\partial/\partial x \ll \partial/\partial y$) and (2) $\cos \gamma$ and $\sin \gamma$ are of the same order of magnitude (the buoyancy force normal to the heated surface is negligible). The latter approximation is valid for a wide range of wedge angle except near $\gamma = 0^\circ$ in Figure (1a) or near $\gamma = 90^\circ$ in Figure (1b) [4]. Therefore, the final form of the momentum equation will be in the following form:

$$\frac{\partial u}{\partial y} = \frac{\rho_\infty \beta g \cos \gamma}{\frac{\mu}{K} + \frac{\sigma \beta_0^2}{\phi}} \frac{\partial T}{\partial y} \quad (4)$$

Where T is temperature; ρ_∞ and T_∞ are the free stream density and temperature respectively; β is the thermal expansion coefficient of the fluid.

3- Energy equation

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho_\infty c_p} \frac{\partial q_r}{\partial y} + \frac{Q_0}{\rho_\infty c_p} (T - T_\infty) \quad (5)$$

where α is the thermal diffusivity of the fluid; c_p is the specific heat of the fluid at constant pressure; q_r is the radiation heat flux, and Q_0 is the heat generation constant.

4- Radiative heat flux

The thermal radiation is assumed to be present in the form of a unidirectional flux in the y -direction i.e. q_r (transverse to the wedge surface). By using the Rosseland approximation [7], the radiative heat flux is given by:

$$q_r = -\frac{4\sigma^*}{3k^*} \frac{\partial T^4}{\partial y} \quad (6)$$

where σ^* is the Stefan-Boltzmann constant and k^* the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If the temperature differences within the flow are assumed to be sufficiently small that T^4 may be expressed as a linear function of temperature [4], i.e.

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (7)$$

5- Boundary conditions

$$\begin{aligned} y = 0, \quad v = 0, \quad T = T_w \\ y \rightarrow \infty, \quad u = U_\infty = Bx^\lambda, \quad T = T_\infty \end{aligned} \quad (8)$$

where U_∞ is the free stream velocity; B is prescribed constant; λ is the wedge angle parameter [$\lambda = \gamma/(\pi - \gamma)$] and γ is the half angle of the wedge. Specifically, the cases of $\lambda = 0, \frac{1}{3},$ and 1 correspond, respectively, to a uniform free stream flowing along a vertical flat plate, a free stream flowing over a 90° wedge, and a stagnation flow normal to a vertical wall [1,4].

6- Dimensionless variables

In order to obtain a system of equations applicable to the entire regime of mixed convection, the following dimensionless variables are introduced [2,4]:

$$\eta = \frac{y}{x} Pe_x^{1/2} \zeta^{-1}, \quad \zeta = \left[1 + \left(\frac{Ra_x}{Pe_x} \right)^{1/2} \right]^{-1} \quad (9)$$

$$f(\zeta, \eta) = \frac{\psi(x, y)}{\alpha Pe_x^{1/2} \zeta^{-1}}, \quad \theta(\zeta, \eta) = \frac{T - T_\infty}{T_w - T_\infty} \quad (10)$$

where η , f , and θ are the pseudosimilarity variable, dimensionless stream function, and dimensionless temperature respectively. ψ is the stream function, which is defined by $u = \partial\psi/\partial y$ and $v = -\partial\psi/\partial x$ such that the continuity equation is automatically satisfied, $Pe_x = U_\infty x/\alpha$ is the local Peclet number, $Ra_x = g_x \beta (T_w - T_\infty) Kx/\nu\alpha$ is the local Rayleigh number, and the parameter ζ is the nonsimilarity mixed convection parameter. A value of $\zeta = 0$ corresponds to pure free convection, while $\zeta = 1$ represents pure forced convection. By substituting equations (9) and (10) into equations (4) and (5) the following nonsimilar system of dimensionless equations are obtained:

7- Dimensionless momentum equation.

$$f'' = (1 - \zeta)^2 \frac{1}{(1+M)} \theta' \quad (11)$$

where $M = \sigma \beta_0^2 K / \mu \phi$ is the square of the Hartmann number.

8- Dimensionless energy equation.

$$\left(1 + \frac{4}{3}R\right) \theta'' + \left[\frac{1}{2}(1 + \lambda\zeta)f\right] \theta' + Q\zeta^2\theta = \frac{\lambda}{2}\zeta(1 - \zeta) \left(f' \frac{\partial \theta}{\partial \zeta} - \theta' \frac{\partial f}{\partial \zeta}\right) \quad (12)$$

where $R = 4\sigma^* T_\infty^3 / k^* k$ is the radiation parameter and $Q = Q_0 x / \rho c_p U_\infty$ is the heat generation parameter.

9- Dimensionless boundary conditions.

$$\begin{aligned} \eta = 0 & , \quad f = 0 & , \quad \theta = 1 \\ \eta \rightarrow \infty & , \quad f' = \zeta^2 & , \quad \theta = 0 \end{aligned} \quad (13)$$

Physical quantities of interest include the velocity components u and v in the x and y directions, the local Nusselt number $Nu_x = hx/k$, where the local heat transfer coefficient $h = q_w / (T_w - T_\infty)$ and $q_w = -\left[k \frac{\partial T}{\partial y}\Big|_{y=0} + \frac{16}{3} \frac{\sigma^* T_\infty^3}{k^*} \frac{\partial T}{\partial y}\Big|_{y=0}\right]$. In terms of the new variables, these quantities have the expression:

$$u = \frac{U_\infty}{\zeta^2} f' \quad (14)$$

$$v = -\frac{\alpha}{x} P e_x^{1/2} \frac{1}{\zeta} \left[\frac{1}{2}(1 + \lambda\zeta)f - \frac{1}{2}(1 - \lambda\zeta)\eta f' + \frac{\lambda}{2}\zeta(1 - \zeta) \frac{\partial f}{\partial \zeta}\right] \quad (15)$$

$$\frac{Nu_x}{P e_x^{1/2} \zeta^{-1}} = -\left(1 + \frac{4}{3}R\right) \theta'(\zeta, 0) \quad (16)$$

The primes in equations (11-16) denote partial differentiation with respect to η . The presence of $\partial/\partial\zeta$ in these equations makes them nonsimilar [10].

Numerical Scheme

The numerical scheme to solve equations (11) and (12) adopted here is based on a combination of the following concepts [6]:

- 1- The boundary conditions for $\eta = \infty$ are replaced by $f'(\zeta, \eta_{max}) = \zeta^2$ and $\theta(\zeta, \eta_{max}) = 0$ where η_{max} is a sufficiently large value of η where the boundary conditions (13) for velocity is satisfied.
- 2- The two dimensional domain of interest (ζ, η) is discretized with an equispaced mesh in the ζ direction and another equispaced mesh in the η direction.
- 3- The partial derivatives with respect to ζ and η are all evaluated by the central difference approximation. The central difference approximation for the partial derivatives with respect to ζ vanish when $\zeta = 0$ and $\zeta = 1$.

- 4- Two iteration loops based on the successive substitutions are used because of the nonlinearity of the equations.
- 5- In each inner iteration loop, the value of ζ is fixed, while each of equations (11) and (12) is solved as a linear second-order boundary-value problem of ordinary differential equation on the η domain. The inner integration is continued until the nonlinear solution converges for the fixed value of ζ .
- 6- In the outer iteration loop, the value of ζ is advanced from 0.1 to 0.9. The derivatives with respect to ζ are updated after every outer iteration step.

Fortran language is used to program the system of nonlinear equations. The program is divided into three parts: the first part obtains the solution of the pure free convection by setting the nonsimilarity parameter equal to zero. The second part obtains the solution of pure forced convection by setting the nonsimilarity parameter equal to one. The third part obtains the solution of mixed convection region for the nonsimilarity parameter values lies between 0 and 1 (i.e. $0 < \zeta < 1$).

In this work step sizes of $\Delta\eta = 0.02$ and $\Delta\zeta = 0.1$ are input to the program. A convergence criterion of $\sum_{j=1}^{N_\eta} |f_{new}(j, i) - f_{old}(j, i)| < 0.0001$ is adopted in the program for all types of convection. Where $f_{new}(j, i)$ and $f_{old}(j, i)$ are the new and old value of f . For the mixed convection region, as well as the above mentioned convergence criterion there is another convergence criterion on the whole region of mixed convection that is:

For $i = 1, \dots, N_\zeta$

$$\sum_{j=1}^{N_\eta} |f_{new}(j, i) - f_{na}(j, i)| < 0.0001$$

if (yes) then next i . If (no) then updates the values of f 's and θ 's for the mixed convection region ($0 < \zeta < 1$) and repeat the solution process for this region. Where $f_{na}(j, i)$ represent the assumed value of f that is not affected by the first convergence criterion.

Results and Discussion

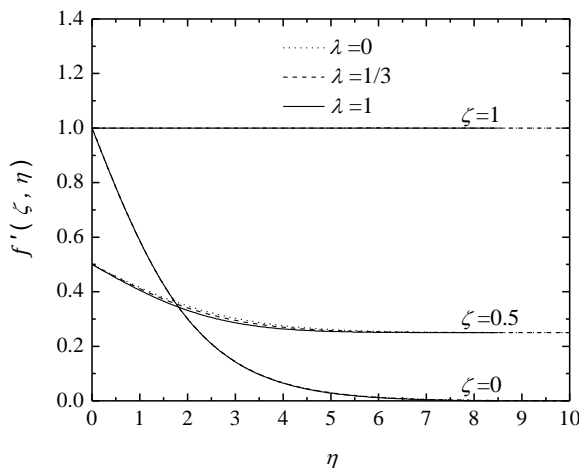
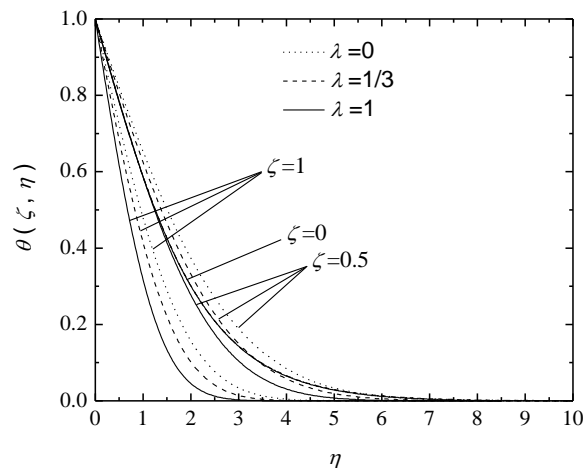
Numerical results were obtained and presented graphically. In order to validate the numerical results, the present results are compared with those of Yih [4] on special case of the problem. This favorable comparison give confidence in the numerical results to be reported in the next sections. Comparison of $Nu_x / (Pe_x^{1/2} \zeta^{-1})$ values for Darcy solution is shown in Table (1). In graphical form it will be shown later in Figure (4). The comparison is found to be in excellent agreement. Numerical results were obtained for the combined convection parameter ζ ranging from 0 to 1, the wedge angle parameter λ ranging from 0 to 1, the square of the Hartmann number M ranging from 0 to 2, the radiation parameter R ranging from 0.5 to 1.5, and the heat generation parameter Q ranging from 0 to 0.5.

Effect of λ : Figure (2) displays the effect of various values of λ and ζ on the velocity profiles. It can be noticed that for mixed convection region ($\zeta = 0.5$) the velocity of fluid decreases as the value of λ increase. This has the effect of enhancing the dimensionless surface temperature gradient as shown if Figure (3). The physical reason is that the motion of the fluid becomes more effective in moving the heat upward relative to conduction, allowing heat to move perpendicular to the surface, and hence the thermal boundary layer becomes thinner and enhances the dimensionless surface temperature gradient.

Table (1): Comparison of $Nu_x/(Pe_x^{1/2}\zeta^{-1})$ values for Darcy solution at values of ζ and λ .

ζ	Yih [4]			Present results		
	$\lambda = 0$	$\lambda = 1/3$	$\lambda = 1$	$\lambda = 0$	$\lambda = 1/3$	$\lambda = 1$
0	0.4437	0.4437	0.4437	0.444	0.444	0.4443
0.1	0.4035	0.4044	0.4049	0.3925	0.3927	0.3927
0.2	0.3732	0.3769	0.3786	0.3698	0.3758	0.3815
0.3	0.355	0.3643	0.3697	0.353	0.3639	0.3756
0.4	0.3505	0.3686	0.3823	0.3509	0.3712	0.3954
0.5	0.3603	0.39	0.4227	0.3615	0.3929	0.4351
0.6	0.3832	0.4261	0.4854	0.3845	0.4283	0.4929
0.7	0.4173	0.4731	0.5599	0.4183	0.4744	0.5626
0.8	0.4602	0.5278	0.6385	0.4607	0.5284	0.639
0.9	0.5097	0.5878	0.7181	0.51	0.5881	0.7181
1	0.5642	0.6515	0.7979	0.5643	0.6516	0.798

This leads to increasing the local Nusselt number as the value of λ increase as shown in Figure (4). However, this increase is small for lower values of ζ . Furthermore, at a given value of λ as ζ increases from 0 the local Nusselt number decreases, reaches a minimum value at a certain value of ζ , and then increases again as ζ approaches 1. This is due to the nature of the local Nusselt number parameter versus the nonsimilarity parameter and does not imply that the actual local Nusselt number value for mixed convection is smaller than that for pure forced or pure free convection. This behavior will be repeated in the next figures of the local Nusselt number.

**Figure (2):** Effect of λ and ζ on the velocity profile ($M=R=Q=0$).**Figure (3):** Effect of λ and ζ on the temperature profile ($M=R=Q=0$).**Effect of M :**

The presence of a magnetic field in an electrically conducting fluid has the effect of reducing the flow due to the resulting resistance magnetic force, which is called the Lorentz force as shown in Figure (5) which, in turn, reduces the rate of heat convection in the flow and this appears in increasing the flow temperature as the magnetic field strength

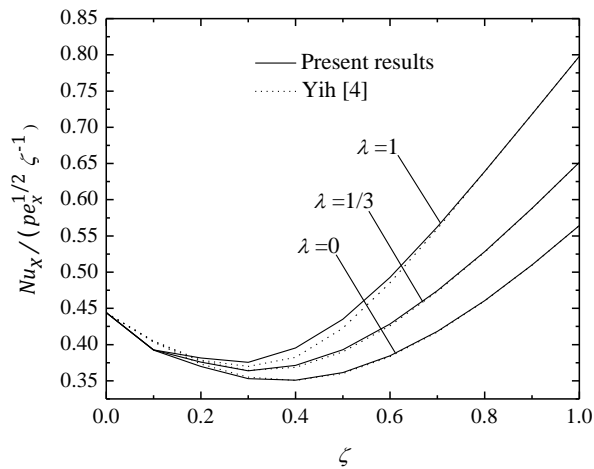


Figure (4): Effect of λ and ζ on the local Nusselt number ($M=R=Q=0$).

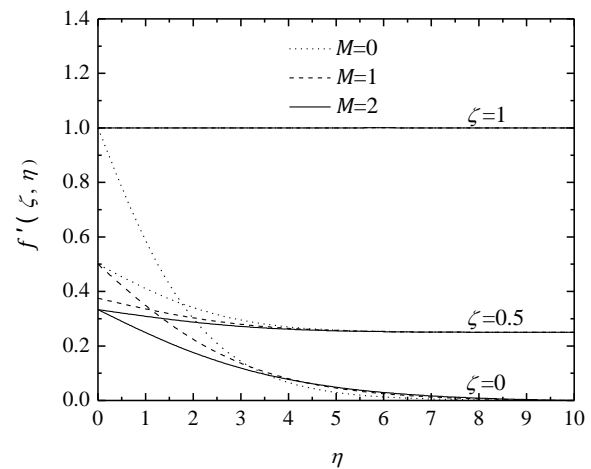


Figure (5): Effect of M and ζ on the velocity profile ($\lambda=1/3, R=0, Q=0$).

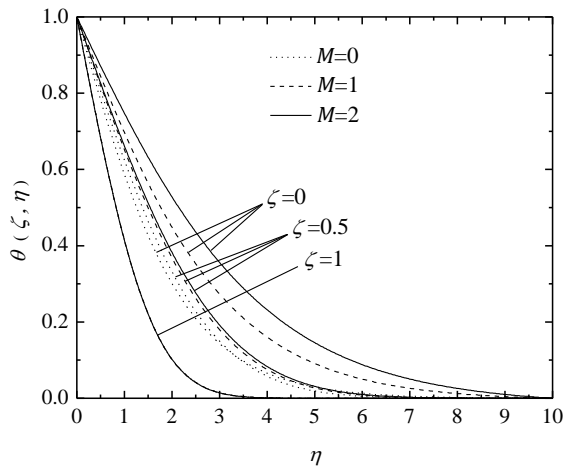


Figure (6): Effect of M and ζ on the temperature profile ($\lambda=1/3, R=0, Q=0$).

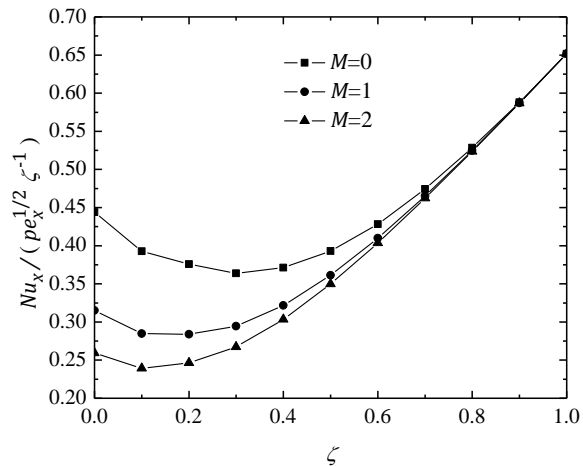


Figure (7): Effect of M and ζ on the local Nusselt number ($\lambda=1/3, R=0, Q=0$).

increases as depicted in Figure (6). This results in decreasing the local Nusselt number as shown in Figure (7). Moreover, it is noticed that the increase in the value of M do not lead to appreciable decrease in the value of the local Nusselt number for large values of ζ .

Effect of R :

Figures (8) and (9) represents the effect of radiation parameter R on the velocity and temperature profiles. It is observed that an increase in the radiation parameter results in increasing velocity and temperature within the boundary layer. Thus, the effect of thermal radiation is to increase the conductive moment in the boundary layer. Increasing the temperature is due to in the presence of radiation the temperature is large. Figure (10) illustrates that the increasing in the radiation parameter leads to an increase in the local Nusselt number. This fact is expected since the value of the local Nusselt number is directly proportional to the value of R in equation (16) and the local Nusselt number is found to be

more sensitive for the radiation parameter than the dimensionless surface temperature gradient $(-\theta'(\zeta, 0))$.

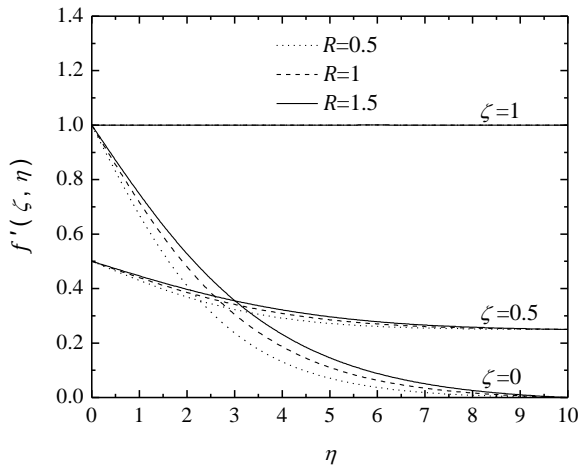


Figure (8): Effect of R and ζ on the velocity profile ($\lambda=1/3, M=0, Q=0$).

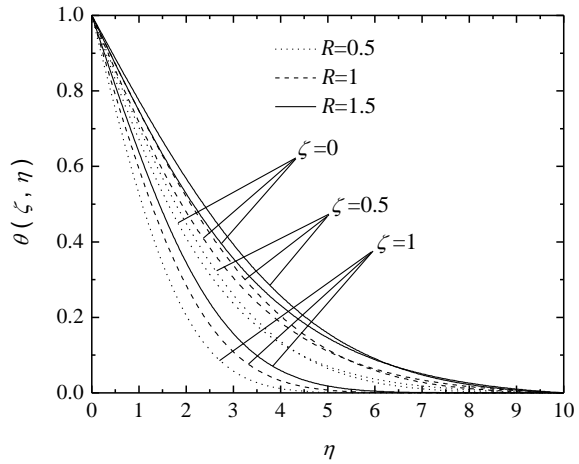


Figure (9): Effect of R and ζ on the temperature profile ($\lambda=1/3, M=0, Q=0$).

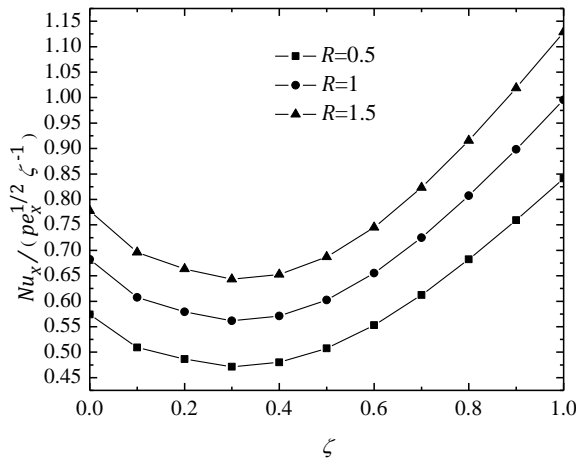


Figure (10): Effect of R and ζ on the local Nusselt number ($\lambda=1/3, M=0, Q=0$).

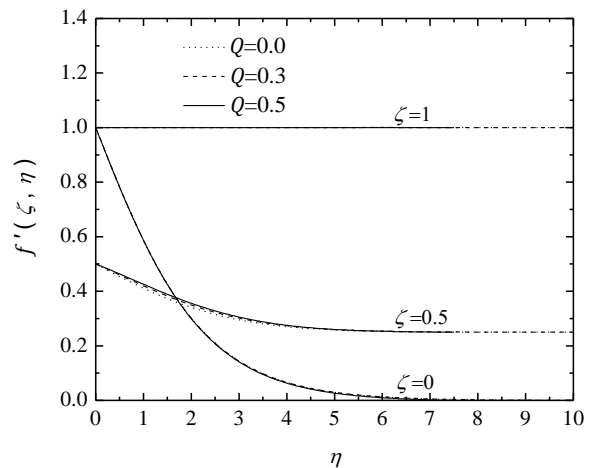


Figure (11): Effect of Q and ζ on the velocity profile ($\lambda=1/3, M=0, R=0$).

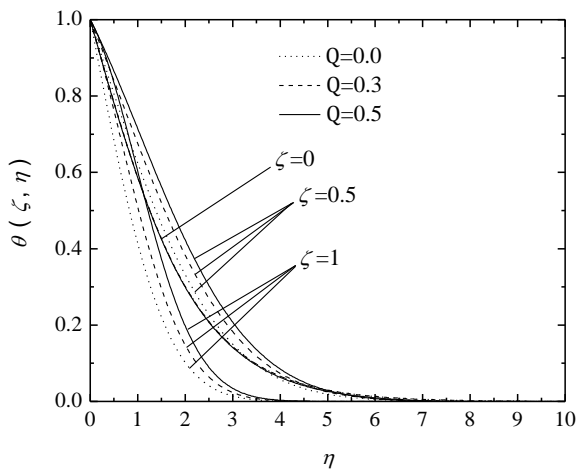


Figure (12): Effect of Q and ζ on the temperature profile ($\lambda=1/3, M=0, R=0$).

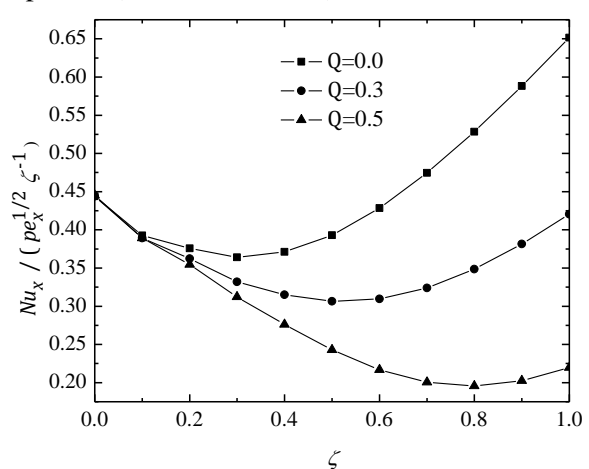


Figure (13): Effect of Q and ζ on the local Nusselt number ($\lambda=1/3, M=0, R=0$).

Effect of Q :

When the heat is generated the buoyancy force increases which induces the flow rate to increase giving rise to the increase in the velocity profiles, but, this increase is neglected in natural convection region and very small in mixed convection region as shown in Figure (11). Also, it is noticed that as Q increases the temperature profiles increases as illustrated in Figure (12). This has the direct effect in decreasing the local Nusselt number with the increasing in the value of Q as depicted in Figure (13). Also, it is noticed that for lower values of ζ the reduction in the value of the local Nusselt number is small as compared with large values of ζ .

Effect of R in the presence of M and Q :

Figures (14-16) presents the effects of R and ζ on the velocity profiles, temperature profiles, and local Nusselt number respectively in the presence of M and Q . From these figures it can be observed that the behavior of the curves shown a similar trends to the behavior of the curves in Figures (8-10) with the exception that, the reduction in the velocity of fluid in Figure (14) as compared to Figure (8). The increase in the temperature of fluid in Figure (15) as compared to Figure (9). This result in reduction in the values of the local Nusselt number in Figure (16) as compared to its counterpart presented in Figure (10).

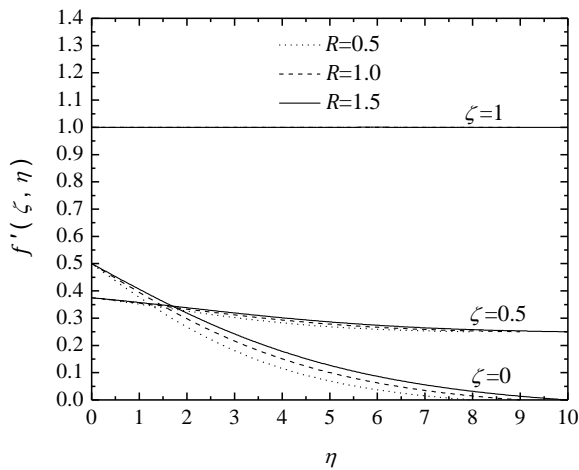


Figure (14): Effect of R and ζ on the velocity profile ($\lambda=1/3, M=1, Q=0.5$).

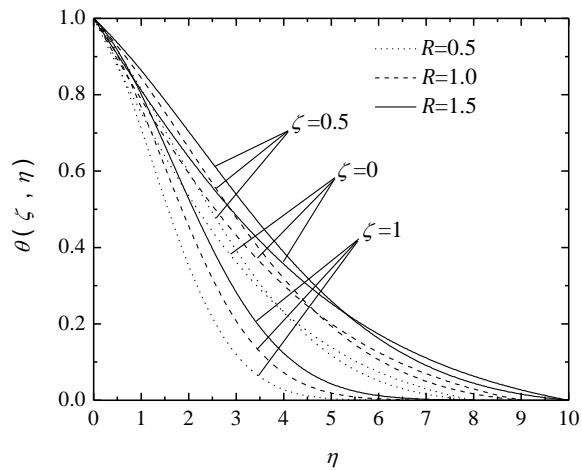


Figure (15): Effect of R and ζ on the temperature profile ($\lambda=1/3, M=1, Q=0.5$).

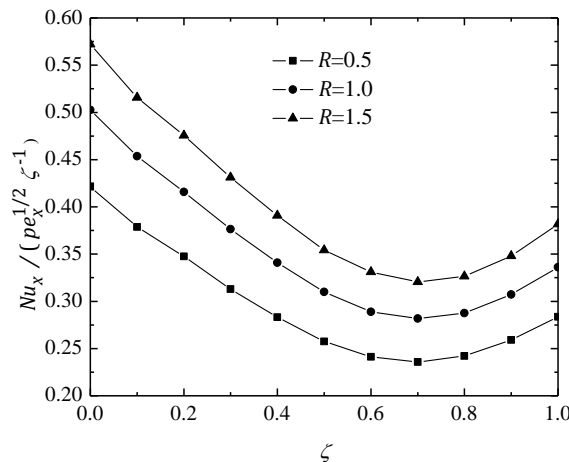


Figure (16): Effect of R and ζ on the local Nusselt number ($\lambda=1/3, M=1, Q=0.5$).

Conclusions

From the previous study it can be concluded that:

- 1- As the wedge angle parameter λ increases the local Nusselt number increases.
- 2- Increasing in the value of the square of the Hartmann number M leads to decreasing the value of the local Nusselt number.
- 3- Increasing in the value of the radiation parameter R leads to an increase in the value of the local Nusselt number.
- 4- Increasing in the value of the heat generation parameter Q leads to decreasing the value of the local Nusselt number.
- 5- Increasing in the value of the radiation parameter R in the presence of the square of the Hartmann number M and the heat generation parameter Q has a similar effect on the local Nusselt number presented above in point 3 but with less values.

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The work was carried out at the college of Engineering. University of Mosul