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Radiation Effect with Eckert Number and Forchimer Number on Heat and Mass Transfer over an Inclined Plate in the Influence of Suction/Injection Flow

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Authors' contributions

This work was carried out in collaboration between all authors. Author MUA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MHR and MO managed the analyses of the study. Author MHR managed the literature searches. All authors read and approved the final manuscript.

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Abstract

In the present context, the effect of Eckert number and Forchimer number on a two dimensional steady free convective heat and mass transfer flow of an electrically conducting fluid through a porous medium with radiation effect has been analyzed. The governing momentum, energy and concentration equations have been solved by using Nachtsheim-Swigert shooting iteration technique with sixth-order Runge-Kutta integration scheme. In both cases of suction and injection flow the results are presented as velocity, temperature and concentration profiles for the pertinent parameters of this work. Moreover, the wall share stress, average heat transfer and average mass transfer are exposed in graphically. In all studied cases, velocity, temperature and concentration distributions are affected by the considered parameters.

Keywords: Radiation; Eckert number; Forchimer number; heat and mass transfer; suction; injection.

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1 Introduction

The recent technological implications have given rise to increased interest in free and forced convection in inclined plate immersed in porous media. The study of heat and mass transfer with the Eckert number and Forcheimer number along with radiation is very important to engineers and scientists because of its numerous applications such as storage of radioactive nuclear waste materials, transpiration cooling, separation processes in chemical industries, filtration, ground water pollution etc.

Researchers have done many conceptual works on mass and heat transfer, among them Jayaraj [1] observed the thermophoresis in laminar flow over cold inclined plates with variable properties. Mohammadein and Mansour [2] investigated radiative effects on natural convection flows in a porous media. Tarkar and Kumari [3] presented computational analysis of coupled radiation-convection dissipative non-grey gas flow in a non-Darcy porous medium using the keller-Box implicit scheme. Ahammad and Shirazul Hoque Mollah [4] discussed MHD free convection flow and mass transfer over a stretching sheet considering Dufour & Soret effects in the presence of magnetic field. Their investigated results showed that the flow field is notably influenced by the considering parameters. Rapits and Perdikis [5] showed unsteady flow through a highly porous medium in the presence of radiation. Alam and Rahaman [6] investigated Dufour and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction. Alam et al. [7] carried out a numerical study of the combined free-forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal duffusion. Alam and Ahammad discussed [8] effects on variable chemical reaction and variable electric conductivity on free convective heat and mass transfer flow along an inclined stretching sheet with heat and mass transfer fluxes under the influence of Dufour and Soret effects. The authors established in their work that the chemical reaction parameter, Dufour number, Soret number and heat (or mass) flux parameter play a crucial role in the solutions. Alam and Rahaman [9] showed thermophoretic particle deposition on unsteady hydromagnetic radiative heat and mass transfer along an infinite inclined permeable surface with viscous dissipation and joule heating. Cortell [10] presented flow and heat transfer of a fluid through a porous medium over a stretching surface with internal heat generation/absorption and suction/blowing. Esmaeil et al. [11] investigated the effect of heat generation on natural convection from an inclined surface embedded in a porous medium. In that work the inclined surface is taken as impermeable.

Kairi and Murthy [12] carried out Soret effect on free convection from a melting vertical surface in a non-Darcy porous medium. Postelnicu [13] investigated influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Ravikumar et al. [14] investigated MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. Samad et al. [15] presented free convection flow through a porous medium with thermal radiation, viscous dissipation and variable suction in presence of magnetic field. Maleque [16] showed MHD non-Newtonian casson fluid heat and mass transfer flow with exothermic/endothermic binary chemical reaction and activation energy. Elbashbeshy [17] analysed heat transfer over a stretching surface with variable surface heat flux. Chen [18] studied effects of magnetic field and suction/injection considering surface heat flux on convection heat transfer of non-Newtonian power-law. Acharya et al. [19] investigated heat and mass transfer over an accelerating surface with heat source in the presence of suction and blowing.

Very recent Veera Krishna [20] focused Hall effects on MHD flow of a visco-elastic fluid through a porous medium. In this study the author considered an infinite oscillating porous plate with heat source and chemical reaction. Ahmad Dar and Elangovan [21] carried out thermal diffusion, radiation and inclined magnetic field effects on oscillatory flow in an asymmetric channel in where heat source and chemical reaction is considered.

The objective of this work is to analyze the behavior of radiation effect along with Eckert number and Forcheimer number simultaneously on heat and mass transfer for both of the suction and injection flow.

2 Mathematical Formulation

Consider a steady MHD laminar free convective heat and mass transfer flow of a viscous and incompressible fluid along an inclined surface from the vertical with an acute angle α embedded in porous media. The surface is assumed to be permeable and moving with velocity, $u_w(x) = bx$ (where b is constant called stretching rate). Fluid suction is imposed at the stretching surface. The flow is assumed to be in x-direction, which is taken along the plate in the upward direction while the y-axis is taken to be normal to the plate. We further assume that there exists a homogeneous *n-th* order chemical reaction between the fluid and species concentration.

With the Boussinesq and the usual boundary-layer approximations the present problem is governed by the continuity, momentum, energy and concentration equations respectively as follows:

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty)\cos\alpha + g\beta^*(C - C_\infty)\cos\alpha - \frac{\upsilon}{k^/}u - \frac{b}{k^/}u^2 \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{\upsilon}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} - K_l\left(C - C_\infty\right)^n \tag{4}$$

By applying Rosseland approximation q_r can be expressed as,

$q_r = -\frac{4\sigma_1}{3k_1}\frac{\partial T^4}{\partial y}$, where σ_1 is the Stefan-Boltzamann constant, k_1 is the mean absorption coefficient and $T^4 \approx 4T_\propto^3 T - 3T_\propto^4$.

Then equation (3) takes the form,

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} + \frac{16\sigma_1 T_\alpha^3}{3\rho c_p k_1}\frac{\partial^2 T}{\partial y^2} + \frac{\upsilon}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{5}$$

where u, v are the fluid velocity components along the x and y directions respectively, υ denotes the kinematic viscosity, g is the gravitational acceleration , ρ is the fluid density, β and β^* is the volumetric coefficient of thermal expansion & concentration expansion respectively, k is the fluid thermal conductivity, c_s is the concentration susceptibility, c_p is the specific heat at constant pressure, T_m is the mean temperature of fluid, k_T is the thermal diffusion ratio, K_l is the reaction rate, D_m is the molecular diffusivity of the species concentration and n stands for the chemical reaction order.

Therefore equation (2) can be re-written as:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)\cos\alpha+g\beta^*(C-C_\infty)\cos\alpha-\frac{1}{Da\,\mathrm{Re}}f'-\frac{Fs}{Da}f'^2=0, \quad (6)$$

Therefore equation (5) can be re-written as:

$$\theta''+\left(\frac{3R}{3R+4}\right)\mathrm{Pr}\,f\theta'+r\,\mathrm{Pr}\left(\frac{3R}{3R+4}\right)f'\theta+\mathrm{Pr}\,Df\left(\frac{3R}{3R+4}\right)\varphi''+\left(\frac{3R}{3R+4}\right)PrEcf''^2=0, \quad (7)$$

The boundary conditions for the model are given as:

$$u=u_w(x)=bx,\ v=\pm\ v_w(x),\ \xrightarrow{-k\frac{\partial T}{\partial y}=q_w=A_1x^r\ ,\ -D_m\frac{\partial C}{\partial y}=M_w=A_2x^r} \text{at } y=0, \quad (8a)$$

$$u=0,\quad T=T_\infty,\quad C=C_\infty\quad \text{as}\quad y\to\infty\ . \quad (8b)$$

where b is a constant called stretching rate and A_1, A_2 are proportionality constants and $v_w(x)$ represents the permeability of the porous surface where its sign indicates suction (< 0) or injection (> 0).

Now, introducing the similarity variables (see Acharya et al. [19]):

$$\left.\begin{aligned}
&u=\frac{\partial\psi}{\partial y},\ v=-\frac{\partial\psi}{\partial x}\\
&\psi=(\upsilon b)^{1/2}xf(\eta),\ \eta=(b/\upsilon)^{1/2}y,\\
&T-T_\infty=\frac{A_1x^r}{k}(\upsilon/b)^{1/2}\theta(\eta),\\
&C-C_\infty=\frac{A_2x^r}{D_m}(\upsilon/b)^{1/2}\phi(\eta).
\end{aligned}\right\} \quad (9)$$

Then equations (2)-(4) yields the following equations

$$f'''+ff''-(f')^2+g_s\theta\cos\alpha+g_c\varphi\cos\alpha-=0, \quad (10)$$

$$\theta''+\left(\frac{3R}{3R+4}\right)\mathrm{Pr}\,f\theta'+r\,\mathrm{Pr}\left(\frac{3R}{3R+4}\right)f'\theta+\mathrm{Pr}\,Df\left(\frac{3R}{3R+4}\right)\varphi''+\left(\frac{3R}{3R+4}\right)PrEcf''^2=0, \quad (11)$$

$$\phi''-rScf'\phi+Scf\phi'+ScSr\theta''-ScK\phi^n=0\,. \quad (12)$$

where the dimensionless parameters are defined as follows:

$Gr=\dfrac{g\beta q_w x^4}{k\upsilon^2}$ is the local Grashof number, $\mathrm{Re}_x=\dfrac{u_w(x)x}{\upsilon}$ is the local Reynolds number, $g_s=\dfrac{Gr}{\mathrm{Re}_x^{5/2}}$ is the temperature buoyancy parameter, $g_c=\dfrac{Gm}{\mathrm{Re}_x^{5/2}}$ is the mass buoyancy parameter,

$Df = \dfrac{D_m M_w k_T}{\upsilon c_s c_p q_w}$ is the Dufour number, $Sr = \dfrac{D_m q_w k_T}{k M_w T_m}$ is the Soret number, $\Pr = \dfrac{\upsilon \rho Cp}{k}$ is the Prandtl number, $Sc = \dfrac{\upsilon}{D_m}$ is the Schmidt number and $K = \dfrac{K_l (C_w - C_\infty)^{n-1} x}{u_w(x)}$ is the chemical reaction parameter, $Ec = \dfrac{u_w^{2}(x)}{C_p (T_w - T_\infty)}$ is the Eckert number, $Fs = \dfrac{b}{x}$ is the Forchimer number, $R = \dfrac{kk_1}{4\sigma_1 T_\alpha^3}$ is the radiation parameter, $Da = \dfrac{k'}{x^2}$ is the Darcy number.

The boundary conditions (8) becomes

$$f = f_w, f' = 1, \theta' = -1, \phi' = -1 \quad \text{at } \eta = 0, \tag{13a}$$

$$f' = 0, \theta = 0, \phi = 0 \quad \text{as, } \eta \to \infty \tag{13b}$$

Here, $f_w = -v_w / (b\upsilon)^{1/2}$ is the non-dimensional wall mass transfer coefficient so that f_w>0 indicates wall suction whereas f_w< 0 indicates wall injection.

For the present problem the local skin-friction coefficient, the local Nusselt number and the local Sherwood number are the parameters of engineering interest which are given respectively as below:

$$\frac{1}{2} Cf_x (\mathrm{Re}_x)^{\frac{1}{2}} = f''(0), \tag{14}$$

$$Nu_x (\mathrm{Re}_x)^{-\frac{1}{2}} = \frac{1}{\theta(0)}, \tag{15}$$

$$Sh_x (\mathrm{Re}_x)^{-\frac{1}{2}} = \frac{1}{\phi(0)}. \tag{16}$$

Applying the boundary condition (13), the system of equations (10)-(12) have been solved numerically by using the Nachtsheim-Swigert [22] shooting iteration technique with sixth-order Runge-Kutta integration scheme. Various groups of the parameters g_s, g_c, f_w, Pr, Sc, Df, Sr, K, n and α were considered in different phases. In all the computations the step size $\Delta\eta = 0.01$ was selected that satisfied a convergence criterion of 10^{-6} in almost all of different phases mentioned above.

3 Code Validation

For the justification of the numerical code of our work, we have compared the local Nusselt number ($1/\theta(0)$) of present study with the previously published work Elbashbeshy [17] and Chen [18] for specific value of Pr with $g_s = g_c = K = r = Sr = R = n = Df = Fs = Da^{-1} = Re^{-1} = 0$, $Sc = 0.22$, $f_w = 0.6$ and $\alpha = 90^0$. The comparison is shown in Table 1 that reveals very tremendous agreement with the mentioned results and thus it makes an assertion of the current numerical code.

Table 1. Comparison of the local Nusselt number with Elbashbeshy [17] and Chen [18] for their Newtonian fluid case and for $g_s = g_c = K = r = Sr = R = n = Df = Fs = Da^{-1} = Re^{-1} = 0$, $Sc = 0.22$, $f_w = 0.6$ and $\alpha = 90^0$ case with different Pr

Pr	Elbashbeshy [17]	Chen [18]	Present study
0.72	0.7711	0.76217	0.7622729
1.00	1.0060	1.00616	1.0062684
10.0	7.0921	7.09205	7.0939394

4 Results and Discussion

In this research we have shown the effect of Eckert number and Forchimer number on a two dimensional steady free convective heat and mass transfer flow of an electrically conducting fluid through a porous medium with radiation effect.

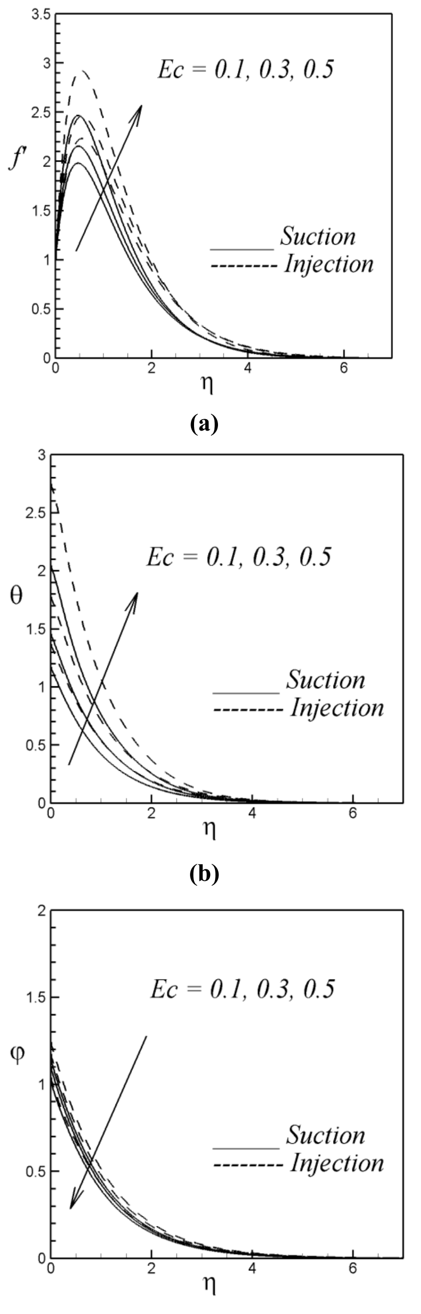
The influence of Eckert number Ec on the velocity, temperature and concentration profiles are displayed in Fig. 1(a)-(c) respectively. It is observed that velocity and temperature profiles that are displayed in Fig. (a) and (b) increase due to the effect of Eckert number for the cases of suction and injection whereas concentration profiles decreases. A remarkable variation is followed for suction/injection flow in velocity and temperature profiles for different values of Eckert number (Ec = 0.1, 0.3, 0.5) but a minor disparity is found in case of concentration field.

Fig. 2(a)-(c) demonstrates the velocity, temperature and concentration distributions for chosen values of the Forchimer number (Fs = 0.5, 1.0, 1.5) for both the fluid suction and injection. These figures reveal that an increase in the Forchimer number leads to decrease the velocity field but the reverse trend is followed for the temperature and concentration fields. Though for various chosen values of Forchimer number no significant dissimilarity is observed in temperature and concentration fields, a noteworthy effect is seen for $\eta < 1.5$ in velocity profile for the mentioned values of Fs.

The effect of radiation parameter on velocity, temperature and concentration fields are shown in Fig. 3(a)-(c) respectively. For both case of suction and injection flow, it can be concluded that higher values of radiation parameter leads to decrease the velocity and temperature distributions but a reverse trend is followed for the concentration profile. One can easily detect a variety for three selected values of radiation parameter (R = 1, 2, 3) in velocity and temperature fields for both of the suction and injection cases while concentration field is identical for these values of R.

Fig. 4(a)-(c) illustrate the mode of the local skin-friction coefficient Cf, local Nusselt number Nu and local Sherwood number Sh which indicate the the wall share stress, average heat transfer and average mass transfer respectively at different values of the Eckert number Ec and the radiation parameter R. It is found that with the rising value of Ec, local skin-friction coefficient and local Sherwood number grow up whereas local Nusselt number shows an opposite effect. In addition as radiation parameter increases local Nusselt number increase but local skin-friction coefficient and local Sherwood number decreases.

Lastly, the influence of Forchimer number Fs and radiation parameter R on the local skin-friction coefficient Cf, local Nusselt number Nu and local Sherwood number Sh are exposed in Fig. 5(a)-(c). From these one can noted that Cf, Nu, Sh are almost flat for the increasing value of Fs. On the other hand, Cf, Sh decrease and Nu increases as R increases.

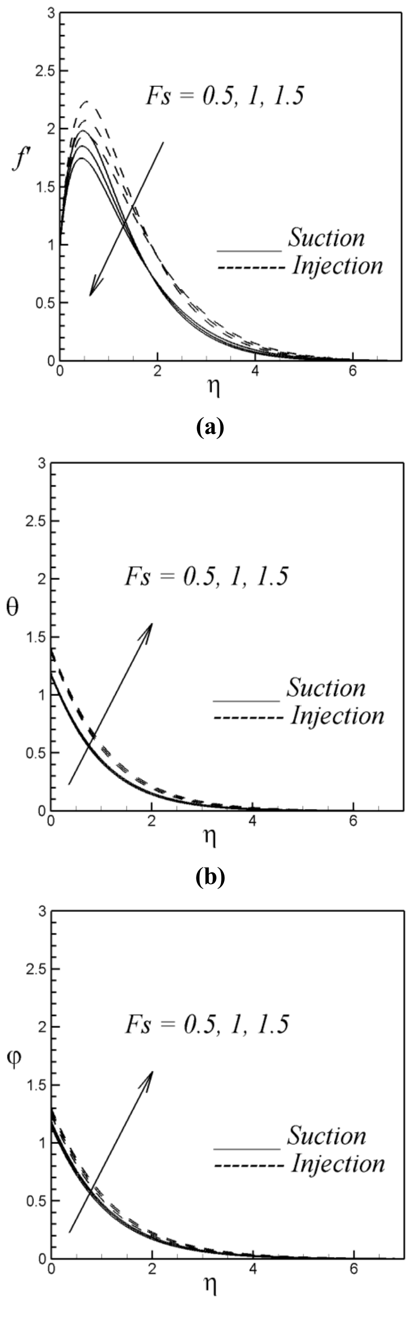


(a)

(b)

(c)

Fig. 1. Variation of dimensionless (a) velocity, (b) temperature and (c) concentration profiles across the boundary layer for different values of Ec and for f_w = 1.0, g_s = 12, g_c = 6, Pr = 0.71, Sc = 0.22, r =1.0, K = 1.0, Fs = 1.0, Sr = 0.60, Df = 0.10, R=1.0, Da=0.50, Re=200, n=1.0 and $\alpha = 30°$

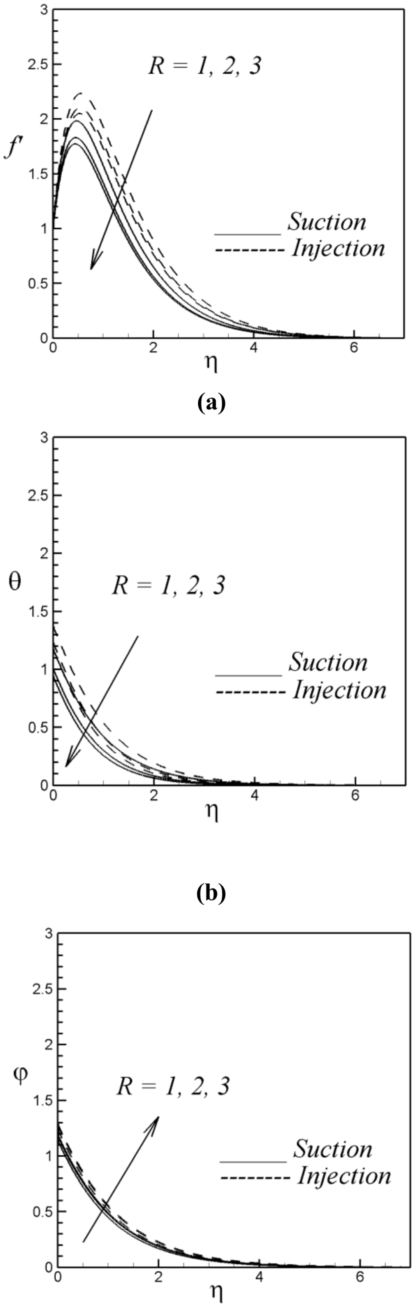


(a)

(b)

(c)

Fig. 2. Variation of dimensionless (a) velocity, (b) temperature and (c) concentration profiles across the boundary layer for different values of Fs and for f_w = 1.0, g_s = 12, g_c = 6, Pr = 0.71, Sc = 0.22, r =1.0, K = 1.0, Fs = 1.0, Sr = 0.60, Df = 0.10, R=1.0, Da=0.50, Re=200, n=1.0 and $\alpha = 30°$

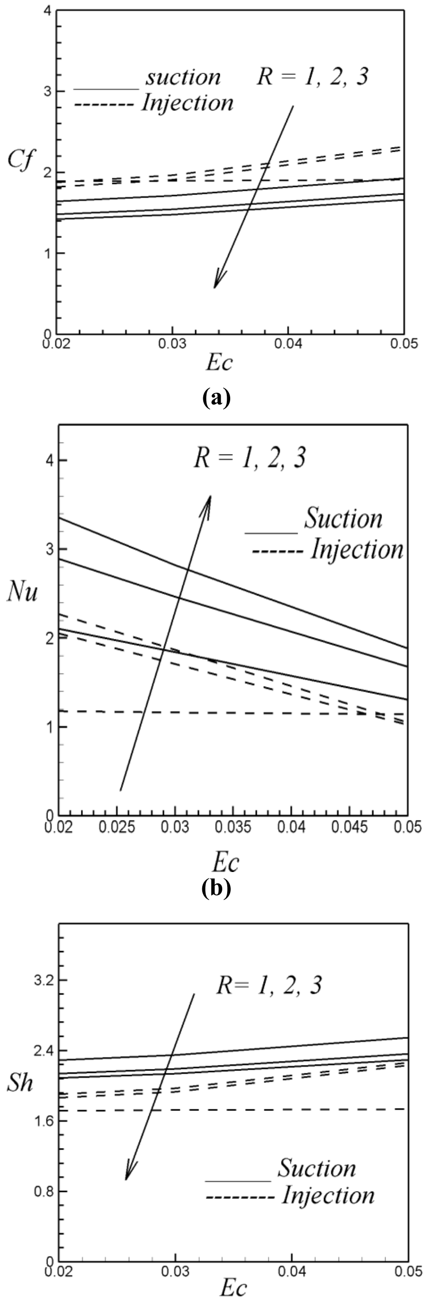


(a)

(b)

(c)

Fig. 3. Variation of dimensionless (a) velocity, (b) temperature and (c) concentration profiles across the boundary layer for different values of *R* and for $f_w = 1.0$, $g_s = 12$, $g_c = 6$, $Pr = 0.71$, $Sc = 0.22$, $r = 1.0$, $n = 1.0$, $Sr = 0.60$, $Df = 0.10$, $Fs = 1.0$, $Da = 0.50$, $Re = 200$, $Ec = 0.01$, $K = 1.0$ and $\alpha = 30°$

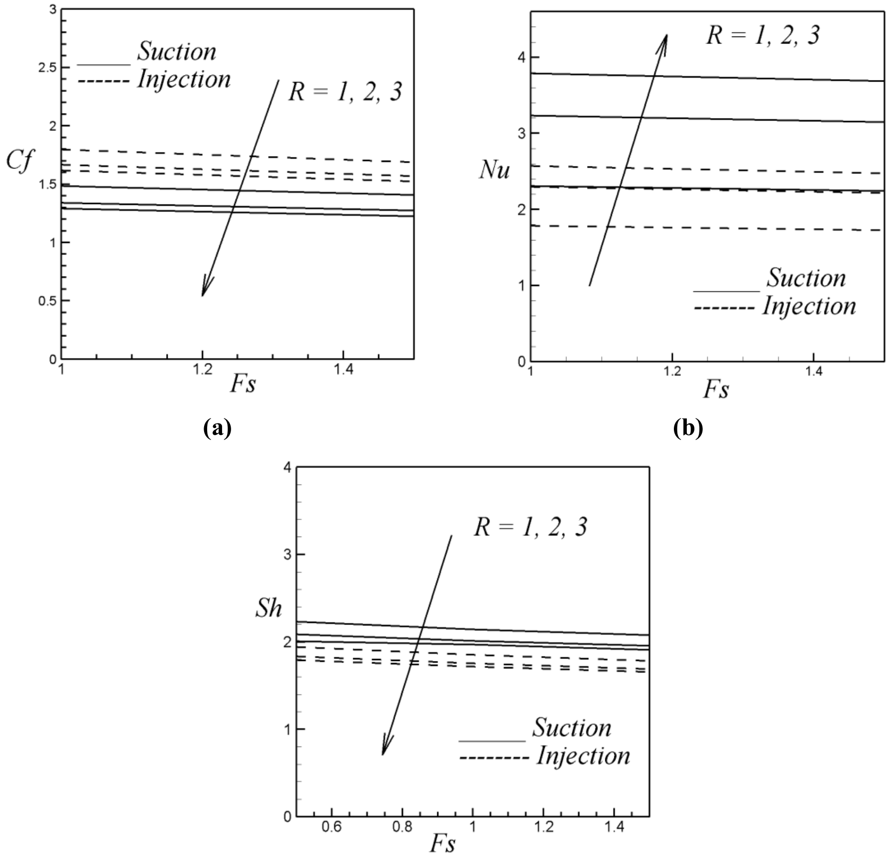


(a)

(b)

(c)

Fig. 4. Effects of *Ec* and *R* on (a) local skin-friction coefficient, (b) local Nusselt number and (c) local Sherwood number for $f_w = 1.0$, $g_s = 12$, $g_c = 6$, $Pr = 0.71$, $Sc = 0.22$, $r = 1.0$, $K = 1.0$, $Fs = 1.0$, $Sr = 0.60$, $Df = 0.10$, $n = 1.0$, $Re = 200$, $Da = 0.50$ and $\alpha = 30°$



(a) (b)

(c)

Fig. 5. Effects of *Fs* and *R* on (a) local skin-friction coefficient, (b) local Nusselt number and (c) local Sherwood number for f_w = 1.0, g_s = 12, g_c = 6, *Pr* = 0.71, *Sc* = 0.22, *r* = 1.0, *K* = 1.0, *Fs* = 1.0, *Sr* = 0.60, *Df* = 0.10, *n* = 1.0, *Re* = 200, *Da* = 0.50 and α = 30°

5 Conclusions

From the present study the followings can be summarized:

The numerical investigations shows that the velocity profiles increase with the increasing value of Eckert number *Ec* and it decreases with growing value of Forchimer number *Fs* and radiation parameter *R*. The temperature profiles increase with the increasing values of Eckert number *Ec,* Forchimer number *Fs* whereas it decreases with increasing values of radiation parameter *R*. The concentration profile decreases with an increasing value of Eckert number *Ec* and it decreases with the rising values of Forchimer number *Fs* and radiation parameter *R*.

As radiation parameter increases, the local skin-friction coefficient and local Sherwood number decrease while local Nusselt number increases with respect to both of the considered parameters *Ec* and *Fs* in all cases of suction and injection flow.

Competing Interests

Authors have declared that no competing interests exist.

References

[1] Jayaraj S. Thermophoresis in laminar flow over cold inclined plates with variable properties. Journal of Heat and Mass Transfer. 1995;30:167-173.

[2] Mohammadein AA, Mansour MA. Radiative effects on natural convection flows in a porous media. Transport porous media. 1998;32(3):263-283.

[3] Tarkar HS, Kumari M. Computational analysis of coupled radiation-convection dissipative non-grey gas flow in a non-Darcy porous medium using the keller-Box implicit scheme. International Journal of Energy Research. 1998;22:141-159.

[4] Ahammad MU, Shirazul Hoque Mollah Md. Numerical study of MHD free convection flow and mass transfer over a stretching sheet considering Dufour & Soret effects in the presence of magnetic field. International Journal of Engineering &Technology IJET-IJENS. 2011;11(5):4-11.

[5] Rapits A, Perdikis C. Unsteady flow through a highly porous medium in the presence of radiation. Transport porous media. 2004;57(2):171-179.

[6] Alam MS, Rahaman MM. Dufour and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction. Nonlinear analysis: Modeling and Control. 2006;11(1):3-12.

[7] Alam MS, Rahaman MM, Samad MA. Numerical study of the combined free-forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal duffusion. Nonlinear analysis: Modeling and Control. 2006;11(4):331-343.

[8] Alam MS, Ahammad MU. Effects on variable chemical reaction and variable electric conductivity on free convective heat and mass transfer flow along an inclined stretching sheet with heat and mass transfer fluxes under the influence of Dufour and Soret effects. Nonlinear analysis: Modeling and Control. 2011;16(1):1-16.

[9] Alam MS, Rahaman MM. Thermophoretic particle deposition on unsteady hydromagnetic radiative heat and mass transfer along an infinite inclined permeable surface with viscous dissipation and joule heating. Engineering e-Transaction. 2012;7(2):116-126.

[10] Cortell R. Flow and heat transfer of a fluid through a porous medium over a stretching surface with internal heat generation/absorption and suction/blowing. Fluid Dyn. Res. 2005;37:231-245.

[11] Esmaeil Khaje, Kayhaniand MH, Sadi M. Effect of heat generation on natural convection from an impermeable inclined surface embedded in a porous medium. Journal of Porus Media. 2013;16(5): 427-443.

[12] Kairi RR, Murthy PVSN. Soret effect on free convection from a melting vertical surface in a non-Darcy porous medium. Journal of Porus Media. 2013;16(2): 97-104.

[13] Postelnicu A. Influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. International Journal of Heat and Mass transfer. 2004;47:1467-1472.

[14] Ravikumar V, Raju MC, Raju GSS, Chamkha AJ. MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. International Journal of Energy & Technology. 2013;5(7):1-8.

[15] Samad MA, Karim ME Mohammad D. Free convection flow through a porous medium with thermal radiation,viscous dissipation and variable suction in presence of magnetic field. The Bangladesh Journal of Scientific Research. 2010;23(1):61-72.

[16] Maleque KA. MHD non-Newtonian casson fluid heat and mass transfer flow with exothermic/ endothermic binary chemical reaction and activation energy. American Journal of Heat and Mass Transfer. 2016;3:166-185.

[17] Elbashbeshy EMA. Heat transfer over a stretching surface with variable surface heat flux. Journal Phys. D, Appl. Phys. 1998;31:1951–1954.

[18] Chen CH. Effects of magnetic field and suction/injection on convection heat transfer of non-Newtonian power-law fluids past a power-law stretched sheet with surface heat flux. International J.Therm. Sci. 2008;47(7):954–961.

[19] Acharya M, Singh LP, Dash GC. Heat and mass transfer over an accelerating surface with heat source in the presence of suction and blowing. International J. Eng. Sci. 1999;37:189–211.

[20] VeeraKrishna M. Hall effects on MHD flow of a visco-elastic fluid through a porous medium over an infinite oscillating porous plate with heat source and chemical reaction. International J. Computer Aided Engineering and Technology; 2017. (In press)

[21] Ahmad Dar Ajaz, Elangovan K. Thermal diffusion, radiation and inclined magnetic field effects on oscillatory flow in an asymmetric channel in presence of heat source and chemical reaction. Journal of Nigerian Mathematical Society. 2016;35(3):488-509.

[22] Nachtsheim PR, Swigert P. Satisfaction of the asymptotic boundary conditions in numerical solution of the system of non-linear equations of boundary layer type. NASA TND-3004; 1965.

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