

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 1, January 2015

## Influence of Chemical Reaction, Heat Source, Soret and Dufour Effects on Heat And Mass Transfer in Boundary Layer Flow Over a Stretching Cylinder Embedded in a Porous Medium using Brinkman-Forchheimer Extended Darcy Model

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**Abstract:** Heat and mass transfer characteristics by boundary layer flow over a stretching cylinder embedded in a porous medium subjected to a chemical reaction and heat source is investigated numerically by taking into account the Soret and Dufour effects using Brinkman-Forchheimer extended Darcy model. The concentration profile is drawn for various values of Reynold's number, Darcy number, chemical reaction parameter, Prandtl number, Schmidt number, heat source, non-darcy parameter, Soret and Dufour numbers. Numerical results of rate of mass transfer for different parameters are presented in tabular form.

**Keywords:** Heat and Mass Transfer, Porous Medium, Stretching Cylinder, Soret and Dufour effects, Chemical Reaction, Heat Source, Brinkman-Forchheimer equation.

### I. INTRODUCTION

Convective flow through porous media has attracted considerable attention in last several decades due to its many important engineering, environmental and geophysical applications. Recent books by Nield and Bejan [1], Ingham and Pop [2] present a comprehensive account of available information in the field. The combined heat and mass transfer problems with chemical reactions have received a considerable amount of attention in recent years. Das [3] have studied the effects of chemical reaction and mass transfer on flow past an impulsively infinite vertical plate with constant heat flux. Andersson [4] have studied the flow and mass diffusion of a chemical species with first order and higher order reactions over a linearly stretching surface. Anjalidevi and Kandasamy [5] have analysed the steady laminar flow along a semi-infinite horizontal plate in the presence of a species concentration and chemical reaction. Muthucumaraswamy [6] has studied the effect of chemical reaction on a moving isothermal vertical infinitely long surface with suction. Chamkha [7] discussed the analytical solutions for heat and mass transfer on MHD mass flow of a uniformly stretched vertical permeable surface with the effects of heat generation/absorption and chemical reaction. El-Kabeir and Modather [8] has studied the effect of chemical reaction on heat and mass transfer by MHD flow over a vertical cone surface in micropolar fluids with heat generation / absorption. Partha [9] obtained similarity solutions for double dispersion effects on free convection hydromagnetic heat and mass transfer in a non-Darcy porous medium with Soret and Dufour effects, showing that in both aiding and opposing buoyancies, Dufour and Soret numbers considerably affect the wall mass transfer rates, both of which are also reduced with stronger magnetic field. Aziz [10] studied the thermal – diffusion and diffusion – thermo effects on the heat and mass transfer characteristics of free convection past a continuously stretching permeable surface in the presence of magnetic field and radiation. Postelnicu [11] has discussed the influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces embedded in fluid – saturated porous medium considering Soret and Dufour effects. Cheng [12] studied the Soret and Dufour effects on natural convection heat and mass transfer from a vertical cone in a porous medium. Pal and Mondal [13] analysed the effects of Soret and Dufour numbers, chemical

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reaction and thermal radiation on MHD non-Darcy unsteady mixed convective heat and mass transfer over a stretching-sheet . Sharma [14] has analysed the Soret and Dufour effects on separation of binary fluid mixture in MHD natural convection in porous media. El.Kabeir (2011) has studied the Soret and Dufour effects on heat and mass transfer due to a stretching cylinder saturated porous medium with chemically-reactive species.

The objective of this paper is to study the chemical reaction , heat source, thermal-diffusion and diffusion-thermo effects on heat and mass transfer due to a stretching cylinder embedded in a porous medium using the Brinkman-Forchheimer extended Darcy model.

## II. ANALYSIS

We consider steady laminar two-dimensional boundary layer flow together with heat and mass transfer of a viscous incompressible fluid mixture over a stretching cylinder of radius ' $a$ ' embedded in a porous medium. Here z-axis is measured along the axis of the cylinder and r-axis in the radial direction. The surface of the cylinder is maintained at a constant temperature  $T_w$  and a constant concentration  $C_w$ . The ambient temperature and concentration far away from the surface of the cylinder which is assumed to be uniform is  $T_\infty$  and  $C_\infty$  respectively where  $T_w > T_\infty$  and  $C_w > C_\infty$ . The physical properties of the fluid are assumed to be constant. The effects of thermal-diffusion, diffusion-thermal, a first order homogenous chemical reaction and heat source on flow, heat and mass transfer are taken into account.

The governing equations of mass, linear momentum using Brinkman-Forchheimer extended Darcy model, energy and mass diffusion are given by

$$\frac{\partial w}{\partial z} + \frac{\partial u}{\partial r} + \frac{u}{r} = 0 \quad \dots(1)$$

$$w \frac{\partial w}{\partial z} + u \frac{\partial w}{\partial r} = \nu \left( \frac{\partial^2 w}{\partial r^2} + \frac{1}{r} \frac{\partial w}{\partial r} \right) - \frac{\nu w}{k} - \frac{b}{k} \sqrt{u^2 + w^2} w \quad \dots(2)$$

$$w \frac{\partial u}{\partial z} + u \frac{\partial u}{\partial r} = -\frac{1}{\rho} \frac{\partial p}{\partial r} + \nu \left( \frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \frac{\partial u}{\partial r} - \frac{u}{r^2} \right) - \frac{\nu u}{k} - \frac{b}{k} \sqrt{u^2 + w^2} u \quad \dots(3)$$

$$w \frac{\partial T}{\partial z} + u \frac{\partial T}{\partial r} = \alpha \left( \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) + \frac{Dk_T}{C_S C_p} \left( \frac{\partial^2 C}{\partial r^2} + \frac{1}{r} \frac{\partial C}{\partial r} \right) + \frac{Q_0}{\rho C_p} (T - T_\infty) \quad \dots(4)$$

$$w \frac{\partial C}{\partial z} + u \frac{\partial C}{\partial r} = D \left( \frac{\partial^2 C}{\partial r^2} + \frac{1}{r} \frac{\partial C}{\partial r} \right) + \frac{Dk_T}{T_m} \left( \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) - K' (C - C_\infty) \quad \dots(5)$$

subject to boundary conditions

$$\left. \begin{aligned} u = 0, w = W_w, T = T_w, C = C_w & \quad \dots \text{ at } r = a \\ w \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty & \quad \dots \text{ at } r \rightarrow \infty \end{aligned} \right\} \quad \dots(6)$$

where  $W_w = 2cz$ ,  $c$  is a positive constant,  $u$  and  $w$  are velocity components in the  $r$  and  $z$  directions respectively,  $\rho$  is density,  $k$  is permeability of porous medium,  $\nu$  is kinematic viscosity,  $T$  and  $C$  are temperature and concentration,  $\alpha$  is thermal diffusivity,  $D$  is mass diffusivity,  $C_p$  is specific heat capacity,  $C_S$  is concentration susceptibility,  $k_T$  is thermal diffusion ratio,  $T_m$  is mean fluid temperature,  $K'$  is dimensional of chemical reaction and  $b$  is Forchheimer's constant.

The similarity transformation is given by

$$\left. \begin{aligned} \eta = \left(\frac{r}{a}\right)^2, u = -\frac{caf(\eta)}{\sqrt{\eta}}, w = 2czf'(\eta), \\ \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty} \text{ and } \phi(\eta) = \frac{C-C_\infty}{C_w-C_\infty} \end{aligned} \right\} \quad \dots(7)$$

Substituting equation (7) in (2), (4) and (5), the following differential equations are

$$f'' = Ref'^2 - \eta f''' - Reff'' + \frac{1}{Da} f' + F_b f' \sqrt{\frac{f^2 + 4\xi^2 f'^2 \eta}{\eta}} \quad \dots(8)$$

$$\eta \theta'' + \theta' + Pr D_f (\eta \phi'' + \phi') + Pr Ref \theta' + Pr Re \alpha_0 \theta = 0 \quad \dots(9)$$

$$\eta \phi'' + \phi' + Sc Ref \phi' + Sc S_r (\eta \theta'' + \theta') - \gamma Sc \phi = 0 \quad \dots(10)$$

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where  $Re = \frac{ca^2}{2\nu}$  is the Reynold number,  $Da = \frac{4k}{a^2}$  is the Darcy number,  $F_b = \frac{a^3b}{4k}$  is non-Darcy parameter,  $Pr = \frac{\nu}{\alpha}$  is Prandtl number,  $\alpha_0 = \frac{Q_0}{2c\rho C_p}$  is heat source,  $Sc = \frac{\nu}{D}$  is Schmidt number,  $D_f = \frac{Dk_T(C_w - c_\infty)}{c_s C_p \nu (T_w - T_\infty)}$  is Dufour number,  $S_r = \frac{Dk_T(T_w - T_\infty)}{T_m \nu (C_w - C_\infty)}$  is Soret number and  $\gamma = \frac{K'a^2}{4\nu}$  is chemical reaction parameter.

The boundary conditions (6) becomes

$$\left. \begin{aligned} f = 0, f' = 1, \theta = 1, \phi = 1 & \quad \text{at } \eta = 1 \\ f' \rightarrow 0, \theta \rightarrow 0, \phi \rightarrow 0 & \quad \text{at } \eta \rightarrow \infty \end{aligned} \right\} \dots(11)$$

The pressure  $p$  can be determined from equation (3) in the form

$$\frac{p}{\rho} = \frac{p_\infty}{\rho} - \frac{c^2 a^2}{2\eta} f^2(\eta) - 2c\nu f'(\eta) \dots(12)$$

### III. RESULTS AND DISCUSSIONS

The ordinary differential equations (8), (9) and (10) with the corresponding boundary conditions (11) have been solved numerically by using bvp4c solver of MATLAB. From the process of numerical computation, the local Sherwood number which is proportional to  $-\phi'(1)$  is worked out and their numerical values are presented in tabular form. Numerical calculations for  $\phi'$  have been carried out by taking various values of parameters  $Da, Re, D_f, S_r, \gamma, Pr, Sc, F_b$  and  $\alpha_0$ .

The following cases for numerical calculation are considered:

Case I:  $Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, Da = (1.0, 2.0, 3.0)$ .

Case II:  $Da = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, Re = (1.0, 2.0, 3.0)$ .

Case III:  $Da = 1.0, Re = 1.0, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, D_f = (0.10, 0.15, 0.20)$ .

Case IV:  $Da = 1.0, Re = 1.0, D_f = 0.15, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, S_r = (0.2, 0.3, 0.4)$ .

Case V:  $Da = 1.0, Re = 1.0, D_f = 0.15, S_r = 0.4, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, \gamma = (0.0, 0.2, 0.4)$ .

Case VI:  $Da = 1.0, Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, Pr = (6.0, 7.0, 8.0)$ .

Case VII:  $Da = 1.0, Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5, Sc = (1.5, 1.6, 1.7)$ .

Case VIII:  $Da = 1.0, Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, \alpha_0 = 0.2, \xi = 0.5, F_b = (0.1, 0.2, 0.3)$ .

Case IX:  $Da = 1.0, Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \xi = 0.5, \alpha_0 = (0.1, 0.2, 0.25)$ .

Case I:

Fig. 1 exhibit concentration profile for various values of  $Da$ . The value of the concentration is more near the surface of the cylinder than its value at the end of the boundary layer. It depicts that concentration increases near the surface of the cylinder with increase in the values of parameter  $Da$  but at about  $\eta = 2.5$  onwards, reverse effect is observed.

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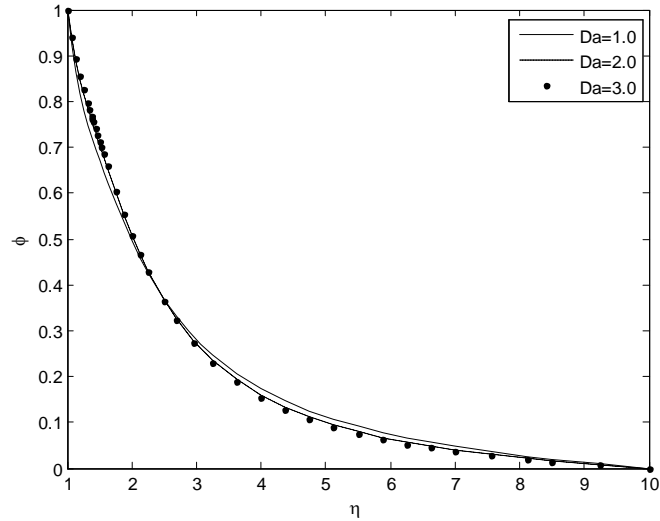


Fig. 1: Concentration profile for  $Da = (1,2,3)$  with  $Re = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$ .

CaseII:

Fig. 2 exhibit concentration profile for various values of  $Re$ . The value of the concentration is more near the surface of the cylinder than its value at the end of the boundary layer. It depicts that concentration increases near the surface of the cylinder with increase in the values of parameter  $Re$  but at about  $\eta = 1.5$  onwards, reverse effect is observed.

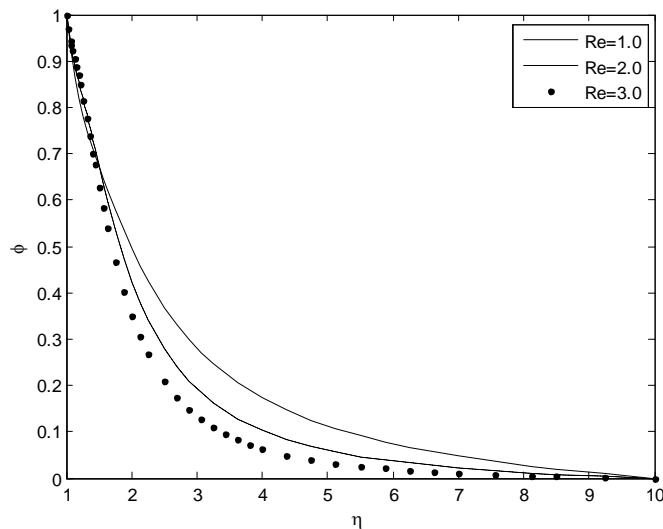


Fig. 2: Concentration profile for  $Re = (1,2,3)$  with  $Da = 1.0, D_f = 0.15, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$ .

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CaseIII:

Fig. 3 exhibit concentration profile for various values of  $D_f$ . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It is also observed that concentration decreases with increase in the values of parameter  $D_f$ .

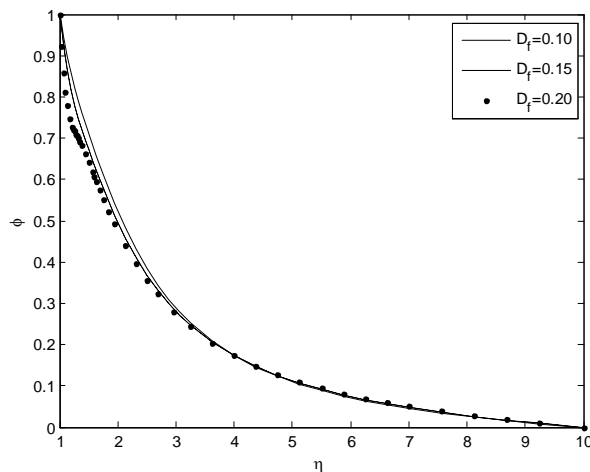


Fig .3: Concentration profile for  $D_f = (0.1, 0.15, 0.2)$  with  $Da = 1.0, Re = 1.0, S_r = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$ .

Case IV:

Fig. 4 exhibit concentration profile for various values of  $S_r$ . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It is also observed that concentration increases with increase in the values of parameter  $S_r$ .

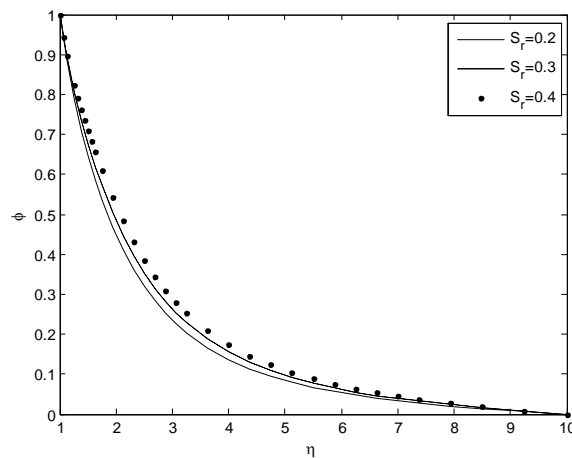


Fig. 4: Concentration profile for  $S_r = (0.2, 0.3, 0.4)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$ .

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Case V:

Fig. 5 exhibit concentration profile for various values of  $\gamma$ . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It is also observed that concentration decreases with increase in the values of parameter  $\gamma$ .

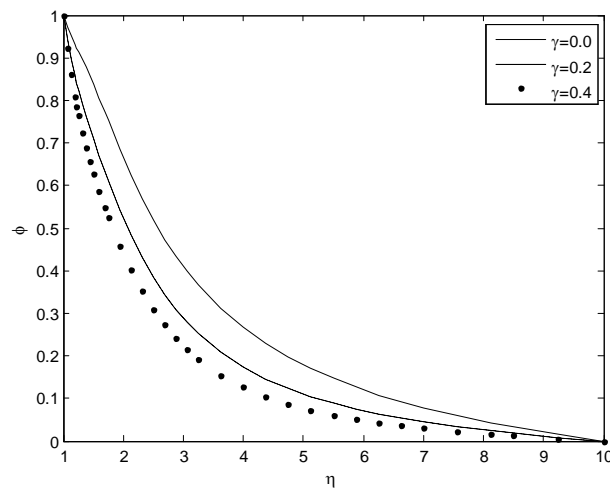


Fig. 5: Concentration profile for  $\gamma = (0.0, 0.2, 0.4)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, Sr = 0.4, Pr = 7.0, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$ .

Case VI:

Fig. 6 exhibit concentration profile for various values of  $Pr$ . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It is also observed that concentration increases with increase in the values of parameter  $Pr$ .

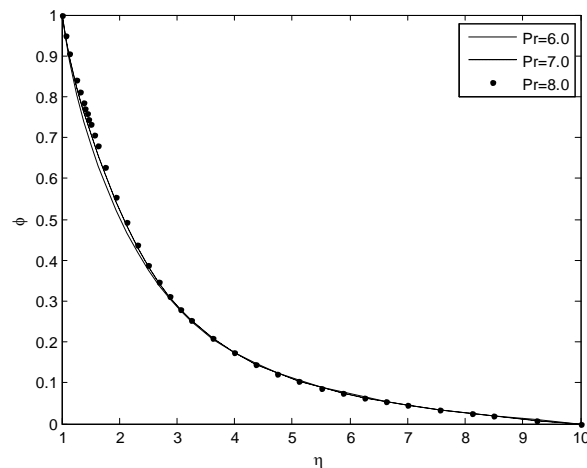


Fig. 6: Concentration profile for  $Pr = (6, 7, 8)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, Sr = 0.4, \gamma = 0.2, Sc = 1.6, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$

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Case VII:

Fig. 7 exhibit concentration profile for various values of  $Sc$  . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It is also observed that concentration decreases with increase in the values of parameter  $Sc$ .

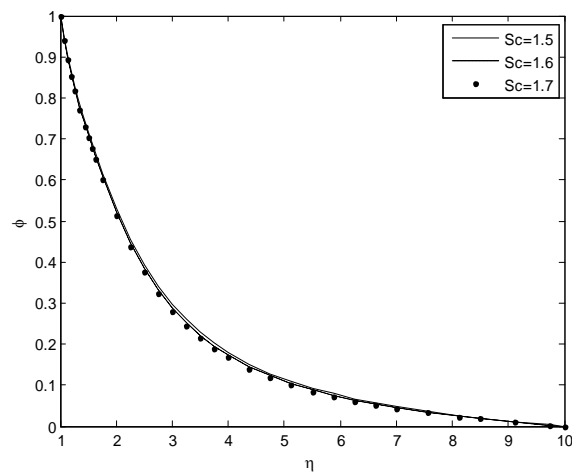


Fig. 7: Concentration profile for  $Sc = (1.5, 1.6, 1.7)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, Sr = 0.4, \gamma = 0.2, Pr = 7.0, F_b = 0.1, \alpha_0 = 0.2, \xi = 0.5$  .

Case VIII:

Fig. 8 exhibit concentration profile for various values of  $F_b$  . It is noticed that concentration decreases exponentially from its maximum value at the surface of the cylinder to its minimum value at the end of the boundary layer. It also observed that concentration decreases very minutely with increase in the values of parameter  $F_b$ .

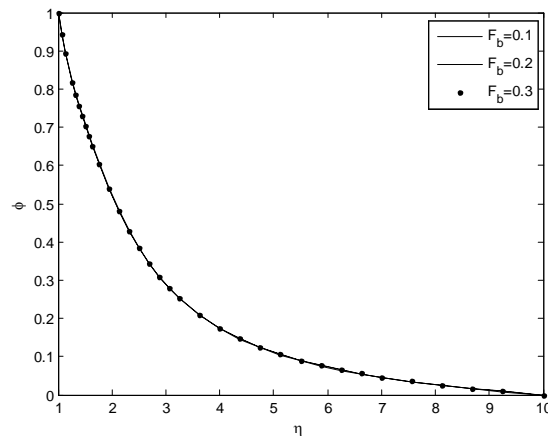


Fig. 8: Concentration profile for  $F_b = (0.1, 0.2, 0.3)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, Sr = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, \alpha_0 = 0.2, \xi = 0.5$  .

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CaseIX:

Fig. 9 exhibit concentration profile for various values of  $\alpha_0$ . The value of the concentration is more near the surface of the cylinder than its value at the end of the boundary layer. It depicts that concentration decreases near the surface of the cylinder with increase in the values of parameter  $\alpha_0$  but at about  $\eta = 4$  onwards, reverse effect is observed.

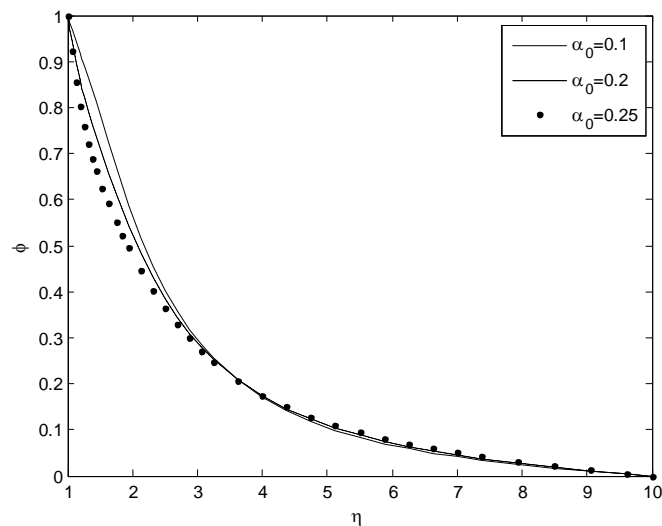


Fig. 9: Concentration profile for  $\alpha_0 = (0.1, 0.2, 0.25)$  with  $Da = 1.0, Re = 1.0, D_f = 0.15, Sr = 0.4, \gamma = 0.2, Pr = 7.0, Sc = 1.6, F_b = 0.1, \xi = 0.5$ .

TABLE 1 : The values of rate of mass transfer in terms of local Sherwood number  $-\phi'(1)$  for selected values of  $Da, Re, D_f, S_r, \gamma, Pr, Sc, F_b$  and  $\alpha_0$  taking  $\xi = 0.5$ .

Da	Re	$D_f$	$S_r$	$\gamma$	Pr	Sc	$F_b$	$\alpha_0$	$-\phi'(1)$
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.3782
2	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.1674
3	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.1054
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.3782
1	2	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.2442
1	3	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.1687
1	1	0.10	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	1.3782



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1	1	0.20	0.4	0.2	7.0	1.6	0.1	0.2	2.7598
1	1	0.15	0.2	0.2	7.0	1.6	0.1	0.2	1.0520
1	1	0.15	0.3	0.2	7.0	1.6	0.1	0.2	1.0233
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.0	7.0	1.6	0.1	0.2	0.4893
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.4	7.0	1.6	0.1	0.2	1.3392
1	1	0.15	0.4	0.2	6.0	1.6	0.1	0.2	1.0505
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.2	8.0	1.6	0.1	0.2	0.9434
1	1	0.15	0.4	0.2	7.0	1.5	0.1	0.2	0.9474
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.2	7.0	1.7	0.1	0.2	1.0466
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.2	7.0	1.6	0.2	0.2	1.0097
1	1	0.15	0.4	0.2	7.0	1.6	0.3	0.2	1.0240
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.1	0.5506
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.2	0.9956
1	1	0.15	0.4	0.2	7.0	1.6	0.1	0.25	1.3762

## IV. CONCLUSION

In this work, chemical reaction, heat source, thermal-diffusion and diffusion-thermo effects on heat and mass transfer due to a stretching cylinder embedded in a Porous medium using the Brinkman-Forchheimer extended Darcy model has been investigated. From this paper as obvious from table 1, we can conclude that the rate of mass transfer decreases in magnitude with increase in  $Da$ ,  $Re$ ,  $S_r$ ,  $Pr$  but increases in magnitude with increase in  $D_f$ ,  $\gamma$ ,  $Sc$ ,  $F_b$  and  $\alpha_0$ .

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