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FINITE ELEMENT ANALYSIS OF MHD MIXED CONVECTIVE HEAT AND MASS TRANSFER STAGNATION-POINT FLOW IN A CIRCULAR ANNULUS IN HIGHLY POROUS MEDIUM WITH RADIATION

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Abstract

We investigate the combined effect of thermal radiation and radiation absorption on free and compelled convection flow through a porous medium in a very co-axial cylindrical duct where the boundaries are maintained at constant temperature and concentration. The Brinkman-Forchhimer extended Darcy equations which takes into consideration the boundary and inertia effects are utilized in the governing linear momentum equations. The effect of density variation is confined to the buoyancy term under Boussinesq approximation. The momentum, energy and diffusion equations are coupled equations. so as to get a stronger insight into this complex problem, we are using Galerkin finite element method with quadratic approximation technique. The behavior of velocity, temperature and concentration is analyzed for various parametric values at different axial positions. The rates of warmth and mass transfer have also been obtained for variations within the governing parameters. The local Nusselt number and native Sherwood number are illustrated to point out interesting features of the result.

Keywords:

Heat & Mass Transfer; Thermal Radiation, Radiation absorption, Porous medium, Circular annulus, Finite element technique .

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1. Introduction

The Convective flow and warmth transfer in porous media has been attracting the eye of enormous number of investigators because of its wide applications in engineering as geophysical thermal and insulation engineering, design of pebble-bed nuclear reactors, fossil fuel drilling, ceramic processing, heat conversion, use of fibrous material within the thermal insulation of buildings, catalytic reactors and compact heat exchangers, heat transfer from storage of agricultural products which generate heat as a results of metabolism, petroleum reservoirs, storage of nuclear wastes, etc. The derivation of the empirical equations which govern the flow and warmth transfer in an exceedingly porous medium has been discussed by Vafai [23], Ingham and Pop [9]discussed Transport Phenomena in Porous Media, Further, thermal radiation heat transfer effects on natural convection flow in porous media are vital within the context of space technology and processes involving high temperatures, and really little is thought about the consequences of radiation on the physical phenomenon flow of radiating fluid past a body. Recent Chemical and Process Engineering Research developments in hypersonic flight, missile reentry, rocket combustion chambers, power plants for interplanetary flight, and gas cooled nuclear reactors have focused attention on thermal radiation as a mode of energy transfer and have emphasized the necessity for an improved understanding of radiative transfer in these processes. Abdus Sattar and Hamid [1] studied unsteady Free-Convection Interaction with Thermal Radiation during a physical phenomenon Flow Past a Vertical Porous Plate. Yih[24] studied the effect of radiation on the warmth transfer characteristics in natural convection over an isothermal vertical cylinder embedded in porous medium. specifically, design engineers require relationships between heat transfer, geometry and boundary conditions which might be utilized in analysis to work out the number of insulation which will yield the most investment. aside from this, the study of flow and warmth transfer within the annular region between the concentric cylinders has applications in nuclear waste disposal research. it's known that canisters crammed with radioactive rays be buried in earth so on isolate them from human population and is of interest to see the surface temperature of those canisters. This surface temperature strongly depends on the buoyancy driven flows sustained by the heated surface and also the possible moment of groundwater past it. This phenomenon is good to the study of convection flow in an exceedingly porous medium contained in an exceedingly cylindrical annulus [22, 21, 20]. Free convection in a very vertical porous annulus has been extensively studied by Prasad [21], Prasad et al [20] both theoretically and experimentally. Dulal pal [18] studied heat and mass transfer in stagnation-point flow towards a stretching surface within the presence of buoyancy force and thermal radiation. Chamkha et al. [5] studied the effect of radiation on combined heat and mass transfer by non-Darcy natural convection about an impermeable horizontal cylinder embedded in porous medium. Sarkar et al [25] studied Magnetohydrodynamic Peristaltic Flow of Nanofluids during a Convectively Heated Vertical Asymmetric Channel in Presence of Thermal Radiation. Natural convection heat transfer within an annulus has been a theme of interest for several decades. Natural convection in an exceedingly finite space is very important for several applications, including the planning of equipment cooling systems, reactor waste transport and storage, solar collectors and thermal storage systems, and thermal management of aviation. Laminar convection in both horizontal and vertical concentric annuli has gained much importance due to its wide spread applications, like in heat exchangers, cooling systems in electrical devices, solar collectors, the cooling of turbine rotors and high speed gas bearings. Heat transfer in porous medium thermal insulation with in vertical cylindrical annuli provide us insight into the mechanism of energy transport and enable engineers to use insulation more efficiently Sudheer Kumar et al [26] have studied the effect of radiation on natural convection over a vertical cylinder in an exceedingly porous media. Padmavathi [17] has analysed the convective heat transfer in a very cylindrical annulus by using finite element method. Recently Mahesha Narayana et al [13] have discussed viscous dissipation and thermal radiation effects on mixed convection from a vertical plate in a very non-darcy porous medium. Yilbas [2001] analyzed entropy generation in cylindrical annuli thanks to conduction and viscous dissipation. Chen and Zhang [6] simulated nonlinear thermal convection in an exceedingly fluid-filled gap between two corotating and concentric cylindrical annuli. Categorization of the flow regimes, in line with the amount of eddies, are established on the Ra–Re plane for various numbers presented by Khanafer and Chamkha [9]. The primary and second law (of thermodynamics) characteristics of fluid flow and warmth transfer inside a cylindrical annulus are investigated analytically. The study of flux effects on an electrically conducting fluid has also been presented Kurt et al. 11] The effect of viscous dissipation in an exceedingly porous medium in vertical annulus was investigated by Badruddin et al. [3] Barletta and Magyari [4] studied buoyant flow with viscous heating in a very vertical circular duct stuffed with a porous medium. Zanchini [25] conducted an analytical study of laminar mixed convection with a temperature-dependent viscosity in an exceedingly vertical annular duct with uniform wall temperatures. Salman et al. [24] studied Study of mixed convection in an annular vertical cylinder full of saturated porous medium, using thermal non-equilibrium model. Morocco et al. [10] conducted Experimental investigation of the turbulent heavy liquid metal heat transfer within the thermal entry region of a vertical annulus with constant heat flux on the inner surface. Malik et al. [14] extended the experimental study of conjugate heat transfer within a bottom heated vertical concentric cylindrical enclosure. Recently, Forooghi et al. [8] studied Buoyancy induced heat transfer deterioration in vertical concentric and eccentric annuli. The warmth and mass transfer simultaneously affect one another that make cross-diffusion.

The heat transfer caused by concentration gradient is named the diffusion-thermo or Dufour effect. On the opposite hand, mass transfer caused by temperature gradients is named Soret or thermal diffusion effect. Thus Soret effect is mentioned species differentiation developing in an initial homogeneous mixture submitted to a thermal gradient and therefore the Dufour effect observed the warmth flux produced by a level gradient. Chamkha et al. [5] studied unsteady double-diffusive natural convective MHD flow along a vertical cylinder within the presence of chemical change, thermal radiation and Soret and Dufour effects. Mallikarjuna et al. [15] studied Soret and Dufour effects on double Diffusive convective flow through a Non-Darcy porous medium in an exceedingly cylindrical annular region within the presence of warmth sources. Motivated by the above-mentioned researchers, the target of this paper is to review the combined effect of thermal radiation and radiation absorption on mixed convection flow with Soret and Dufour effects through a porous medium in a very circular duct where the outer cylinder is maintained at constant heat flux and also the inner cylinder is at a relentless temperature. The concentration on the cylinders is taken to be uniform. The Brinkman-Forchhimer extended Darcy equations which takes under consideration the boundary and inertia effects are utilized in the governing linear momentum equations. The effect of density variation is confined to the buoyancy term under Boussinesq approximation. The momentum, energy and diffusion equations are coupled equations. so as to get a stronger insight into this complex problem, we make use of Galerkin finite element analysis with quadratic approximations. The Galerkin finite element analysis has two important features. Firstly, the approximation solution is written directly as a linear combination of approximation functions with unknown nodal values as coefficients. Secondly, the approximation polynomials are chosen exclusively from the lower order piecewise polynomials restricted to contiguous elements. The behavior of velocity, temperature and concentration is analyzed at different axial positions. The speed of warmth and mass transfer has been obtained for variations within the governing parameters.

2. FORMULATION OF THE PROBLEM

We consider the free and compelled convection flow during a vertical circular annulus through a porous medium whose walls are maintained at a continuing temperature and concentration. The flow, temperature and concentration within the fluid are assumed to be fully developed. Both the fluid and porous region have constant physical properties and therefore the flow may be a mixed convection flow going down under thermal and molecular buoyancies and uniform axial pressure gradient.

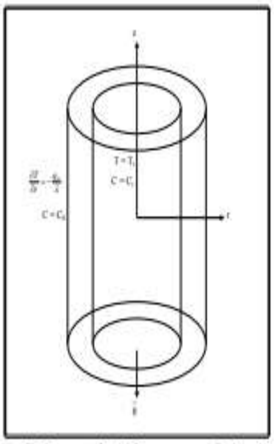


Figure 1. Schematic Diagram of the Problem

The Boussinesq approximation is invoked so the density variation is confined to the thermal and molecular buoyancy forces. The Brinkman-Forchhimer-Extended Darcy model which accounts for the inertia and boundary effects has been used for the momentum equation within the porous region. The momentum, energy and diffusion equations are coupled and non-linear. Also the flow is unidirectional along the axial direction of the cylindrical annulus. Making use of the above assumptions the governing equations are

$$\rho c_p w\frac{\partial T}{\partial z}=\lambda\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)+Q(T_o-T)+k_{12}\left(\frac{\partial^2 C}{\partial r^2}+\frac{1}{r}\frac{\partial C}{\partial r}\right)+Q_1'(C-C_o)-\frac{\partial}{\partial r}\left(\frac{1}{r}q_R\right)$$

where w is that the axial velocity within the porous region, T, C are the temperature and concentration of the fluid,k is that the permeability of porous medium, F could be a function that depends on Reynolds number, the microstructure of the porous medium, D1 is that the molecular diffusivity, β0andβ1 are the coefficient of the thermal expansion, • β is that the coefficient of volume expansion, Cp is that the heat, ρ is density, g is gravity and kc is chemical change parameter. The relevant boundary conditions are

w= 0 , T = Ti , C = Ci , at r = a, w= 0 , λ qw r T −= ∂ ∂ , C = C0 , at r = a+s. (2.4) Invoking Rosseland approximation Raptis and Perdikis[1999] and using Taylors expansion we find that

$$z^*=\frac{z}{a},r^*=\frac{r}{a},w^*=\frac{a}{\gamma}w,p^*=\frac{pa\delta}{\rho\gamma^2},\theta^*=\frac{\lambda(T-T_0)}{aq_w},s^*=\frac{s}{a},C^*=\frac{C-C_i}{C_0-C_i},A=\frac{\partial T}{\partial z},B=\frac{\partial C}{\partial z},$$

Introducing these non-dimensional variables, the governing equations in the non-dimensional form are (on removing the stars)

With w $= 0.\theta = 0; C = 0, atr = 1,$

$$w = 0, \frac{d\theta}{t} = -1; C = 1, atr = 1 + s,$$

$\Lambda = FD^{-1}$ (Inertia parameter or Forchheimer number), $G = \frac{g\beta\, q_w a^4}{v^2\lambda}$ (Grashof number), $P_r = \frac{\rho v C_p}{\lambda}$(Prandtl number)

Sc=V/D_1 (Schmidt number), S_o=(k_11 ΔC)/vΔT (Soret parameter)

$N_1 = \frac{4\sigma^* T_e^3}{\beta_R k_f}$ (Radiation parameter),$\pi = \frac{\partial P}{\partial Z}$(Pressure gradient parameter). Other important parameters of interest in this present study are the local skin friction C_f), local Nusselt number Nu and the local Sherwood number Sh defined by

3. Numerical procedure The Finite Element Method (FEM) is numerical and computer-based technique of solving a range of practical engineering problems that arise in several fields. it's been applied to variety of physical problems, where the governing differential equations are available. the tactic essentially consists of assuming the piecewise continuous function for the answer and obtaining the parameters of the functions in a very manner that reduces the error within the solution. The steps involved within the finite element analysis are as follows: • Discretization of the domain into set of finite elements. • Weighted integral formulation of the equation. • Defining an approximate solution over the element. • Substitution of the approximate solution and therefore the generation of the element equations. • Asslembly of the Stiffness matrices for every element. • Imposition of the boundary conditions. • Solution of assembled equations. the complete flow domain is split into 10000 quadratic elements of equal size. Each element is threenoded and so the entire domain contain 20001 nodes.A system of equations has been obtained which is solved by the Gausse limination method.The code of the algorithm has been executed in MATLAB running on a PC. Excellent convergence was achieved for all results.

4. Results and Discussion In this analysis, we discuss the combined influence of non-linear density relation and thermal radiation effects on convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium confined in an annular region between the cylinder r = a and r = b within the presence of warmth generating sources. The governing equations of flow, heat and mass transfer are solved by employing Galerkin finite element analysis. Also we consider the chemical action effect on flow phenomenon. It should be mentioned that the results obtained herein are compared with the results of the thermal radiation N1=0 the results obtained herein are compared with Mathew [2009] as shown in Table 1. within the comparison, the results are found to be in good agreement. Table 1. Comparison of Nu and Sh at r=1 and r=2 with Mathew [2009] with thermal radiation N1= 0

	Mathew [2009]			Present results		
	Nu	Sh				
	r=1	r=1	r=2	r=1	r=1	r=2
2	2 -	2.8935	-	-4.7987	2.893	-0.51768

	4.796		0.51765		8	
4	-8.8858	4.17348	-1.40724	-8.8860	4.17350	-1.40723
6	-12.9413	5.437	-2.2884	-12.9415	5.4372	-2.2885

5.1 Velocity profiles The axial velocity (w) is shown in figures 2-8 for various values of ʌ, Q1, S0, Du, Kc. the particular axial velocity w is in vertically upward direction and hence w<0 represents a reversal flow.

Fig.2 represents the variation of axial velocity w with ʌ. it's found that lesser the Forchheimer number, axial velocity decreases within the flow region. Fig. 3 depicts the axial velocity w with radiation absorption parameter Q1. it's found that the axial velocity reduces with increase in Q1≤1.5 and enhances with higher values of Q1≥2.5. From Fig. 4, we observed the variation of axial velocity w with Soret parameter S0and Dufour parameter Du. it's found that the axial velocity w depreciates with increase in S0 (or decrease inDu). Fig. 5 is exhibits the variation of axial velocity w with chemical change parameter Kc . it's noticed that the axial velocity w enhances within the degenerating chemical change case and depreciates within the generating reaction case.

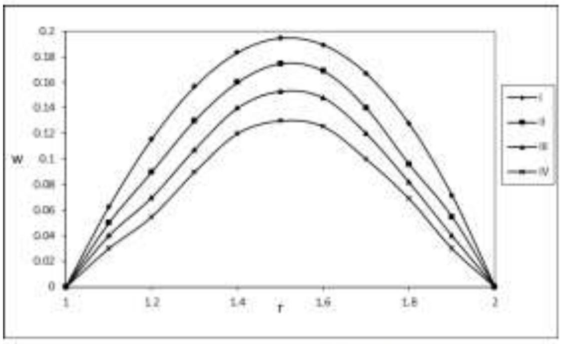


Figure 2. Effect of Forchheimer Number ʌon axial velocity profile w; $G=10^3$, M=2, Sc=1.3, N=1, K_c=0.5, γ=0.01, So=2, Du=0.03, Q_1=0.5, N_1=0.5, α=2; for different values of ʌ (0.5, 1, 1.5, 2)

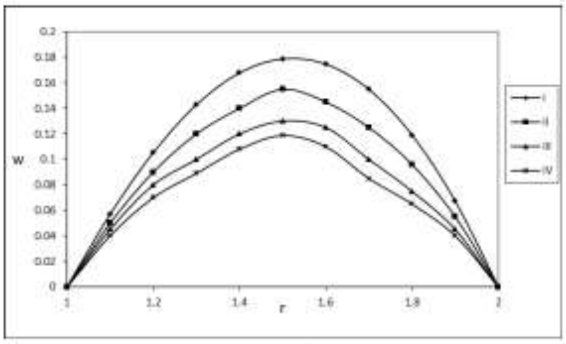
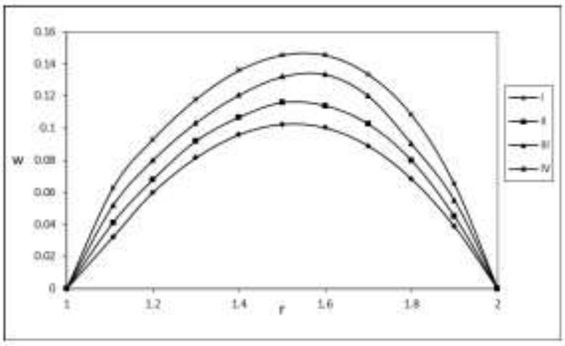
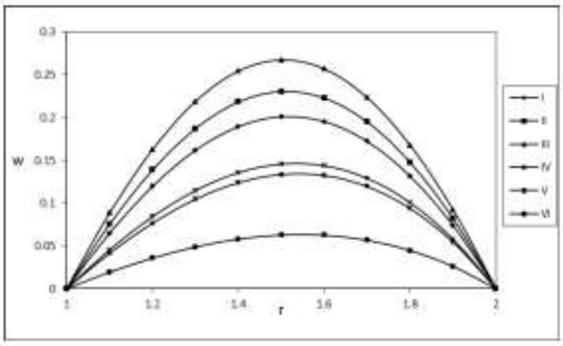


Figure 3. Effect of Radiation Absorption Parameter Q_1 on axial veloci profile w; $G=10^3$, M=2, Sc=1.3, N=1,K_c=0.5,γ=0.01,So=2,Du=0.0 N_1=0.5, D^{-1}=0.5,α=2; for different values of Q_1 (0.5, 1, 1.5, 2)





5.2 Temperature Profiles The non-dimensional temperature (θ) is shown in Figs. 6-9 for various parametric values of ʌ, Q1, So, Du, kc . We follow the convention that the non-dimensional temperature is positive or negative according because the actual temperature (T) is greater/lesser than the ambient temperature. The variation of temperature θ with Forchheimer number ʌ is exhibited in Fig. 6. it's observed from the Figure that lesser the Forchheimer number larger the particular temperature. Higher the radiation heat flux larger the temperature within the flow region. Fig.7 shows the variation of temperature profile θ with radiation absorption parameter Q1. it's observed from the Figure that higher the radiation absorption larger the particular temperature within the flow region. this is often because of the actual fact that the thermal physical phenomenon thickness increases with radiation absorption parameter Q1. The variation θ with Soret parameter S0 (or decrease in Dufour parameter Du) is shown in Fig. 8. We observed form the graphical notation that increase within the Soret parameter (or decrease within the Dufour parameter Du) results an enhancement within the actual temperature within the flow region. The variation temperature profile θ with reaction parameter kc is shown in Fig. 9. it's found that the particular temperature reduces with enhances with generating chemical process parameter kc>0, while it reduces within the generating reaction case. it's because of the actual fact that the thermal physical phenomenon thickness decreases with increase of chemical change parameter and enhances with decrease in chemical process parameter.

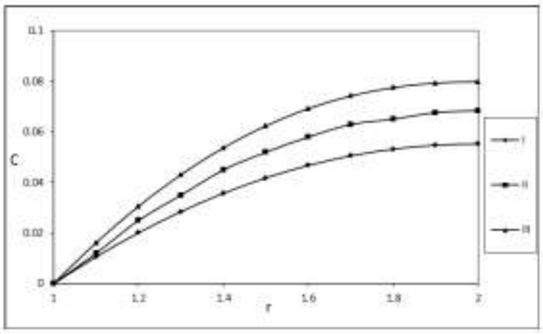


Figure 6. Effect of Inertia Parameter ʌ on Temperature profile θ; $G=10^3$, M=2,Sc=1.3, N=1, $K_c=0.5$,γ=0.01, So=2, Du=0.03, $Q_1=0.5$, $N_1=0.5$, α=2; for different values of ʌ (0.5, 1, 1.5, 2)

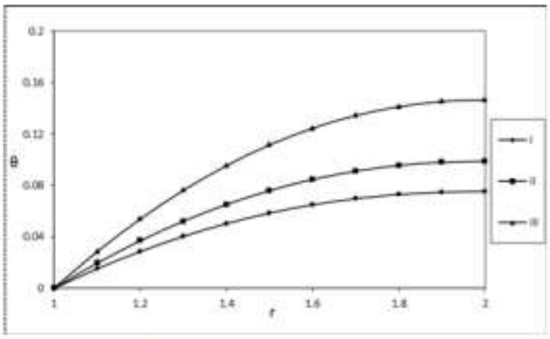
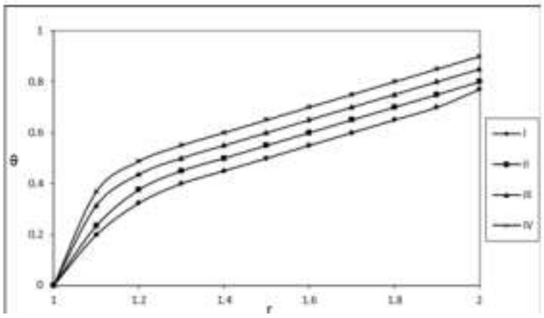
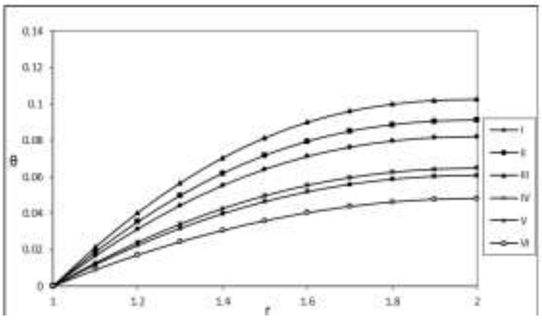


Figure 7. Effect of Radiation Absorption Parameter Q_1 on Temperature profile θ; $G=10^3$, M=2,Sc=1.3, N=1, $K_c=0.5$, γ=0.01, So=2, Du=0.03, $N_1=0.5$, $D^{-1}=0.5$,α=2; for different values of Q_1 (0.5, 1, 1.5, 2)





5.3 Concentration Profiles The non-dimensional concentration profile C is shown in Figs. 10-13 for various parametric values of ʌ, Q1, So, Du, kc . We follow the convention that the non-dimensional concentration positive / negative according as actual concentration is greater/lesser than the non-dimensional concentration. The variation of concentration profile C with Forchheimer number ʌ is shown in Fig. 10. From the figure we identified that smaller the Forchheimer number, the temperature within the flow region is reduces. The variation of the concentration profile C with radiation absorption parameter Q1 is exhibited in Fig. 11. it's found from the graphical notation that the particular concentration enhances with increase in radiation absorption parameter Q1. Fig.12 represents the variation of concentration profiles C with Soret parameter So (or decrease in Dufour parameter Du). it's observed from the figure that the particular concentration reduces with increase in So (or decrease in Dufour parameter Du) within the entire flow region. It will be seen from the profiles that the rise within the Soret parameter So (or decrease in Dufour parameter Du) ends up in a depreciation within the concentration within the flow region. The effect of reaction parameter kc with concentration profiles C is represented in Fig. 13. From the figure we identified that the particular concentration increases with increase within the degenerating chemical change case and therefore the concentration reduces within the generating chemical action case within the entire flow region.

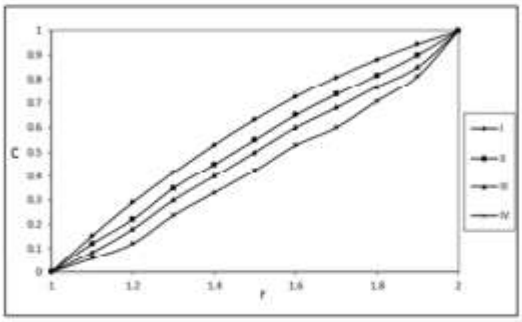


Figure 10. Effect of Forchheimer Number on Concentration profile C; $G=10^3$, $M=2$, $Sc=1.3$, $N=1$, $K_c=0.5$, $\gamma=0.01$, $So=2$, $Du=0.03$, $Q_1=0.5$, $N_1=0.5$, $\alpha=2$; for different values of Λ (0.5, 1, 1.5, 2)

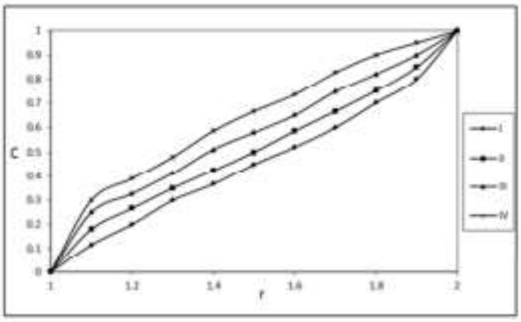
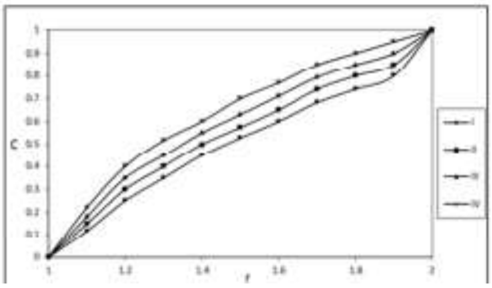
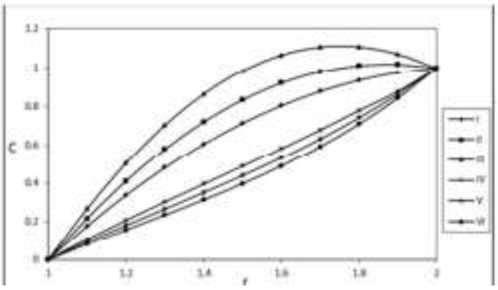


Figure 11. Effect of Radiation Absorption Parameter Q_1 on Concentration profile C; $G=10^3$, $M=2$, $Sc=1.3$, $N=1$, $K_c=0.5$, $\gamma=0.01$, $So=2$, $Du=0.03$, $N_1=0.5$, $D^{-1}=0.5$, $\alpha=2$; for different values of Q_1 (0.5, 1, 1.5, 2)





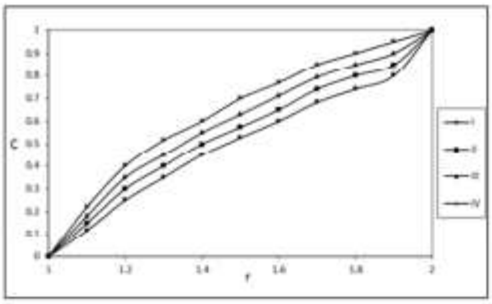


Figure 12. Effect of Soret So, Dufour Du Parameters on Concentration profile C; $G=10^3$, $M=2$, $Q_1=0.5$, $Sc=1.3$, $K_c=0.5$, $\gamma=0.01$, $N=1$, $N_1=0.5$, $D^{-1}=0.5$, $\alpha=2$; for different values of So (0.6, 1, 1.5, 2), Du (1, 0.6, 0.4, 0.3)

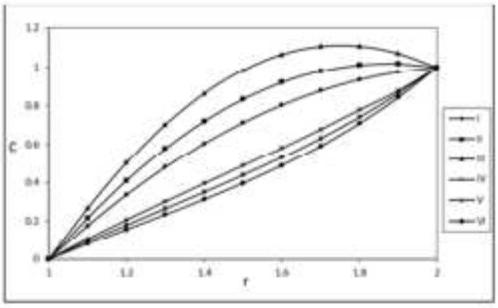
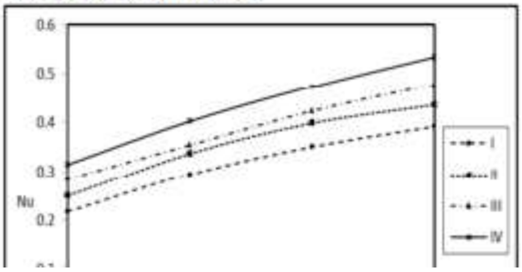
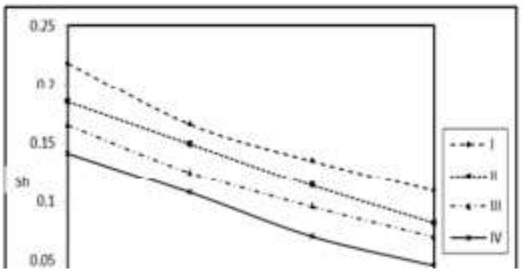


Figure 13. Effect of Chemical Reaction Parameter K_c on Concentration profile C; $G=10^3$, $M=2$, $Q_1=0.5$, $Sc=1.3$, $So=2$, $Du=0.03$, $\gamma=0.01$, $N=1$, $N_1=0.5$, $D^{-1}=0.5$, $\alpha=2$; for different values of K_c (0.5, 1.5, 2.5, -0.5, -1.5, -2.5)

The skin friction, the rate of heat and mass transfer are exhibited in Figures (14-17) for different variations of Q_1. The rate of heat transfer enhances on r=1 and r=2 with increase in Hartmann number M. The rate of mass transfer decreases on r=1 and r=2 with increase in Hartmann number in the case of radiation absorption parameter Q_1.





The rate of warmth transfer (Nusselt number) at the inner cylinder r = 1 is shown in Table 3 for various parametric values of N1, So & Du, Kcand ʌ. it's observed form the Table that the skin friction (τ) enhances with increase in M or N1. The magnitude of τ enhances on r=1 and r=2 in both the degenerating and generating chemical change cases. Increasing Soret parameter So (or decreasing Dufour parameter Du) results in a depreciation in |τ| on r=1 and r=2. the speed of warmth transfer enhances on r=1 and reduces r=2 with increase in Hartmann number (M). the speed of warmth transfer reduces on r=1 and r=2 within the degenerating chemical change case, while in generating chemical action case |Nu| enhances at r=1 and reduces at r=2. Higher the radiative heat flux, larger |Nu| on r=1 and smaller on r=2. Increasing Soret parameter So (or decreasing Dufour parameter Du) results in a rise in |Nu|on r=1 and r=2. a rise within the Forchheimer (ʌ) enhances |Nu| on both the cylinders. the speed of mass transfer (Sherwood number Sh) enhances with increase in M on r=1 and r=2. the speed of mass transfer increases in both degenerating and generating chemical change case on r=1 and r=2. Higher the radiative heat flux larger the speed of mass transfer. Increasing Soret parameter So (or decrease in Dufour parameter Du) leads to a depreciation in |Sh| on both the cylinders. a rise in Forchheimer (ʌ) reduces the speed of mass transfer on both the cylinders. the speed of warmth transfer enhances on r=1 and r=2 with increase in Hartmann number. Table 3. Variation of Nusselt number and Sherwood number on different parametric values.

Parameter	Parameter Values	Nu1	Nu2	Sh1	Sh2

6. Conclusions The problem referring to the combined effect of thermal radiation, radiation absorption on mixed convective flow and warmth and mass transfer in an exceedingly circular annulus within the presence of warmth generation/absorption has been analyzed. The numerical results were obtained and compared with previously reported cases available within the literature and that they were found to be in good agreement. Graphical results for various parametric conditions were presented and discussed for various values. the most findings are summarized below Smaller the Forchheimer number ʌ larger the axial velocity, temperature, concentration and also the rate of warmth and mass transfers.

The enhancement of radiation absorption parameter Q1, axial velocity reduces for a few region and enhances in remaining flow region. For larger the radiation absorption parameter Q1, the particular temperature and concentration enhances within the fluid region. the speed of warmth transfer enhances with increase in radiation absorption parameter. Whereas the reversal effect observed within the rate of mass transfer. Increasing of Soret parameter S0 (decrease within the Dufour parameter Du), the axial velocity and concentration depreciates and an enhancement occurs within the actual temperature. the speed of warmth and mass transfer enhances when an enhancement within the Soret parameter So (depreciation within the Dufour parameter Du). Increase in degenerating chemical action parameter kc>0, the axial velocity and concentration enhances whereas temperature reduces. within the case of increase in generating chemical action parameter Kc.

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