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Dear Sir/Madam,

RE: INVITATION TO AN INTERNATIONAL CONFERENCE ON SCIENCE, TECHNOLOGY AND INNOVATION FOR SUSTAINABLE DEVELOPMENT IN DRYLAND ENVIRONMENTS

Umma University in Kajiado County, South Eastern Kenya University (SEKU) in Kitui County, Lukenya University in Makueni County and Machakos University in Machakos County, together with other partners,are jointly organizing an international Conference entitled *"Science, Technology and Innovation for Sustainable Development in Dryland Environments"* to be held on 19th-23rd November 2018. The theme of the conference is *"Harnessing Dryland Natural Resources for Sustainable Livelihoods in the Era of Climate Change*". The conference will be two-phased with a two day pre-conference training workshop on 19th-20th November 2018 at SEKU and the main conference on 21st-23rd November 2018 at Umma University. The conference will provide an excellent platform for the academia from around the world to engage with the industry, innovators, policy makers, value chain developers, farmers, and service providers among others so that higher education in Africa contributes to solving the problems of natural resources governance in the era of climate change.

We are therefore pleased to invite you to attend the pre-conference training workshop at SEKU Main Campus in Kitui on 19th-20th November 2018 and the Main conference at Umma University on 21st to 23rd November 2018. Please note that you will be responsible for your travel and accommodation arrangements and conference registration fee.

Yours Sincerely,

DR. ALI ADAN ALI
FOR THE: VICE-CHANCELLOR

Cross-diffusion effects on magneto hydrodynamics fluid flow through a vertical Annulus

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Abstract: The cross-diffusion effects on magneto hydrodynamic mixed convective fluid flow through an annulus filled with a fluid-saturated porous medium. Vertical fluid flow configurations and coordinate system was investigated and the governing equations for momentum, heat and mass transfer transformed into a system of coupled ordinary differential equations in the non-dimensional form using suitable dimensionless variables. The accuracy, validity and convergence of the solutions obtained using this method were tested by comparing the calculated results with those in the published literature, and results obtained using other numerical methods.
The effects of various physical parameters on the fluid properties and heat and mass transfer characteristics on the velocity, temperature and concentration fields are discussed with the help of graphs.
The study sought to (i) investigate cross-diffusion effects on momentum, heat and mass transport through vertical annulus in a non-Darcy porous medium saturated with porous non-Newtonian electrically conducting fluid in presence of constant heat source and transverse magnetic field effects, (ii) Study cross-diffusion effects on exponentially stretching vertical annulus in porous medium and (iii) apply finite difference technique to solve the highly nonlinear and coupled governing equations. We further sought to show that this method is accurate, efficient and robust by comparing it with established methods in the literature. We showed that Cross-diffusion has a significant effect on heat and mass-transfer processes and cannot be neglected.

Keywords: Cross-diffusion, magneto hydrodynamics, temperature and concentration profiles

NOMENCLATURE

Roman Symbols

C	Dimensionless Concentration
C_p	Specific heat at constant pressure
C_s	Concentration susceptibility
Δr	Space marching step, m
Δt	Time marching step, s
D_m	Mass diffusivity
g	Acceleration due to gravity
h	Convective heat transfer coefficient
k_1	Coefficient of thermal conductivity
p	Pressure of the fluid.
P_r	Prandtl number
q	Velocity vector of the fluid, ms^{-1}
r	Radius of the Cylinder
S	Dimensionless suction velocity
S_c	Schmidt number
T	Temperature, K
U	Uniform velocity

Greek Symbols

K	Thermal diffusivity
β	Thermal coefficient, K^{-1}
β'	concentration coefficient, K^{-1}
σ	Fluid electrically conductivity, $\Omega^{-1}m^{-1}$
τ	Turbulence time scale, s
θ	Dimensionless Temperature
ρ	Fluid Density, kgm^{-3}
μ	The coefficient of viscosity, $kgm^{-1}s^{-1}$
ϕ	Viscous dissipation function, s^{-2}

Introduction

Magneto hydrodynamics is the multi-disciplinary study of the flow of electrically conducting fluids in electromagnetic fields. The fundamental concept behind MHD is that magnetic fields can induce currents in a moving conductive fluid, which in turn creates forces on the fluid and also changes the magnetic field itself.

Therefore, in this section, contributions of earlier researchers in the flow field of Natural and mixed convective Heat and Mass transfer is discussed. A comprehensive survey of relevant papers may be found in the recent monograph by Nield and Bejan (2006). Most of the studies included there refer to bodies of relatively simple geometry such as flat plates, cylinders, and spheres. It gives a clear description of the work already done in this field and brings out the knowledge gap existing and where the geometry under consideration fits. Free and MHD mixed convective Heat and Mass transfer and their limitations/consequences are discussed. Chen and Yuh (1979) presented the heat and mass transfer characteristics of natural convection flow along a vertical cylinder under the combined buoyancy effects of thermal and species diffusion. The analysis is restricted to processes in which the diffusion-thermo and thermo-diffusion effects as well as the inter-facial velocities from species diffusion are negligible. Recently, Chitti, D.B. *et al.* (2010) has analyzed the combined effect of Soret effect and constant heat sources on hydro magnetic natural convective heat and mass flow through a porous medium in a porous cylindrical annulus. The study did not provide the physical interpretation of MHD mixed convective heat and mass flow. Finally, Balasubrahmanyam, *et al.* (2011) has studied the problem of Soret effect on mixed convective heat and mass transfer through a porous medium in a cylindrical annulus under a radial magnetic field in the presence of a constant heat source/sink. Likewise the study did not take care of cross-diffusion effect. Therefore in this research we investigate the problem of the combined influence of cross-diffusion effect and constant heat source using the finite difference method expressions taking the Magnetic field into account.

Formulation of the problem

Consider a mixed convective unsteady, laminar electrically conducting and fully developed viscous fluid flow through a porous medium in a vertical co-axial porous annulus as shown in the Figure 1.

We choose the cylindrical polar coordinates system $o(r,z)$ such that the flow direction is parallel to the vertical $z-$axis. The walls of the annulus are chosen relative to the origin of the axes such that the pipes are on the planes $r=a$ and $r=a+s$ these pipes are taken to be electrically non-conducting.

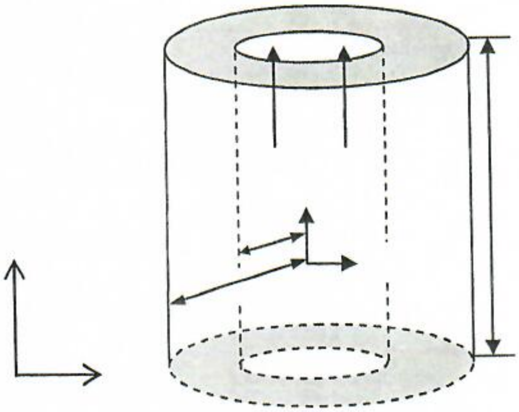

Figure 1: Schematic representation of solution domain for vertical annulus

The fluid flows in the positive z direction with velocity u. Since the flow is fully developed,

$$\frac{\partial u}{\partial r}=0 \tag{1}$$

Considering a uniform suction at the top with velocity u_o and on integrating equation (1) reduces to

$$u=u_o \tag{2}$$

The study considers a fluid flow moving at slow velocity such that the buoyancy force resulting from temperature and concentration differences in the flow field are comparable with the inertia and viscous forces. According to the Boussinesq approximation, the density of the mixture is related to the temperature and solute concentration through the following linear relation of state:

$$\rho(T,C)=\rho_o\left[1-\beta(T-T_o)-\beta'(C-C_o)\right]$$

Where β and β' are respectively the coefficients for thermal and concentration expansions.

Using the Boussinesq approximation the thermodynamic state of a fluid depends on the pressure, temperature and concentration. And considering small density variations at constant pressure then

$$\rho \cong \rho_\infty + \left(\frac{\partial \rho}{\partial T'}\right)_p (T'_o - T'_i) + \left(\frac{\partial \rho}{\partial C'}\right)_p (C'_o - C'_i) \tag{3}$$

T'_i and C'_i are the reference temperature and concentration respectively. Given that

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T'}\right)_p \text{ and } \beta'' = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial C'}\right)_p \tag{4}$$

Equation (3) reduces to

$$\rho_\infty - \rho = \rho\beta (T'_o - T'_i) + \rho\beta' (C'_o - C'_i) \tag{5}$$

To determine the pressure gradient term the momentum equation is evaluated at the edge of the boundary layer where $\rho \to \rho_\infty$. A pressure gradient will exist in z' direction due to change in elevation and we have the pressure gradient[1] due to fluid density ρ_∞ given as

$$\frac{dp}{dz'} = -\rho_\infty g \tag{6}$$

The body force term in the momentum conservation equation along the z' direction that is $-\nabla p - \rho g$ gives

$$-\frac{dp}{dz'} - \rho g \tag{7}$$

Substituting equations (4) in equation (3) and using equation (2) we have

$$-\rho g - \frac{dp}{dz'} = -\rho g + \rho_\infty g = \rho g\left[\beta (T'_o - T'_i) + \beta' (C'_o - C'_i)\right] \tag{8}$$

The linear momentum equation takes the dimensional form

$$\rho\left(\frac{\partial v'}{\partial t'} + u_o \frac{\partial v'}{\partial r'}\right) = \mu\left(\frac{\partial^2 v'}{\partial r'^2} + \frac{1}{r'}\frac{\partial v'}{\partial r'}\right) - \frac{\mu}{k} v' + \rho g\left[\beta (T'_o - T'_i) + (C'_o - C'_i)\right] \tag{9}$$

The prime superscript has been used to represent the dimensional quantities. By taking into account the effect of viscous dissipation and constant heat source, the energy equation and the concentration conservation equation respectively takes the form

$$\rho C_p\left(\frac{\partial T'}{\partial t'} + u'_o \frac{\partial T'}{\partial r'}\right) = k\left(\frac{\partial^2 T'}{\partial r'^2} + \frac{1}{r'}\frac{\partial T'}{\partial r'}\right) + \mu\left(\frac{\partial u'}{\partial r'}\right)^2 + \frac{D_m k_t}{C_s}\left(\frac{\partial^2 C'}{\partial r'^2} + \frac{1}{r'}\frac{\partial C'}{\partial r'}\right) + \frac{Q}{r'} \tag{10}$$

and

$$\frac{\partial C'}{\partial t'} + u'_o \frac{\partial C'}{\partial r'} = D\left(\frac{\partial^2 C'}{\partial r'^2} + \frac{1}{r'}\frac{\partial C'}{\partial r'}\right) + \frac{D_m k_t}{C_s C_p}\left(\frac{\partial^2 T'}{\partial r'^2} + \frac{1}{r'}\frac{\partial T'}{\partial r'}\right) \tag{11}$$

Using the scaling variables and the non-dimensional parameters quoted above to non-dimensionalize the equations governing the fluid flow under consideration. The relevant corresponding boundary conditions in non-dimensional form are

$$\left.\begin{matrix} u = 0, \theta = 0, C = 1 \\ u = 0, \theta = 1, C = 1 \end{matrix}\right\} \text{ at } \begin{cases} r = 1 \\ r = 1 + s \end{cases} \tag{12}$$

we have momentum profile as

$$\frac{\partial v}{\partial t} + S\frac{\partial v}{\partial r} = \frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} - \left(D^{-1} + \frac{M^2}{r^2}\right)v + G_r\theta + G_m C \tag{13}$$

Energy profile

$$\frac{\partial \theta}{\partial t} + S\frac{\partial \theta}{\partial r} = \frac{1}{p_r}\left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\frac{\partial \theta}{\partial r}\right) + E_c\left(\frac{\partial u}{\partial r}\right)^2 + D_u\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r}\right) + \frac{\alpha}{r} \tag{14}$$

And concentration profile as

$$\frac{\partial C}{\partial t} + S\frac{\partial C}{\partial r} = \frac{1}{S_c}\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r}\right) + S_r\left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\frac{\partial \theta}{\partial r}\right) \tag{15}$$

Equations (13), (14) and (15) respectively give the final set of conservation of momentum, energy and concentration equations in non-dimensional form for vertical annulus with heat source parameter and in presence of Magnetic strength parameter.

Methodology

We seek a solution of the system of equations (13), (14) and (15) together with the non-dimensional form of initial and boundary conditions (12). The system of equations is nonlinear and we apply the numerical approximation method of finite differences. We use the forward differences as approximations to the derivatives. The finite difference form of the initial conditions and the boundary conditions (12) is given below

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[1] This is the force which results when there is difference in pressure across a surface.

$$\left.\begin{aligned} u(1,0) &= u(2,0) = 0 \\ \theta(1,0) &= \theta(2,0) = 0 \\ C(1,0) &= C(2,0) = 0 \end{aligned}\right\} \text{ at } j = 0 \qquad (16)$$

and

$$\left.\begin{aligned} u(1,j) &= 0 \\ u(2,j) &= 0 \\ \theta(2,j) &= 0 \\ \theta(2,j) &= 1 \\ C(2,j) &= 0 \\ C(2,j) &= 1 \end{aligned}\right\} \text{ at } j > 0 \qquad (17)$$

In this case unit vectors i and j represent r and t respectively.

The finite difference form of the momentum equations (13) the energy conservation equation (14) and concentration equation (15) which governs the fluid flow will reduce to

$$u_{i,j+1} = \Delta t\frac{dp}{dz} + \frac{\Delta t}{(\Delta r)^2}\left(u_{i-1,j} - 2u_{i,j} + u_{i+1,j}\right) + \frac{\Delta t}{\Delta r}\left(\frac{1}{r_{i,j} - S}\right)\left(u_{i+1,j} - u_{i,j}\right) - \left[\Delta t D^{-1} + 1\right]u_{i,j} \qquad (18)$$

$$\theta_{i,j+1} = \frac{\Delta t}{(\Delta r)^2}\frac{1}{p_r}\left[\left(\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j}\right) + \frac{\Delta r}{r_{i,j}}\left(\theta_{i+1,j} - \theta_{i,j}\right)\right] + \frac{\Delta t}{(\Delta r)^2}E_c\left(u_{i+1,j} - u_{i,j}\right)^2$$
$$+ \frac{\Delta t}{(\Delta r)^2}D_u\left[\left(C_{i-1,j} - 2C_{i,j} + C_{i+1,j}\right) + \frac{\Delta r}{r_{i,j}}\left(C_{i+1,j} - C_{i,j}\right)\right] + \frac{\Delta t\alpha}{r} - S\frac{\Delta t}{\Delta r}\left(\theta_{i+1,j} - \theta_{i,j}\right) + \theta_{i,j}$$
(19)

And

$$C_{i,j+1} = \frac{\Delta t}{(\Delta r)^2}\frac{1}{S_c}\left[\left(C_{i-1,j} - 2C_{i,j} + C_{i+1,j}\right) + \frac{\Delta r}{r_{i,j}}\left(C_{i+1,j} - C_{i,j}\right)\right]$$
$$+ \frac{\Delta t}{(\Delta r)^2}S_r\left[\left(\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j}\right) + \frac{\Delta r}{r_{i,j}}\left(\theta_{i+1,j} - \theta_{i,j}\right)\right] - S\frac{\Delta t}{\Delta r}\left(C_{i+1,j} - C_{i,j}\right) + C_{i,j} \qquad (20)$$

Results and discussions

In this section, discussion of the numerical results of the study and their interpretation are presented for the effect of Cross-diffusion (effect of a heat and solute source location) on MHD mixed convective flow in the presence of constant heat source of a viscous conducting fluid through a vertical porous annulus.

These values of the parameters were varied one at a time and input into computer program. Computations were done using the simultaneous equations (4.21), (4.22) and (4.23); the initial conditions (4.19) and the boundary conditions (4.20) and curves plotted for each case. The results for the velocity profiles with

Velocity profiles

The effects of various parameters on the velocity of the fluid flow were considered as discussed below with reference to Figure 1. The velocity profiles patterns were as follows

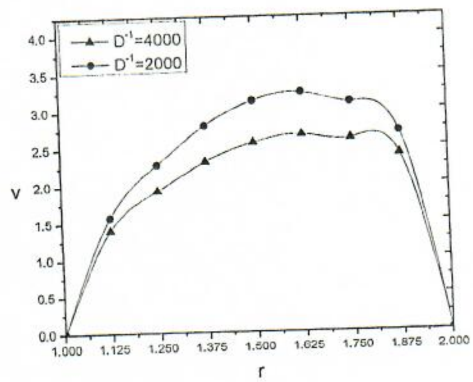

Figure 2: Velocity variations with Non-Darcy parameter

The increase in non-Darcy parameter implies that the porous medium is offering more resistance to the fluid flow. This results in reduction in the velocity profiles. This is true because the effect of porosity parameter on the velocity field is that as it increases, the velocity profile increases.

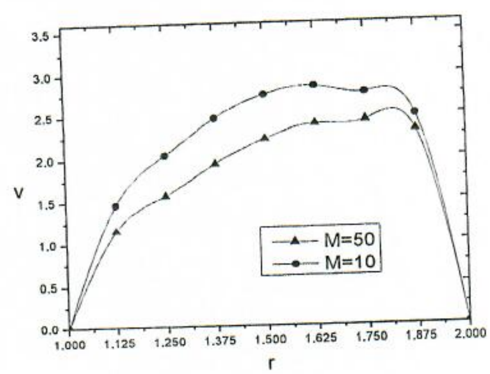

Figure 3: Velocity variations with Magnetic strength parameter

When the applied magnetic field intensity increases, there is a decrease in the velocity profile. That is the dimensionless velocity profile v within the annulus.

It is clear that increasing values of M leads to decrease in velocity components at a given point within the annulus. Accordingly, the thickness of the momentum boundary layer decreases. This happens due to Lorentz force arising from the interaction of magnetic and electric fields during the motion of the electrically conducting fluid. To reduce momentum boundary layer thickness the generated Lorentz force reduces the fluid motion in the boundary layer region.

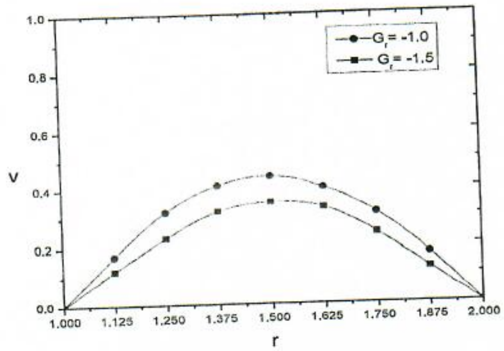

Figure 4: Velocity variations with Grashof parameter

Two different values of Grashof number are used. Here the negative values of Grashof number (< 0) physically corresponds to heating of the annulus. Hence it is observed from the comparison of the curves that an increase in thermal Grashof number (thermal boundary layer thickness increase), leads to an increase in the velocity due to enhancement in buoyancy forces. Increase of Grashof number indicates small viscous effects in the momentum equation and cosequently, causes increase in the velocity profiles.

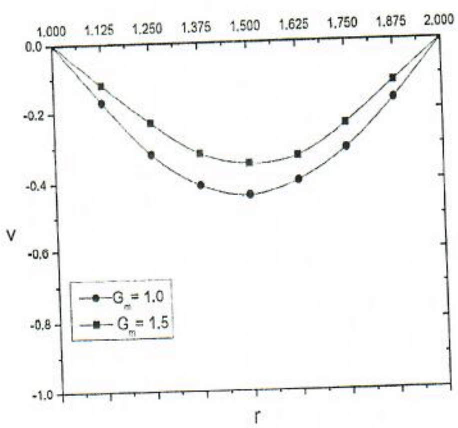

Figure 5: Velocity variations with Modified Grashof parameter

Here the positive values of Grashof number (> 0) is the mondified grashof number denoted by, which represents cooling of the annulus.

It illustrates that velocity increase with increasing Modified Grashof number in a similar manner as we noticed in the case of Grashof number. The modified Grashof number defines the ratio of the species buoyancy force to the viscous hydrodynamic force. As expected, the fluid velocity increases and the peak value is more distinctive due to increase in the species buoyancy force.

Temperature profiles

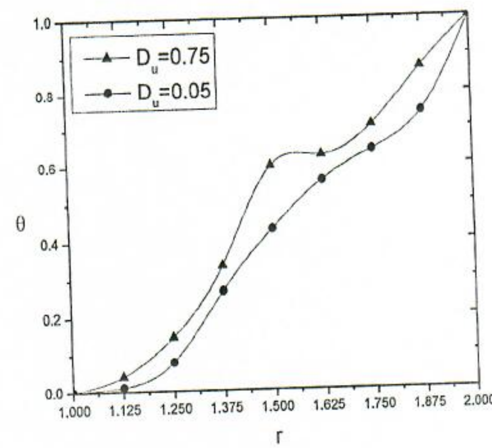

Figure 6: Temperature variations with Dufour parameter

The variation of Dufour parameter shows that the actual temperature enhances gradually with increase with Dufour parameter. The diffusion-thermo effect is observed to create an anomalous situation in temperature and velocity profiles for small Prandtl numbers.

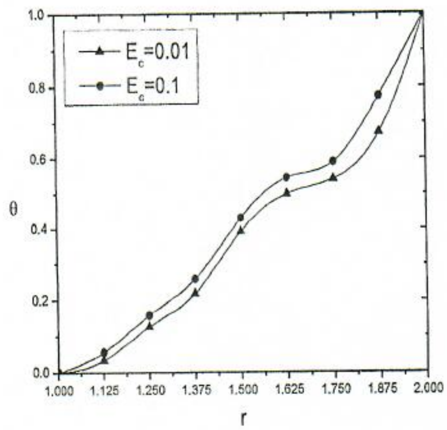

Figure 7: Temperature variations with Eckert parameter

An increase in the value of the Eckert number is seen to decrease the temperature of the fluid at any point within the annulus. Although an increase in the temperature profiles, as well as the thickness of the boundary layer, is observed with an increase in the Eckert number, it yields a decrease in the rate of heat transfer. Thus, by varying the Eckert number, the wall temperature distribution can be manipulated. The Figure 4.7 depicts the heat transfer rate decrease with the Eckert number, where the interception point between temperature gradient profiles, indicates faster decrement for lower Eckert numbers.

Concentration profiles

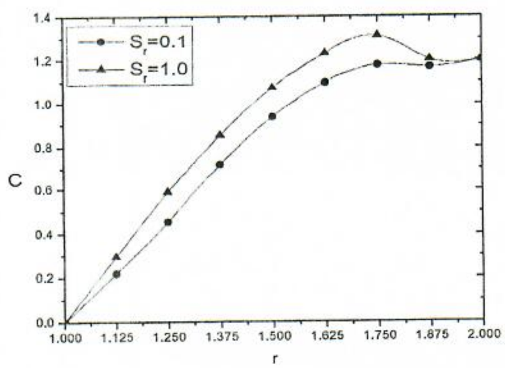

Figure 8: Concentration variations with Soret parameter

The concentration increases with increasing values. From this figure we observe that the concentration profiles increase significantly with increase of the Soret number values.

These results are similar to the earlier findings by Balasubrahmanyam (2011) and Chitti, B (2010) although the latter studies were subject to injection/suction. On the other hand an increase in the Soret effect reduces the temperature within the thermal boundary layer leading to an increase in the temperature gradient at the wall and an increase in heat transfer rate at the wall.

The Soret number has increasing effects on the concentration distributions. This is because there would be a decrease of the concentration boundary layer thicknesses with the increase of values of *Sr*.

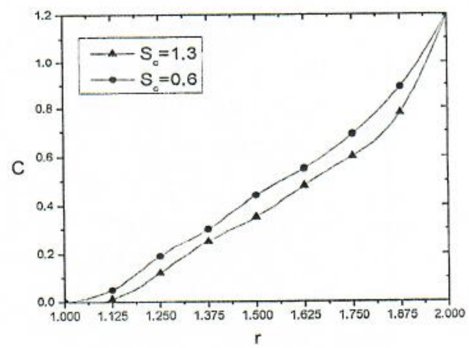

Figure 9: Concentration variations with Schmidt number

It is noticed that as the Schmidt number increases, the concentration of the fluid medium decreases. That is The more the molecular diffusivity is, the smaller the concentration in the flow field.

The variation of concentration with buoyancy shows that when the molecular buoyancy force dominates over the thermal buoyancy force the actual concentration experiences an enhancement when the buoyancy forces act in the same direction while for the forces acting in the opposite directions experiences depreciation in the flow region (Fig. 9).

Conclusions

The section highlights and illustrate the details of the flow and heat transfer characteristics and their dependence on the various parameters.

Based on the results presented above, the following specific conclusions have been reached:

It is evident that magnetic field retards the fluid motion due to the opposing Lorentz force generated by the magnetic field. Both the magnetic field and the Eckert number tend to enhance the heat transfer efficiency. While increasing the Darcy number (increasing permeability) reduces the skin friction so increasing the fluid velocity.

The effect of Grashof number on the velocity profiles in the vicinity of the annulus, first increases and attains a maximum and then starts decreasing and uniformly mixes with the ambient fluid.

We find that an increase in the Eckert number has the decreasing effect on the temperature field. Also, we have considered the case when there is no variation in the thermal conductivity and this result is shown by dashed lines.

Recommendations

Clearly, since the present study provides approximate solutions and can be used as bench mark by numerical analysts; the research work provides a basis for further investigation while including the following considerations.

Study more complex phenomenon and geometrical configurations. For example

i. rectangular and spherical coordinate systems.
ii. Strong magnetic field whereby the system is not stationary and inclined at an angle
iii. Varying heat sources and fluid viscosity.

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