EFFECT OF MAGNETIC FIELD AND DOUBLE DISPERSION ON MIXED CONVECTION HEAT AND MASS TRANSFER IN NON-DARCY POROUS MEDIUM

M. A. El-Hakiem[1, a], F. Ahmad[2, b], S. Hussain[3]
[1]ma.ahmed@mu.edu.sa, [2]f.ishaq@mu.edu.sa, [3]s.nawaz@mu.edu.sa
[1,2,3] Mathematics Department, Majmaah University, College of Science, Alzulfi, KSA
a: Mathematics Department, Faculty of Science, South Valley University Aswan, EGYPT
b: Correspondence author, f.ishaq@mu.edu.sa

ABSTRACT: *Similarity solution has been obtained for the problem of hydromagnetic dispersion in non- Darcy mixed convection heat and mass transfer from a vertical surface embedded in a porous media. The Forchheimer extension is considered in the flow equations. The flow induced by density variations is compared with the free stream flow. The heat and mass transfer in the boundary layer region for buoyancies in the flow has been analyzed. The structure of the flow, temperature, and concentration fields in the Darcy and non-Darcy porous media are governed by complex interactions among the diffusion rate* Le, *buoyancy ratio* N *and magnetic field parameter* Mn *in addition to the flow driving parameter* Ra / Pe. *Detailed numerical results for velocity, temperature and concentration are computed and presented in tablular, graphical forms.The present results have been checked against previously published work and found to be in excellent agreement. The combined effect of magnetic field, thermal dispersion and solutal diffusivity, for the non-Darcy porous medium, on the velocity, heat and mass variation are discussed.*

AMS Subject Classification: 76M20.
Key Words: Mixed convection, double dispersion, porous medium, non-Darcy, Boundary layer, heat and mass tansfer, magnetic field

1. INTRODUCTION

Themal and solutal transport by fluid flowing through a porous matrix is a phenomenon of great interest from both the theory and application point of view. The flow phenomenon is relatively complex rather than that of the pure thermal convection process. Heat and mass transfer processes in porous media are often encountered in the study of dynamics concerned with hot and salty springs of a sea, and in the chemical industry, in reservoir engineering in connection with thermal recovery process. Underground speading of chemical wastes and other pollutants, grain storage, evaporation cooling and solidification are other important application areas where the combined thermo-solutal mixed convection in porous media are obseved.

Combined heat and mass transfer by free convection under boundary layer approximations has been studied by Bejan and Khair [1], Murthy and Singh [2]. Study of the thermal dispersion effects become prevalent in the porous media flow region. The thermal and solutal dispersion effects become more important when the inertial effects are prevalent. Fried and Combarnous [3] proposed a linear function to expressed the thermal dispersion. Thermal dispersion effects have been studied by Lai and Kulacki [4], Amiri and Vafai [5], Murthy and Singh [6]. All these authors have derived systematic governing equations with various types of approximations and they presented useful results. Using scale analysis arguments, Telles, and Trevisan [7] analyzed the double dispersion phenomenon in a free convection boundary layer adjacent to a vertical wall in a Darcian fluid-saturated porous medium. Murthy and Singh [8] studied the convective heat transfer in non-Darcy porous media. Coupled heat and mass transfer phenomenon in non-Darcy flows are studied by Karimi-Fard et al. [9] and Murthy and Singh [2]. Mansour and El-Amin [10] studied the thermal dispersion effects on non-Darcy axisymmetric free convection in a saturated porous medium. Double dispersion effects on natural convection heat and mass transfer in non-Darcy porous medium studied by El-Amin [11]. Mixed convection boundary layer flow on a surface in a saturated porous medium studied by Merkin [12] Coupled heat and mass transfer by mixed convection in Darcian fluid-saturated porous medium has been analyzed by Lai [13]. The effect of double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium has been analyzed under boundary layer approximations using the similarity solution technique by Murthy [14]. El-Hakiem, [15] Studied radaitive effects on non-Darcy natural convection from a heated a vertical plate in saturated porous media with mass transfer for non-Newtonian fluid. Chamkha, et al [16] investigated heat and mass transfer by non-Darcy free convection from a vertical cylinder embedded in porous media with temperature dependent viscosity. El-Hakiem, [17] has analyzed heat transfer from moving surfaces in a micro polar fluid with internal heat generation. El-Hakiem, [18] Studied the effects of radiation and double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium.

Ahmad et al. [19] obtained exact solution of MHD Flow over Porous Stretching Sheet. Ali et al. [20] presented numerical solution of MHD flow of fluid and heat transfer over porous stretching sheet. Sajjad et al. [21] considered MHD stagnation point flow of micropolar fluids towards a stretching sheet.

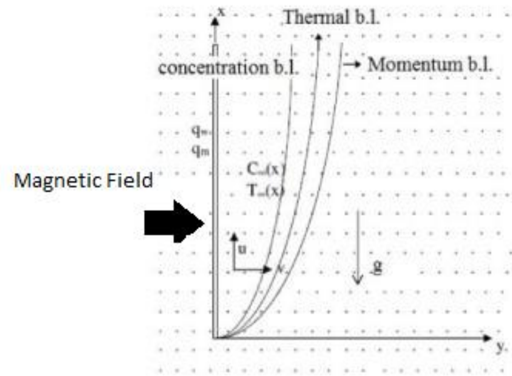
There has been a renewed interest in studying MHD flow and heat transfer in porous and non-porous media due to the effect of magnetic fields on the flow control and on the performance of many systems using electrically-conducting fluids. Some useful applications of Magnetic field in hyderodynamics are found in many important technological processes such as MHD power generators, the cooling of nuclear reactors, plasma studies, purification of molten metals from non-metallic inclusion, geothermal energy extractions etc. Rapits et al. [22] have analyzed hydromagnetic free convection flow through a porous medium between two parallel plates. Aldoss et al. [23] have studied mixed convection from a vertical plate embedded in porous medium in the presence of a magnetic field. Bian et al. [24] have reported on the effect of an electromagnetic field on natural convection in an inclined porous medium. Buoyancy-driven convection in a rectangular enclosure with a transverse magnetic field has been considered by Garandet, et al. [25]. Chamkha and Khaled [26] studied hydromagnetic simultameous heat and mass transfer by mixed convection from a vertical plate embedded in a stratified porous medium thermal dispersion effect. Mansour and El-Shaer [27] studied effect of magnetic field on non-Darcy axisymmetric free convection in a power-law fluid saturated porous medium with variable permeability. El-Kabeir, et al [28] have analyzed the heat and mass transfer by MHD stagnation-point flow of a power-law fluid towards a stertching surface with radiation, chemical reaction and soret and dufor effects. The Effect of magnetic field on non-Darcy axisymmetric free convection in a power-law fluid saturated porous medium with variable permeability has been considered by Mansour and El-Shaer [29].

The purpose of this work is to study the effects of magnetic field and double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium. The Forchheimer flow model is considered and the porous medium porosity is assumed to be low so that the boundary effects in the medium may be neglected. The heat and mass transfer in the boundary layer region is analyzed for aiding and opposing buoyancies. The flow, temperature and concentration fields in non-Darcy porous media are observed to be governed by complex interactions among the diffusions rate Le, buoyancy ratio N, Pe_γ and Pe_ξ the dispersion thermal and solutal diffusivity parameters respectively and magnetic field parameter Mn.

2. MATHEMATICAL ANALYSIS

Mixed convection heat and mass transfer from the impermeable vertical flat wall in a fluid-saturated porous medium in the presence of magnetic field is considered for the study. A magnetic field of uniform strength B_0 is applied normal to the plate. The x-axis is taken along the plate and the y-axis normal to it. The wall is maintained at constant temperature and concentration, T_w and C_w respectively, and these values are asumed to be greater than the ambient temperature and concentration T_∞ and C_∞ respectively. The gravitational acceleration g is in a direction opposite to x-direction.

The governing equations for the boundary layer flow, heat and mass transfer from the wall $y=0$ into the fluid-saturated porous medium $x \geq 0$ and $y > 0$.



Schematic Diagram

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

$$\frac{\partial u}{\partial y}+\frac{c\sqrt{K}}{\nu}\frac{\partial u^2}{\partial y}=\left(\frac{Kg\beta_T}{\nu}\right)\frac{\partial T}{\partial y}+\left(\frac{Kg\beta_C}{\nu}\right)\frac{\partial C}{\partial y}-\frac{\sigma B_0^2 K}{\rho\nu}\frac{\partial u}{\partial y}, \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\partial}{\partial y}\left(\alpha_{ff}\frac{\partial T}{\partial y}\right), \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{\partial}{\partial y}\left(D_C\frac{\partial C}{\partial y}\right), \tag{4}$$

The boundary conditions are:

$$y=0: \quad v=0, \quad T=T_w, \quad C=C_w$$
$$y\to\infty: \quad u=u_\infty, \quad T=T_\infty, \quad C=C_\infty \tag{5}$$

Here x and y are the cartesian coordinates, u and v are the averaged velocity components in x and y-directions respectively; T the temperature; C the concentration; ν the kinematic viscosity of the fluid; β_T the coefficient of thermal expansion; β_C the coefficient of solutal expansion; K the permeability of the porous medium; c an empirical constant; g the acceleration due to gravity; ρ the fluid density; σ the fluid electrical conductivity; α the equivalent thermal diffusivity of the porous medium; α_{ff} and D_C are the effective thermal and solutal diffusivities, respectively. Telles and Trevisan [8] considered $\alpha_{ff}=\alpha+\gamma du$, $D_C=D+\xi du$, whereas γdu and ξdu represent dispersion thermal and solutal diffusivities, respectively.

Proceeding with the analysis, we define the following transformations:

$$\eta = (\frac{y}{x})Pe_x^{1/2}, \quad f(\eta) = \frac{\psi}{\alpha Pe_x^{1/2}},$$

$$\theta(\eta) = \frac{(T - T_\infty)}{(T_w - T_\infty)}, \quad \phi(\eta) = \frac{(C - C_\infty)}{(C_w - C_\infty)}, \qquad (6)$$

Substituting the expressions in (6) into equations (2), (3) and (4), the transformed governing equations may be written as:

$$(1 + Mn + 2F_0 Pef')f'' = \frac{Ra}{Pe}[\theta' + N\phi'] \qquad (7)$$

$$\theta'' + \frac{1}{2}f\theta' + Pe_\gamma[f'\theta'' + f''\theta'] = 0 \qquad (8)$$

$$\phi'' + \frac{1}{2}Lef\phi' + LePe_\xi[f'\phi'' + f''\phi'] = 0 \qquad (9)$$

The boundary conditions (5) transform into the following form

$$\eta = 0: \quad f = 0, \quad \theta = 1, \quad \phi = 1$$

$$\eta \to \infty: \quad f' = 1, \quad \theta = 0, \quad \phi = 0 \qquad (10)$$

The important parameters involved in the present study are the magnetic field parameter $Mn = \frac{\sigma B_0^2 K}{\rho\nu}$, the local Peclet number $Pe_x = \frac{u_\infty x}{\alpha}$ the local Darcy-Rayleigh number $Ra_x = \frac{gK\beta_T\theta_w x}{\alpha\nu}$, which is defined with reference to the temperature difference alone, $Pe = \frac{u_\infty d}{\alpha}$ and $Ra = \frac{gK\beta_T\theta_w d}{\alpha\nu}$, are the pore diameter-dependent Peclet and Rayleigh number, respectively. The inertial parameter is $F_0 Pe = \frac{c\sqrt{K}u_\infty}{\nu}$ (in the present study $F_0 Pe = 1.0$) the buoyancy ratio is $N = \frac{\beta_C\phi_w}{\beta_T\theta_w}$ and the diffusivity ratio is $Le = \alpha / D$. The Lewis number is nothing but the ratio of the Schmidt number ν / D and Prandtl number ν / α and $\theta_w = T_w - T_\infty$. The flow governing parameter is Ra / Pe and is independent of x. When $Ra / Pe = 0$, it represents the forced convection flow. The flow asymptotically reaches the free convection flow limit as this parameter tends to ∞. The parameters Pe_γ and Pe_ξ represent thermal and solutal dispersion parameters, respectively, and are defined here as $Pe_\gamma = \frac{\gamma U_\infty d}{\alpha}$ and $Pe_\xi = \frac{\xi U_\infty d}{\alpha}$. In the present investigation, we consider the thermal and solutal dispersion parameters Pe_γ and Pe_ξ with γ and ξ included in the parameters. The heat and mass transfer coefficients, in terms of the Nusselt and Sherwood numbers in the presence of thermal and solutal dispersion diffusivities, can be written as

$q_w = -k_c \left.\frac{\partial T}{\partial y}\right|_{y=0}$, q_w the effective heat transfer coefficient; $k_c = k + k_d$ where k_c effective thermal conductivity; k_d the dispersion thermal conductivity

$j_w = -D_c \left.\frac{\partial C}{\partial y}\right|_{y=0}$, j_w the convective mass transfer coefficient; $D_c = D + \xi du$ mass diffusivity

$$\frac{Nu}{Pe_x^{1/2}} = \frac{q_w}{T_w - T_\infty}\frac{x}{k_e} = -[1 + Pe_\gamma f'(0)]\theta'(0) \qquad (11)$$

$$\frac{Sh}{Pe_x^{1/2}} = \frac{j_w x}{D_c(C_w - C_\infty)} = -[1 + Pe_\xi f'(0)]\phi'(0) \qquad (12)$$

when $Pe_\gamma = Pe_\xi = 0$, Eqs. (11) and(12) become

$$\frac{Nu}{Pe_x^{1/2}} = -\theta'(0) \text{ and } \frac{Sh}{Pe_x^{1/2}} = -\phi'(0).$$

3. RESULTS AND DISCUSSION

In order to get the physical insight, the system of ordinary differential equations (7)-(9) along with the boundary conditions (10), are integrated numerically by means of the fourth-order Runge-Kutta method with shooting technique. The step size $\Delta\eta = 0.05$ is used and five-decimal accuracy as the criterion for convergence. The accuracy of the afore mentioned numerical method was validated by direct comparisons with the numerical results reported earlier by [15] for the case $Mn = 0.0$ in the presence of other parameters. Extensive calculations have been performed to obtain the flow, temperature and concentration fields for a wide range of parameter namely, $0 \le Ra / Pe \le 5$, $0 \le Mn \le 5.0$, $F_0 Pe = 1.0$, $N = -0.5,$ 1.0, $0 \le Le \le 20$, $0 \le Pe_\gamma \le 1.0,$ $0 \le Pe_\xi \le 1.0$. When $Mn = 0,$ $F_0 Pe = 0,$ (Darcian case), $Pe_\gamma = 0$ and $Pe_\xi = 0$, the present problem reduces to heat and mass transfer by Darcian mixed convection in porous media analyzed by Lia [14]. While, for $F_0 Pe = 1.0$ with variation of other parameter, the present results have been compared with those of Murthy [15] as shown in Table I. It can be seen from the Table I, that excellent agreement between the results exists. The presence of a magnetic field in an electrically conducting fluid tends to produce a body force against the flow. This type of resistive force tends to slow down the flow which, in turn, reduces the rate of heat convection in the flow and this appears in increasing the flow temperatures as in Fig. (3). As a result, the velocity component f' near the wall decreases while, the temperature increases as depicted in Figs. (1)-(4). The wall temperature gradient presented in Table II when $F_0 Pe = 0.0$, $N = -0.5$ and $N = 1.0$. The value of $f'(0)$ depends on

Mn. From the Table II, it is clear that $f'(0)$ depends on the buoyancy ratio N . The variation of the heat transfer coefficient with Ra/Pe for nonzero values of Pe_γ is studied for a wide range of

Table I:Values for $f'(0)$ and $-\theta'(0)$ for varying Ra/Pe, Pe_γ with $Pe_\xi = 0$, $N = -0.5$, $Le = 1$

	Murthy (2000)			
Ra/Pe	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	1.0	0.56421	0.47040	0.39895
0.1	1.01602	0.56795	0.47121	0.39999
0.5	1.08113	0.57794	0.47420	0.40084
1.0	1.15831	0.9224	0.47791	0.40270
2.0	1.30277	0.62109	0.48500	0.40975
5.0	1.67940	0.67933	0.50377	0.41863

	The present work			
Ra/Pe	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	1.0	0.56419	0.47050	0.39907
0.1	1.01611	0.56799	0.47126	0.40001
0.5	1.08121	0.57801	0.47426	0.40101
1.0	1.15833	0.59250	0.47795	0.40299
2.0	1.30281	0.62117	0.48504	0.41003
5.0	1.67945	0.67998	0.50385	0.42010

Table II: Variation of $-\frac{Nu}{Pe_x^{1/2}}$ and $-\frac{Sh}{Pe_x^{1/2}}$ for varying of Mn, Ra/Pe, Pe_γ and Pe_ξ with $Le = 1.0$ and $F_0 Pe = 0.0$ (Non-Darcy case).

		$N = -0.5$			
Mn	Ra/Pe	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.08113	0.58100	0.73063	0.86975
	2.0	1.30277	0.61884	0.80099	0.96698
	5.0	1.67945	0.68029	0.92695	1.14496
2	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.04950	0.57549	0.72086	0.85640
	2.0	1.19258	0.60000	0.76581	0.91746
	5.0	1.45804	0.64375	0.85073	1.03720
5	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.03112	0.57228	0.71522	0.84874
	2.0	1.12310	0.58813	0.74350	0.88739
	5.0	1.30116	0.61790	0.79943	0.96504

Mn	Ra/Pe	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.08113	0.58100	0.72472	0.85716
	2.0	1.30277	0.61884	0.77514	0.91153
	5.0	1.67945	0.68029	0.85533	0.99233
2	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.04950	0.57549	0.71738	0.84895
	2.0	1.19258	0.60000	0.75011	0.88484
	5.0	1.45804	0.64375	0.80763	0.94514
5	0.0	1.00000	0.56684	0.70575	0.83592
	0.5	1.03112	0.57228	0.71307	0.84414
	2.0	1.12310	0.58813	0.73430	0.86763
	5.0	1.30116	0.61790	0.77373	0.90999

		$N = 1.0$		
Mn	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	1.00000	0.56684	0.70575	0.83592
	1.30277	0.61884	0.78804	0.93921
	2.00000	0.72987	0.97928	1.18032
	3.00000	0.87074	1.25278	1.52808
2	1.00000	0.47050	0.70575	0.83592
	1.19258	0.47720	0.75768	0.90104
	1.70156	0.48964	0.89424	1.07263
	2.53113	0.50111	1.11479	1.35098
5	1.00000	0.47050	0.70575	0.83592
	1.12310	0.47465	0.73888	0.87746
	1.47213	0.48317	0.83182	0.99409
	2.09902	0.49206	0.99592	1.20031

Mn	$f'(0)$	$Pe_\gamma = 0$	$Pe_\gamma = 0.5$	$Pe_\gamma = 1$
0	1.00000	0.56684	0.70575	0.83592
	1.30277	0.61884	0.78804	0.93921
	2.00000	0.72987	0.97928	1.18032
	3.00000	0.87074	1.25278	1.52808
2	1.00000	0.56684	0.70575	0.83592
	1.19258	0.62121	0.75768	0.90104
	1.70156	0.73942	0.89424	1.07263
	2.53113	0.89178	1.11479	1.35098
5	1.00000	0.56684	0.70575	0.83592
	1.12310	0.60142	0.73888	0.87746
	1.47213	0.68846	0.83182	0.99409
	2.09902	0.81834	0.99592	1.20031

values of Le. The effect of thermal dispersion on the heat transfer is studied keeping $Pe_\xi = 0$. Consistent with the results presented by Lai and Kulacki [4], the value of $-\theta'(0)$ decreases as the thermal dispersion coefficient Pe_γ increases. Also for large Pe_γ, in a very small region near the wall, temperature gradient is greatly increased and as a result heat transfer is greatly enhanced due to thermal dispersion. The value of $-\theta'(0)$ decreases as the magnetic parameter Mn increases. The value $-\theta'(0)$ increases with increase in the values of Ra/Pe, and the value of Le enhances $-\theta'(0)$ when $N = -0.5$, but, it reduces when $N = 1.0$ .The effect of magnetic field, solutal dispersion and the other parameters on the mass transfer coefficient $-\phi'(0)$ has been analyzed keeping $Pe_\gamma = 0$. The effect of the other physical parameters on $-\phi'(0)$ is same as observed for $-\theta'(0)$.

Fig.1 and fig.2 illustrate velocity profiles of f' as a function of the similarity variable η for two cases $N = -0.5$ (opposing buoyancy) and $N = 1.0$ (aiding buoyancy) and for $F_0 Pe = 0.0$, $F_0 Pe = 1.0$ (Darcy and non-Darcy) respectively. Fig.1 and fig.2 show the velocity distribution f' for varying values of magnetic parameter Mn for Darcy and non-Darcy cases, without dispersion ($Pe_\gamma = Pe_\xi = 0$) with $Le = 2.0$, $N = -0.5$ and $N = 1.0$. From these figures, we observe that the velocity profiles of f' decrease with increasing values of magnetic parameter Mn . Also, we observe that the increase of $F_0 Pe$ reduces the maximum velocity near the surface, while the opposite is the true for from it. The temperature profiles for the case $N = -0.5$ (opposing buoyancy) is presented in Fig. (3). It is evident from this figure the magnetic parameter Mn enhances the temperature profiles. It can be seen that as the buoyancy parameter N increases, the temperature profiles decrease. Also, this figure clearly indicate the favorable influence of the thermal dispersion on the temperature profiles. The temperature profiles θ as a function of η increases with increase of thermal dispersion Pe_γ for $N = -0.5$, $N = 1.0$. Fig. (4) displays the result for the concentration distributions, for the two cases, aiding and opposing buoyancy and varying the magnetic parameter Mn. It is noticed in Fig. (4), that as the buoyancy parameter N increases the concentration profiles decrease, while an increases in magnetic parameter Mn enhances the concentration profiles.

The heat transfer coefficient as a function of Lewis number Le for varying N , Mn without dispersion ($Pe_\gamma = Pe_\xi = 0$) and $F_0 Pe = 0.0$, $F_0 Pe = 1.0$ (Darcy and non-Darcy) is plotted in Figs. (5,6). From these figures it can be seen that an increase in the value of the mixed convection and magnetic parameter Mn decreases the heat transfer rate decreases. Also, with increases of $F_0 Pe$ reduces heat transfer coefficient, but from both these figures, it can be seen that an increase in Lewis number Le enhances the heat transfer rate for the opposing buoyancy case ($N < 0$), while the opposite is true for the aiding buoyancy case ($N > 0$). For fixed values of other parameters the magnitude of $\frac{Nu}{Pe_x^{1/2}} = \theta'(0)$ for $N = 1.0$ is higher than $N = -0.5$ for all values of Le . Similarly, for the magnitude of mass transfer

and Mn increase.

coefficient $\frac{Sh}{Pe_x^{1/2}} = \phi'(0)$, as a function of Lewis number Le for varying N , Mn without dispersion ($Pe_\gamma = Pe_\xi = 0$) and $F_0 Pe = 0.0$, $F_0 Pe = 1.0$ (Darcy and non-Darcy) is plotted in Figs. (7,8). From these figures we, observe that, magnetic field parameter Mn and $F_0 Pe$ reduces the mass transfer coefficient but from these two figures, it can be seen that an increase in Lewis number Le enhances the mass transfer rate for two cases the (opposing buoyancy case ($N < 0$)) and (aiding buoyancy case ($N > 0$)).

Figs. (9,10) illustrate velocity profiles of f' as a function of similarity variable η for two cases aiding and opposing buoyancy and for varying of Mn, Ra / Pe with non-Darcy case ($F_0 Pe = 1.0$), $Le = 1.0$, without and with dispersion ($Pe_\gamma = Pe_\xi = 0$ and $Pe_\gamma = Pe_\xi = 0.5$) respectively. Fig. 9 Shows the velocity distribution of f' for varying value of Mn and Ra / Pe. From this figure, it can be seen that an increase in parameter Mn reduces the maximum velocity near the surface, while the opposite is true far from it. Also, we observe that an increases of Ra / Pe enhances tha maximum velocity profile near the surface. Fig. (10) indicates that as the buoyancy parameter N and Ra / Pe inceases the velocity component f' increases near the surface, and it has no effect far from it with dispersion ($Pe_\gamma = Pe_\xi = 0.5$). The temperature profiles as a function of η for the two cases (aiding and opposing buoyancy) are presented in Figs. (11-13). It is evident from Fig. (11) that with increase in the buoyancy parameter N , the temperature profiles decrease when $Pe_\gamma = Pe_\xi = 0.5$. Also, we observe from this figure that the temperature profiles decrease with increase of Ra / Pe. It is notable that the temperature profiles increase with increasing values of Mn and Pe_γ (see Fig. (12)). Fig.(13) displays the results for concentration distributions as a function of η, for the two cases, aiding and opposing buoyancy. It is noteworthy, from Fig. (13) that as the buoyancy parameter N increases the concentration profiles decrease and it shows that the concentration profiles increase as the coefficient of dispersion solutal diffusivity Pe_ξ

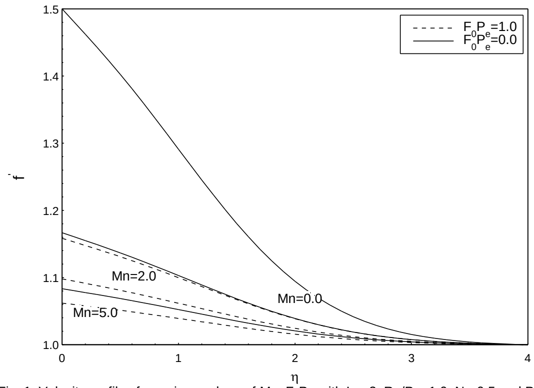


Fig. 1: Velocity profiles for various values of Mn, F_0Pe with Le=2, Ra/Pe=1.0, N=-0.5 and $P_\gamma=Pe_\xi=0.0$

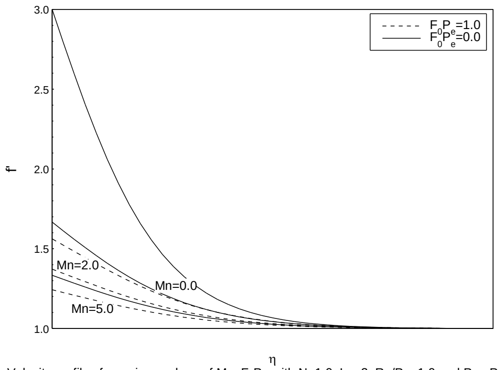


Fig. 2: Velocity profiles for various values of Mn, F_0Pe with N=1.0, Le=2, Ra/Pe=1.0 and $Pe_\gamma=Pe_\xi=0.0$

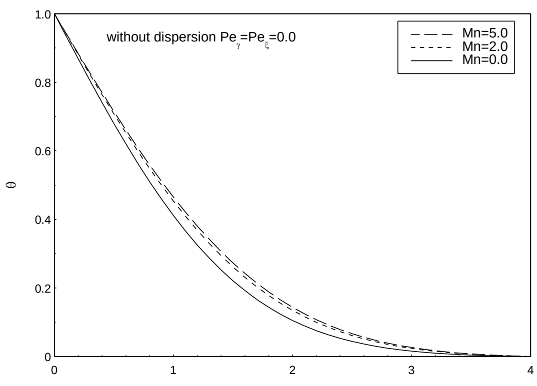


Fig. 3: Temperature profiles for various Mn with N=-0.5, $F_0Pe=0.0$ (Darcy case), Ra/Pe=1.0, Le=2.0

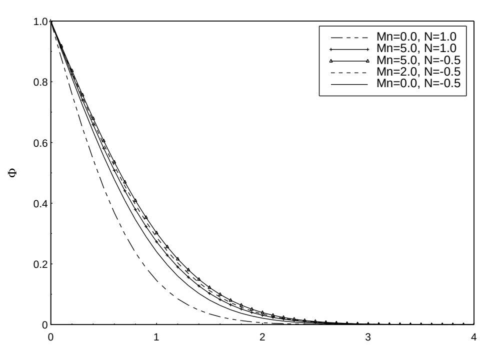


Fig. 4: Variation of concentration profiles with similarity η, for varying N, Mn when Ra/Pe=1.0, Le=2.0 $F_0Pe=0.0$ (Darcy case) and without dispersion ($Pe_\gamma=Pe_\xi=0.0$)

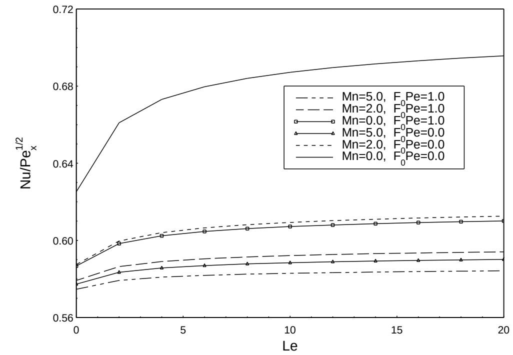


Fig. 5: Variation of heat transfer coefficient as a function of Lewis number Le, for varying of Mn, F_0Pe, when N=-0.5 (N<0.0 opposing buoyancy) without dispersion ($Pe_\gamma=Pe_\xi=0.0$)

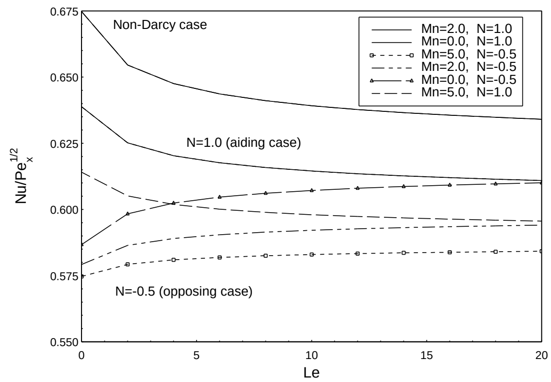


Fig. 6: Variation for heat transfer coefficient as a function of Lewis number Le, for varying Mn, N without dispersion ($Pe_\gamma=Pe_\xi=0$), with Ra/Pe=1.0 and $F_0Pe=1.0$

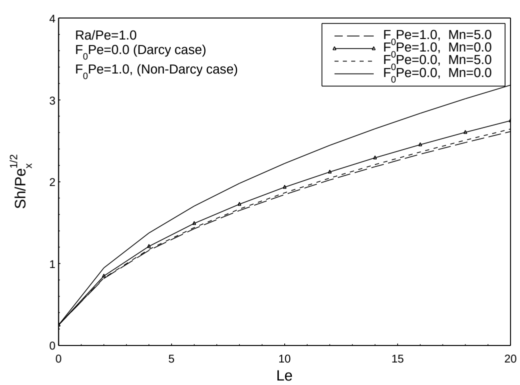


Fig. 7: Variation of mass transfer coefficient as a function of Lewis number Le, for varying Mn, F_0Pe, when N=-0.5 (N<0.0 opposing buoyancy) without dispersion ($Pe_\gamma=Pe_\xi=0.0$)

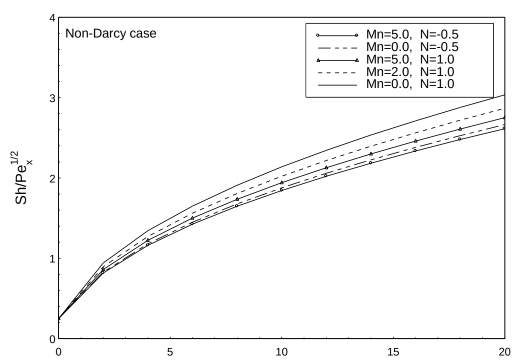


Fig. 8: Variation of mass transfer coefficient as a function of Lewis number Le, for varying Mn, N, without dispersion ($Pe_\gamma=Pe_\xi=0.0$), with Ra/Pe=1.0 and $F_0Pe=1.0$

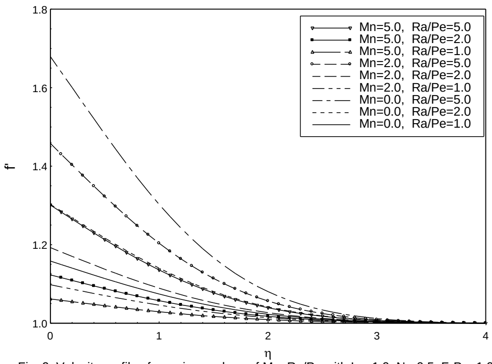


Fig. 9: Velocity profiles for various values of Mn, Ra/Pe with Le=1.0, N=-0.5, F_0Pe=1.0,and without dispersion ($Pe_\gamma=Pe_\zeta=0.0$)

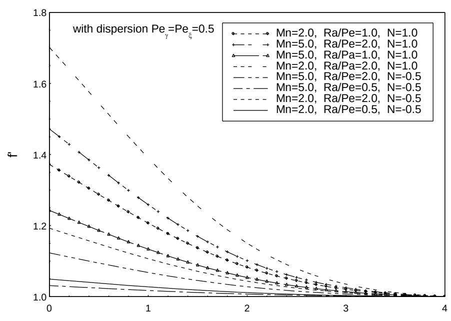


Fig. 10: Velocity profiles for various values of Mn, Ra/Pe for two cases N<0.0 (opposing buoyancy), N>0.0 (aiding buoyancy) with F_0Pe=1.0 (non-Darcy case) and Lewis number Le=1.0

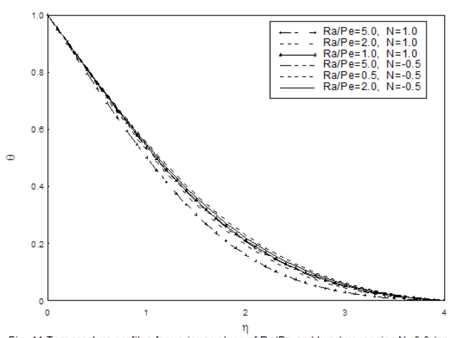


Fig. 11:Temperature profiles for various values of Ra/Pe and two buoyancies N<0.0 (opposing buoyancy), N>0.0 (aiding buoyancy) with Mn=2.0, Le=1.0 and F_0Pe=1.0

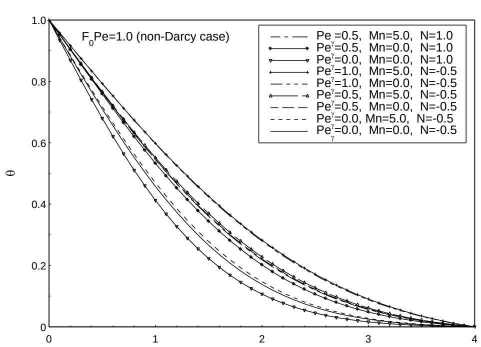


Fig. 12: Temperature profiles for various values of Pe_γ, Mn, N with Le=1.0, Ra/Pe=1.0, Pe_ζ=0.0

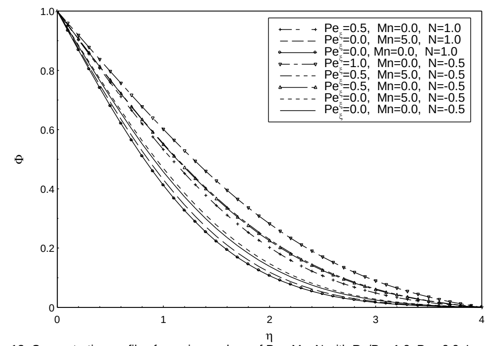


Fig. 13: Concentration profiles for various values of Pe_ζ, Mn, N with Ra/Pe=1.0, Pe_γ=0.0, Le=1.0

4. CONCLUSION

Similarity solution for hydromagnetic dispersion in mixed convection heat and mass transfer near vertical surface embedded in a porous medium in the presence of the magnetic field has been presented. The heat and mass transfer in the boundary layer region has been analyzed for aiding and opposing buoyancies. The structure of the flow, temperature and concentration fields in the Darcy and non-Darcy porous media are governed by complex interactions among the diffusion rate Le and buoyancy ratio N in addition to the flow driving parameter Ra/Pe and magnetic parameter Mn. For small values of Le in the opposing buoyancy, flow reversal near the wall is observed. Extensive calculations for a wide range of these parameters are performed. As the magnetic field parameter Mn increase the value of $f'(0)$, $-\theta'(0)$ and $-\phi'(0)$ decreases. The heat transfer coefficient always increases with Ra/Pe and decrease with the magnetic field parameter Mn. Thermal dispersion favors the heat transfer. As Le increases the effect of solutal dispersion on the nondimensional mass transfer coefficient becomes less predictable in both aiding and opposing buoyancies, and as Mn increase, the mass transfer coefficient decrease. It was found that, while the local Nusselt number decreases as a result of the presence of the magnetic field, negative free stream temperature stratification or positive wall mass transfer, it increased due to imposition of both negative wall mass transfer and free stream temperature stratification. A reduction in the heat and mass transfer coefficients is seen with increasing values of Ra/Pe. The Lewis number has compex impact on the heat and mass transfer mechanism.

REFERENCES

1. Bejan, A. and Khair, K. R., "Heat and mass transfer by natural convection in a porous medium." Int. J. Heat Mass Transfer 28, 909-918 (1985).
2. Murthy, P. V. S. N. and Singh, P., "Heat and mass transfer by natural convection in a non-Darcy porous medium."Acta Mech. 136, 135-142 (1999).
3. Fried, J. J. and Combarnous, M., "Dispersion in porous media, Adv. Hydrosc. Vol. 1, 169-282 (1976).
4. Lai, F. C. and Kulacki, F. A., "Non-Darcy mixed

convection along a vertical wall in Saturated porous medium." ASME J. Heat Transfer, 113, 252-255 (1991b).

5. Amiri, A. and Vafai, K., "Analysis of dispersion effects and non-theormal equilibrium, non-Darcian variable porosity incomressible flow through porous media." Int. J. Heat Mass Transfer, 37, 936-954, (1994).
6. Murthy, P.V.S.N. and Singh, P., "Thermal dispersion effects on non-Darcty natural convection over horizontal plate surface mass flux."Arch. Appl. Meck. 67, 487- 495 (1997).
7. Telles, R. S. and Trevisan, O. V., "Dispersion in heat and mass transfer natural convection along vertical boundaries in porous media." Int. J. Heat Mass Transfer, 36, 1357-(1993).
8. Murthy, P.V. S. N. and Singh, P.,"Thermal dispersion effects on non-Darcy natural convection with lateral mass flux."Heat Mass Transfer, vol. 33, 1-5 (1997).
9. Karimi-Fard, M., Charrier-Mojtabi, M. C. and Vafai, K., "Non-Darcian effects on double diffusive convection within a porous medium." Numer. Heat Transfer, Part A, 31, 837-852 (1997).
10. Mansour, M. A. and El-Amin, M. F., "Termal dispersion effects on non-Darcy axisymmetric free convection in a saturated porous medium with lateral mass tranfer ."Applied Mechanics and Engineering, 4 (4), 727-737 (1999).
11. El-Amin, M. F., "Double dispersion effects on natural convection heat and mass transfer in non-Darcy porous medium." Applied Mathematics and Computation, 156, pp. 1-17 (2004).
12. Merkin, J. H., "Mixed convection boundary layer flow on a surface in a saturated porous medium." J. Engng. Math. 14, 301-313 (1980).
13. Lai, F. C., "Coupled heat and mass transfer by mixed convection from a vertical plate in a saturated porous medium" Int. Commun. Heat Mass Tranfer, 18, 93-106 (1991).
14. Murthy, P. V. S. N., "Effect of double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium." ASME J. 122, 476-484 (2000).
15. El-Hakiem, M. A., Radaitive effects on non-Darcy natural convection from heated a vertical plate in saturated porous media with mass transfer for non-Newtonian fluid., J. of Porous Media, 12, 1, 89-99, (2009).
16. Chamkha, A. J., El-Kabeir, S. M. M., and Rashad, A. M., Heat and mass transfer by non-Darcy free convection from a vertical cylinder embedded in porous media with temperature dependent viscosity., Int. J. Numer. Method & FlF., 21(7), 847-863, (2011).
17. El-Hakiem, M. A., Heat transfer from moving surfaces in a micro polar fluid with internal heat generation., J. Engineering and Appled Science, 1(1), 30-36, (2014).
18. El-Hakiem, M. A., Effects of radiation and double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium., J. Engineering and Technology, In press. (2014).
19. Ahmad, F., Hussain, S., Ali, M., An Analytical Solution of MHD Flow over Porous Stretching Sheet, *J. Basic Appl. Sci. Res.* 4(3): 160-167, 2014.
20. Ali, M., Ahmad, F., Hussain, S., Numerical Solution of MHD Flow of Fluid and Heat Transfer over Porous Stretching Sheet, *J. Basic Appl. Sci. Res.* 4(5): 146-152, 2014.
21. Sajjad H., Kamal, M. A., Ahmad, F., and Shafique, M., MHD stagnation point flow of micropolar fluids towards a stretching sheet, Sci.Int.(Lahore), 26(5), 1921-1929, 2014.
22. Rapits, A., Massias, C. and Tzivanidis, G., "Hydromagnetic free convection flow through a porous medium between two parallel plates." Phys. Lett. 90A: 288-289, (1982a).
23. Aldoss, T. K., Al-Nimr, M. A., Jarrah, M. A. and Al-Sha'er, B. J.,"Magnetohydro-dynamic mixed convection from a vertical plate embedded in a porous medium." Num. Heat Transfer 28A, 635-645, (1995).
24. Bian, W., Vasseur, P. and Meng, F., "Effect of electromagnetic field on natural convection in an inclined porous medium." Int. J. Heat Fluid Flow, 17, 36-44, (1996).
25. Garandet, J. P., Alboussiere, T. and Moreau, R., "Driven convection in a rectangular enclosure with a transverse magnetic field." Int. J. Heat Mass Transfer, 34, 741-748, (1992).
26. Chamkha, A. J. and Khaled, A. R. A., "Hydromagnetic simultaneous heat and mass transfer by mixed convection from a vertical plate embedded in stratified porous medium with thermal dispersion effects. "Heat and Mass Transfer, 36, 63-70, (2000).
27. Mansour, M. A., and El-Shaer, N. A., Effect of magnetic field on non-Darcy axisymmetric free convection in a power-law fluid saturated porous medium with variable permeability, J. Magn. Magn. Mater. 250, 57-64, (2002).
28. El-Kabeir, S. M. M., Chamkha, A. J., and Rashad, A. M., Heat nd mass transfer by MHD stagnation-point flow of a power-law fluid towards a stertching surface with radiation, chemical reaction and soret and dufor effects., Int. J. of Chemical Reaction Engineering, 8, 1-18, 2010.
29. Mansour, M. A. and El-Shaer, N. A., Effect of magnetic field on non-Darcy axisymmetric free convection in a power-law fluid saturated porous medium with variable permeability, *Journal of Magnetism and Magnetic Materials*, 250, 57-64, 2002.