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Double Diffusive Natural Convection in Power-Law Fluid Saturated Porous Medium with Soret and Dufour Effects

The effects of double diffusive natural convection heat and mass transfer along a vertical plate embedded in a power-law fluid saturated Darcy porous medium in the presence of Soret and Dufour effects are studied. The governing partial differential equations are transformed into ordinary differential equations using similarity transformations and then solved numerically. A parametric study of the physical parameters involved in the problem is conducted and a representative set of numerical results is illustrated graphically.
Keywords: *natural convection, boundary layer, Darcy porous medium, power-law fluid, Soret and Dufour effects*

Introduction

The study of flow, heat and mass transfer about natural convection of non-Newtonian fluids in porous media has gained much attention from the researchers because of its engineering and industrial applications. These applications include design of chemical processing equipment, formation and dispersion of fog, distributions of temperature and moisture over agricultural fields and groves of fruit trees and damage of crops due to freezing and pollution of the environment, etc. Several investigators have extended the convection of heat and mass transfer problems to fluids exhibiting non-Newtonian rheology. Different models have been proposed to explain the behavior of non-Newtonian fluids. Among these, the power law model gained importance. Although this model is merely an empirical relationship between the stress and velocity gradients, it has been successfully applied to non-Newtonian fluids experimentally. Free convection from a horizontal line heat source in a power-law fluid-saturated porous medium was studied by Nakayama (1993). The study of free convection in boundary layer flows of power law fluids past a vertical flat plate with suction/injection was done by Sahu and Mathur (1996). They observed that the suction/injection has significant effect on the velocity and temperature fields. Free convection heat and mass transfer of non-Newtonian power law fluids with yield stress from a vertical flat plate in a saturated porous media was studied by Rami and Arun (2000). They concluded that the velocity, temperature, and concentration profiles as well as the local heat and mass transfer rates are significantly affected by the fluid rheology in addition to the buoyancy ratio and the Lewis number of the fluid. The flow of natural convection heat and mass transfer of non-Newtonian power law fluids with yield stress in porous media from a vertical plate with variable wall heat and mass fluxes was considered by Cheng (2006). He observed that the existence of threshold pressure gradient in the power law fluids tends to decrease the fluid velocity and the local Nusselt and Sherwood numbers. Also, an increase in the power law exponent increased the local Nusselt and Sherwood numbers. Free convection heat transfer from a vertical flat plate embedded in a thermally stratified non-Newtonian fluid saturated non-Darcy porous medium is analyzed by Kairi and Murthy (2009).

Pantokratoras and Magyari (2010) considered the steady forced convection flow of a power-law fluid over a horizontal plate embedded in a saturated Darcy-Brinkman porous medium. They found that far away from the leading edge, the velocity boundary layer always approaches an asymptotic state with identically vanishing transverse component. Abdel-Gaied and Eid (2011) presented a numerical analysis of the free convection coupled heat and mass transfer for non-Newtonian power-law fluids with the yield stress flowing over a two-dimensional or axisymmetric body of an arbitrary shape in a fluid-saturated porous medium. Their results showed that the existence and the increase of the dimensionless rheological parameter in the power-law fluids increase the thermal and concentration boundary layer thicknesses, in the opposite of the increasing power-law exponent. Further, the heat and mass transfer rates are strongly dependent on the high yield stress parameters.

Double-diffusive convection is referred to buoyancy-driven flows induced by combined temperature and concentration gradients. The study of double-diffusive natural convection in fluid-saturated porous media has been motivated by its wide range of applications in many engineering fields such as evaporative cooling of high temperature systems, underground disposal of nuclear wastes, spread of pollutants, drying processes, contaminant transport in saturated soils and crystal growth from liquid phase. Hyun and Lee (1990) made a numerical study of double-diffusive convection in a rectangular cavity with combined horizontal temperature and concentration gradients. They imposed the boundary conditions at the vertical side walls in such a way that the thermal and solutal buoyancy effects are counteracting, resulting in an opposing gradient flow configuration. Numerical study of double-diffusive natural convection in a porous cavity using the Darcy Brinkman formulation was done by Goyeau et al. (1996). They observed that the strong influence of the Darcy number on heat transfer is more complex than in thermal convection, and then the behavior of the thermosolutal flow in porous media is different from the behavior already assessed for fluids. Mamou et al. (1996) have carried out analytical and numerical study of double diffusive convection in a vertical enclosure. In his analytical study, he applied a scale analysis to the two extreme cases of heat-transfer and mass-transfer-driven flows and then an analytical solution, based on the parallel flow approximation, is reported for tall enclosures. Cheng (2010) studied the double diffusive natural convection near an inclined wavy surface in a fluid saturated porous medium with constant wall temperature and concentration. Using a coordinate transformation the complex wavy surface was transformed to a smooth surface, and the obtained boundary layer equations are solved by the cubic spine collocation method.

When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of a more intricate nature. It has been observed that an energy flux can be generated not only by temperature gradients, but also by concentration gradients. The energy flux caused by a concentration gradient is termed the diffusion-thermo (Dufour) effect. On the other hand, mass fluxes can also be created by temperature gradients and this embodies the thermal-diffusion (Soret) effect. In most of the studies related to heat and mass transfer process, Soret and Dufour effects are neglected on the basis that they are of a smaller

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order of magnitude than the effects described by Fourier's and Fick's laws. But these effects are considered as second order phenomena and may become significant in areas such as hydrology, petrology, geosciences, etc. The Soret effect, for instance, has been utilized for isotope separation and in mixture between gases of very light molecular weight and of medium molecular weight. The importance of these effects in convective transport in clear fluids has been reported in the book by Eckert and Drake (1972). Dursunkaya and Worek (1992) studied diffusion-thermo and thermal-diffusion effects in transient and steady natural convection from a vertical surface. Kafoussias and Williams (1995) presented the same effects on mixed convective and mass transfer steady laminar boundary layer flow over a vertical flat plate with temperature dependent viscosity. They concluded that to predict more accurate results the variable viscosity effect and the thermal-diffusion and diffusion thermo effects have to be taken into consideration in the fluid, heat and mass transfer flow. Postelnicu (2004) has analyzed the simultaneous heat and mass transfer by natural convection from a vertical flat plate embedded in an electrically conducting fluid saturated porous medium using the Darcy Boussinesq model in the presence of Dufour and Soret effects and made a remark that as magnetic parameter increases, thickness of the hydrodynamic/thermal/concentration boundary layer increases. Both free and forced convection boundary layer flows with Soret and Dufour have been addressed by Abreu et al. (2006). The effect of Soret and Dufour parameters on free convection heat and mass transfers from a vertical surface in a doubly stratified Darcian porous medium has been reported by Lakshmi Narayana and Murthy (2007). Mahdy (2010) presented a non-similar boundary layer analysis to study the flow, heat and mass transfer characteristics of non-Darcian mixed convection of a non-Newtonian power law fluid from a vertical isothermal plate embedded in a homogeneous porous medium with the effect of Soret and Dufour and in the presence of either surface injection or suction. It was observed by him that increases in the Soret number tended to increase the local heat transfer rate while decreasing the mass transfer rate. Tai and Char (2010) numerically studied the combined laminar free convection flow with thermal radiation and mass transfer of non-Newtonian power-law fluids along a vertical plate within a porous medium in the presence of Soret and Dufour effects. They concluded from their study that when both heat diffusion and mass diffusion combine to drive the flow, the local Nusselt number increases with an increase in the power-law index n and the Soret number or a decrease in the radiation parameter and the Dufour number.

From the literature survey, it seems that the problem of Double-diffusive natural convection heat and mass transfer from vertical plate in Darcy porous media saturated in power-law fluid with Soret and Dufour effects has not been investigated so far. Thus this work aims to study the effects of Soret and Dufour on Double-diffusive natural convection in a power-law fluid embedded in a Darcy porous medium with variable surface temperature and concentration.

Nomenclature

A = *dimensional constant*
B = *dimensional constant*
C = *concentration*
C_p = *specific heat at constant pressure*
C_s = *concentration susceptibility*
D_f = *Dufour number*
D_m = *mass diffusivity in porous medium*
g = *gravitational acceleration*
K = *Darcy permeability*
k_T = *thermal diffusion ratio*
Le = *Lewis number (diffusivity ratio)*
N = *Buoyancy parameter*
n = *power-law index*
Nu_x = *local Nusselt number*
Sh_x = *local Sherwood number*
S_r = *Soret number*
T = *temperature*
T_∞ = *ambient temperature*
T_m = *mean fluid temperature*
T_w = *wall temperature*
u,v = *Darcian velocity component in x and y directions*
x,y = *coordinates along and normal to the plate*

Greeks

α_m = *thermal diffusivity in porous medium*
B_C = *coefficient of concentration expansion*
B_T = *coefficient of thermal expansion*
η = *similarity variable*
θ = *dimensionless temperature*
μ = *viscosity*
ρ = *density*
Φ = *dimensionless concentration*
Ψ = *stream function*

Superscript

' = *differentiation with respect to* η

Formulation of the Problem

Consider the natural convection heat and mass transfer along a vertical plate in a non-Newtonian power-law fluid saturated Darcy porous medium. Choose the coordinate system such that x-axis is along the vertical plate and y-axis normal to the plate. The plate is maintained at variable surface temperature and concentration, $T_w(x)$, and $C_w(x)$, respectively. The temperature and concentration of the ambient medium are T_∞ and C_∞ respectively. Assume that the fluid and the porous medium have constant physical properties except for the density variation required by the Boussinesq approximation. The flow is steady, laminar, two dimensional. The porous medium is isotropic and homogeneous. The fluid and the porous medium are in local thermodynamical equilibrium. In addition, the Soret and Dufour effects are taken into consideration. Under these conditions, the governing equations describing the fluid flow can be written as follows:

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

$$u^n=\frac{\rho K g}{\mu}\left(\beta_T\left(T-T_\infty\right)+\beta_C\left(C-C_\infty\right)\right) \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_m\frac{\partial^2 T}{\partial y^2}+\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} \tag{4}$$

where u and v are the Darcian velocity components along x and y directions, T is the temperature, C is the concentration, k_T is the thermal diffusion ratio, μ is the viscosity, ρ is the density, K is the permeability, g is the acceleration due to gravity, β_T is the coefficient of thermal expansion, β_C is the coefficient of concentration expansion,

α_m is the thermal diffusivity, D_m is the mass diffusivity of the porous medium, C_p is the specific heat capacity, C_s is the concentration susceptibility, T_m is the mean fluid temperature and *n* is the power-law index. When *n = 1*, Eq. (2) represents a Newtonian fluid. Therefore, deviation of n from a unity indicates the degree of deviation from Newtonian behavior. For n < 1, the fluid is shear thinning and for n > 1, the fluid is shear thickening.

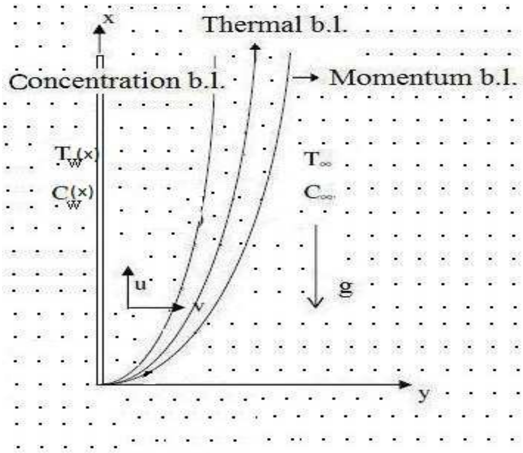

Figure 1. Physical model and coordinate system.

The boundary conditions are

$$v = 0,\ T = T_w(x),\ C = C_w(x) \text{ at } y = 0 \tag{5a}$$

$$u \to 0,\quad T \to T_\infty,\ C \to C_\infty \quad as \quad y \to \infty \tag{5b}$$

where the subscripts w and ∞ indicate the conditions at the wall and at the outer edge of the boundary layer respectively.

In view of the continuity equation (1), we introduce the stream function ψ by

$$u = \frac{\partial \psi}{\partial y},\quad v = -\frac{\partial \psi}{\partial x} \tag{6}$$

Substituting Eq. (6) in Eqs. (2)-(4) and then using the following similarity transformations

$$\left.\begin{aligned} &\eta = B\, y\, x^{-1/3},\quad \psi = A\, x^{2/3}\, f(\eta), \\ &\theta(\eta) = \frac{T - T_\infty}{T_w(x) - T_\infty},\ T_w(x) - T_\infty = E\, x^{n/3} \\ &\phi(\eta) = \frac{C - C_\infty}{C_w(x) - C_\infty},\ C_w(x) - C_\infty = F\, x^{n/3} \end{aligned}\right\} \tag{7}$$

we get the following nonlinear system of differential equations. Here A, B, E, and F are constants.

$$(f')^n = \theta + N\phi \tag{8}$$

$$\theta'' = \frac{1}{3}\left(n\, f'\theta - 2\, f\theta'\right) - D_f\,\phi'' \tag{9}$$

$$\phi'' = \frac{Le}{3}\left(n\, f'\phi - 2\, f\phi' - 3S_r\,\theta''\right) \tag{10}$$

where primes denote differentiation with respect to η alone.

$$S_r = \frac{D_m k_T (T_w - T_\infty)}{\alpha_m T_m (C_w - C_\infty)} \text{ is the Soret number,} \tag{11a}$$

$$D_f = \frac{D_m k_T (C_w - C_\infty)}{\alpha_m C_p C_s (T_w - T_\infty)} \text{ is the Dufour number,} \tag{11b}$$

$$N = \frac{\beta_C (C_w - C_\infty)}{\beta_T (T_w - T_\infty)} \text{ is the buoyancy ratio,} \tag{11c}$$

$$Le = \frac{\alpha_m}{D_m} \text{ is the Lewis number.} \tag{11d}$$

Making use of dimensional analysis, we get

$$A = \left(\frac{\rho\, EgK\, \beta_T\, \alpha_m^n}{\mu}\right)^{1/2n} \text{ and } B = \left(\frac{\rho\, EgK\, \beta_T}{\mu\, \alpha_m^n}\right)^{1/2n} \tag{12}$$

The boundary conditions (5) in terms of *f*, *θ*, and *ϕ* become

$$f(0) = 0,\ \theta(0) = 1,\ \phi(0) = 1 \tag{13a}$$

$$f'(\infty) = 0,\ \theta(\infty) = 0,\ \phi(\infty) = 0 \tag{13b}$$

The parameters of engineering interest for the present problem are the Nusselt and Sherwood numbers, which are given by the expressions

$$\frac{Nu_x}{Bx^{2/3}} = -\theta'(0) \text{ and } \frac{Sh_x}{Bx^{2/3}} = -\phi'(0) \tag{14}$$

Numerical Procedure

The flow Eq. (8) coupled with the energy and concentration Eqs. (9) and (10) constitute a set of nonlinear non-homogeneous differential equation for which closed-form solution cannot be obtained. Hence the problem has been solved numerically using shooting technique along with fourth order Runge-Kutta integration. The basic idea of shooting method for solving boundary value problem is to try to find appropriate initial condition for which the computed solution "hit the target" so that the boundary conditions at other points are satisfied. Furthermore, the higher order non-linear differential equations are converted into simultaneous linear differential equations of first order and they are further transformed into initial valued problem applying the shooting method, incorporating fourth order Runge-Kutta method. The iterative solution procedure was carried out until the error in the solution became less than a predefined tolerance level.

The non-linear differential equations (8)-(10) are converted into the following system of linear differential equations of first order by defining new dependent variables $\{f, f^1, \theta, \theta^1, \phi, \phi^1\}$:

$$\left.\begin{aligned} &\frac{df}{d\eta} = f^1,\ \frac{d\theta}{d\eta} = \theta^1,\ \frac{d\phi}{d\eta} = \phi^1, \\ &\frac{df^1}{d\eta} = \frac{\theta^1 + N\phi^1}{n\left(f^1\right)^{n-1}}, \\ &\frac{d\theta^1}{d\eta} = \frac{n f^1\theta - 2 f\theta^1 - D_f\, Le(nf^1\phi - 2f\phi^1)}{1 - S_r D_f\, Le} \\ &\frac{d\phi^1}{d\eta} = Le\,(n f^1\phi - 2f\theta^1) - S_r\frac{d\theta^1}{d\eta} \end{aligned}\right\}, \quad (15)$$

The boundary conditions in terms of $f, f^1, \theta, \theta^1, \phi, \phi^1$ are

$$f(0) = 0,\ \theta(0) = 1,\ \phi(0) = 1,\ f^1(\infty) = 0,\ \theta(\infty) = 0,\ \phi(\infty) = 0 \quad (16)$$

Here, η at ∞ is taken as η_{max} and chosen large enough so that the solution shows little further change for η larger than η_{max}.

As the initial values for f^1, θ^1 and ϕ^1 are not specified in the boundary conditions (16), assume some values for $f^1(0)$, $\theta^1(0)$ and $\phi^1(0)$. Then Eqs. (15) are integrated using the 4th order Runge-Kutta method from $\eta = 0$ to $\eta = \eta_{max}$ over successive steps $\Delta\eta$. The accuracy of the assumed initial values $f^1(0)$, $\theta^1(0)$ and $\phi^1(0)$ is then checked by comparing the calculated values of $f^1(0)$, $\theta^1(0)$ and $\phi^1(0)$ at $\eta = \eta_{max}$ with their given value at $\eta = \eta_{max}$ in (16). If a difference exists, another set of initial values for $f^1(0)$, $\theta^1(0)$ and $\phi^1(0)$ must be assumed and the process is repeated. This process is continued until the agreement between the calculated and the given condition at $\eta = \eta_{max}$ is within the specified degree of accuracy.

In the present study, η_{max} has been suitably chosen at each time such that the velocity, temperature and concentration profiles approach zero at the outer edge of the boundary layer. The effect of Soret and Dufour numbers and power law index parameter is studied on the heat and mass transfer rates for some selected combinations of parameter values.

Results and Discussion

To validate the accuracy of the present numerical scheme, a comparison of the heat and mass transfer coefficients for the case of Newtonian fluid flow (n = 1) in the absence of Soret and Dufour parameters is made with the previously published results of Yih (1999). The comparison is listed in Table 1 and found in excellent agreement.

Table 1. Comparison of values of $-\theta'(0)$ and $-\phi'(0)$ for various values of N and Le.

N	Le	Yih (1999) with λ = 1/3		Present results with $S_r = 0$, $D_f = 0$ and n = 1	
		$-\theta'(0)$	$-\phi'(0)$	$-\theta'(0)$	$-\phi'(0)$
1	1	0.9583	0.9583	0.9583	0.9583
1	10	0.8053	3.3394	0.8053	3.3394
1	100	0.7233	10.8298	0.7233	10.8298
4	1	1.5153	1.5153	1.5153	1.5153
4	10	1.0668	5.0070	1.0668	5.0070
4	100	0.8126	16.0127	0.8126	16.0127

In order to study the effects of Soret number S_r, Dufour number D_f and power law index explicitly, computations were carried out by taking the buoyancy ratio N as 1. The values of Soret number S_r and Dufour number D_f are chosen in such a way that their product is constant according to their definition provided that the mean temperature T_m is kept constant.

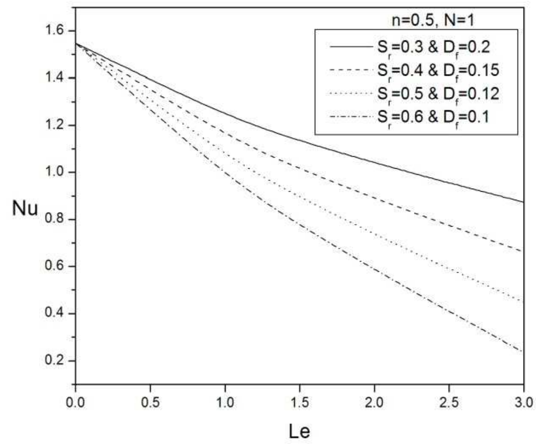

Figure 2. Variation of non-dimensional heat transfer coefficient with Le for varying S_r and D_f for shear thinning fluids.

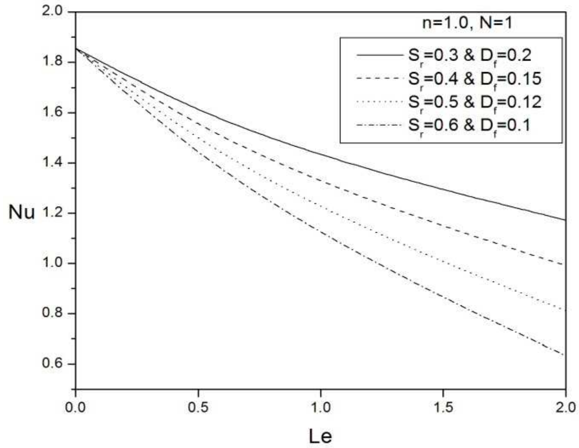

Figure 3. Variation of non-dimensional heat transfer coefficient with *Le* for varying S_r and D_f for Newtonian fluids.

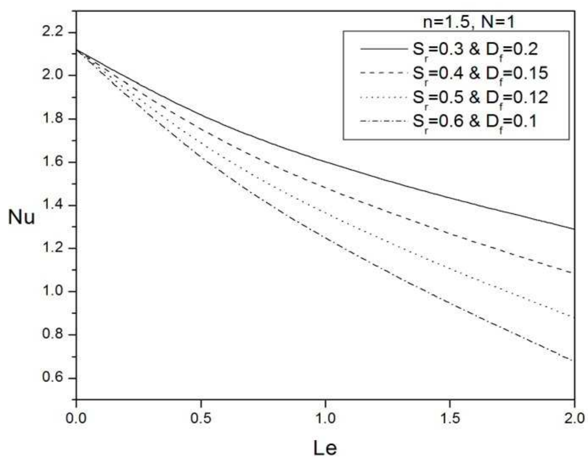

Figure 4. Variation of non-dimensional heat transfer coefficient with *Le* for varying S_r and D_f for shear thickening fluids.

The non-dimensional heat transfer coefficient (Nu_x) is plotted against Lewis number (Le) for different values of Soret number (S_r), Dufour number (D_f) in Figs. 2-4 with $N = 1$ for three different cases n = 0.5, n = 1 and n = 1.5 of power law index. It is observed that increasing the Lewis number Le decreases Nusselt number (Nu_x) for all values of power-law index n. It is clear that increasing the Soret number (decreasing of Dufour number) decreases the heat transfer coefficient. This is because either a decrease in concentration difference or an increase in temperature difference leads to an increase in the value of the Dufour parameter. Hence, decreasing the Dufour parameter D_f decreases Nu_x.

Figures 5-7 depict the variation of mass transfer coefficient (Sherwood number, Sh_x) with Lewis number (Le) for different values of Soret number, Dufour number, power-law index and $N = 1$. It is observed from these figures that increasing Lewis number increases the Sherwood number for all values of power law index. Also, increasing the Soret number (decreasing of Dufour number) increases Sh_x. The Dufour effect enhances the mass fluxes and lowers the heat fluxes. Therefore, decreasing D_f value increases the mass transfer coefficient.

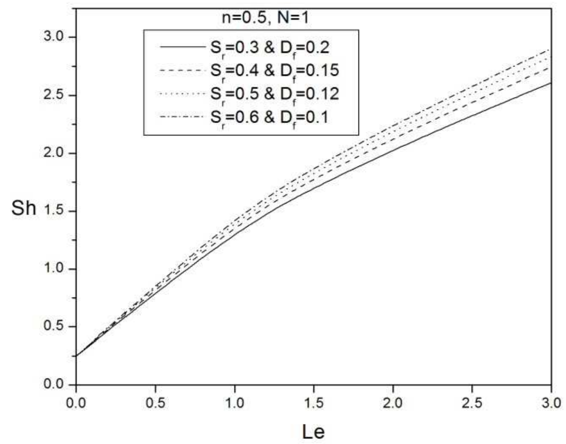

Figure 5. Variation of non-dimensional mass transfer coefficient with *Le* for varying S_r and D_f for shear thinning fluids.

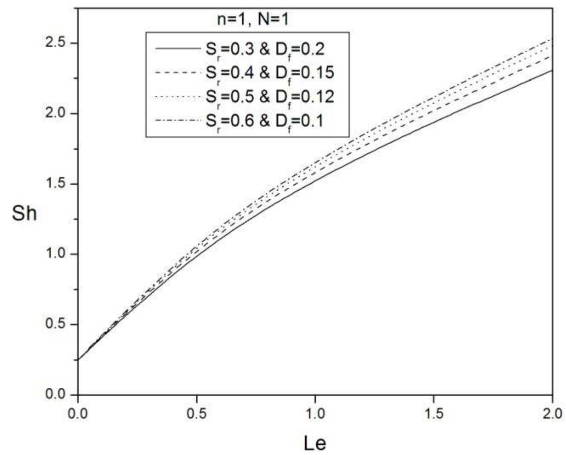

Figure 6. Variation of non-dimensional mass transfer coefficient with Le for varying S_r and D_f for Newtonian fluids.

The effect of power-law index on Nusselt number for different values of Soret and Dufour numbers is displayed in Fig. 8. It is observed that the heat transfer coefficient increases with increasing the value of the power-law index (n). Figure 9 demonstrates the effect of power law index on Sherwood number for different values of Soret and Dufour numbers. It is noticed that increasing power law index increases the mass transfer coefficient. It is interesting to note that both the Nusselt number (Nu_x) and Sherwood number (Sh_x) for Newtonian fluids are more than that of shear thinning fluids and less than shear thickening fluids.

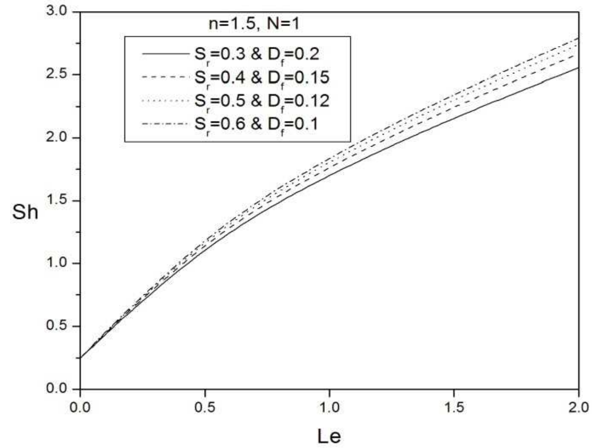

Figure 7. Variation of non-dimensional mass transfer coefficient with *Le* for varying S_r and D_f for shear thickening fluids.

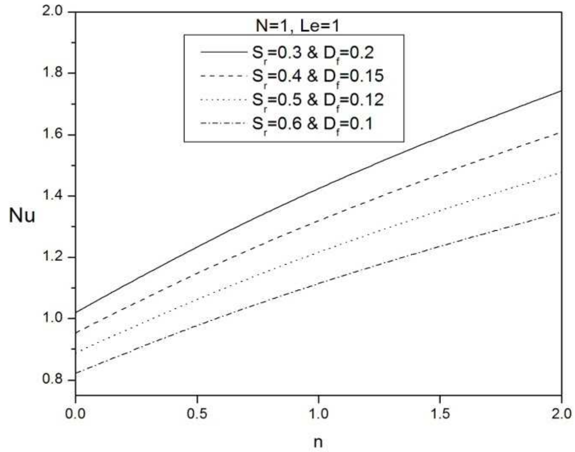

Figure 8. Variation of non-dimensional heat transfer coefficient with n for varying S_r and D_f for N = 1, Le = 1.

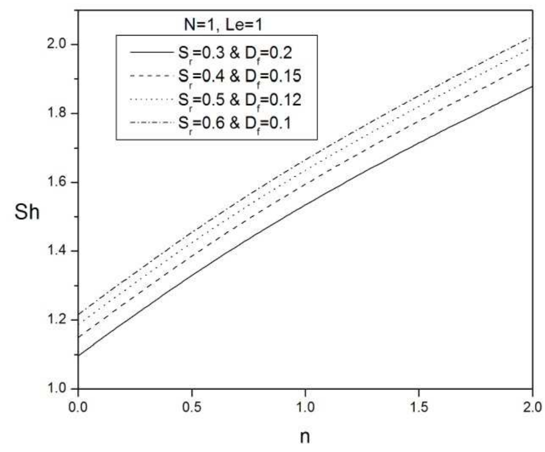

Figure 9. Variation of non-dimensional mass transfer coefficient with n for varying S_r and D_f for N = 1, Le = 1.

Conclusions

In this paper, natural convection heat and mass transfer along a vertical plate embedded in a power-law fluid saturated Darcy porous medium in presence of the Soret and Dufour effects has been considered. The plate is maintained at variable surface temperature and concentration, $T_w(x)$, and $C_w(x)$, respectively. It can be concluded from the present analysis that increasing the Soret number (or decreasing the Dufour number) decreases the Nusselt number, but increases the Sherwood number for shear thinning, Newtonian and shear thickening fluids.

References

Abdel-Gaied, S.M. and Eid, M.R., 2011, “Natural convection of non-Newtonian power-law fluid over axisymmetric and two-dimensional bodies of arbitrary shape in fluid-saturated porous media”, *Applied Mathematics and Mechanics*, Vol. 32, pp. 179-188.

Abreu, C.R.A., Alfradique, M.F. and Silva, A.T., 2006, “Boundary layer flows with Dufour and Soret effects: I: Forced and natural convection”, *Chemical Engineering Science*, Vol. 61, pp. 4282-4289.

Ching-Yang Cheng, 2010, “Double diffusive natural convection along an inclined wavy surface in a porous medium”, *Int. Comm in Heat and Mass Transfer*, Vol. 37(10), pp. 1471-1476.

Ching-Yang Cheng, 2006, “Natural convection heat and mass transfer of non-Newtonian power-law fluids with yield stress in porous media from a vertical plate with variable wall heat and mass fluxes”, *Int. Commun. Heat Mass Transfer*, Vol. 33, pp. 1156-1164.

Dursunkaya, Z. and Worek, W.M., 1992, “Diffusion-thermo and thermal diffusion effects in transient and steady natural convection from a vertical surface”, *Int. J. Heat Mass Transfer*, Vol. 35, pp. 2060-2065.

Eckert, E.R.G. and Drake, R.M., 1972, “Analysis of heat and mass transfer”, McGraw Hill, New York.

Goyeau, A., Songbe, J.P., Gobin, D., 1996, “ Numerical study of double -diffusive natural convection in a porous cavity using the Darcy Brinkman formulation”, *Int. J. Heat Mass Transfer*, Vol. 39, pp. 1363-1378.

Hyun, J.M., Lee, J.W., 1990, “Double-diffusive convection in a rectangle with cooperating horizontal gradients of temperature and concentration gradients”, *Int. J. Heat Mass Transfer*, Vol. 33, pp. 1605-1617.

Kafoussias, N.G. and Williams, N.G., 1995, “Thermal-diffusion and diffusion-thermo effects on mixed free forced convective and mass transfer boundary layer flow with temperature dependent viscosity”, *Int. J. Engng. Sci.*, Vol. 33, pp. 1369-1384.

Kairi, R.R. and Murthy, P.V.S.N., 2009, “Free Convection in a Thermally Stratified Non-Darcy Porous Medium Saturated with a Non-Newtonian Fluid”, *Int. J. of Fluid Mech. Res*, Vol. 36(5).

Lakshmi Narayana, P.A. and Murthy, P.V.S.N., 2007, “Soret and Dufour effects in a doubly stratified Darcy porous medium”, *J. Porous Media*, Vol. 10, pp. 613-624.

Mahdy, A., 2010, “Soret and Dufour effect on double diffusion mixed convection from a vertical surface in a porous medium saturated with a non-Newtonian fluid”, *J. of Non-Newtonian Fluid Mech*., Vol. 165, pp. 568-575.

Mamou, M., Vasseur, P., Bilgen, E., 1996, “Analytical and numerical study of double diffusive convection in a vertical enclosure”, *Heat Mass Transfer*, Vol. 32, pp. 115-125.

Nakayama, A., 1993, “Free convection from a horizontal line heat source in a power-law fluid-saturated porous medium”, *Int. J. of Heat and Fluid Flow*, Vol. 14, pp. 279-283.

Pantokkratoras Asterios and Magyari Eugun, 2010, “Forced Convection Flow of Power-Law Fluids Over a Flat Plate Embedded in a Darcy-Brinkman Porous Medium”, *Transport in Porous Media*, Vol. 85, pp. 143-155.

Postelnicu, A., 2004, “Influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects”, *Int. J. Heat Mass Transfer*, Vol. 47, pp. 1467-1472.

Rami, Y.J. and Arun, S.M., 2000, “Free convection heat and mass transfer of non-Newtonian power law fluids with yield stress from a vertical flat plate in a saturated porous media”, *Int. Commun. Heat Mass Transfer*, Vol.27, pp.485-494.

Sahu, A.K. and Mathur, M.N., 1996, “Free convection in boundary layer flows of power law fluids past a vertical flat plate with suction/injection”, *Indian Journal of Pure and Applied Mathematics*, Vol. 27, pp. 931-941.

Tai Bo-Chen and Char Ming-I, 2010, “Soret and Dufour effects on free convection flow of non-Newtonian fluids along a vertical plate embedded in a porous medium with thermal radiation”, *Int. Commun. Heat and Mass Transfer*, Vol. 37, pp. 480-483.

Yih, K.A., 1999, “Coupled heat and mass transfer by free convection over a truncated cone in porous media: VWT/VWC or VHF/VMF”, *Acta Mechanica*, Vol. 137, pp 83-97.