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Heat and mass transfer by Natural convection in a doubly stratified porous medium saturated with Power-law fluid

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Abstract: *This paper studies the effects of natural convection heat and mass transfer through a vertical plate embedded in a power-law fluid saturated Darcy's porous medium in addition to double stratification By using similarity transformations, the governing partial differential equations are transformed into ordinary differential equations and consequently solved using shooting method. Taking into account the physical parameters involved in a problem, a parametric study is carried out and the representative set of numerical results are graphically illustrated.*

I. INTRODUCTION

In view of their extensive occurrence in many realistic situations, heat and mass transfer problems in fluid systems have concerned the attention of many researchers for a long time. Even the initial focus was on viscous fluids [1], interest has been increased in non-Newtonian fluids [2-5]. This has been aggravated by many industries (molten plastics, polymeric liquids, foodstuffs). Among all, the power- law fluid has gained its significance which gives an experiential relationship between the stress and velocity gradients [6-7]. In view of significance, Zheng et al. [8] studied the influence of chemical reaction on power-law fluid flow through a porous medium with heat generation. Most recently, Xia et al. [9] presented the nature of poiseuille induced flow of power-law fluids in a circular cylinder.
The impact of stratification is significant in heat and mass transfer analysis. The variations in temperature or the differences in concentration, or the presence of different fluids of different densities causes the formation of layers called stratification. Several investigations have been reported in the literature on the influence of stratification in fluid saturated porous medium. Lare [10] investigated the effects of stratification on Casson fluid flow with variable viscosity and thermal conductivity over an exponential stretching sheet. Srinivasacharya et al. [11] analyzed the nature of free convection boundary layer flow over a vertical surface in a doubly stratified fluid-saturated porous medium in the presence of constant suction. Hayat et al. [12] reported the influence of thermal radiation and stratification process on unsteady viscous nano fluid flow caused by an inclined stretching sheet. Srinivasacharya and Surender [13] considered the effects of double stratification and thermal radiation on the natural convective flow in a non-Darcy porous medium. Reddy et al. [14] addressed the impact of double stratification on MHD three dimensional Casson nano fluid flow over a stretching sheet. Most recently, Srinivasacharya and Jagadeeshwar [15] studied the impact of double stratification, Cross-Diffusion and Hall currents on the flow over an exponentially stretching sheet.
The earlier literature clearly exhibits that the present study has not been reported elsewhere. In view of applications and significance, the authors are motivated to take this present study on double stratifications on free convection flow saturated power-law fluid from a vertical plate though darcy porous medium.

II. MATHEMATICAL FORMULATION

Here, steady incompressible laminar two dimensional free convection flow along a vertical flat plate in a power-law fluid through a Darcy porous medium. The plate is maintained at variable surface heat flux $q_w(x)$ and mass flux $q_m(x)$. The temperature and concentration of the ambient medium are $T_\infty(x)$ and $C_\infty(x)$ respectively. It has been assumed that the fluid properties are constant density variation in the Boussinesq approximation. Thermal and solutal stratification effects are considered and the ambient medium is vertically non-linearly stratified with respect to both temperature and concentration in the form of $T_\infty(x) = T_{\infty,0} + Gx^l$ and $C_\infty(x) = C_{\infty,0} + Hx^m$ respectively, where G and H are constants and varied to alter the intensity of stratification in the medium. Thus we have the following equations:

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

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

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_m \frac{\partial^2 T}{\partial y^2} \tag{3}$$

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

With

$$v = 0,\ -k\frac{\partial T}{\partial y} = q_w(x),\ -D_m\frac{\partial c}{\partial y} = q_m(x) \text{ at } y = 0 \text{ and } u \to 0,\ T \to T_\infty(x),\ C \to C_\infty(x) \text{ as } y \to \infty \tag{5}$$

where u and v are the Darcian velocity components in x and y directions, T is the temperature, C is the concentration, k_T is the thermal diffusion ratio, υ is the kinematic viscosity, K is the permeability, g is the acceleration due to gravity, β_T and β_C are the thermal and solutal expansions, α_m is the thermal diffusivity, D_m is the mass diffusivity of the porous medium, and n is the power-law index. When $n = 1$, the Eq. (2) represents a Newtonian fluid. Therefore, deviation of n from a unity indicates the degree of deviation from Newtonian behavior. The fluid is shear thinning and thickening when $n< 1$ and $n> 1$ respectively.

III. SOLUTION OF THE PROBLEM

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

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

Substituting (6) in (2), (3) and (4) and then using the following similarity transformations

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

We get the following nonlinear system of differential equations.

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

$$\theta'' = \frac{1}{3}\left(n\ f'\theta - 2\ f\theta' + \varepsilon_1 f'\right) \tag{9}$$

$$\phi'' = \frac{Le}{3}\left(n\ f'\phi - 2\ f\phi' + \varepsilon_2 f'\right) \tag{10}$$

Where primes denote differentiation with respect to η, $\varepsilon_1 = \frac{nG}{E}$ and $\varepsilon_2 = \frac{nH}{F}$ are the thermal and solutal stratification parameters respectively, $N = \frac{\beta_C F}{\beta_T E}$ is the buoyancy ratio, is the $Le = \frac{\alpha_m}{D_m}$ is the Lewis number.

$A = \left[\frac{EgK\beta_T \alpha_m^n}{\nu} \right]^{\frac{1}{2n}}$ and $B = \left[\frac{EgK\beta_T}{\nu \alpha_m^n} \right]^{\frac{1}{2n}}$

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

$f(0) = 0$, $\theta'(0) = -1$, $\phi'(0) = -1$, $f'(\infty) = 1$, $\theta(\infty) = 0$, $\phi(\infty) = 0$

The expressions of Nusselt and Sherwood numbers are given by

$\frac{Nu_x}{Bx^{2/3}} = \frac{1}{\theta\ (0)}$ and $\frac{Sh_x}{Bx^{2/3}} = \frac{1}{\phi\ (0)}$

IV. RESULTS AND ISCUSSION

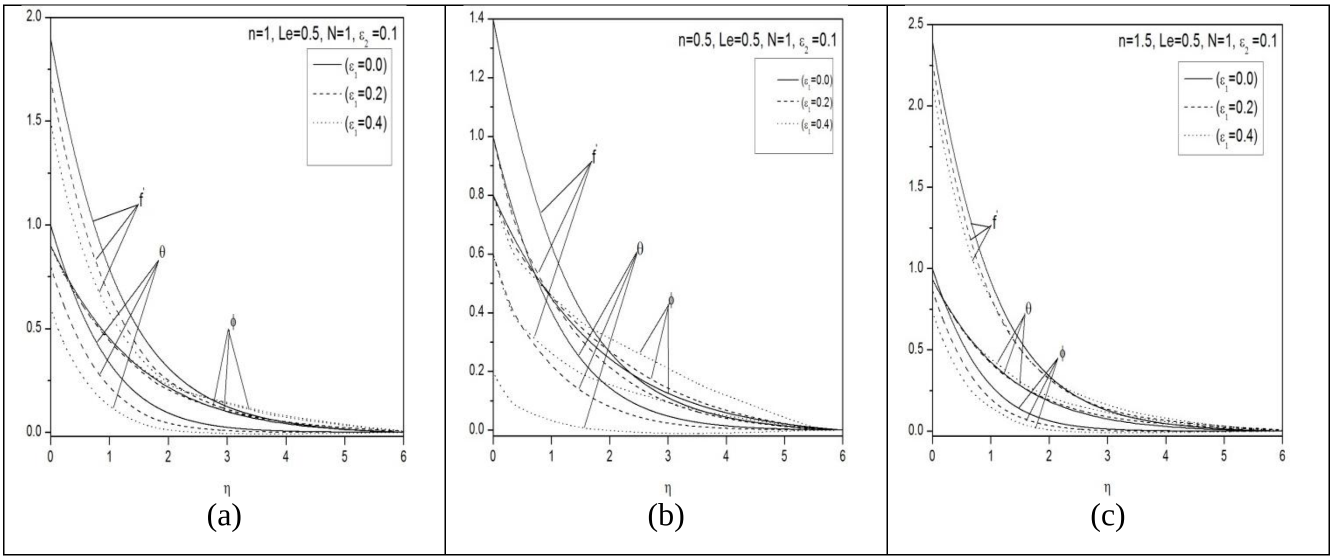

Figure 1: Velocity, Temperature and Concentration profiles for various values of ε_1 for (a) Pseudo-plastic fluids**,** (b) Newtonian and (c) dilatant fluids.

The non-dimensional velocity, temperature and concentration are plotted for N = 1, Le= 0.5, $\varepsilon_2 = 0.1$ in Figs1(a)-1(c) with varying thermal stratification parameter by considering pseudo-plastic(n=0.5), Newtonian(n=1) and dilatant fluids.Figs1(a)-1(c)demonstrates that the velocity and temperature of the fluid decreased with increasing the value of thermal stratification parameter where asthe concentration of the fluid is increased.

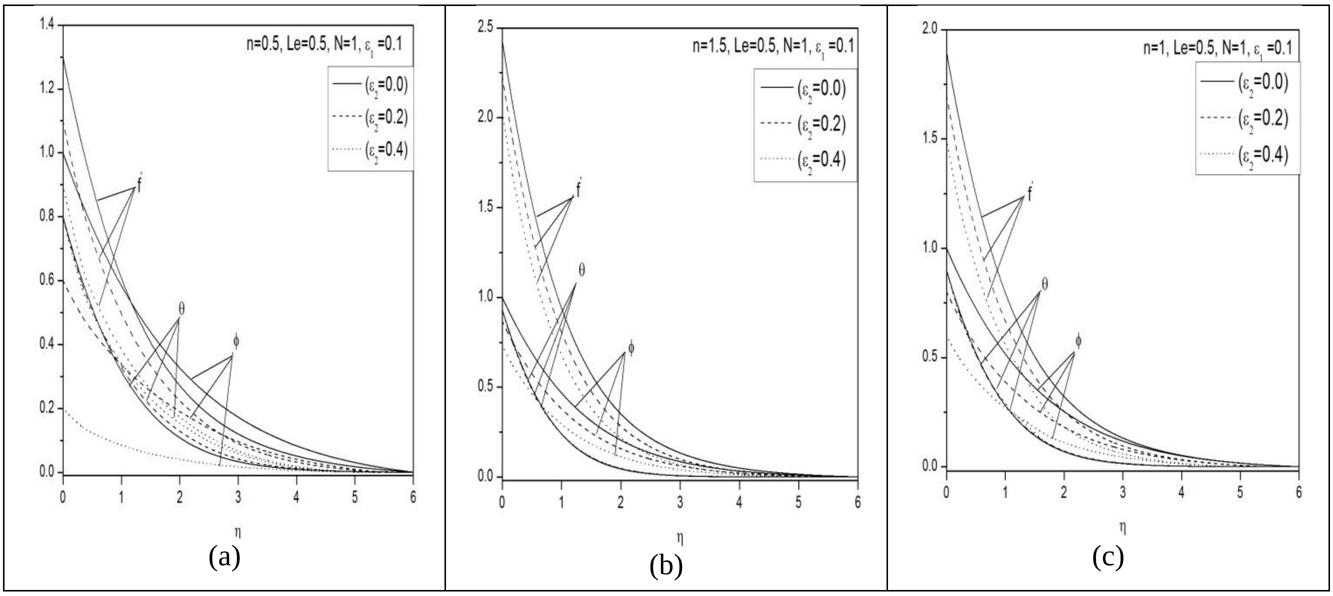

Figure 2: Velocity, Temperature and Concentration profiles for various values of ε_2 for(a) Pseudo-plastic fluids**,**(b) Newtonian and (c) dilatant fluids.

The non-dimensional velocity, temperature and concentration are plotted for N = 1, Le = 0.5, $\varepsilon_1 =$ 0.1 in Figs2 (a)-2(c) with varying solutal stratification parameter by considering pseudo-plastic (n=0.5), Newtonian (n=1) and dilatant fluids. It can be observed from Figs2 (a)-2(c) that the velocity and concentration of the fluid decreased whereas the temperature of fluid is increased with increasing the value of solutal stratification parameter.

V. CONCLUSIONS

In this study, free convection power-law fluid flow with heat and mass transfer along a vertical plate embedded in a saturated Darcy porous medium. The influence of thermal and solutal stratification parameters has been studied. It is seen from the present study that the higher values of thermal and solutal stratification parameter result in lower velocity. Temperature of the fluid decreases and concentration increases with an increase in thermal stratification. Whereas there is a reverse trend noticed incase of concentration stratification parameter.

References

[1] M. A. Hossain, M.S. Munir, I. Pop, Natural convection flow of a viscous fluid with viscosity inversely proportional to linear function of temperature from a vertical wavy cone, International Journal of Thermal Sciences, Volume 40, Issue 4, 2001, Pages 366-371.

[2] A.V. Shenoy, R.A. Mashelkar, Thermal Convection in Non-Newtonian Fluids, Advances in Heat Transfer, Volume 15,1982, Pages 143-225.

[3] Rajagopal, K.R. & Na, T.Y., Natural convection flow of a non-Newtonian fluid between two vertical flat plates, Acta Mechanica (1985) 54(3-4): 239-246

[4] T.-Y. Wang, Mixed convection heat transfer from a vertical plate to non-Newtonian fluids,International Journal of Heat and Fluid Flow, Volume 16, Issue 1,1995,Pages 56-61.

[5] Sima Baheri Islami, Mir Aydin Khoddam Tabrizi, Reza Gharraei, a numerical study on mixed convection of non-newtonian fluid flow in porous channel with aiding and opposing natural convection effects, Journal of Porous Media, Volume 20, 2017, 1, 85-98**.**

[6] Srinivasacharya, D, and Swamy Reddy, G , "Mixed convection heat and mass transfer over a vertical plate in a Power-law fluid saturated porous medium with radiation and chemical reaction effects", Heat Transfer – Asian Research, Vol. 42 (6), pp 485 - 499, 2013.

[7] Pranitha, J., VenkataSuman,G. and Srinivasacharya, D., Scaling Group Transformations for Mixed Convection in a Power-Law Fluid Saturated Porous Medium with effects of Soret, Radiation and Variable Properties, Frontiers in Heat and Mass Transfer, Vol. 9, Paper No 39, (2017).

[8] Liancun Zheng, Chengru Jiao, Yanhai Lin & Lianxi Ma (2017) Marangoni Convection Heat and Mass Transport of Power-Law Fluid in Porous Medium with Heat Generation and Chemical Reaction, Heat Transfer Engineering, 38:6, 641-652.

[9] Yi Xia, Jian zhong Lin, Xiaoke Ku, Flow-induced rotation of circular cylinder in Poiseuille flow of power-law fluids, Journal of Non-Newtonian Fluid Mechanics, Volume 260, 2018, Pages 120-132.

[10] A. I. Lare, Casson fluid flow of variable viscocity and thermal conductivity along Exponentially stretching sheet embedded in a thermally stratified medium with exponentially heat generation, Journal of Heat and Mass Transfer Research, Vol 2, No. 2, 2015.

[11] D. Srinivasacharya, S. S. Motsa, O. Surender, Numerical study of free convection in a doubly stratified non-Darcy porous medium using spectral quasilinearization method, Int. J. Nonlinear Sci. Numer. Simul. 16, 173–183(2015).

[12] T. Hayat, M. Imtiaz and A. Alsaedi, Unsteady flow of nanofluid with double stratification and magnetohydrodynamics, International Journal of Heat and Mass Transfer, Vol 92, pp. 100-109, 2016.

[13] Srinivasacharya, D. and Surender, O., “Natural convection in a non-darcy porous medium with double stratification and cross diffusion effects”, Heat Transfer Research, Vol 47 (1), pp. 29–40, 2016

[14] M. G. Reddy, P. Padma, and R. S. R. Gorla, “Influence of double stratification on MHD three dimensional Cassonnanofluid flow over a stretching sheet: A numerical study,” Journal of Nanofluids, vol. 6, no. 1, pp. 71-79, 2017.

[15] Srinivasacharya, D. and Jagadeeshwar, P., “Effect of Double Stratification, Cross-Diffusion and Hall currents on the Flow over an Exponentially Stretching Sheet”, Journal of Nanofluids, Vol 7(5), pp. 961-973, 2018.