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Procedia Materials Science 10 (2015) 563 – 571
Procedia Materials Science
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2nd International Conference on Nanomaterials and Technologies (CNT 2014)

Effect of viscous dissipation, soret and dufour effect on free convection heat and mass transfer from vertical surface in a porous medium

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Abstract

In the present approach, a two dimensional steady free convection flow of heat and mass transfer from a vertical surface in porous media with viscous dissipation has been analyzed numerically considering Soret and Dufour effects. The governing non linear partial differential equations have been transformed by a similar transformation in to a system of ordinary differential equations, which are solved numerically by using implicit finite difference scheme. The dimensionless velocity, temperature and concentration profiles are displayed graphically showing the effects for the different values of the Lewis number, soret number and viscous dissipation parameter.

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Peer-review under responsibility of the International Conference on Nanomaterials and Technologies (CNT 2014)

Keywords: Free convection; Porous medium; Viscous dissipation; Dufour effect; Soret effect; Finite difference method;

1. Introduction

Owing to its wide range of applications in the field of chemical engineering, electrical machineries, atomic power, and aeronautics, the process of natural convection flow has drawn the attention of several authors. Various studies have been found to analyze the influence of the combined heat and mass transfer process by natural

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Peer-review under responsibility of the International Conference on Nanomaterials and Technologies (CNT 2014)
doi:10.1016/j.mspro.2015.06.007

convection in a thermal and /or mass stratified porous medium, owing to its wide applications, such as development of advanced technologies for nuclear waste management, hot dike complexes in volcanic regions for heating of ground water, separation process in chemical engineering, etc. Here stratified porous medium means that the ambient concentration of dissolved constituent and/or ambient temperature is not uniform and varies as a linear function of vertical distance from the origin. Processes involving heat and mass transfer in porous media are often encountered in the chemical industry, in reservoir engineering in connection with thermal recovery process, in the study of dynamics of hot and salty springs of a sea. Underground spreading of chemical waste and other pollutants, grain storage, evaporation cooling and solidification are few other application areas where combined thermo/ solutal convection in porous media can be observed.

When heat and mass transfer occur simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of more intricate nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The energy flux caused by a composition gradient is called the Dufour or diffusion-thermo effect. On the other hand, mass fluxes can also be created by temperature gradient and this is the Soret or thermal–diffusion effect. These effects are considered as second-order phenomena, on the basis that they are of smaller order of magnitude than the effects described by Fourier's and Fick's laws, but they may become significant in areas such geosciences or hydrology.

Steady and transient free convection coupled heat and mass transfer by natural convection in a fluid-saturated porous medium has attracted considerable attention in the last years, due to many important engineering and geophysical applications. Recent books by Nield and Bejan (2006) and Ingham and Pop (1998, 2002) present a comprehensive account of the available information in the field. Effect of doubly stratification on free convection in Darcian porous medium has been studied by Murthy et al. (2004). Recently, Lakshmi Narayana and Murthy (2007) investigated the effects of Soret and Dufour on free convection heat and mass transfer from a vertical surface in a doubly stratified darcy porous medium. They have neglected effect of MHD, (Viscous dissipation).

Partha et al. (2006) studied the effect of magnetic field and double dispersion on free convection heat and mass transport considering the Soret and Dufour effects in a non – darcy porous medium. Sharma and Singh (2009) studied the effect of variable thermal conductivity and heat source/sink on MHD flow near a stagnation point on a linearly stretching sheet. Adrian postelnicu (2004) studied the heat and mass transfer characteristics of natural convection about a vertical surface embedded in a saturated porous medium subjected to a chemical reaction by taking account the dufour and soret effects. Israel cooky et al. (2003) investigated the effect of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. Gnaneshwar reddy (2010) studied soret and dufour effect on steady MHD free convection flow past a semi infinite moving vertical plate in a porous medium with viscous dissipation.

The objective of this paper is to study simultaneous heat and mass transfer by natural convection from a vertical surface embedded in a fluid saturated darcian porous medium including soret and dufour effects with viscous dissipation effect.

Nomenclature

S_r	Soret number
T	Temperature
x, y	Cartesian co-ordinates along and normal to the surface, respectively
α_m	Thermal diffusivity
C	Concentration
C_p	Specific heat at constant pressure
C_s	Concentration susceptibility
Ra_x	Local Rayleigh number
θ	Dimensionless temperature
u, v	Darcian velocities in the x and y directions
ρ	Density
ψ	Stream function
β_T	Coefficient of thermal expansion
β_C	Coefficient of concentration expansion
ϕ	Dimensionless concentration
η	Similarity variable
υ	Kinematic viscosity
D_m	Mass diffusivity
f	Dimensionless stream function
K	Darcy permeability
k_T	Thermal diffusion ratio

2. Problem formulation

Consider the natural convection in a porous medium saturated with a Newtonian fluid on a vertical flat plate. The x-coordinate is measured along the surface and the y-coordinate normal to it (see Fig. 1). The temperature of the ambient medium is T_∞ and the wall temperature is T_w. The flow along the vertical flat plate contains a species A slightly soluble in the fluid B, the concentration at the plate surface is C_w and the solubility of A in B far away from the plate is C_∞.

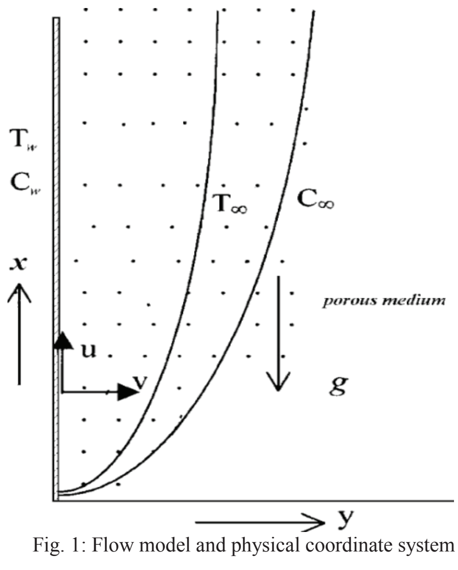

Fig. 1: Flow model and physical coordinate system

Several assumptions are used throughout the present paper: (a) the fluid and the porous medium are in local thermodynamic equilibrium; (b) the flow is laminar, steady state and two-dimensional; (c) the porous medium is isotropic and homogeneous; (d) the properties of the fluid and porous medium are constant; (e) the Boussinesq approximation is valid and the boundary layer approximation is applicable; (f) the concentration of dissolved A is small enough. In-line with these assumptions, the governing equations describing the conservation of mass, momentum, energy and concentration can be written as follows

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

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

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

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

where all quantities are defined in the nomenclature.
The boundary conditions of the problem are

$$y=0: v=0, T=T_W, C=C_W \tag{5a}$$

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

where T_W, T_∞, C_W and C_∞ have constant values.
Equations (1), (2), (3), (4), (5) are now nondimensionalized using the following quantities:

$$\psi=\alpha_m Ra_x^{1/2} f(\eta),\quad \theta=(T-T_\infty)/(T_W-T_\infty),$$

$$\phi=(C-C_\infty)/(C_W-C_\infty),\quad \eta=\frac{y}{x}Ra_x^{1/2}, \tag{6}$$

Where the stream function ψ is defined in the usual way

$$u=\frac{\partial\psi}{\partial y}, v=-\frac{\partial\psi}{\partial x} \tag{7}$$

and $Ra_x=gK\beta(T_W-T_\infty)x/(\upsilon\alpha_m)$ is the local Rayleigh number.
The governing equations become

$$f'=\theta+N\phi \tag{8}$$

$$\theta''-f\theta'+D_f\phi''+E_c f''^2=0 \tag{9}$$

$$\frac{1}{Le}\phi''+f\phi'+S_r\theta''=0 \tag{10}$$

Where Le, D_f, S_r, E_c and N are Lewis, Dufour, Soret numbers,Eckert number and sustentation parameter, respectively

$$Le=\frac{\alpha_m}{D_m}, D_f=\frac{D_m k_T(C_W-C_\infty)}{C_s C_p\alpha_m(T_W-T_\infty)},\quad S_r=\frac{D_m k_T(T_W-T_\infty)}{C_s C_p\alpha_m(C_W-C_\infty)},\quad N=\frac{\beta_c(C_W-C_\infty)}{\beta_T(T_W-T_\infty)} \tag{11}$$

We notice that N is positive for thermally assisting flows, negative for thermally opposing flows and zero for thermal-driven flows. We notice that prime denotes differentiation with respect to η

The transformed boundary conditions are

$$f(0)=0, \theta(0)=1, \phi(0)=1 \tag{12a}$$

$$\theta \to 0, \phi \to 0 \text{ as } y \to \infty \tag{12b}$$

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

$$Nu_x / Ra_x^{1/2} = -\theta'(0), \quad Sh_x / Ra_x^{1/2} = -\phi'(0). \tag{13}$$

3. Mathematical solution

Here, we use Crank Nicolson implicit finite difference method to obtain numerical solution for the set of non-linear ordinary differential equations (8) - (10) with boundary conditions (12). In all cases a step size of $\Delta\eta = 0.01$ was selected to be satisfactory for a convergence criteria of 10^{-5} . The value of η_∞ was found to each iteration loop by the statement $\eta_\infty = \eta_\infty + \Delta\eta$. In order to see the effect of step size $\Delta\eta$ we ran the code for our model with two different step sizes $\Delta\eta = 0.01$, $\Delta\eta = 0.001$ and each case we found very good agreement between them.

4. Results and discussion

Numerical Calculations are carried out for different values of D_f , S_r , E_c , Le and N . To discuss the effect of various parameters on the flow behaviour some numerical calculations have been carried out for non dimensional velocity profiles f' , temperature profiles θ , and concentration profiles ϕ . In fig. 2, the velocity profile f' increases with the increasing of *N*. From fig.3 and fig.4, we observed that the velocity profile increases with the increasing of Lewis number *Le* and Eckert number E_c respectively. Fig.5 and fig.6 are display that the temperature profiles for different parameters E_c and S_r .We can conclude from fig.5 and fig.6 that, the temperature profile increases with the increase of Soret number S_r and decreases with the increase of Eckert number E_c respectively. In fig.7, the concentration profile plotted for different Lewis number *Le* and we observed that the concentration profile decreases with the increase of Lewis number. Fig. 8 shows the concentration profile decreases with the increase of Eckert number E_c .

5. Concluding remarks

We obtained numerical solution for two dimensional steady free convection flow of heat and mass transfer from vertical surface by considering Soret and Dufour effects through porous medium with viscous dissipation. Following are the observations of the present investigation.

- The velocity profiles increases with the increase of various parameters
- The concentration profiles decreases with the increase of different parameters

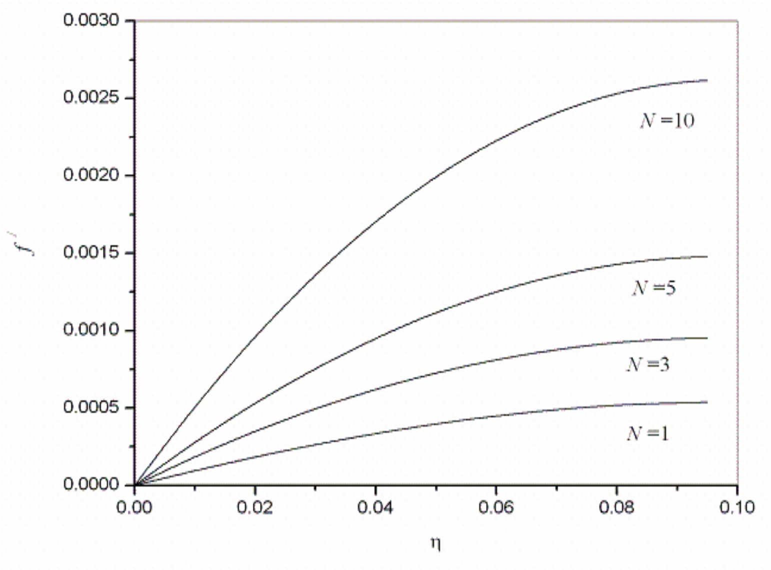

Fig.2: Velocity profiles for different values of N with $S_r = 0.001, D_f = 10.0$

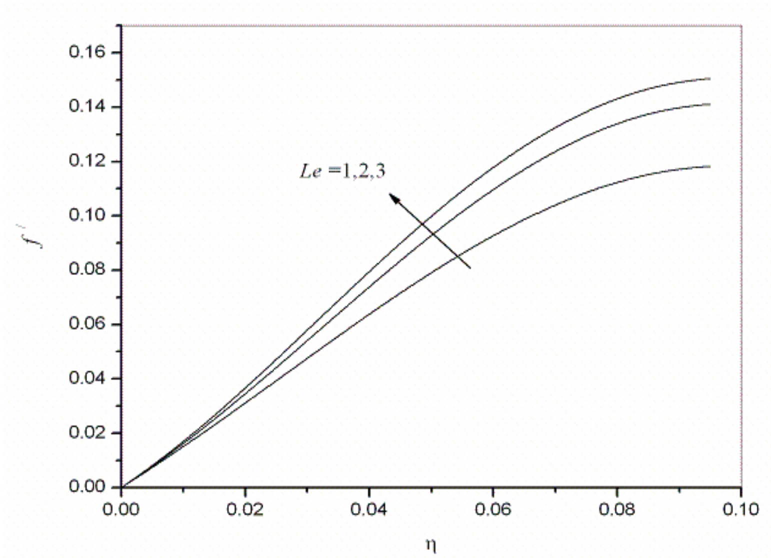

Fig.3: Velocity profiles for different Le with $S_r = 0.001, D_f = 10.0, N = 1$

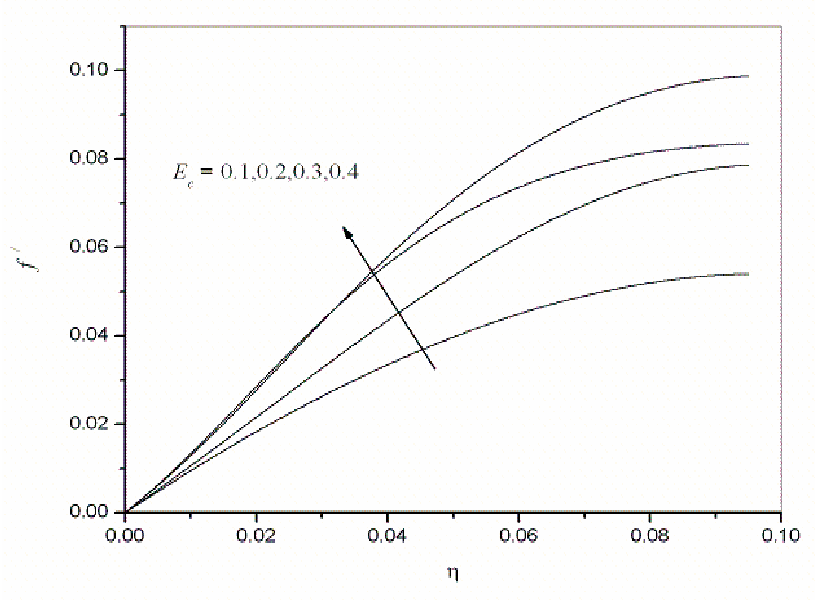

Fig.4: Velocity profiles for different Eckert parameters with $S_r = 0.001, D_f = 10.0$

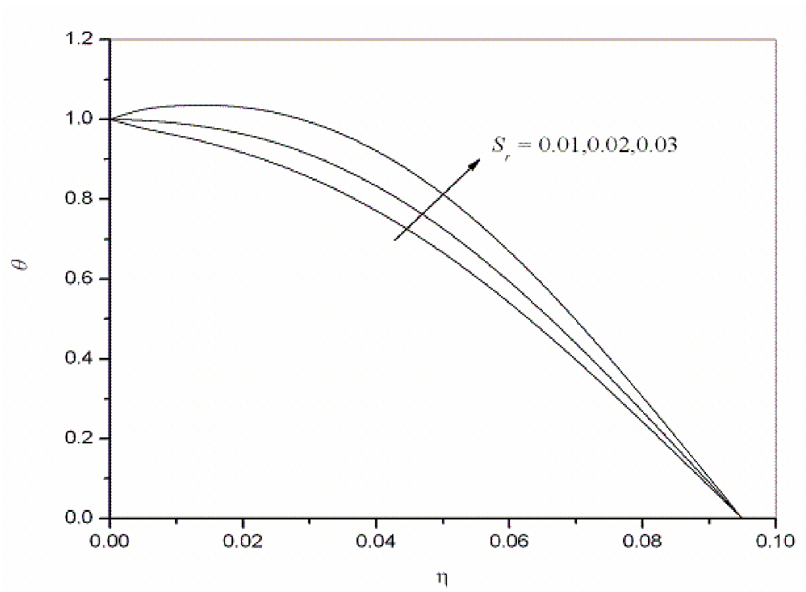

Fig.5: Temperature profiles for different soret parameters with $D_f = 10.0, N = 1$

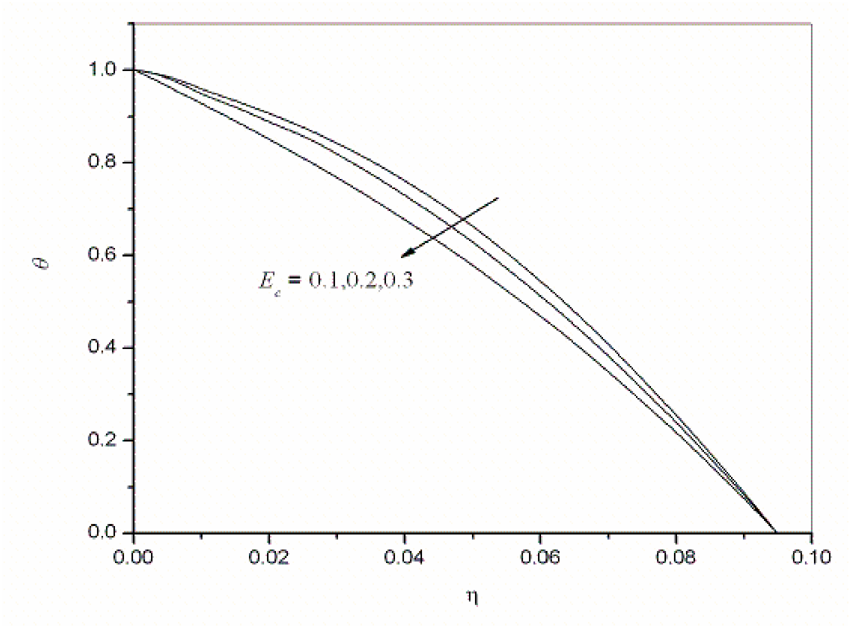

Fig.6: Temperature profiles for different Eckert parameters with $S_r = 0.001, D_f = 10.0$

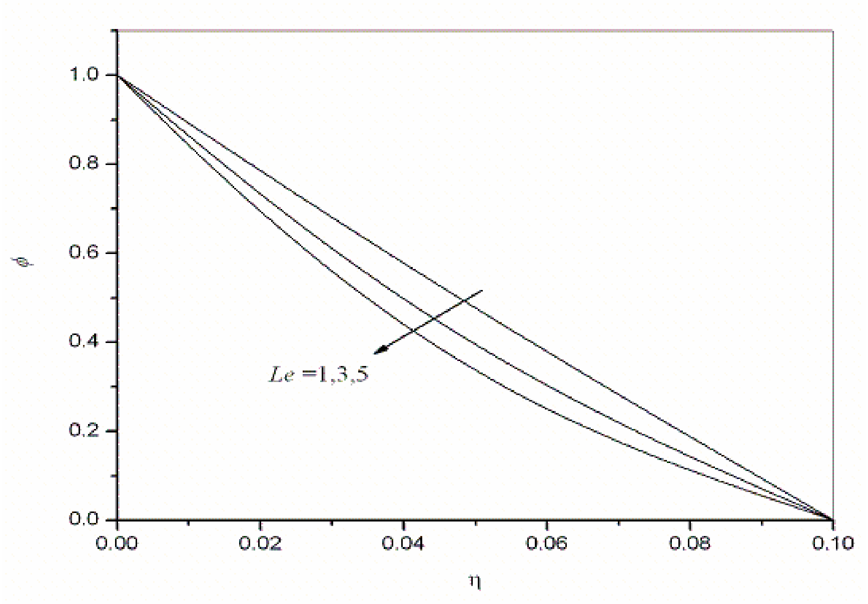

Fig.7: Concentration profiles for different Le with $D_f = 10.0, S_r = 0.001$

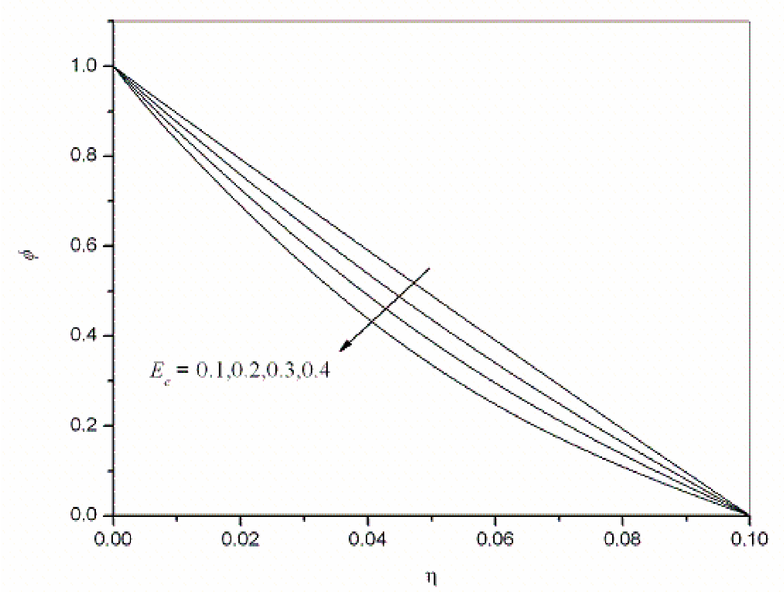

Fig.8: Concentration profiles for different E_c with $Df = 10.0, Sr = 0.001$

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