Volume-5, Issue-1, January -2016 • ISSN No 2277 - 8160

GLOBAL JOURNAL FOR RESEARCH ANALYSIS International

Research Paper | Mathematics

Soret and Dufour Effects on Unsteady free Convective Flow Along a Vertical Surface Adjacent to a Porous Medium

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ABSTRACT

In this paper, we have studied Soret and Dufour effects on unsteady viscous incompressible free convective flow along a vertical surface adjacent to a porous medium. The dimensionless governing equations of flow field are solved by an iterative technique based on finite difference scheme. The velocity, temperature and concentration distributions are shown graphically.

KEYWORDS :

Introduction:

Free convection flow arises in the fluid when temperature gradient causes density variation leading to buoyancy forces acting on the fluid element. Sometimes along with the free convection currents caused by difference in temperature the flow is also affected by concentration or material constitution. In view of its wide applications, Raptis et al.[1] discussed radiation and free convection flow past a moving plate. Chamkha and Takhar [2] used the blotter difference method to study laminar free convection flow of air past a semi infinite vertical plate in the presence of chemical species concentration and thermal radiation effects. Cookey et al. [3] examined the effect of viscous dissipation and thermal radiation on unsteady MHD free convection flow past an infinite heated vertical surface in a porous medium with time-dependent suction. S.Bagai [4] studied the effect of variable viscosity on free convective over a non isothermal axisymmetric body in a porous medium with internal heat generation, Das et al. [5] investigated numerically the unsteady free convective MHD flow past an accelerated vertical plate with suction and heat flux. Ahmed [6] analysed numerically the magnetohydrodynamic chemically reacting and radiating fluid past a non-isothermal uniformly moving vertical surface adjacent to a porous regime.

Soret and Dufour effects with heat and mass transfer play an important role in chemical engineering and aerodynamics. The flux of mass caused due to temperature gradient is known as the Soret effect or the thermal-diffusion effect. The energy flux caused by a concentration gradient is referred to as the Dufour effect or diffusion-thermo effect. Gaikwad et al. [7] investigated the onset of double diffusive convection in two component couple of stress fluid layer with Soret and Dufour effects using both linear and nonlinear stability analysis. Osalusi et al. [8] investigated Soret and Dufour effects on combined heat and mass transfer of a steady hydromagnetic convective and slip flow due to a rotating disk in the presence of viscous dissipation and ohmic heating. Sharidan et al. [9] considered the similarity solutions for the unsteady boundary layer flow and heat transfer over a stretching sheet for special distributions of the stretching velocity and surface temperature. Pal and Hiremath [10] determined the heat transfer characteristics in the laminar boundary layer flow over an unsteady stretching sheet which is placed in a porous medium in the presence of viscous dissipation and internal absorption or generation.

Mathematical Formulation:

We consider unsteady two dimensional free convective flow of a viscous incompressible fluid past a vertical surface adjacent to porous medium. The plate is taken along x' axis in vertically upward direction and y'axis is taken normal to the plate. Let,u' and v' be the velocity components of the fluid generated along x' axis and y'axis respectively. It is assumed that initially the plate and the fluid were at the same temperature T'_∞ and concentration level C'_∞. At time t'>0, the temperature of the plate is raised to $T'_w = T'_\infty + ax^n$ and concentration level is also raised to $C'_w = C'_\infty + bx^m$ where n is surface temperature power law exponent, m is surface concentration power law exponent. m is surface concentration power law exponent.

Using Bousinesq's approximation, the unsteady flow is governed by the following equations

$$\frac{\partial u'}{\partial x'} + \frac{\partial v'}{\partial y'} = 0, \qquad (1)$$

$$\frac{\partial u'}{\partial t'} + u'\frac{\partial u'}{\partial x'} + v'\frac{\partial u'}{\partial y'} = g\beta_T(T' - T'_\infty) + g\beta_C(C' - C'_\infty) - \frac{\nu}{K'}u' + \nu\frac{\partial^2 u'}{\partial y'^2}, \qquad (2)$$

$$\frac{\partial T'}{\partial t'} + u'\frac{\partial T'}{\partial x'} + v'\frac{\partial T'}{\partial y'} = \left(\frac{k}{\rho C_p}\right)\frac{\partial^2 T'}{\partial y'^2} + \frac{D_m k_t}{C_s C_p}\frac{\partial^2 C'}{\partial y'^2} \qquad (3) \text{ and}$$

$$\frac{\partial C'}{\partial t'} + u'\frac{\partial C'}{\partial x'} + v'\frac{\partial C'}{\partial y'} = D_m\frac{\partial^2 C'}{\partial y'^2} + \frac{D_m k_t}{T_m}\frac{\partial^2 T'}{\partial y'^2}. \qquad (4)$$

The initial and boundary conditions are as follows,

$$t' \le 0,\ u' = 0,\ v' = 0,\ T' = T'_\infty,\ C' = C'_\infty \quad \text{for all } y', \qquad (5)$$

$$t' > 0,\ u' = u_0,\ v' = 0,\ T' = T'_\infty + ax^n,\ C' = C'_\infty + bx^m \text{ at } y' = 0, \qquad (6)$$

$$u' = 0,\ T' = T'_\infty,\ C' = C'_\infty \quad \text{at } x' = 0 \qquad (7) \text{ and}$$

$$u' \to 0,\ T' \to T'_\infty,\ C' \to C'_\infty \quad \text{as } y' \to \infty. \qquad (8)$$

where, D_m is mass diffusivity, C_p is the specific heat at constant pressure, C_s is concentration susceptibility, T_m is the mean fluid temperature, k_t is the thermal diffusivity ratio, g is the acceleration due to gravity, β_T, β_C are coefficients of thermal expansion and concentration expansion, k is the thermal conductivity, ρ is the density, ν is the kinematic viscosity.

On introducing the following non-dimensional quantities,

$$\left.\begin{aligned} & x = \frac{u_0 x'}{\nu},\ y = \frac{u_0 y'}{\nu},\ u = \frac{u'}{u_0},\ v = \frac{v'}{u_0},\ t = \frac{t' u_0^2}{\nu},\ Sc = \frac{\nu}{D_m},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\ \varphi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \\ & Pr = \frac{\rho\nu C_p}{k},\ Gr = \frac{g\beta_T \nu(T'_w - T'_\infty)}{u_0^3},\ Gm = \frac{g\beta_c \nu(C'_w - C'_\infty)}{u_0^3},\ K = \frac{u_0^2 K'}{\nu^2}, \\ & Sr = \frac{D_m k_t (T'_w - T'_\infty)}{T_m \nu (C'_w - C'_\infty)},\ Du = \frac{D_m k_t (C'_w - C'_\infty)}{C_s C_p \nu (T'_w - T'_\infty)} \end{aligned}\right\} \qquad (9)$$

where *Pr* is prandtl number, *Gr* is Grashof number, *Gm* is mass Grashof number, *K* is permeability parameter, *Sc* is Schmidt number, *t* is time in dimensional coordinate, *Sr* is Soret number, *Du* is Dufour number, the governing equations, on using (9) into (1) to (8), reduce to the following :

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \qquad (10)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = Gr\theta + Gm\,\varphi - \frac{u}{K} + \frac{\partial^2 u}{\partial y^2}, \qquad (11)$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{Pr}\frac{\partial^2 T}{\partial y^2} + Du\frac{\partial^2 C}{\partial y^2} \qquad (12)$$

and

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + Sr\frac{\partial^2 T}{\partial y^2} \qquad (13)$$

The initial and boundary conditions (5) – (8) is non- dimensional form reduce to

$$\left.\begin{aligned} & t \le 0,\ u = 0,\ v = 0,\ T = 0, C = 0 && \text{for all } y \\ & t > 0,\ u = 1,\ v = 0,\ T = x^n, C = x^m && \text{at } y = 0, \\ & u = 0,\ T = 0,\ C = 0 && \text{at } x = 0 \ \ and \\ & u \to 0,\ T \to 0,\ C \to 0 && \text{as } y \to \infty. \end{aligned}\right\} \qquad (14)$$

Method of solution:

The dimensionless governing differential equations (10)-(13) subject to the initial and boundary conditions (14) are reduced to a system of difference equations using the following finite difference scheme

$$\frac{\partial v}{\partial y} = \frac{v^{i+1}{}_{j,n} - v^{i}{}_{j,n}}{\Delta y}, \quad \frac{\partial^2 v}{\partial y^2} = \frac{v^{i+1}{}_{j,n} + v^{i-1}{}_{j,n} - 2v^{i}{}_{j,n}}{(\Delta y)^2}$$

and then the system of difference equations is solved numerically by an iterative method.

Result and Discussion:

The Soret and Dufour effects on the velocity, temperature and concentration profiles are studied by supplying various values of the parameters. Numerical calculations have been carried out for different values of time (*t*), Soret number (*Sr*), Dufour number (*Du*) and for fixed values of Prandtl number (*Pr*) = 0.71, Schmidt number (*Sc*) = 0.6, Grashof number (*Gr*) = 5, mass Grashof number (*Gm*) = 5, porosity (*K*) = 0.8.

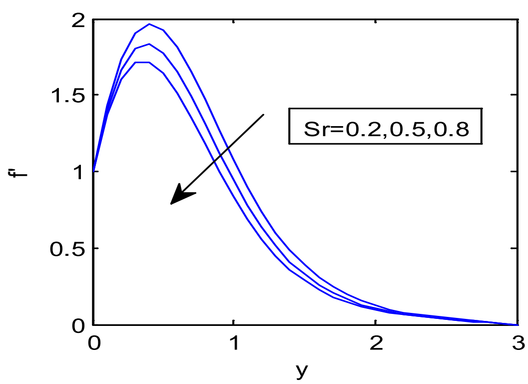

Fig.1.Velocity profile for Soret number

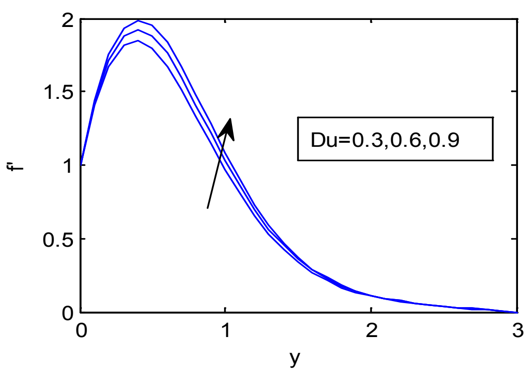

Fig.2. Velocity profile for Dufour number

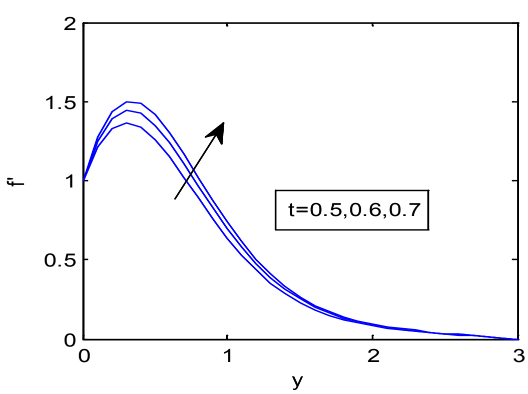

Fig.3. Velocity profile for time

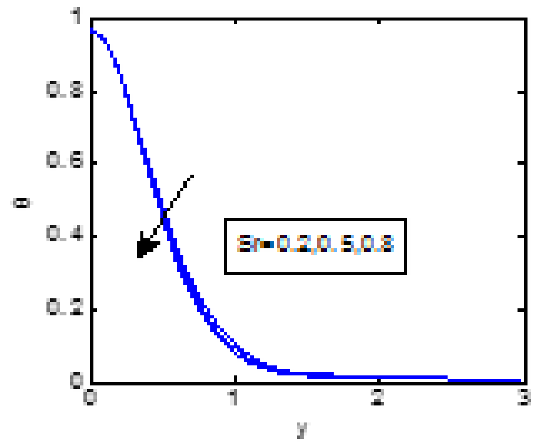

Fig.4. Temperature profile for Soret number

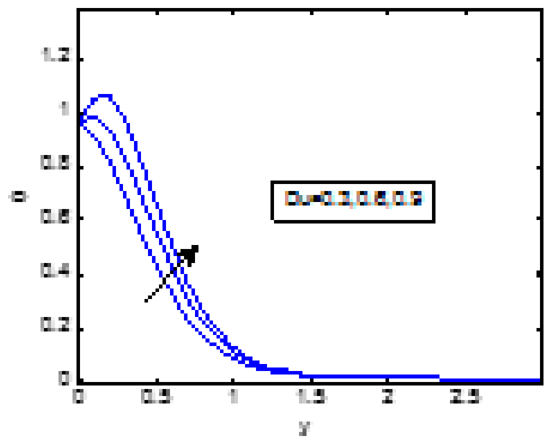

Fig.5.Temperature profile for Dufour number

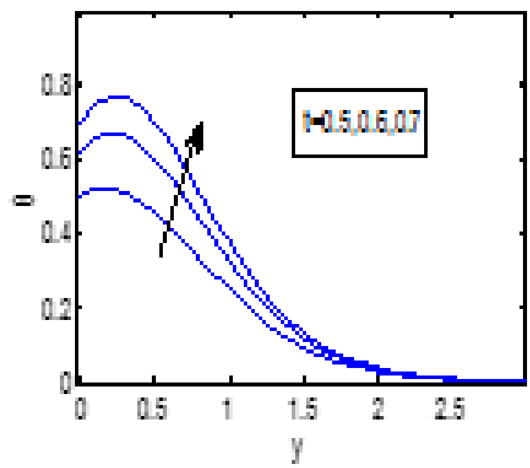

Fig.6. Temperature profile for time

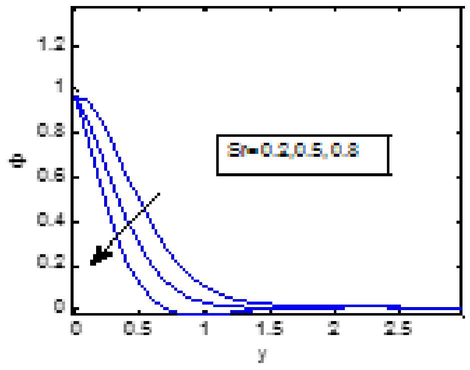

Fig.7. Concentration profile for Soret number

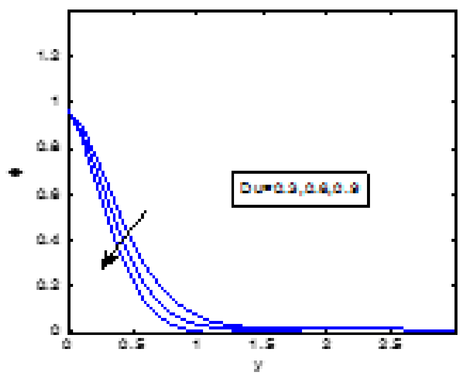

Fig.8. Concentration profile for Dufour number

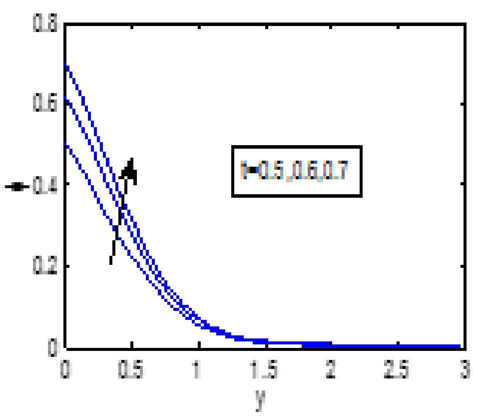

Fig.9. Concentration profile for time

The velocity profiles are illustrated in Fig.1 to 3, the temperature profiles are illustrated in Fig. 4 to 6 and the concentration profiles are illustrated in Fig.7 to 9 for different values of Soret number, Dufour number and time.

From Figs. 1, 2 and 3 it is clear that the velocity increases for *y* less than 0.5 and then decreases exponentially in the boundary layer. In Fig.1, it is noticed that, the velocity decreases with increase in Soret number and likewise Fig. 2 reveals that, the velocity increases with increase in Dufour number. Similarly, Fig. 3 indicates that, the velocity increases whenever time increases.

In Fig.4 it is seen that the temperature decreases with increasing Soret number, Fig. 5 reveals that, the temperature increases with increase in Dufour number, Fig. 6 shows that the temperature increases with increase in time.

In Fig.7 it shows that the concentration decreases with increase in Soret number and likewise Fig.8 indicates that, the concentration decreases whenever Dufour number increases. Similarly, Fig.9 reveals that, the concentration increases with increase in time.

Conclusion:

In this study, effects of Soret, Dufour and time are examined on free convective flow of a viscous incompressible fluid past along vertical surface adjacent to porous medium. The dimensionless governing equations are solved by an iterative technique based on finite difference scheme. The effect of Soret, Dufour and time has been shown graphically and results indicate that:

- Increasing Soret number (Sr) decelerates the flow, the temperature and the concentration values in the porous medium.
- The flow and the temperature are accelerated but the concentration is decelerated with the increase of Dufour number (Du).
- With an increase in time (t), the flow, the temperature and the concentration are progressively accelerated.

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