Dufour and Soret Effects of a Transient Free Convective Flow with Radiative Heat Transfer Past a Flat Plate Moving Through a Binary Mixture.

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ABSTRACT

An approximate numerical solution for the Dufour and Soret effects of a transient free convective flow with radiative heat transfer past a flat plate moving through a binary mixture for a Sisko fluid has been obtained by solving the governing equations using numerical technique. Numerical calculations are carried out for different values of dimensionless parameters and an analysis of the results obtained shows that the flow is influenced appreciably by the chemical reaction, heat source and suction or injection at the wall and also the influence of Dufour and Soret in Sisko fluid. A parametric study illustrating the influence of H and m on the skin friction, Nusselt number, and Sherwood number is conducted. The obtained results are presented graphically and in tabular form and physical aspects of the problem are discussed.

(Keywords: radiative heat, Arrhenius kinetics, boundary layer flow, binary mixture, porous plate, Dufour and Soret effects)

INTRODUCTION

It is now well known that most of the fluids used in industry do not hold commonly accepted assumptions of a linear relationship between the stress and the rate of strain and, thus are characterized as non-Newtonian fluids. The flows of such fluids present exciting challenges to engineers, mathematicians, physicists, modelers and numerical simulists. The inadequacies of the classical Navier–Stokes theory to describe rheological complex fluids such as polymer solutions, blood, paints, certain oils, and greases, have led to the development of several theories of non-Newtonian fluids. In this theory, relation connecting shear stress and shear rate is not usually linear; that is, the 'viscosity' of a non-Newtonian fluid is not constant at a given temperature and pressure, but depends on the rate of shear or on the previous kinematic history of the fluid [11]. Hence, there is no constitutive relation able to predict all non-Newtonian behaviors that can occur. So, several models were developed for predicting non-Newtonian effects like the Maxwell, the generalized Newtonian liquid (GNL) [3, 13] and the models based on differential and integral constitutive equations. The Sisko model [8], which is a special case of the GNL, is used to predict the pseudoplastic and dilatant behaviors of the fluid.

The study of non-Newtonian fluids is of special interest from both fundamental and practical point of view. The understanding of physics involved in the flows of such fluids can have immediate effects on polymer processing, coating, ink-jet printing, micro fluidics, geological flows in the earth mantle, homodynamic, the flow of colloidal suspensions, liquid crystals, additive suspensions, animal blood, turbulent shear flows, and many others. In view of this, a lot of interest has been shown towards the study of non-Newtonian flows and hence extensive literature regarding analytic and numerical solutions is available on the topic. It is also accepted now that in general, the governing equations of non-Newtonian fluids are highly non-linear and of higher order than the Navier–Stokes equations. Because of the non-linearity and the inapplicability of the superposition principle, the exact solutions are even difficult to be obtained for the case of viscous fluids [4-7].

Several excellent studies of stretching flows in materials processing were presented by Karwe and Jaluria [9, 10]. Ahmed [1] examined the similarity solution in MHD: effects of thermal diffusion and diffusion thermo on free convective heat and mass transfer over a stretching surface considering suction or injection. Tsai and Huang investigated [12] the numerical study of Soret and Dufour effects on heat and mass transfer from natural convection flow over a vertical porous medium with variable wall heat fluxes. Alan and Rahman [2] also investigate the Dufor and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction. Therefore, the objective of the present paper is to investigate the Dufour and Soret effects on an unsteady free convection flow with radiative heat transfer past a flat plate moving through a binary mixture for a Sisko fluid which the previous researchers did not take into account.

MATHEMATICAL ANALYSIS

Consider an unsteady one–dimensional convective flow of a viscous incompressible fluid with radiative heat transfer past a flat plate moving through a binary mixture (Figure 1).

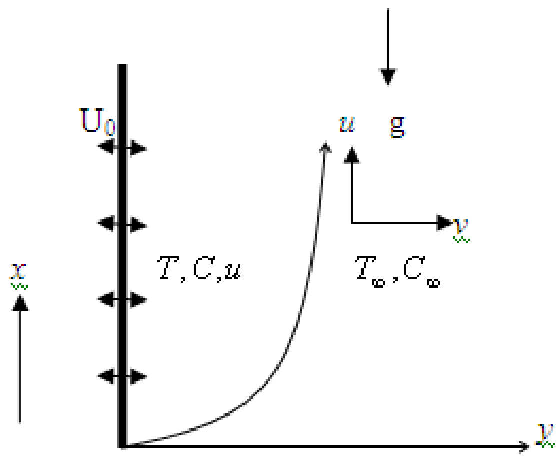

Figure 1: Flow Configuration and Coordinate System.

Let the x-axis be taken along the plate in the vertically upward direction and the y-axis be taken normal to it. Let u and v be the velocity components along the x and y directions, respectively. The physical variables are functions of y and t only. Hence, under the Boussinesq's approximation, the fluid motion in the vicinity of the plate is described by the following set of equations:

$$\frac{\partial v}{\partial y} = 0 , \quad (1)$$

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \frac{\partial}{\partial y}\left\{\left(\upsilon + h\left|\frac{\partial u}{\partial y}\right|^{m-1}\right)\frac{\partial u}{\partial y}\right\} + g\beta(T - T_\infty) + g\beta_c(C - C_\infty) \quad (2)$$

$$\rho\, c_p \left(\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial y^2} + Q - 4\sigma\alpha T^4 + \frac{Dk_T}{c_s}\frac{\partial^2 C}{\partial y^2} \quad (3)$$

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} - R_A + \frac{Dk_T}{T_m}\frac{\partial^2 T}{\partial y^2} \quad (4)$$

where u and v are components of the velocity in x and y directions, respectively, g is the acceleration due to gravity, β and β_c are coefficient of volume expansion and the coefficient of expansion with concentration ,respectively , υ is the Kinematic viscosity of the fluid , D is the chemical molecular diffusivity , k is the thermal conductivity of the fluid, ρ is the density of the fluid, T_w and T_∞ are the temperature of the fluid in the boundary layer and away from the plate, respectively, C_w and C_∞ are the concentration in the boundary layer and away from the plate, respectively, Q is the heat source, T is the temperature and t is the time.

Where $Q = (-\Delta H)R_A$ is the heat of chemical reaction; $\Delta\mathrm{H}$ is the activation enthalpy.

$R_A = k_r C_A^n$ for nth order irreversible reaction.

We employed Arrhenius type of the n^{th} order irreversible reaction given by,

$$R_A = ae^{-E/R_G T}C^n \quad (5)$$

where R_G is the universal gas constant.

The appropriate initial and boundary conditions are:

$$u(y,0) = 0,\ T(y,0) = T_w,\ \ C(y,0) = C_w \tag{6}$$

$$u(0,t) = U_0,\ T(0,t) = T_w,\ C(0,t) = C_w\ ,\ t \succ 0 \tag{7}$$

$$\frac{\partial u}{\partial y} \to 0, u \to 0,\ T \to T_\infty,\ C \to C_\infty\ as\ \ y \to \infty\ , t \succ 0 \tag{8}$$

Where U_0 is the plate characteristic velocity. We introduce similarity variables and dimensionless quantities, i.e.:

$$\eta = \frac{y}{\sqrt{4\upsilon t}} \quad ; \quad v = -c\sqrt{\frac{\upsilon}{t}}$$

$$u = \cup_0\ f(\eta); (\theta, \theta_w) = \frac{(T, T_w)}{T_\infty}; (\varphi, \varphi_w) = {(C_A, C_w)}\big/{C_\infty};$$

$$G_r = \frac{8\upsilon tg\beta T_\infty}{\cup_0}\ ; G_c = \frac{8\upsilon tg\beta_c C_\infty}{\cup_0};\ \ p_r = \frac{k}{\rho\ c_p \upsilon}; R = \frac{16\sigma\alpha T_\infty{}^3 t}{\rho c_p} \tag{9}$$

$$S_c = \frac{\upsilon}{D}; \gamma = \frac{E}{R_G T_\infty}; Du = \frac{Dk_T C_\infty}{c_s T_\infty \rho c_p \upsilon}; S_r = \frac{Dk_T T_\infty}{\upsilon T_m}; H = \frac{mh}{\upsilon}\left(\frac{U_0}{2\sqrt{\upsilon t}}\right)^{m-1}$$

From Equation (1), v is either constant or a function of time. We choose:

$$v = -c\left(\frac{\upsilon}{t}\right)^{\frac{1}{2}}, \tag{10}$$

where $c \succ 0$ is the suction parameter and $c \prec 0$ is the injection parameter. Then Equations (2) – (4) become,

$$f''\left(1 + H(f')^{m-1}\right) + 2(\eta + c) f' = -G_r(\theta - 1) - G_c(\varphi - 1) \tag{11}$$

$$\frac{1}{p_r}\theta'' + 2(\eta + c)\theta' + Du\varphi'' = -bD_a\varphi^n \exp\left(\gamma\left(1 - \frac{1}{\theta}\right)\right) + R\theta^4 \tag{12}$$

$$\frac{1}{S_c}\varphi'' + 2(\eta + c)\varphi' + S_r\theta'' = D_a\varphi^n \exp\left(\gamma\left(1 - \frac{1}{\theta}\right)\right), \tag{13}$$

with the boundary conditions

$$\begin{aligned} &f(0) = 1\ ;\ f'(\infty) = 0; \quad f(\infty) = 0 \\ &\theta(0) = \theta_w\ ;\ \theta(\infty) = 1 \\ &\varphi(0) = \varphi_w\ ;\ \varphi(\infty) = 1, \end{aligned} \tag{14}$$

where *b* is the heat generation parameter, *Da* is the Damköhler number, *Ra* is the radiation parameter, γ is the activation energy parameter, G_r is the thermal Grashof number and G_c solutal Grashof number, B is the non-Newtonian parameter and d is … Other physical quantities of interest in this problem, namely; the skin friction parameter (τ) and the Nusselt number (*Nu*) and Sherwood number (*Sh*) can be easily computed.

These quantities are defined in dimensionless terms as: $\tau = -F'(0)$, $Nu = \theta'(0)$ and $Sh = \varphi'(0)$, where the prime symbol denotes differentiation with respect to η.

NUMERICAL PROCEDURE

The set of non-linear ordinary differential Equations (11)–(13) with boundary conditions in (14) have been solved numerically by using the Runge–Kutta integration scheme with a modified version of the Newton–Raphson shooting method with B, d, G_c, G_r, γ, *Ra*, *Da*, θ_w, φ_w, c, *b*, *n*, *Sc,* and *Pr* as prescribed parameters.

The computations were done by a program which uses a symbolic and computational computer language MAPLE [2]. A step size of $\Delta\eta$ = 0.001 was selected to be satisfactory for a convergence criterion of 10^{-7} in nearly all cases. The value of y_∞ was found to each iteration loop by the assignment statement $\eta_\infty = \eta_\infty + \Delta\eta$. The maximum value of η_∞, to each group of parameters B, d, G_c, G_r, γ, *Ra*, *Da*, θ_w, φ_w, c, *b*, *n*, *Sc,* and *Pr* is determined when the values of unknown boundary conditions at η = 0 do not change to a successful loop with an error less than 10^{-7}.

RESULTS AND DISCUSSION

The problem of unsteady free convective flow with radiative heat transfer past a flat plate moving through a binary mixture has been formulated, solved numerically, and analyzed. In order to point out the effects of various parameters on flow characteristic. The following discussion is set out: To be realistic, the values of Schmidt number (Sc) are chosen for hydrogen (Sc = 0.22), water vapor (Sc = 0.62), ammonia (Sc = 0.78), and Propyl Benzene (Sc = 2.62) at temperature 25°C and one atmospheric pressure.

The values of Prandtl number is chosen to be Pr = 0.71 which represents air at temperature 25°C and one atmospheric pressure. Attention is focused on positive values of the buoyancy parameters (i.e., Grashof number G_r > 0 (which corresponds to the cooling problem) and solutal Grashof number G_c > 0 (which indicates that the chemical species concentration in the free stream region is less than the concentration at the boundary surface). The cooling problem is often encountered in engineering applications; for example in the cooling of electronic components and nuclear reactors. It is should be mentioned here that *Da* > 0 indicates an increase in the chemical reaction rate.

All parameters are primarily chosen as follows: $m=2$, $\gamma=0.1$, $Da=0.1, Sc=0.22$, $c=0.1, Ra=0.1, n=1, Gr\tau=0.1, Grc=0.1$, $H=0.1, Sr=0.1, Du=0.1, \phi_w=0.1, \theta_w=0.1$, unless otherwise stated. The effect of each flow parameters on the concentration, temperature and velocity distribution of the flow field are presented with the help of concentration profile (Figures (2) – (5)), temperature profile (Figures (6) – (9)), and velocity profiles (Figures (10) - (13)).

<u>Concentration Profile</u>

The concentration distribution of the flow field in presence of foreign species, such as water vapor (*Sc* = 0.62) is shown in Figures (2) – (4). It is affected by four flow parameters, namely Damköhler number (Da), suction parameter (c), Shroudal number (Sr) and Schmidt number (*Sc*). In Figure (2), it is observed that concentration distribution is vastly affected by the Damköhler number in the flow field. A comparative study of the curves of Figure 1 shows that the concentration distribution of the flow field decreases as Da becomes larger. Thus greater Damköhler number leads to a faster decrease in concentration of the flow field.

The effect of presence of foreign chemical species is shown in Figure (3), it is shown that concentration distribution decreases as the density of the species, thus Ammonia is expected to have the highest concentration distribution followed by water vapor and then hydrogen as depicted in Figure (3).

Figure (4) shows that concentration distribution of the flow field decreases when there is blowing (*c<0*) of the species away from the system and increases when there is injection (*c>0*) of the foreign species in to the system. Hence, concentration increases with an increase in suction parameter.

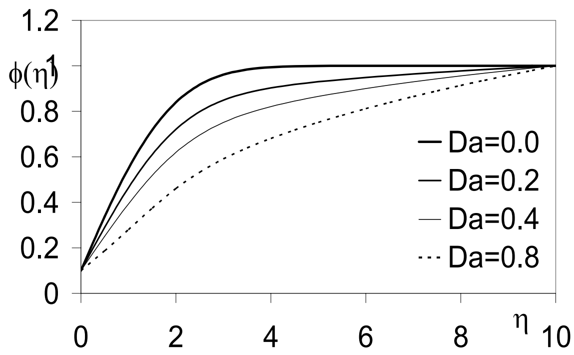

Figure 2: Concentration Profiles for various Da .

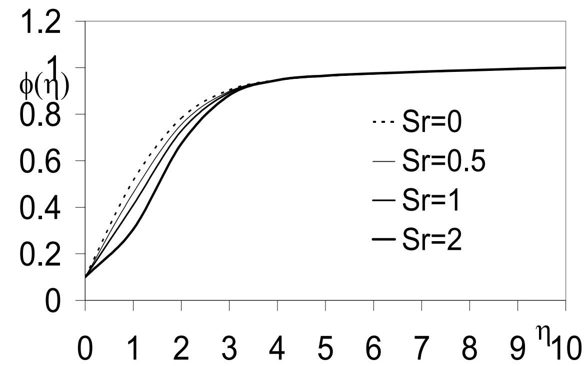

Figure 5: Concentration Profiles for various Shroudal numbers.

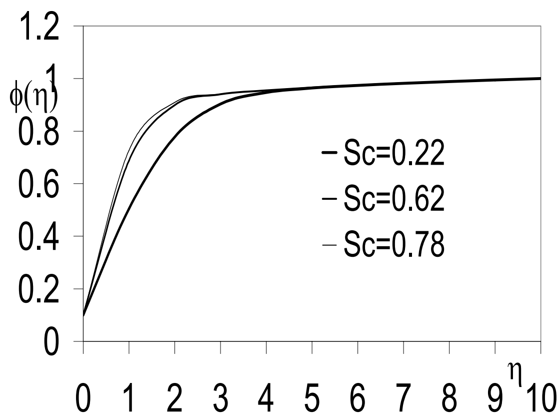

Figure 3: Concentration Profile for various Schmidt numbers.

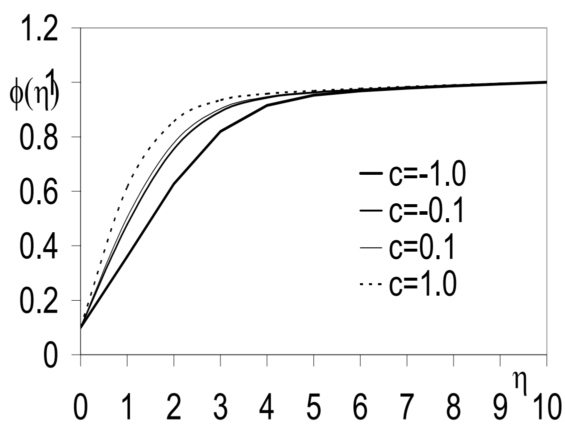

Figure 4: Concentration Profiles for various Suction Parameter.

Temperature Profile

The temperature of the flow field is mainly affected by four five parameters, namely, Damköhler number (Da), suction parameter (c), radiation parameter (Ra) and Dufour number (Du).

The effects of these parameters on the temperature field are shown graphically in Figures ((6) – (9)) and the following discussion is set out.

It is observed in Figure (6) that temperature distribution increases as the Damköhler number increases. Moreover, we observed that for higher values of Damköhler number, maximum temperature occurs, in the body of the fluid close to the surface.

Figure (7) shows that temperature distribution of the flow field in the presence of foreign species. It is observed that suction increases the temperature of the flow field close to the surface, but away from the plate, suction reduces the temperature distribution.

From Figure (8) we show that temperature distribution of the flow field increases when the radiation of heat into the system increases. This lead to occurrence of maximum temperature in the body of the fluid close to the surface. radiation increases the growth of the thermal boundary layer. It is interesting to note that at η = 2, the temperature is maximum near the plate boundary before decreasing and this could have been as a result of many parameters entering the problem.

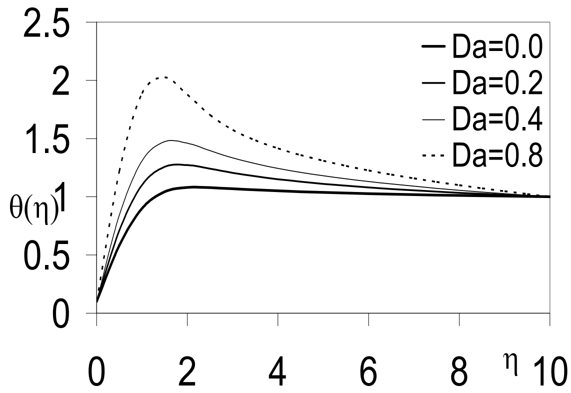

Figure 6: Temperature Profiles for various Da .

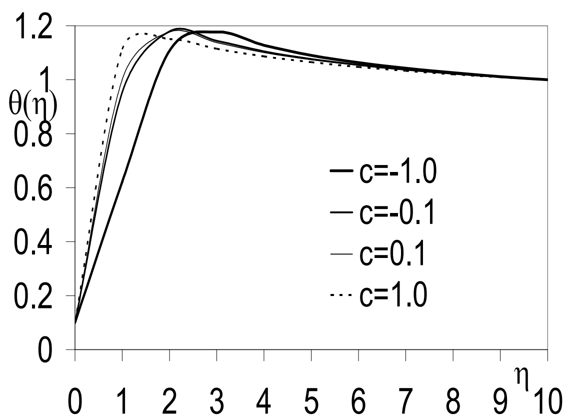

Figure 7: Temperature Profiles for various Suction Parameter.

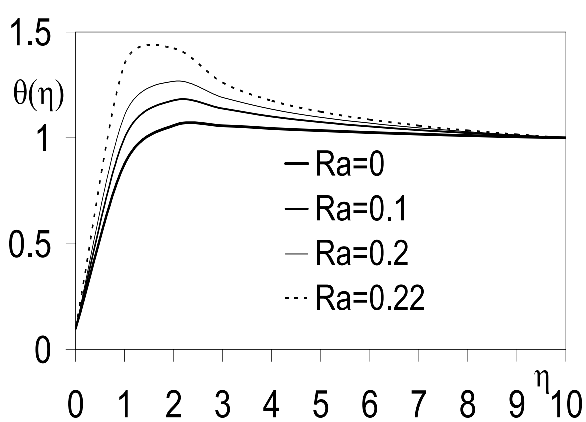

Figure 8: Temperature Profiles for various Radiation Parameters.

The effect of Dufour number on the temperature field is shown in Figure (9). We observe that temperature reduces as the Dufour number increases. Also the thermal boundary layer reduces with an increase in Dufour number.

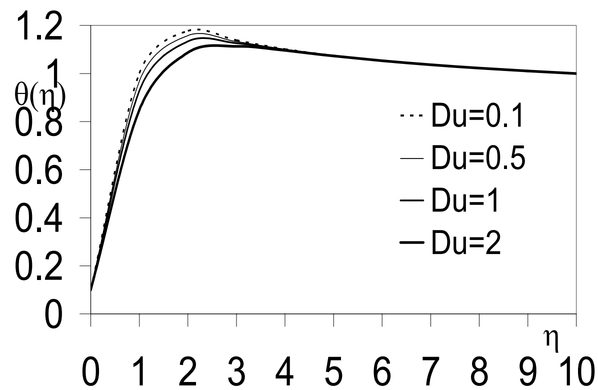

Figure 9: Temperature Profiles for various Dufour Numbers.

Table (1) (left hand side) depicts the effect of order of the chemical reaction on the temperature distribution of the flow field. We observed that temperature distribution reduces as the order of chemical reaction ***n*** increases. This is self evident from the last five columns of Table 1.

Velocity Profile

The velocity of the flow field is found to change more or less with the variation of the flow parameters. The effect of the flow parameters on the velocity field is analyzed with the help of Figures (10) - (13). Our attention is on the case of cooling of plate.

Figure (10) depicts the effect of Damköhler number (Da) on the velocity of the flow field. Here, we discovered that during cooling of the surface, velocity increases as the Damköhler number increases. This is because the presence of foreign species has the tendency to increase mass buoyancy. The velocity boundary layer also increases with an increase in Damköhler number.

In Figure (11), we show the velocity distribution of the flow field in the presence of foreign species. We observed that suction *(c<0)* increases the velocity of the flow field. On the other hand,

Table 1: Effect of n on Concentration and Temperature Distributions.

	$\phi(\eta)$				$\theta(\eta)$			
y	N=0	n=1	n=3	n=5	n=0	n=1	n=3	n=5
0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1	0.49438	0.504246	0.513612	0.518332	1.021446	1.000977	0.980801	0.970351
2	0.770041	0.77768	0.786961	0.792785	1.185768	1.177142	1.165192	1.156932
3	0.899267	0.903034	0.908499	0.912542	1.14104	1.138241	1.133509	1.1296
4	0.945358	0.947023	0.949783	0.952066	1.102651	1.101372	1.099071	1.09705
5	0.96315	0.963948	0.965382	0.966651	1.075206	1.074523	1.07326	1.072114
6	0.973596	0.974005	0.974768	0.975469	1.054102	1.05374	1.053057	1.052423
7	0.981732	0.981932	0.982313	0.982671	1.037063	1.036888	1.036553	1.036235
8	0.988629	0.988711	0.98887	0.989023	1.022828	1.022759	1.022626	1.022496
9	0.99465	0.994672	0.994714	0.994755	1.010638	1.010622	1.01059	1.010559
10	1	1	1	1	1	1	1	1

blowing *(c>0)* reduces the velocity of the flow. This is so because suction ensures the availability of chemical species with increase the buoyancy of the flow.

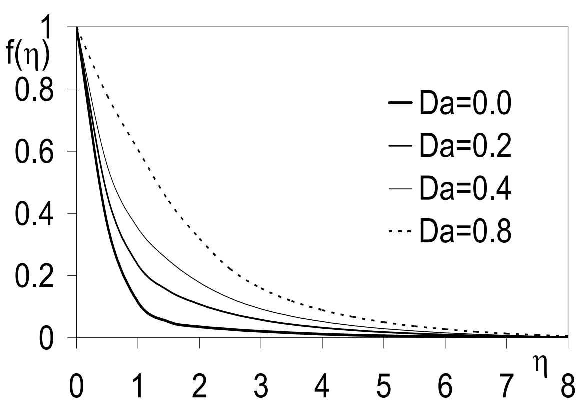

Figure 10: Variation of Velocity for Various Values of Da.

The effect of thermal Grashof number on the velocity of the flow field is presented in Figure (12). In the figure, we show that the Grashof number for heat transfer (*Grt*) accelerate the velocity of the flow field. Comparing the curves of Figure (3), it is further observed that the increase in velocity of the flow field is more significant in presence higher thermal buoyancy. Thus, heat transfer has a dominant effect on the flow field.

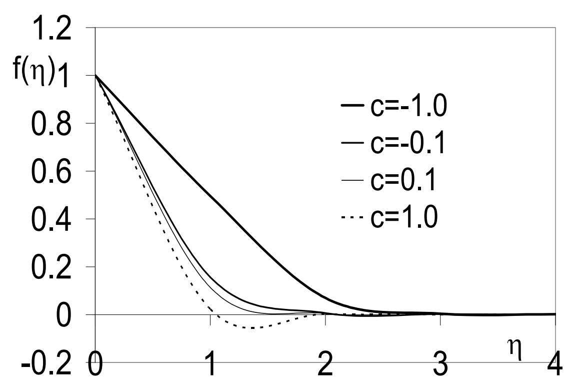

Figure 11: Variation of Velocity for Various Suction Parameters.

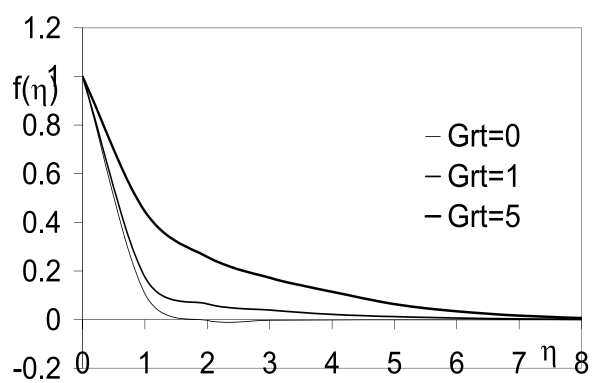

Figure 12: Variation of Velocity for Various Values of Grt.

The effects of Grashof numbers for mass transfer (Gc) on the velocity of the flow field is presented in Figure (13). A study of the curves of the figure (13) shows that the Grashof number for mass transfer decelerates the velocity of the flow field. Comparing the curves of Figure (13), it is further observed that the reverse in velocity of the flow is more pronounced with higher mass Grashof number in cooling of surface.

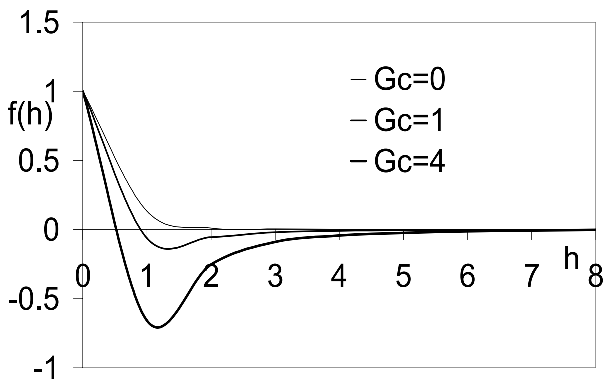

Figure 13: Variation of Velocity for Various Values of Gc.

In Figure (2), it is observed that concentration distribution is vastly affected by the Damköhler number in the flow field. A comparative study of the curves of Figure 1 shows that the concentration distribution of the flow field decreases as Da becomes larger. Thus greater Damköhler number leads to a faster decrease in concentration of the flow field.

The effect of presence of foreign chemical species is shown in Figure (3), it is shown that concentration distribution decreases as the density of the species, thus Ammonia is expected to have the highest concentration distribution followed by water vapor and then hydrogen as depicted in Figure (3).

Figure (4) shows that concentration distribution of the flow field decreases when there is blowing (*c<0*) of the species away from the system and increases when there is injection (*c>0*) of the foreign species in to the system. Hence, concentration increases with an increase in suction parameter.

We display in Figure (5) the effect of Shroudal number on the concentration distribution of the flow field. It is observed that concentration distribution decreases as Shroudal number increases.

Table (1) (left hand side) depict the effect of order of the chemical reaction on the concentration distribution of the flow field. We observed that concentration distribution increase as the order of chemical reaction ***n*** increases.

The effect of parameters H and m on the velocity field is shown in Table 2. It could be seen that velocity distribution reduces as both parameters increases.

Table 2: Effect of H and m on Velocity Distributions.

$f(\eta)$								
Y	H=0	H=0.1	H=0.2	H=0.3		m=1	m=2	M=3
0	1	1	1	1		1	1	1
1	0.122618	0.11359	0.104240754	0.083846		0.142369	0.128124855	0.11359
2	0.004371	0.0041	0.003836183	0.003307		0.006034	0.004516085	0.0041
3	0.001835	0.001834	0.001832806	0.001831		0.001853	0.00183547	0.001834
4	0.00117	0.00117	0.00116952	0.00117		0.001175	0.001169525	0.00117
5	0.000665	0.000665	0.000665264	0.000665		0.000668	0.000665265	0.000665
6	0.000354	0.000354	0.000354272	0.000354		0.000356	0.000354273	0.000354
7	0.00017	0.00017	0.000170232	0.00017		0.000171	0.000170232	0.00017
8	6.64E-05	6.64E-05	6.64186E-05	6.64E-05		6.68E-05	6.64187E-05	6.64E-05
9	1.53E-05	1.53E-05	1.52601E-05	1.53E-05		1.54E-05	1.52601E-05	1.53E-05
10	0	0	0	0		0	0	0

Table 3: Effect of Flow Control Parameters on the Values of τ, Sh and Nu for $\Pr = 0.71$.

Da	Sc	c	Ra	n	$Gr\tau$	Grc	H	Sr	Du	m	$-f'(0)$	$\phi'(0)$	$\theta'(0)$
0.0	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.712143	0.485941	1.056578
0.2	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.470197	0.3869	1.342419
0.4	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.232588	0.303242	1.635647
0.8	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	0.663565	0.168625	2.468758
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.589885	0.434327	1.199877
0.1	0.62	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.570562	0.722858	1.197894
0.1	0.78	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.567352	0.811581	1.195178
0.1	0.22	-1.0	0.1	1	0.1	0.1	0.1	0.1	0.1	1	0.299316	0.226731	0.323845
0.1	0.22	-0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.124677	0.391938	1.00246
0.1	0.22	0.0	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.262556	0.412889	1.099531
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	3.164877	0.647555	2.207697
0.1	0.22	0.1	0.0	1	0.1	0.1	0.1	0.1	0.1	1	1.424658	0.437475	1.031414
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.15	1	0.1	0.1	0.1	0.1	0.1	1	1.3982	0.43163	1.345562
0.1	0.22	0.1	0.2	1	0.1	0.1	0.1	0.1	0.1	1	1.376621	0.406731	1.711749
0.1	0.22	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	1	1.408885	0.415952	1.250444
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	3	0.1	0.1	0.1	0.1	0.1	1	1.410478	0.44705	1.165544
0.1	0.22	0.1	0.1	5	0.1	0.1	0.1	0.1	0.1	1	1.41091	0.452527	1.150807
0.1	0.22	0.1	0.1	1	0.0	0.1	0.1	0.1	0.1	1	1.389858	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	1	1.0	0.1	0.1	0.1	0.1	1	1.589885	0.434327	1.199877
0.1	0.22	0.1	0.1	1	5.0	0.1	0.1	0.1	0.1	1	2.432429	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.0	0.1	0.1	0.1	1	1.335514	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.1998
0.1	0.22	0.1	0.1	1	0.1	1.0	0.1	0.1	0.1	1	2.102611	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	4.0	0.1	0.1	0.1	1	4.919865	0.434327	1.1998
0.1	0.22	0.1	0.1	1	0.1	0.1	0.0	0.1	0.1	1	1.341782	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.2	0.1	0.1	1	1.499761	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.4	0.1	0.1	1	1.905623	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.0	0.1	1	1.40881	0.452418	1.199585
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.5	0.1	1	1.413218	0.361826	1.201055
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	1	0.1	1	1.417626	0.270883	1.202551
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	2	0.1	1	1.426443	0.087909	1.205625
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	0.0	1	1.408993	0.434074	0.434074
0.1	0.22	0.1	0.1	1	0.1	0.1	0.3	0.1	0.1	1	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.5	0.1	0.5	1	1.412471	0.435338	1.147255
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	1	1	1.415917	0.436603	1.081651
0.1	0.22	0.1	0.1	1	0.1	0.1	0.1	0.1	2	1	1.422731	0.439147	0.950676
0.1	0.22	0.1	0.1	1	0.1	0.1	0.3	0.1	0.1	1	1.270703	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.3	0.1	0.1	2	1.409691	0.434327	1.199877
0.1	0.22	0.1	0.1	1	0.1	0.1	0.3	0.1	0.1	3	1.291043	0.434327	1.199877

CONCLUSIONS

In this article we studied numerically the influence of Dufour and Soret effects on a transient free convective flow with radiative heat transfer past a flat plate moving through a binary mixture for hydrogen-air mixture as the non-chemical reacting fluid pair.

From the present work we have found that wall suction stabilizes the velocity, thermal, as well as concentration boundary layer growth. The present analysis has shown that the flow field is appreciably influence by the Dufour and Soret effects. Therefore, we can conclude that for fluids with medium molecular weight (H_2, air), Dufour and Soret effects should not be neglected. This agrees perfectly with Alam [2].

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