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TIME-DEPENDENT DOUBLE DIFFUSIVE FLOW OVER A SEMI - FINITE VERTICAL PLATE

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ABSTRACT

The focus of this investigation is on the investigation of a one-dimensional time-dependent double-diffusive mass and heat flow across a semi-infinite vertical plate, with a convective surface boundary condition. The nonlinear partial differential equations that regulate the system have been converted into a set of coupled nonlinear ordinary differential equations via the use of Similarity Transforms. These equations are then solved through the utilization of the Homotopy Perturbation Method. The purpose of this study is to investigate the unsteady MHD double diffusive natural convection flow of a viscous, incompressible, electrically conducting, heat absorbing, radiating, and chemically reactive fluid as it passes an exponentially accelerated moving inclined plate in a fluid-saturated porous medium. This flow is investigated in a situation where the temperature of the plate and the concentration at the surface of the plate have ramped profiles. Under the Boussinesq approximation, the Laplace transform approach is used to generate exact solutions for the fluid velocity, fluid temperature, and species concentration. These solutions are obtained in closed form. It is also possible to obtain the formulas for the shear stress, the rate of heat transfer, and the rate of mass transfer at the plate.

Keywords: *Time-Dependent; Double-Diffusive Flow; SemiInfinite Vertical Plate, similarity transform, Homotopy Perturbation Method*

INTRODUCTION

The phenomena of time-dependent double-diffusive flow has been shown to have several applications in a variety of scientific, engineering, and industrial activities. This flow concept is used in a wide variety of fields, including the cooling of electronic devices, the aerodynamics of nuclear reactors, the drawing of copper wires, the extrusion of plastic sheets, and the cooling of metallic plates. Numerous academics have devoted a significant amount of time and effort to investigating the issues of time-dependent double-diffusive flow (mass and heat) across a semiinfinite vertical plate. A study was conducted in 1980 by Soundalgekar, V.M. and Ganesan, P. to examine the phenomenon of transient free convective flow across a semi-infinite vertical plate with mass transfer. Elbashbeshy, E.M.A. and Ibrahim, F.N. (1993) investigated the flow of steady free convection down a vertical plate while taking into account the presence of variable viscosity and thermal diffusivity.For the transient Free Convection Past a Semi-Infinite Vertical Plate with Variable Surface Temperature, Takhar, H.S., Ganesan, P., Ekambavanan, K., and Soundalgekar, V.M. published their findings in 1997.

In their statement, they said that this kind of flow issue happens in a variety of technical and industrial applications. An investigation of the effects of varying viscosity and thermal conductivity on steady free convective flow and heat transfer down an isothermal vertical plate in the presence of a heat sink was carried out by Gaur, P. and Mahanti, N.C. in 2009. Similarity Solution for Laminar Thermal Boundary Layer over a Flat Plate with a Convective Surface Boundary Condition was the subject of research conducted by Aziz, A. (2009). Makinde, O.D. and Olanrewaju, P.O. (2010) conducted research on the effects of a convective surface boundary condition on the thermal boundary layer that was present over a vertical plate structure. The authors of the study, Aiyesimi, Y.M., Abah, S.O., and Okedayo, G.T. (2011), conducted an analysis of the flow of heat and mass transfer across a stretching vertical plate while using suction. At the 2012 conference, Abah, S.O., Eletta, B.E., and Omale, S.O. presented a numerical analysis of the effect of free convection heat and mass transfer on the flow of an unsteady boundary layer past a vertical plate. Both the conventional perturbation technique and the homotopy approach have been combined to create the Homotopy Perturbation Method. This method has been able to overcome the constraints that were associated with the previous perturbation techniques. Homotopy perturbation method, a novel nonlinear analytical methodology, was the topic of discussion in He J.H.'s publication from 2003. He's Homotopy Perturbation Method was used by Dehghan M. and Shakeri F. (2008) in order to solve a partial differential equation that arose during the modeling of flow in porous media. In this study, the governing equations were first converted into ordinary differential equations by using the similarity transformation approach, and then, the Homotopy Perturbation approach was used to solve the equations.

OBJEACTIVES

1. The Study Time-Dependent Double Diffusive Flow.
2. The Study A Semi - Finite Vertical Plate.

Mathematical Formulation

We take into consideration a time-dependent one-dimensional double-diffusive flow of a viscous, incompressible fluid across a semi-infinite vertical plate. This flow involves the transfer of mass and heat throughout the fluid. In the direction of the upward movement of the vertical semi-infinite plate, the x-axis is drawn, and the y-axis is drawn in a direction that is normal to the plate. The governing equation of the flow, which is based on the Boussinesq's approximation, is comprised of the following equations: the continuity equation, the momentum equation, the mass transfer equation, and the heat transfer equation:

$$\frac{\partial v}{\partial y} = 0$$
$$\frac{\partial u}{\partial t} = v\frac{\partial^2 u}{\partial y^2} + g\beta_c(c - c_\infty) + g\beta_T(T - T_\infty)$$
$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial y^2}$$
$$\frac{\partial T}{\partial t} = \alpha\frac{\partial^2 T}{\partial y^2}$$

The following are the boundary conditions that are suitable for this flow.

$$u = U, T = T_w, C = C_w, \text{ at } y=0$$
$$u \to 0, T \to T_\infty, C \to C_\infty, as\ y \to \infty\ at\ t > 0.$$

The dimensionless variable is introduced by the use of the similarity transform in order to transfer the governing momentum, energy, and concentration equations, as well as the boundary conditions, from partial differential equations to ordinary differential equations.

$$f(\eta) = \frac{u}{u_\infty}, \eta = \frac{y}{2\sqrt{vt}}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, G_c = \frac{4tg}{u}\beta_c(C_w - C_\infty), G_T = \frac{4tg}{u}\beta_T(T_w - T_\infty), P_r = \frac{v}{\alpha}, S_c = \frac{v}{D}$$

When we substitute the dimensionless values mentioned above into the governing equations through and the boundary conditions, we are able to construct the dimensionless version of the ordinary differential equation that is shown below:

$$\frac{d^2 f}{d\eta^2} + 2\eta\frac{df}{dn} + G_T\theta(\eta) + G_c\phi(\eta) = 0,$$
$$\frac{d^2\phi}{d\eta^2} + 2\eta s_c\frac{d\phi}{dn} = 0,$$
$$\frac{d^2\theta}{d\eta^2} + 2\eta p_r\frac{d\theta}{dn} = 0.$$

The Homotopy Perturbation Method is used in order to perform the solution of the governing boundary layer equations together with the boundary conditions There is a non-linear differential equation represented by equations The following is what we will present in order to answer these equations: Homotopy is a.

$$D(f,p) = (1-p)\left[\left(\frac{d^2 f}{d\eta^2} - \frac{d^2 f_I}{d\eta^2}\right)\right] + p\left[\frac{d^2 f}{d\eta^2} + 2\eta\frac{df}{dn} + G_T\theta + G_c\phi\right] = 0$$
$$D(\phi,p) = (1-p)\left[\frac{d^2\phi}{d\eta^2} - \frac{d^2\phi_I}{d\eta^2}\right] + P\left[\frac{d^2\phi}{dn^2} + 2\eta s_c\frac{d\phi}{dn}\right] = 0$$
$$D(\theta,p) = (1-p)\left[\frac{d^2\theta}{d\eta^2} - \frac{d^2\theta_I}{d\eta^2}\right] + P\left[\frac{d^2\theta}{dn^2} + 2\eta p_r\frac{d\theta}{dn}\right] = 0$$

It is assumed that the following is true.

$$
\begin{aligned}
f &= f_0 + pf_1 + p^2 f_2 + \cdots \\
\phi &= \phi_0 + p\phi_1 + p^2\phi_2 + \cdots \\
\theta &= \theta_0 + p\theta_1 + p^2\theta_2 + \cdots
\end{aligned}
$$

We get the zeoth order equation by including equation and then comparing the powers of p that are similar to each other.,

$$
\begin{aligned}
&\frac{d^2 f_0}{d\eta^2} - \frac{d^2 f_1}{d\eta^2} = 0, \\
&\frac{d^2 \phi_0}{d\eta^2} - \frac{d^2 \phi_1}{d\eta^2} = 0, \\
&\frac{d^2 \theta_0}{d\eta^2} - \frac{d^2 \theta_1}{d\eta^2} = 0,
\end{aligned}
$$

Through the process of solving equations with related boundary conditions and adding up the results, it is possible to derive the following functions in a sequential manner provided that p is equal to 1:

$$
f(\eta) = e^{-\eta}(2\eta + 1) + 4(\eta^2 e^{-\eta} + 4\eta e^{-\eta} + 6e^{-\eta}) - 2(\eta e^{-\eta} + 2e^{-\eta})(1 - G_T - G_C + G_T P_r + G_C S_C) - e^{-\eta}\frac{\eta^-}{2}(G_T - 4P_r G_T + G_C - 4S_C G_C) - 24e^{-\eta} + 4(G_T - 4P_r G_T + G_C - 4S_C G_C)
$$

$$
\theta(\eta) = e^{-\eta} + 2\eta S_c e^{-\eta} + 4(S_c)^2 e^{-\eta}(\eta^2 + 5\eta + 8) - 32(S_c)^2 e^{-\eta} - \frac{\eta^3 S_c}{3}
$$

$$
\phi(\eta) = e^{-\eta} + 2\eta P_r e^{-\eta} + 4(P_r)^2 e^{-\eta}(\eta^2 + 5\eta + 8) - 32(P_r)^2 e^{-\eta} - \frac{\eta^3 P_r}{3}
$$

Nomenclatures

In order to convert the governing momentum, energy, and concentration equations, as well as the boundary conditions, from partial differential equations to ordinary differential equations by using the similarity transformation approach, we will now add the dimensionless variables and quantities that are listed below:

By substituting the dimensionless values mentioned above into the governing equations through and the boundary conditions, we are able to construct the dimensionless version of the ordinary differential equation that contains the following:

When compared to the magnetic field that is applied, it is presumed that the induced magnetic field that is produced by the velocity of the fluid is insignificant. This assumption holds true for metallic liquids and partly ionized fluids, both of which are often used in a variety of industrial operations. Hence, the equation 0 B B is equivalent to The governing equations for unsteady hydromagnetic natural convection flow of a viscous, incompressible, electrically conducting, temperature-dependent heat-absorbing, optically thick radiating, and chemically reactive fluid through a fluid saturated porous medium with combined heat and mass transfer are given following the Boussinesq approximation. These equations are given in consideration of the assumptions that were made earlier.

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} - \sigma \frac{B_0^2}{\rho} u' - \frac{\nu}{K_1} u'$$
$$+ g\beta_T (T' - T'_\infty)\cos\theta + g\beta_C (C' - C'_\infty)\cos\theta,$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial y} - g\beta_T (T' - T'_\infty)\sin\theta - g\beta_C (C' - C'_\infty)\sin\theta$$

$$\rho c_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r'}{\partial y} - Q_0 (T' - T'_\infty),$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} - K_2'(C' - C'_\infty),$$

equation because fluid flow is generated owing to the movement of the plate as well as buoyant forces operating in the x-direction that are acting on the fluid. The existence of buoyant forces operating in the y-direction may cause the fluid pressure, denoted by the symbol p, to change in the y-direction, as shown by the equation. As a result, the change in fluid pressure that occurs from the plate to the border of the boundary layer is influenced by the different thermal and solutal buoyancy forces that interact with one another.

In the case of fluid flow, the beginning and boundary conditions are as follows:

$$u' = 0,\ T' = T'_\infty,\ C' = C'_\infty \qquad \text{for } y' \geq 0 \text{ and } t' \leq 0,$$

$$u' = U_0 e^{a't'} \qquad \text{at } y' = 0 \text{ and } t' > 0$$

$$\left.\begin{aligned} T' &= T'_\infty + (T'_w - T'_\infty)t'/t_0, \\ C' &= C'_\infty + (C'_w - C'_\infty)t'/t_0 \end{aligned}\right\} \qquad \text{at } y' = 0 \text{ and } 0 < t' \leq t_0$$

$$T' = T'_w,\ \ C' = C'_w \qquad \text{at } y' = 0 \text{ and } t' > t_0$$

$$u' \to 0,\ T' \to T'_\infty,\ C' \to C'_\infty \qquad \text{as } y' \to \infty \text{ and } t' > 0$$

In the case of an optically thick emitting fluid, in addition to emission, there is also self-absorption, and the absorption coefficient is often significant and depending on the wavelength of the radiation. Therefore, using the Rosseland approximation, the radiating flux vector may be written as.

$$q_r' = -\frac{4\sigma^*}{3k^*}\frac{\partial T'^4}{\partial y'},$$

$$u = 0,\ T = 0,\ C = 0, \qquad \text{at } y \geq 0 \text{ and } t \leq 0,$$

$$u = e^{at} \qquad \text{at } y = 0 \text{ and} t > 0,$$

$$T = t,\ C = t \qquad \text{at } y = 0 \text{ and } 0 < t \leq 1,$$

$$T = 1,\ C = 1 \qquad \text{at } y = 0 \text{ and } t > 1$$

$$u \to 0, T \to 0, C \to 0 \qquad \text{as } y \to \infty \text{ for } t > 0.$$

SOLUTION IN THE CASE OF UNIT SCHMIDT NUMBER

The answers for species concentration and fluid velocity, respectively, are not valid when the Schmidt number Sc is equal to This is something that should be mentioned. Sc = 1 relates to fluids that have the same order of magnitude of boundary layer thicknesses for both the momentum boundary layer and the concentration boundary layer. This is because the Schmidt number indicates the relative potency of the fluid's momentum diffusivity and chemical molecule diffusivity. On the other hand, there are several fluids that fall under this For the purpose of solving equations using the Laplace transform, Sc = 1.

$$G_1(\mathrm{y},\mathrm{t}) = -\alpha_1 \cos\theta \Big[\big\{ f_2(y, \alpha_2^2, p_1, t, 1) - f_2(y, \alpha_2^2, \phi, t, \alpha) \big\} + \frac{1}{\alpha_2^2} \times \big\{ f_1(y, -\alpha_2, p_1, t, 1) - f_1(y, -\alpha_2, \mathrm{K}_2, t, 1) \big\}$$
$$+ \frac{1}{\beta_2^2} \big\{ f_1(\mathrm{y}, -\beta_2, p_1, \mathrm{t}, 1) - f_1(\mathrm{y}, -\beta_2, \mathrm{K}_2, \mathrm{t}, 1) \big\} \Big],$$

$$p_1 = M + \frac{1}{K},\ \alpha = \frac{N+1}{P_r},\ \beta = \frac{1}{S_c}, \eta_1 = \frac{\alpha G_r \cos\theta}{\alpha - 1}, \eta_2 = \frac{\beta G_c \cos\theta}{\beta - 1}, \xi_1 = \frac{\phi - p_1\alpha}{1-\alpha},\ \xi_2 = \frac{\mathrm{K} - p_1\beta}{1-\beta},\ a_1 = N+1,$$
$$\alpha_1 = \frac{G_r}{1 - P_r / a_1},\ \alpha_2 = \frac{P_r\phi - \gamma a_1}{P_r - a_1},\ \beta_1 = \frac{G_c}{1 - S_c},\ \beta_2 = \frac{K_2 S_c - \gamma}{S_c - 1},$$

Solution in the Case of Isothermal Plate with Uniform Surface Concentration

A comparison between the fluid flow near an accelerated moving inclined plate with ramped temperature and ramped surface concentration and the fluid flow near an accelerated moving vertical plate with uniform temperature and uniform surface concentration may be worthwhile in order to highlight the effects of ramped temperature and ramped surface concentration on fluid flow. This comparison may be worthwhile because it will highlight the effects of these two factors on fluid flow. The solutions for fluid temperature, species concentration, and fluid velocity for natural convection flow past an exponentially accelerated moving inclined isothermal plate with uniform surface concentration are obtained and expressed in the following form. These solutions are obtained by keeping in mind the assumptions that were made earlier.

$$T(y,t)=f_1(y,0,\phi,t,\alpha),$$

$$C(y,t)=f_1(y,0,K_2,t,\alpha),$$

$$u(y,t)=f_1(y,a,p_1,t,1)-\frac{\eta_3}{\xi_3}\left[\{f_1(y,0,p_1,t,1)+f_1(y,-\xi_3,\phi,t,\alpha)\}-\{f_1(y,-\xi_3,p_1,t,1)+f_1(y,0,\phi,t,\alpha)\}\right]$$
$$-\frac{\eta_4}{\xi_4}\left[\{f_1(y,0,p_1,t,1)+f_4(y,-\xi_4,K_2,t,S_c)-\{f_1(y,-\xi_4,p_1,t,1)+f_4(y,0,K_2,t,S_c)\}\right],$$

Where

$$\eta_3=\frac{\alpha G_r\cos\theta}{\alpha-1},\ \xi_3=\frac{\phi-p_1\alpha}{1-\alpha},\ \eta_4=\frac{G_c\cos\theta}{1-S_c}\ \text{and}\ \xi_4=\frac{K_2S_c-p_1}{S_c-1}.$$

For Plate with Ramped Temperature and Ramped Surface Concentration

$$\tau=-f_5(p_1,a,1,t)+G_2(y,t)+G_2(y,t-1)H(t-1),$$

$$N_u=\left(\frac{1}{2\sqrt{\alpha\phi}}+t\sqrt{\frac{\phi}{\alpha}}\right)\left[Erfc\left(\sqrt{t\phi}\right)-1\right]+\sqrt{\frac{t}{\pi\alpha}}e^{-t\phi},$$

$$S_h=-\left[\frac{te^{-K_2t}}{\sqrt{\pi t\beta}}+\sqrt{\frac{K_2}{\beta}}\left(t+\frac{1}{2\beta}\right)\left\{1-Erfc\left(\sqrt{K_2t}\right)\right\}\right].$$

For Plate with Uniform Temperature and Uniform Surface Concentration

$$\tau=\frac{-e^{at}}{2}f_6(p_1,a,1,t,1)-\frac{\eta_3}{\xi_3}\left[\{f_6(p_1,0,1,t,1)-f_7(\phi,0,\alpha,t,1)\}+e^{-\xi_3t}\{f_6(\phi,-\xi_3,\alpha,t,1)-f_6(p_1,-\xi_3,1,t,1)\}\right]$$
$$-\frac{\eta_4}{\xi_4}\times\left[\{f_6(p_1,0,1,t,1)-f_7(K_2,0,1,t,S_c)\}+e^{-\xi_4t}\{f_6(K_2,-\xi_4,1,t,S_c)-f_6(p_1,-\xi_4,1,t,1)\}\right],$$

$$N_u=f_6(\phi,0,\alpha,t,1),$$

$$S_h=\sqrt{\frac{K_2}{\beta}}\left\{1-erfc\left(\sqrt{K_2t}\right)\right\}+\frac{e^{-K_2t}}{\sqrt{\pi\beta t}},$$

Where

$$G_2(y,t)=\eta_1\left[\frac{e^{-t\xi_1}}{\xi_1^2}\{-f_6(\phi,-\xi_1,\alpha,t,1)+f_5(p_1,-\xi_1,1,t)\}+\frac{1}{\xi_1}\{-f_5(\phi,\xi_1,\alpha,t)+f_5(p_1,\xi_1,1,t)\}\right]$$
$$+\eta_2\left[\frac{e^{-t\xi_2}}{\xi_2}\times\{-f_6(K_1,-\xi_2,\beta,t,1)+f_5(p_1,\xi_2,1,t)\}+\frac{1}{\xi_2^2}\{-f_5(K_1,\xi_2,\beta,t)+f_5(p_1,\xi_2,1,t)\}\right].$$

CONCLUSION

A time-dependent double-diffusive flow across a semi-infinite vertical plate has been the subject of a rigorous theoretical investigation that has been carried out. Both the Runge-Kutta technique and the shooting method, which is included within the Maple program, are used in order to solve the nonlinear equations that control the issue using numerical methods. A series of numerical experiments were carried out in order to demonstrate the influence that the different physical factors have on the velocity, temperature, and concentration profile.It is possible to derive the skin-friction coefficient, the Nusselt number, and the Sherwood number by receptive means. demonstrates the numerical calculations that were performed for a variety of values of the thermal Grashoff number, the concentration Grashoff number, the Prandtl number, and the Schmidt number Sc for the skin friction coefficient. The numerical values of temperature distribution are shown to decrease as the Schmidt number SC rises, as seen in Table 2. illustrate the fact that the numerical values of the Concentration distribution drop as the Prandtl number grows.

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