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Research Article

BUOYANCY EFFECTS OF OIL SPILL ON THE SEA SURFACE WITH THERMAL AND CHEMICAL REACTION

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Abstract

Pollution arises when the concentration of various chemical or biological components is more than what is thought to be advantageous for resources, the environment, human health, and amenity. One of the main environmental hazards that often has long-term consequences. The main objective of response activities is to lessen the effects of an oil spill on the environment and public health. This research allows us to fully comprehend the impact of the oil spill in the presence of concentration and thermal buoyancy effects. The perturbation technique is used to solve the governing equations and associated boundary conditions analytically once they have been converted into dimensionless form. A variety of physical properties, such as chemical reactions and the Grash of, Prandtl and Schmidt Number.

Keywords: *Oil spill, Concentration of oil particle, Heat and mass transfer, Chemical reaction, Perturbation technique.*

Introduction

Marques et al. take into account the impact of fluid slippage at the wall for Coutte flow. Many scholars have investigated steady two-dimensional oblique stagnation point flow of various fluids on a stretching surface. Gupta and Reza. The MHD flow of a micropolar fluid approaches a non-linear stretching surface close to a stagnation point. Additionally, Nadeem et al. Mustafa et al. looked into the stagnation point flow of a nano fluid in the direction of a stretching sheet. They were the first to use the Nield and Kuznets model to investigate boundary layer flow over a stretching sheet. Rokni and Sheikholeslami talked about the significance of magnetic fields in nanofluid frameworks. Three-dimensional stagnation-point flow and heat transport in a nanofluid were examined by Bachok et al.

Mathematical Formulation

The balance laws of mass, linear momentum in the presence of thermal and concentration buoyancy effects, including the force of Corioil (caused by earth rotation), the energy equation, and the concentration equation with homogeneous first order chemical reaction serve as the foundation for the governing equations for this problem.

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

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \vartheta\left(1 + \frac{1}{\beta c}\right)\frac{\partial^2 u}{\partial y^2} + g\beta_T(T - T_1) + g\beta_c(C - C_1) + fv \tag{2}$$

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = \mathrm{D}\frac{\partial^2 C}{\partial y^2} - k_1(C - C_1) \tag{4}$$

Where the components of velocities along the x and y directions are denoted by u and v, respectively. T represents the oil's temperature, C its concentration, and T_1 and C_1 its temperature and concentration at the oil's upper surface, respectively. The following are the proper boundary conditions for the velocity, temperature, and concentration fields under these assumptions: ρ is the oil density, ϑ is the kinematic viscosity, Cp is the specific heat at constant pressure, D is the mass diffusivity, g is the gravitational acceleration, f is the Corioils parameter, k is the thermal conductivity, and K_1 is the chemical reaction parameter.

$u = 0$, T=$T_0 + \varepsilon e^{nt}(T_0 - T_1)$, C= $C_0 + \varepsilon e^{nt}(C_0 - C_1)aty = 0$ (5)

$u = u_0, T = T_1, C = C_1$, at $y = 1$

Where ε is the perturbation parameter, u_0 and n are constants, and T_0 and C_0 are the temperature and concentration at the oil's lower surface, respectively.

Using non-dimensional quantities:

$u' = \frac{u}{v_0}, t' = \frac{t{v_0}^2}{\vartheta}, \quad y' = \frac{yv_0}{\vartheta}, \quad \theta = \frac{T-T_1}{T_0-T_1} \quad , \quad \varphi = \frac{C-C_1}{C_0-C_1}$

Where, θ and $\varphi$are dimensionless temperature and concentration respectively.

Making use of the non-dimensional variables in equation (1) to (4), neglecting the (′) symbol gives

$\frac{\partial v}{\partial y} = 0$ (6)

This suggests that v=v_0, where v_0 is a real positive constant that is also referred to as the characteristic velocity.

$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial y} = \left(1 + \frac{1}{\beta_c}\right)\frac{\partial^2 u}{\partial y^2} + G_r\theta + G_C\varphi + \frac{1}{R_0}$(7)

$\frac{\partial \theta}{\partial t} + \frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2}$(8)

$\frac{\partial \varphi}{\partial t} + \frac{\partial \varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} - K\varphi$ (9)

Where,

Gr=$\frac{\vartheta g \beta_T (T_0 - T_1)}{v_0^3}$ – Thermal Grashof number,

Gc =$\frac{\vartheta g \beta_c (C_0 - C_1)}{v_0^3}$–Mass Grash of number,

Pr = $\frac{\rho C_p \vartheta}{k}$ –Prandtl number,

Ro = $\frac{v_0}{fv}$ –Rossby number,

Sc = $\frac{\vartheta}{D}$ – Schmidt number,

K = $\frac{k_1 \vartheta}{v_0^2}$ –Chemical reaction parameter.

The boundary conditions (5) in non-dimensional form are;

u =0, $\theta = 1 + \varepsilon e^{nt}, \varphi = 1 + \varepsilon e^{nt} at\ y = 0$

$u = 1, \theta = 0, \ \varphi = 0$ at$y = 1$

(10)

Manner of Solution

The partial differential equations in equations (7) through (9) are a group of problems that are challenging to solve in closed form. However, by using the perturbation approach, it may be reduced to a set of ordinary differential equations that can be solved analytically (1, 7, 8, and 9). To do this, the velocity, temperature, and concentration can be represented as follows:

$u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2)$ (11)

$\theta(y,t) = \theta_0(y) + \varepsilon e^{nt}(y) + O(\varepsilon^2)$ (12)

$\varphi(y,t) = \varphi_0(y) + \varepsilon e^{nt}(y) + O(\varepsilon^2)$ (13)

Using the perturbation technique and the following set of differential equations for$u_0, \theta_{0,} \varphi_0\ and\ u_{1,} \theta_1, \varphi_1$ and ignoring the higher order of (ε^2)

Zero Order Equation

$(1 + \frac{1}{\beta_c})u_{0yy} - u_{0y} + Gr\theta_0 + Gc\varphi_0 + \frac{1}{Ro} = 0$ (14)

$\theta_{0yy} - Pr\theta_{0y} = 0$ (15)

$\varphi_{0yy} - Sc\varphi_{0y} - ScK\varphi_0 = 0$ (16)

Subject to the boundary conditions

$u_0 = 0, \theta_0 = 1, \varphi_0 = 1\ at\ y = 0$

$u_0 = 1, \theta_0 = 0, \varphi_0 = 0\ at\ y = 1$

First order Equation

$\left(1 + \frac{1}{\beta_c}\right)u_{1yy} - u_{1y} - nu_1 + Gr\theta_1 + Gc\varphi_1 = 0$

$\theta_{1yy} - Pr\theta_{1y} - Prn\theta_1 = 0$(16)

$\varphi_{1yy} - Sc\varphi_{1y} - Sc(n + k)\varphi_1 = 0$ (17)

Subject to the boundary conditions,

$u_1 = 0, \theta_1 = 1, \varphi_1 = 1\ at\ y = 0$

$u_1 = 1, \theta_1 = 0, \varphi_1 = 0 \; at \; y = 1$(19)

Using ordinary differential equations to solve the zeroth order equations while taking the boundary conditions into consideration

$$\left(1 + \frac{1}{\beta_c}\right) u_{0yy} - u_{0y} + G_r \theta_0 + G_c \varphi_0 + \frac{1}{R_0} = 0$$

$$\begin{aligned}\left(1 + \frac{1}{\beta_c}\right) u_{0yy} - u_{0y} + G_r \left[\frac{1}{(1 - e^{P_r})} (e^{P_r y} - e^{P_r})\right] \\ + G_C \left[\frac{1}{e^{m_1} - e^{m_2}} (e^{m_1} e^{m_2 y} \right. \\ \left. - e^{m_2} e^{m_1 y})\right] + \frac{1}{R_0} = 0\end{aligned}$$

$S_1 u_{0yy} - u_{0y} + S_2 + S_3 + S_4 = 0$

$$S_1 u_{0yy} - u_{0y} + S_5 = 0$$

$(S_1 D^2 - D) u_0 + S_5 = 0$

$$D(S_1 D - 1) u_0 + S_5 = 0$$

$u_0 = \frac{1}{(e^{m_{10}} - 1)} (e^{m_{10} y} - 1) + S_5$(20)

$$\theta_{0yy} - P_r \theta_{0y} = 0$$

$$(D^2 - P_r D)\theta_0 = 0$$

$$D(D - P_r)\theta_0 = 0$$

$$\theta_0 = A_5 e^{m_5 y} + A_6$$

$\theta_0 = \frac{1}{(1 - e^{P_r})} (e^{P_r y} - e^{P_r})$(21)

$$\varphi_{0yy} - S_c \varphi_{0y} - S_c k \varphi_0 = 0$$

$$(D^2 - S_c D - S_c k)\varphi_0 = 0$$

$$\varphi_0 = A_1 e^{m_1 y} + A_2 e^{m_2 y}$$

$\varphi_0 = \frac{1}{e^{m_1} - e^{m_2}} (e^{m_1} e^{m_2 y} - e^{m_2} e^{m_1 y})$(22)

By applying ordinary differential equations to the 1st order equations, the boundary conditions are taken into consideration.

$$\begin{aligned}\left(1 + \frac{1}{\beta_c}\right) u_{1yy} - u_{1y} - n u_1 \\ + G_r \left[\frac{1}{e^{m_7} - e^{m_8}} (e^{m_7} e^{m_8 y} \right. \\ \left. - e^{m_8} e^{m_7 y})\right] \\ + G_c \left[\frac{1}{e^{m_3} - e^{m_4}} (e^{m_4 y} e^{m_3} \right. \\ \left. - e^{m_4} e^{m_3 y})\right]\end{aligned}$$

$$\left(1 + \frac{1}{\beta_c}\right) u_{1yy} - u_{1y} - n u_1 + S_6 + S_7 = 0$$

$$(S_1 u_{1yy} - u_{1y} - n u_1) + S_8 = 0$$

$(S_1 D'' - D' - n) u_1 + S_8 = 0$

$$u_1 = A_{11} e^{m_{11} y} + A_{12} e^{m_{12} y}$$

$$u_1 = 0 + S_8$$

$u_1 = S_8$(23)

$$\theta_{1yy} - P_r \theta_{1y} - P_r n \theta_1 = 0$$

$$(D^2 - P_r D - P_r n)\theta_1 = 0$$

$$\theta_1 = A_7 e^{m_7 y} + A_8 e^{m_8 y}$$

$\theta_1 = \frac{1}{e^{m_7} - e^{m_8}} (e^{m_7} e^{m_8 y} - e^{m_8} e^{m_7 y})$(24)

$$\varphi_{1yy} - S_c \varphi_{1y} - S_c (n + k)\varphi_1 = 0$$

$[D^2 - S_c D - S_c (n + k)]\varphi_1 = 0$

$$\varphi_1 = A_3 e^{m_3 y} + A_4 e^{m_4 y}$$

$\varphi_1 = \frac{1}{e^{m_3} - e^{m_4}} (e^{m_3} e^{m_4 y} - e^{m_4} e^{m_3 y})$(25)

The velocity, temperature, and concentration distributions are obtained by applying the boundary conditions to the solutions of equations (20)–(22) and (23)–(25).

$$\begin{aligned}u(y,t) = \frac{1}{(e^{m_{10}} - 1)} (e^{m_{10} y} - 1) + s_5 \\ + \varepsilon e^{nt} S_8\end{aligned}$$

$$\begin{aligned}\theta(y,t) = \frac{1}{(1 - e^{P_r})} (e^{P_r y} - e^{P_r}) \\ + \varepsilon e^{nt} [\frac{1}{e^{m_7} - e^{m_8}} (e^{m_7} e^{m_8 y} \\ - e^{m_8} e^{m_9 y})\end{aligned}$$

$$\begin{aligned}\varphi(y,t) = \frac{1}{e^{m_1} - e^{m_3}} (e^{m_1} e^{m_2 y} - e^{m_2} e^{m_1 y}) \\ + \varepsilon e^{nt} [\frac{1}{e^{m_3} - e^{m_4}} (e^{m_3} e^{m_4 y} \\ - e^{m_4} e^{m_3 y})]\end{aligned}$$

Conclusion

approach, integrating scientific research, technological innovation, and policy development to protect marine ecosystems and sustain human activities dependent on the health of our oceans.

Appendix

$$m_1 = \frac{S_c + \sqrt{S_c^2 + 4 S_c k}}{2},$$

$$m_2 = \frac{S_c - \sqrt{S_c^2 + 4 s_c k}}{2},$$

$$m_3 = \frac{S_C + \sqrt{S_c^2 + 4 S_c (n + k)}}{2},$$

$$m_4 = \frac{S_C - \sqrt{S_c^2 + 4 S_c (n + k)}}{2},$$

$$m_5 = 0,$$

$$m_6 = P_r,$$

$$m_7 = \frac{P_r + \sqrt{P_r^2 + 4P_r n}}{2},$$

$$m_8 = \frac{P_r - \sqrt{P_r^2 + 4P_r n}}{2},$$

$$m_9 = 0,$$

$$m_{10} = \frac{1}{S_1}$$

$$A_1 = \frac{-e^{m_2}}{e^{m_1} - e^{m_2}}$$

$$A_2 = \frac{e^{m_1}}{e^{m_1} - e^{m_2}}$$

$$A_3 = \frac{-e^{m_4}}{e^{m_3} - e^{m_4}}$$

$$A_4 = \frac{e^{m_3}}{e^{m_3} - e^{m_4}}$$

$$A_5 = \frac{1}{(1 - e^{P_r})}$$

$$A_6 = \frac{-e^{P_r}}{(1 - e^{P_r})}$$

$$A_7 = \frac{-e^{m_8}}{e^{m_7} - e^{m_8}}$$

$$A_8 = \frac{e^{m_7}}{e^{m_7} - e^{m_8}}$$

$$A_9 = \frac{-1}{(e^{m_{10}} - 1)}$$

$$A_{10} = \frac{1}{(e^{m_{10}} - 1)}$$

Nomenclature

K −Chemical reaction parameter

Sc −Schmidt number

T' − Fluid temperature

ϑ − Kinematic viscosity

ρ − Fluid density

θ − Dimensionless temperature

φ − Viscous dissipation per unit volume

β − Volumetric expansion for heat transfer

c' − Species Concentration

$C_\infty{}'$ − Species Concentration in free stream

$C_\omega{}'$ − Species Concentration at the plate

C_ρ − Specific heat at constant pressure

D_M − Mass diffusion coefficient

Ec − Eckert number

Gr− Grashof number for heat transfer

Gm− Grashof number for mass transfer

K' − Rate of first order chemical reaction

k' − Permeability of porous medium

$k_\rho{}'$ − Mean permeability

k_ρ − Permeability parameter

p_∞ − Pressure in the free stream

Pr− Prandtl number

Re − Reynolds number

Sc − Schmidt number

T' − Fluid temperature

$T_\infty{}'$ −Temperature at the free stream

$T_\omega{}'$ − Temperature at the plate

$\propto$ − Velocity ratio parameter

μ − Coefficient of viscosity

k − Thermal conductivity

$\emptyset$ − Dimensionless concentration

β' − Volumetric expansion for mass transfer.

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