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Radiated chemical reaction impacts on natural convective MHD mass transfer flow induced by a vertical cone

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ABSTRACT

The consequence of thermal radiation in laminar natural convective hydromagnetic flow of viscous incompressible fluid past a vertical cone with mass transfer under the influence of chemical reaction with heat source/sink is presented here. The surface of the cone is focused to a variable wall temperature (VWT) and wall concentration (VWC). The fluid considered here is a gray absorbing and emitting, but non-scattering medium. The boundary layer dimensionless equations governing the flow are solved by an implicit finite-difference scheme of Crank–Nicolson which has speedy convergence and stable. This method converts the dimensionless equations into a system of tri-diagonal equations and which are then solved by using well known Thomas algorithm. Numerical solutions are obtained for momentum, temperature, concentration, local and average shear stress, heat and mass transfer rates for various values of parameters Pr, Sc, λ, Δ, R_d are established with graphical representations. We observed that the liquid velocity decreased for higher values of Prandtl and Schmidt numbers. The temperature is boost up for decreasing values of Schimdt and Prandtl numbers. The enhancement in radiative parameter gives more heat to liquid due to which temperature is enhanced significantly.

Introduction

Numerical investigations of convection stimulated by the effect of buoyancy forces ensuing from thermal diffusion have always been significant attention to many researchers. Every natural convection process occurs in nature or in any scientific and engineering applications. Many researchers examined natural convection boundary layer flow of an electrically conducting fluid in the existence of MHD because of its relevances [1–5]. Inclusion of radiation field completely reliable with the fluid, called radiative hydrodynamics. Further, the radiative flows are commonly occurred in different engineering and ecological growth, e.g., heating and cooling compartments, relic energy burning, and desertion from vast open water tanks, planetary moves, and astral power tools [6–10].

Several authors developed similarity solutions for two-dimensional axi-symmetric problems of natural convection laminar flow over a vertical cone under steady state situation. General relations for similarity solutions on isothermal axi-symmetric and vertical cone problems have been established by Merk and Prins [11,12]. Hering and Grosh [13] showed that similarity solutions exist for steady free convection flow over vertical cone with variable surface temperature, and it varies as a power-law function of the distance from the apex along the cone ray. Numerical solutions of the transformed boundary layer equations were obtained for both an isothermal and linear surface temperature at the Prandtl number Pr = 0.7. Also noticed that the velocity and temperature in the case of an isothermal surface are higher by 22% than the corresponding values of these parameters in the case of linear surface temperature distribution.

Hering [14] extended the problem of Hering and Grosh [3] for low-Prandtl-number fluids and obtained numerical solutions for liquid metals. He concluded that the boundary layer thickness is greater for low-Prandtl-number fluids. Kafoussias [15] analyzed the effects of mass transfer on a free convective flow past a vertical cone surface embedded in an infinite, incompressible, and viscous fluid. Vajravelu and Nayfeh [16] methodically described the convection flow and heat transfer in a viscous heat generating fluid near a cone and wedge with variable surface temperature and internal heat generation or absorption. The governing flow and heat transfer equations are solved numerically by using a variable order, variable step size finite-difference method. Abd El-Naby et al. [17] obtained the solutions for the effects of radiation on an unsteady magneto hydrodynamic free convection flow past a

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Nomenclature

a, b	constants
C'	concentration in the fluid [mol m^{-3}]
C_P	specific heat [JKg^{-1}K^{-1}]
Gr_L	Grashof number (thermal)
g	gravitational force [ms^{-2}]
k_1	chemical reaction parameter (dimensional) [J]
L	referal length [m]
n	variationalpower law exponent in surface temperature
Nu_x	heat transfer rate (local)
Nu_X	local Nusselt number (non-dimensional)
Pr	Prandtl number
Q_0	heat generation and absorption coefficient (dimensional) [Wm^{-3}]
R_d	radiation (dimensionless)
Sc	Schmidt number
T	temperature (non-dimensional)
t	time (non-dimensional)
u	momentum over x direction (dimensional) [ms^{-1}]
v	momentum over y direction (dimensional)
x	spatial co-ordinate alongside the cone generator (dimensional) [m]
y	spatial co-ordinate perpendicular to cone generator (dimensional) [m]
B_0	magnetic field induction [*telsa*]
C'_∞	concentration far-away from cone surface
D	mass diffusivity [m^2 s^{-1}]
Gr_c	Grashof number (mass)
k	thermal conductivity [Wm^{-1} K^{-1}]
k^*	mean absorption coefficient [m^2]
m	variationalpower law exponent in surface concentration
N	ratio due to buoyancy force (non dimensional)
$\overline{Nu_L}$	heat transfer rate (average)
$\overline{Nu}$	average heat transfer rate (non-dimensional)
q_r	thermal radiation (dimensional)
R	local radius (dimensionless)
r	local radius of the cone [m]
T'	Temperature [K^0]
t'	Time [s]
U	momentum along X direction (non-dimensional)
V	momentum along Y direction (non-dimensional)
X	spatial co-ordinate alongside the cone generator (non-dimensional)
Y	spatial co-ordinate perpendicular to cone generator (non-dimensional)

Greek symbols

α	thermal diffusivity [m^2 s^{-1}]
β_c	coefficient of volumetric expansion due to concentration [^{0}k^{-1}]
λ	Parameter of chemical reaction (non-dimensional)
σ	electrical conductivity [sm^{-1}]
ϕ	cone apex half-angle [rad]
Δt	time step (non-dimensional)
ΔY	grid size (Ydirection) (non-dimensional)
ν	kinematic viscosity [m^2 s^{-1}]
τ_X	local shear stress (non-dimensional)
$\overline{\tau}$	average shear stress (non-dimensional)
β	volumetric thermal expansion [^{0}k^{-1}]
Δ	heat generation/absorption parameter (non-dimensional)
ρ	density [kg m^{-3}]
σ^*	Stefan-Boltzmann constant
$-\theta'(\infty, 0)$	local Nusselt number
ΔX	grid size (X direction) (non-dimensional)
μ	dynamic viscosity [kg m^{-1} s^{-1}]
τ_x	local shear stress
$\overline{\tau_L}$	average shear stress

Subscripts

w	wall condition
∞	free-stream condition

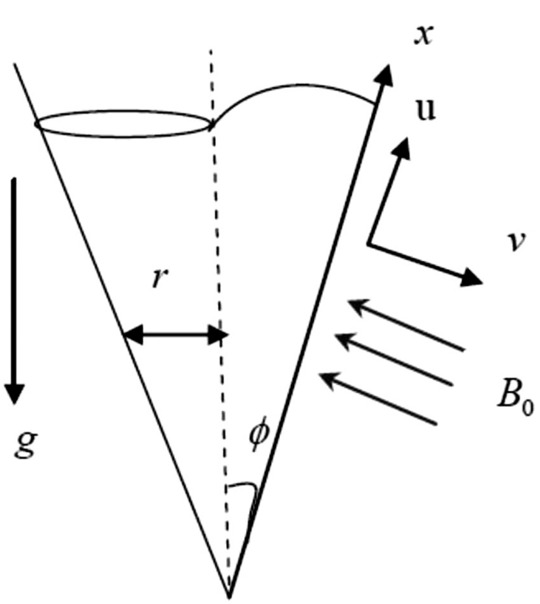

Fig. 1. Physical model and coordinate system.

Table 1
Comparison of steady-state local skin friction and local Nusselt number values at $X = 1.0$ with those of Chamkha [39] for full cone, for various values of Pr when $n = 0$, $M = 0, N = 0$ and $R_d = 0$.

	Local skin friction		Local Nusselt number	
	Chamkha [39]	Present values	Chamkha [39]	Present results
Pr	$f''(\infty, 0)$	$\tau_X/Gr_L^{\frac{3}{4}}$	$-\theta'(\infty, 0)$	$Nu_X/Gr_L^{\frac{1}{4}}$
0.001	1.5135	1.4149	0.0245	0.0294
0.01	1.3549	1.3356	0.0751	0.0797
0.1	1.0962	1.0911	0.2116	0.2115
1	0.7697	0.7688	0.5111	0.5125
10	0.4877	0.4856	1.0342	1.0356
100	0.2895	0.2879	1.9230	1.9316
1000	0.1661	0.1637	3.4700	3.5186

semi-infinite vertical porous plate in the presence of a transverse uniform magnetic field. Thandapani et al. [18] discussed the influence of a magnetic field and thermal radiation on natural convection over a vertical cone subjected to a variable surface temperature and they used Rosseland approximation to describe the radiative heat flux in the energy equation and the set of non-dimensional governing equations are solved by the finite-difference method. The unsteady mixed convection flow from a