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Unsteady radiative flow of chemically reacting fluid over a convectively heated stretchable surface with cross-diffusion gradients

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ABSTRACT

The unsteady radiative flow of chemically reacting fluid over bilaterally stretching surface is under consideration. The surface is convectively heated and influence of thermal and concentration gradients is also taken into account. The resulting nondimensional form of the radiative flow model is obtained after utilizing the feasible set of self-similar variables. Further, model is treated numerically with the help of Runge-Kutta scheme after reduced the model into coupled system of first order initial value problem. Influence of the different flow parameters specially Biot's number, Radiation and chemical reaction parameters are discussed for different values. Also, steady and two dimensional case of the current model is plotted. The graphically comparison between thermal and concentration fields is also provided in the presence and absence of thermal and concentration gradients. Impact of ingrained physical parameters on skin friction coefficient, heat and mass transfer gradients performed numerically. The significant effects of Radiation and chemical reaction parameters on thermal and concentration of the fluid observed. Finally, core findings of the study are mentioned in the last section of the letter.

1. Introduction

The analysis of viscous incompressible fluid in the presence of thermal radiation, chemical reaction, thermal and concentration gradients over convectively heated bi-literally stretching surface is a motive of great interest. Such type of Newtonian flow models has many applications particularly in industrial and engineering sides. Few applications are in power generation, fiber production, wire drawing, glass and cooling of electronics devices.

The earlier work in the era of 3D flow over stretchable surface (either Newtonian or non-Newtonian) in rotating or non-rotating frame was done by Crane [1] in 1970. Afterwards, in 1977, Gupta et al. [2] explored the influence of suction or blowing parameter on 3D flow over bi-directionally stretchable surface. Influence of various flow parameters on thermal and concentration of the fluid is part of his analysis. Afterwards, heat transfer of the fluid over uninterruptedly surface reported in Ref. [3]. The flow of rotating fluid over stretching surface situated in Cartesian coordinate system investigated by Wang [4] in 1988. They discussed the influence of a very significant dimensionless parameter λ in fluid model. Aforementioned parameter is the ration of revolution to stretching rate of the sheet. Further, they explored the solutions of the model by means of regular perturbation technique and performed the solutions for smaller values of the parameter λ.

In 2016, Sharidan et al. [5] investigated the time dependent boundary layer flow over stretchable porous surface. Cross-diffusion gradients (thermo-diffusion and diffusion-thermo effects) play vital role in the flow filed in different geometries like converging/diverging channels [6], Riga plates [7], parallel plates and stretchable surface etc. Recently, in 2016, thermo-diffusion and diffusion-thermo effects (also known as soret and dufour effects) on 3D unsteady flow over expanding surface explored by Reddy et al. [8]. They also discussed the influence of applied magnetic field. Their study also covered the variations in the flow field duo to varying thermophoresis parameter and non-uniform heat generation and absorption. Recently, Khan et al. [9] reported the flow of

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Nomenclature

a, b	Constants
C_w	Concentration at the wall
c	Stretching ratio parameter
$\boldsymbol{B}$	Imposed magnetic field
c_p	Specific heat capacity
B_0	Strength of magnetic field
t	Time
u	Velocity component along x-axis
v	Velocity component along y-axis
z	Velocity component along z-axis
u_w	Stretching sheet velocity along x-axis
v_w	Stretching sheet velocity along y-axis
x, y, z	Coordinates
ρ	Density
μ	Dynamic viscosity
k	Thermal conductivity
K_T	Thermal diffusion
D	Mass diffusivity
T_m	Mean temperature
C_s	Concentration susceptibility
σ^*	Stefan Boltzmann constant
k^*	mean absorption coefficient
S	Unsteady parameter
Rd	Radiation parameter
Pr	Prandtl number
D_f	Dufour number
Sc	Schmidt number
Sr	Soret number
γ	Chemical reaction parameter
B_i	Biot's number
η	Similarity variable
F	Dimensionless velocity
β	Dimensionless temperature
ϕ	Dimensionless concentration field
Re_x	Local Reynold number
C_F	Skin friction coefficient
Nu	Local Nusselt number
Sh	Local Sherwood number

three dimensional flow Newtonian fluid in rotating channel. The lower wall of the is being stretched. The fluid is saturated with carbon nanotubes and they studied the flow model numerically. In 2016, Ahmad et al. [10] studied the heat transfer enhancement in electrically conducting fluid over a stretching sheet which stretched in two lateral directions and investigated the influence of porosity in the flow field. The flow model tackled analytically with Homotopy Analysis method and calculated the values for heat and mass transfer rates. Another study of [11] explored the heat transfer in Hydromagnetic flow over a bi-directionally stretching sheet placed in a porous media. The flow time dependent non-Newtonian fluid over linearly stretching sheet inspected by Ullah et al. [12]. They also investigated the cross-diffusion effects, convective flow condition, viscous dissipation and heat absorption/generation on velocity and thermal fields. For further analysis of various flow models and influence of respective pertinent parameters in the flow regimes, we can study [13,14].

In 2006, Sharidan et al. [15] investigated the unsteady boundary layer flow over stretching surface and tackled the model analytically. Flow of the micropolar fluid over stretchable surface by considering thermophoresis effects was reported in Ref. [16]. In 2015, Jonnadula et al. [17] explored the influence of linear thermal radiation on chemically reacting fluid over a stretchable sheet. They solved the nonlinear flow model by means of efficient numerical scheme called Keller Box technique. Further, graphical behavior of the velocity, temperature and concentration discussed due to varying chemical reaction parameter, Brownian and thermophoresis parameters and under certain conditions compared presented results with already existing ones in the literature and found to be in better agreement. For further nonlinear flow models having great importance in industries and engineering, we can study [18-27] and many other references embedded therein.

In 2010, Noor et al. [28] explored the Hydromagnetic flow in a thin liquid film over a stretchable surface. For solution purpose, they adopted Homotopy Analysis method. Thermocapillarity and impacts of Lorentz force in a thin film liquid over stretching sheet and heat and mass transfer analysis on magnetohydrodynamic flow over permeable surface reported in Refs. [29,30], respectively. In 2017, Sheikholeslami [31,32] investigated the effects of imposed magnetic field on in a porous lid driven cavity and they carried out the computations of the model by employing Lattice Boltzmann method. The influence of copper nanoparticles diluted in water discussed by Sheikholeslami [22] and the effects of magnetic field and thermal radiation in cavity with elliptic inner cylinder reported in Ref. [33]. Many researchers analyzed the magneto nanofluid in porous media [34].

From literature investigation, it is reveals that no one explored the radiative flow of chemically reacting fluid over bi-directional stretchable sheet in the presence of thermo-diffusion and diffusion thermo effects. The problem is described in section 2 and formulated successfully. Then, particular nonlinear flow model is solved by an efficient numerical technique called Runge-Kutta numerical scheme. Influence of thermal radiation, chemical reaction, cross diffusion and other parameters comprised in the model discussed in the flow regime. The values for skin friction coefficient, local rate of heat and mass transfer are also tabulated. Finally, major observations regarding to presented article given in the last section of the manuscript.

Description of the problem

The unsteady radiative flow of chemically reacting incompressible fluid is under consideration over a convectively heated surface placed in Cartesian coordinate system. The surface is stretched bilaterally in opposite directions with two forces equal in magnitude. Further, the sheet meet the plane $z = 0$. The fluid flows in the region $z > 0$. The stretchable components of the velocities in x and y directions are $u_w(x,t) = ax(1-\alpha t)^{-1}$ and $v_w(y,t) = by(1-\alpha t)^{-1}$, respectively. Here, $a > 0$ and $b > 0$ are both constants. The stretchable surface is maintained at invariable temperature and concentration. Fig. 1 depicts the physical model of the flow problem in Cartesian coordinate system:

The feasible set of partial differential equations that represents the three dimensional radiative flow of chemically reacting fluid over stretchable surface (placed in Cartesian coordinate system) in the presence of thermo-diffusion and diffusion-thermo effects is as