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ORIGINAL ARTICLE

Unequal diffusivities case of homogeneous–heterogeneous reactions within viscoelastic fluid flow in the presence of induced magnetic-field and nonlinear thermal radiation

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Abstract This article presents the effects of nonlinear thermal radiation and induced magnetic field on viscoelastic fluid flow toward a stagnation point. It is assumed that there exists a kind of chemical reaction between chemical species *A* and *B*. The diffusion coefficients of the two chemical species in the viscoelastic fluid flow are unequal. Since chemical species *B* is a catalyst at the horizontal surface, hence homogeneous and heterogeneous schemes are of the isothermal cubic autocatalytic reaction and first order reaction respectively. The transformed governing equations are solved numerically using Runge–Kutta integration scheme along with Newton's method. Good agreement is obtained between present and published numerical results for a limiting case. The influence of some pertinent parameters on skin friction coefficient, local heat transfer rate, together with velocity, induced magnetic field, temperature, and concentration profiles is illustrated graphically and discussed. Based on all of these assumptions, results indicate that the effects of induced magnetic and viscoelastic parameters on velocity, transverse velocity and velocity of induced magnetic field are almost the same but opposite in nature. The strength of heterogeneous reaction parameter is very helpful to reduce the concentration of bulk fluid and increase the concentration of catalyst at the surface.

1. Introduction

The study of fluid flow over a horizontal stretchable surface has extensive applications in pharmaceutical companies (i.e. medicinal pharmaceutical technology), production of polythene and paper, polymer extrusion, cooling of elastic sheets, fiber technology, production of plastic materials, science and

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Nomenclature

u	velocity component in x direction
v	velocity component in y direction
B_1, B_2	magnetic components in x and y directions
B_o	magnetic component in free stream flow
C_f	skin friction coefficient
C_p	specific heat at constant pressure
x	distance along the surface
y	distance normal to the surface
f	dimensionless velocity
N_u	local Nusselt number
P_r	Prandtl number
q_w	heat transfer
T	dimensional fluid temperature
u_w	stretching velocity at the wall
u_e	stretching velocity at the free stream
T_w	wall temperature
T_∞	ambient temperature
R_{ex}	local Reynolds number
g, g'	dimensionless induced magnetic velocities field in y and x directions respectively
a, c	stretching rate at the wall and free stream
K, K_s	strength of Homogeneous and Heterogeneous reaction parameters
$G(\eta)$	concentration of Specie A
$G'(\eta)$	conc. gradient of specie A
$H(\eta)$	conc. of cpecie B
$H'(\eta)$	conc. gradient of specie B

Greek symbols

λ	stretching ratio parameter
Γ	viscoelastic parameter
δ	ratio of diffusion coefficients chemical specie A to B
ε	reciprocal magnetic Prandtl number
κ	thermal conductivity
η	similarity variable
θ	dimensionless temperature
ϑ	kinematics viscosity
α	thermal diffusivity
σ	electrical conductivity
σ^*	Stefan–Boltzmann constant
k^*	mean absorption coefficient
β	magnetic parameter
σ	electric conductivity
θ	dimensionless temperature
ψ	stream function
μ_e	magnetic permeability

engineering technology. It is worth mentioning that almost all the fluids mentioned above are materials (fluids) which exhibit viscous and elastic characteristics when undergoing deformation. Viscoelastic fluid flow over a stretching surface was investigated by Rajagopal et al. [1]. Chethan et al. [2] examined the slip condition on viscoelastic liquid flow over an exponentially stretching surface. Rashidi et al. [3] analyzed the effects of Soret and Dufour on magnetohydrodynamic viscoelastic fluid flow past a vertical stretching surface. Singh and Agarwal [4] studied the variable thermal conductivity effect on the flow of viscoelastic fluid over a permeable exponentially stretching surface. Hayat et al. [5] discussed the boundary layer analysis of viscoelastic nanofluid flow over a stretching cylinder. A stagnation point is a point in a flow field where the local velocity is zero. In fluid dynamics, when this occurs at the surface of an object, the fluid flow is often brought to rest. To induce such fluid to flow, Paul Richard Heinrich Blasius in 1908 considered the report of Prandtl Ludwig together with the principle of stretching fluid layers at the free stream [6]. It is pertinent to note that in the work of Blasius, the fluid motion is maintained by the stretching of fluid layers at the free stream. Thereafter, Hiemenz [7] presented two dimensional stagnation-point flow over a flat plate. Abolbashari et al. [8] presented the analysis of non-Newtonian fluid flow induced by stretching sheet. Heat transfer characteristics of viscoelastic fluid past a stretching surface in the presence of thermal radiation and viscous dissipation was presented by Cortell [17]. The dynamics of micropolar fluid at constant vortex viscosity toward a stagnation point formed on a melting stretchable surface can be seen in Ọrísẹ̀kọ̣ [9]. Just of recent, Sandeep et al. [10] discussed the dual solutions of governing equation which models Stagnation-point flow of a Jeffrey nanofluid over a stretching surface with induced magnetic field and chemical reaction.

It is a well-known fact that all bodies radiate heat, the higher the temperature the greater the radiation such that when two bodies at different temperatures are within each other the hotter body will supply heat to the colder body until they reach the same temperature. This scientific statement is known as Prevost's Theory of Exchange, often referred to as the starting point from which the modern physical theory of thermal radiation was developed in the 19th century; for more details, see Putley [11]. Considering this mode of transfer of heat energy, Raju et al. [12] discussed the effect of radiation on the flow past a stretching sheet in the presence of inclined magnetic field. Heat transfer characteristics of MHD flow over a nonlinear stretching sheet in the presence of thermal radiation were studied by Cortell [13]. In the study conducted by Ganji et al. [14] on effects of thermal radiation within magnetohydrodynamics nanofluid flow between two horizontal rotating plates, it was pointed out that Nusselt number has direct relationship with radiation parameter. Heat transfer analysis of magnetohydrodynamic nanofluid flow over a stretching/shrinking surface was scrutinized by Sandeep et al. [15]. Raju et al. [18] analyzed the thermal radiation effect on ferrofluid flow past a flat plate in the presence of aligned magnetic field. It is also important to remark that in most of the studies mentioned above, nonlinear temperature (Rosseland approximation) is simplified by using Taylor series expansion and the higher order terms are truncated. Consequently, the non-dimenzionalization and parametrization of thermal radiation model become a simple task. Physically, the electromagnetic radiation that occurs in the fluid as it flows during some of the industrial processes may not be realistic if interpreted as