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Simultaneous effects of melting heat transfer and inclined magnetic field flow of tangent hyperbolic fluid over a nonlinear stretching surface with homogeneous–heterogeneous reactions

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ABSTRACT

The purpose of present article is to investigate homogeneous–hetrogeneous reactions and melting heat transfer in the flow of magnetohydrodynamic (MHD) mixed convective flow of hyperbolic tangent fluid. Flow by nonlinear stretching sheet is addressed in presence of non-uniform heat source/sink. Governing equations through conservations laws are obtained. Series solutions of dimensionless problems are developed within the frame of homotopic theory. Convergence solution is achieved and suitable values are found. The velocity, temperature and concentration are analyzed graphically within the frame of various pertinent variables. Skin friction coefficient, local Nusselt number and wall concentration have been scrutinized through plots. An increase in space and temperature dependent non-uniform heat source/sink variables show rise to temperature.

1. Introduction

There are several applications of non-Newtonain materials like food products (mayonnaise, milk, apple sauce, ice creams, alcoholic beverages, ketchup, chocolates in liquefies form, yogurt etc.), biological stuff (blood, syrups, vaccines, synovial fluid etc.), chemical material (cosmetics, tooth pastes, grease, shampoos, pharmaceutical chemicals, paints, oil reservoirs etc.) which don't obey the Newton's law of viscosity [1–10]. These materials are deliberated as the non-Newtonian liquids. Such materials cannot describe the properties in view of typical Navier–Stokes expressions. The mathematical modeling for flows of non-Newtonian liquids as a rule is extremely tedious. The non-Newtonian liquids at present are argued through three main classifications namely the rate, the differential and the integral. The differential type model exhibits the shear phenomena of thinning and thickening. There is a preliminary subclass of differential type liquids recognized as Second-grade model. This liquid model shows only normal stress differences and can not predict the shear thinning/thickening properties. The tangent hyperbolic fluid theory is capable of investigating both the effects of shear thinning and thickening. Thus Hayat et al. [11] studied mixed convective flow of tangent hyperbolic fluid with convective conditions and thermal radiation. Heat transfer analysis in flow of tangent hyperbolic liquid is examined by Gaffar et al. [12]. This studies is presented through numerical technique. Characteristics of mixed convective flow of tangent hyperbolic liquid in view of magnetic field are analyzed by Hayat et al. [13]. Hayat et al. [14] also scrutinized nonlinear thermal radiation aspect in mixed convection flow of tangent hyperbolic nanofluid with convective conditions.

Various chemical reacting structure include both homogeneous and heterogeneous reactions. Several reactions have the capability to continue gradually or in no way, shape or form, without the animation of a catalyst. The connection amongst homogeneous and heterogeneous reactions is extremely complex including the consumption and production of reactant descriptions at various rates both inside liquid and on catalytic sheets. Particularly chemical reaction consideration is very important in food processing, chemical processing equipment design, hydrometallurgical industry, fibrous insulation, dispersion and formation of fog, manufacturing of ceramics, generation of electric power and polymer production, groves of fruit trees and crops damage via freezing. An isothermal behavior of homogeneous-heterogeneous reactions in stretched flow of viscous liquid over a flat surface is examined by Merkin [15]. Bachok et al. [16] scrutinized the stagnation-point flow past a stretched surface in view of homogeneous-heterogeneous reactions. Impact of homogeneous-heterogeneous reactions in flow analysis of Jeffrey Fluid with Cattaneo–Christov heat flux is analyzed by Hayat et al. [17]. Animasaun et al. [18] considered stretched flow of viscoelastic fluid employing homogenous–heterogeneous reactions. They processed numerical results closed to the leading edge of a smooth surface.

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Nomenclature

u, v	velocity components
x, y	space coordinates
T	fluid temperature
T_∞	ambient temperature
T_m	melting surface temperature
T_0	surface temperature
a	concentration of chemical specie $\tilde{A}$
b	concentration of chemical specie $\tilde{B}$
ν	kinematic viscosity
n^*	material power law index
u_w	stretching velocity
Γ	time dependent material constant
ψ	angle of inclination
σ	electrical conductivity
$B(x)$	non-uniform magnetic field
g^*	gravitational acceleration
β_T	thermal expansion coefficient
k	thermal conductivity
ρ	fluid density
μ	dynamic viscosity
c_p	specific heat
q^*	space and temperature dependent non-uniform heat source/sink
$D_{\tilde{A}}$	diffusion coefficient of specie $\tilde{A}$
$D_{\tilde{B}}$	diffusion coefficient of specie $\tilde{B}$
$\tilde{A}$, $\tilde{B}$	chemical species
a_0	positive dimensional constant
k_c	homogeneous rate constant
k_s	heterogeneous rate constant
λ^*	fluid latent heat
$(c_p)_s$	solid surface heat capacity
η	dimensionless space variable
f	dimensionless velocity
θ	dimensionless temperature
g, h	dimensionless concentration
ϕ	stream function
n	power law index
c	dimensional constant
W_e	Weissenberg number
H_a	magnetic parameter
λ_T	mixed convection parameter
Pr	Prandtl number
Sc	Schmidt number
M	melting parameter
k_1	measure of the strength of the homogeneous reaction
k_2	measure of the strength of the heterogenous reaction
δ^*	coefficient of diffusion ratio
Gr	Grashof number
τ_w	surface shear stress
q_w	surface heat flux
C_{f_x}	skin friction coefficient
Re_x	local Reynolds number
$\mathcal{L}_f$, $\mathcal{L}_\theta$, $\mathcal{L}_g$	linear operator for velocity, temperature and concentration
$\mathcal{N}_f$, $\mathcal{N}_\theta$, $\mathcal{N}_g$	linear operator
$\mathcal{R}_m^f$, $\mathcal{R}_m^\theta$, $\mathcal{R}_m^g$	mth order non-linear operators

Yang et al. [19] explored the mechanisms of homogeneous and heterogeneous reaction and kinetics of mercury oxidation in coal-fired flue gas with bromine addition. Impacts of thermal radiation and homogeneous–heterogeneous reactions in peristaltic flow of Prandtl fluid in an inclined asymmetric channel with Joule heating is described by Hayat et al. [20]. Lu et al. [21] deliberated homogeneous–heterogeneous reactions of premixed hydrogen–air mixture in a planar catalytic micro-combustor. Hayat et al. [22] found dual behavior of homogeneous/heterogeneous reactions and Hall current in peristalsis.

The investigation of magnetohydrodynamics (MHD) has significance in various applications such as pumps, electrical power generators, magnetic cell separation, magnetic resonance imaging (MRI), targeted transport of drugs utilizing magnetic particles as drug carrier and many others [23–28]. Moreover, melting heat transfer characteristics has attracted the scientists and engineers due to its widespread utilization in the sectors of advanced industrial and technological performance. Researchers have demonstrated their keen attention for the development of some more proficient and sustainable technologies of energy storage. Such energy storage tools are associated with waste heat recovery, solar energy and mutual heat and power plants. There are three techniques which are more compelling for the thermal energy storage (a) energy conservation through sensible heat, (b) energy conservation through latent heat, and (c) chemical thermal energy conservation. In these techniques energy storage in view of latent heat is more compelling and sustainable economically. In a material process melting phenomenon is utilized for the thermal energy storage. The thermal energy stored is recouped again by freezing the material. The freezing of soil around the heat exchanger coils of a ground based pump, magma crystallization, melting of soil, frozen grounds, melting of permafrost, the construction of semiconductor material, thawing of the welding and casting of a finishing animation are the examples of melting paradox. Cheng and Lin [29] explored the features of melting phenomenon in mixed convective heat transfer within the frame of aiding and opposing outer flows from the vertical surface in a fluid-saturated porous medium. Ishak et al. [30] investigated the melting heat transfer in steady laminar flow over moving sheet. Idiosyncrasy of a compound phase change material manufactured by paraffin and metal foam with the impact of melting heat transfer has been investigated by Zhang et al. [31]. Kameswaran et al. [32] discussed the melting phenomenon and convective heat transfer in flow filling non-Darcy porous medium. Hayat et al. [33] considered melting heat transfer in magnetohydrodynamic (MHD) flow of Cu-water nanoliquid with Joule heating and viscous dissipation. Gao et al. [34] considered the Boltzmann method to simulate solid–liquid phase change in porous media under local thermal non-equilibrium conditions.

The main purpose of present work is to model and analyze the MHD mixed convective flow of tangent hyperbolic fluid bounded by nonlinear stretching sheet. Homogeneous–heterogeneous reactions characteristics are clearly focused. Heat transfer phenomenon has been studied in view of melting heat transfer and non-uniform heat source/sink. Effect of non-uniform inclined magnetic field is also attended. Implementation of suitable variable yields nonlinear ordinary differential problems. Resulting problems have been solved through homotopy analysis technique (HAM) [35–43]. The behavior of sundry physical quantities on velocity, thermal and concentration fields are demonstrated graphically. Representation of skin friction coefficient, Nusselt number and dimensionless wall concentration are addressed. The solutions acquired by HAM are preferred than the numerical solutions in perspective of the following points. (i) HAM gives the solutions within the domain of interest at each point while the numerical solutions hold just for discrete points in the domain. (ii) Algebraically developed approximate solutions require less effort and having a sensible measure of precision when compared to numerical solution which are more convenient for the scientist, an engineer or an applied mathematician. (iii) Although most of the scientific packages required some initial approximations for the solution are not generally convergent. In such conditions approximate solutions can offer better initial guess that can be readily advanced to the exact numerical solution in the limited iterations. Finally an approximate solution, if it is analytical, is most pleasing than the numerical