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Entropy optimization and quartic autocatalysis in MHD chemically reactive stagnation point flow of Sisko nanomaterial

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ABSTRACT

This research article deals with entropy generation and heat generation/absorption analysis for MHD stagnation point flow of Sisko-nanomaterial towards stretchable sheet. Homogeneous-heterogeneous reactions are considered. Nanomaterial comprises thermophoresis and Brownian diffusion effect. Through implementation of second law of thermodynamics the total entropy generation is calculated. In addition, entropy generation for fluid friction, mass transfer and heat transfer is discussed. This study is specially investigated for the impact of homogeneous-heterogeneous reactions with entropy generation subject to distinct flow parameters. The nonlinear systems are computed. Influence of pertinent flow variables on the velocity, entropy, concentration and temperature are discussed. Coefficient of skin friction (velocity gradient) and Nusselt number (temperature gradient) are calculated and examined graphically. The obtained results indicate that entropy rate directly depends upon Brinkman number, diffusion parameter, temperature and concentration difference parameters, magnetic parameter and volumetric entropy number.

1. Introduction

Heat transport is flow of energy through which some extra movement happens, for example molecular vibration, molecular friction, spin moment, inside displacement of molecule, mixing of fluids, kinetic energy, chemical reaction, inelastic deformation of solids and electric resistance, etc. More energy is lost due to these extra activities and this produce entropy. Entropy is the incapability of system to use the 100% convenient energy. The entropy generation measures the performance of thermal system and it is necessary to reduce the rate of entropy generation to increase productivity of thermal system. Analysis of stretched flows with entropy concept can be found from Refs. [1–10]. Qing et al. [11] addressed MHD non-Newtonian nanomaterial flow with entropy generation. Sithole et al. [12] examined entropy generation in MHD second grade nanomaterial flow via viscous dissipation and nonlinear thermal radiation. Nouri et al. [13] analyzed flow of nanomaterial in the presence of entropy generation by a spherical heat source. Afridi et al. [14] analyzed entropy optimization in MHD stagnation point flow with frictional heating and convection. Hayat et al. [15] investigated MHD radiative flow of viscous liquid with entropy. Reddy et al. [16] scrutinized entropy generation in flow of Casson liquid with thermal radiation. Kumar et al. [17] presented time dependent MHD flow of couple stress liquid with entropy optimization through isothermal vertical plate. Salman et al. [18] addressed entropy generation in squeezing flow of viscous material. Rashad et al. [19] worked on entropy generation in MHD forced convective flow of nanomaterial in an inclined porous cavity. Khait et al. [20] discussed entropy generation by a double circuit vertex tube.

Investigation of nanomaterials has received much consideration of the scientists and engineers. It is due to their numerous mechanical and industrial applications. The concept of nanofluid has been introduced to intensify the thermal ability of base fluid. Since in mechanical and industrial process, the low thermal conductivity base fluid do not meet the requirement of cooling. The nanomaterials can be categorized as substance that fluctuating through nanoparticles in size from 1 to 100 nm. The size of nanomaterials may differ from bulk material. Some examples of viscoelastic nanomaterials are $ethylene\ glycol - CuO$, $ethylene\ glycol - Al_2O_3$, $ethylene\ glycol - ZnO$, etc. Initially Choi [21] used the concept of nano-sized materials in continuous phase liquid. He showed experimentally that nanomaterials enhance the thermal ability of continuous phase liquid. There are numerous studies in literature regarding nanomaterials. Usman et al. [22] discussed slip flow of Casson

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nanomaterial with thermal radiation through collocation technique. Eid et al. [23] presented two-dimensional nanomaterial flow of Carreau fluid over nonlinear stretchable surface. Hayat et al. [24] examined MHD nonlinear convective of thixotropic fluid over sheet having variable thickness. Hayat et al. [25] explored stagnation point flow of viscoelastic nanofluid over a stretchable sheet. Mair et al. [26] studied heat and mass transport in flow of Williamson nanomaterial with inclined Lorentz force. Ghadikolaei et al. [27] discussed magneto flow of Casson nanomaterial in presence of Joule heating and nonlinear thermal radiation. Naramgari and Sulochana [28] analyzed MHD dusty flow of nanofluid over a stretched sheet. Khan et al. [29] worked on generalized Fourier's and Fick's laws in flow of Jeffrey nanofluid for thermal and solutal diffusions. Gireesha et al. [30] considered nonlinear convective flow of Oldroyd-B nanomaterial with heat source/sink. Some recent attempts regarding nanofluid can be mentioned through Refs. [31–45].

Here we aim to investigate the MHD quartic autocatalysis in chemically reactive flow of Sisko nanomaterial over a stretched. Sheet with nonlinear velocity. Total entropy rate is calculated through implementation of second law of thermodynamics. The present problem is modeled for homogeneous-heterogeneous reactions, magnetohydrodynamics, heat generation/absorption and thermophoresis and Brownian motion. Existing literature review witness that such type of flow is not discussed so far. Thus nonlinear PDE's are converted to ordinary ones through appropriate transformations. Homotopy technique [46–68] is utilized for the local similar solutions. Velocity and temperature gradients are calculated and analyzed graphically.

2. Formulation

Analysis of steady and incompressible steady laminar flow and heat transport of Sisko nanofluid over a stretched sheet is addressed. Brownian motion and thermophoresis are accounted. Entropy generation has been discussed subject to mass transfer irreversibility, fluid friction irreversibility and heat transfer irreversibility. Fluid is conducting by an applied magnetic field having constant strength B_0. Physical sketch of considered flow is shown in Fig. 1.

Here homogeneous-heterogeneous reactions are considered. The sheet is stretched with velocity $u = cx^s$ which causes disturbance in liquid. The model of quartic chemical reaction [16] in boundary layer region with species A^* and B^* is presented as [34]:

$$A^* + 2B^* \rightarrow 3B^*, \quad rate = k_1 C_1 C_2^2,$$

where specie B has larger concentration on surface. The single first order isothermal reaction on the catalyst is

$$A^* + B^* \rightarrow 3B^*, \quad rate = k_2 C_2.$$

Here C_1 and C_2 respectively represent concentrations of species A^* and B^* and k_1 and k_2 denote the rate constants. The governing equations are represented as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = u_e\frac{du_e}{dx} + \frac{a}{\rho}\frac{\partial^2 u}{\partial y^2} - \frac{b}{\rho}\frac{\partial}{\partial y}\left(-\frac{\partial u}{\partial y}\right)^n - \frac{\sigma}{\rho}B_0^2(u - u_e), \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left[D_B\left(\frac{\partial T}{\partial y}\frac{\partial C_1}{\partial y} + \frac{\partial T}{\partial y}\frac{\partial C_2}{\partial y}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] + \frac{Q_0}{\rho c_p}(T - T_\infty), \tag{3}$$

$$u\frac{\partial C_1}{\partial x} + v\frac{\partial C_1}{\partial y} = D_{A^*}\left(\frac{\partial^2 C_1}{\partial y^2}\right) + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} - k_1 C_1 C_2^2, \tag{4}$$

$$u\frac{\partial C_2}{\partial x} + v\frac{\partial C_2}{\partial y} = D_{B^*}\left(\frac{\partial^2 C_2}{\partial y^2}\right) + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} + k_1 C_1 C_2^2, \tag{5}$$

$$\left.\begin{array}{l} u = u_w = a_1 x^s,\ v = 0,\ T = T_w,\ D_{A^*}\frac{\partial C_1}{\partial y} = -D_{B^*}\frac{\partial C_2}{\partial y} = k_2 C_1,\ \text{at}\ y = 0 \\ u \rightarrow u_e = a_2 x^s,\ T \rightarrow T_\infty,\ C_1 \rightarrow C^*{}_\infty,\ C_2 \rightarrow 0\ \ \text{when}\ y \rightarrow \infty, \end{array}\right\} \tag{6}$$

where u, v highlight the velocity components, x, y the Cartesian coordinates, u_e the free stream velocity, ρ the density, a represents the high shear rate viscosity, n the power law index, b represents the consistency index, σ the electrical conductivity, T the temperature, α the thermal conductivity, D_B the Brownian diffusion coefficient, τ the ratio of heat capacity of continuos phase liquid and nanoparticle material, D_{C_1} and D_{C_2} denotes the diffusion coefficients with respect to concentration C_1 and C_2, D_T the thermal diffusion, Q_0 the coefficient of heat generation, T_∞ the ambient temperature and a_1, a_2 the dimensional constants.

Applying the following appropriate transformations

$$\left.\begin{array}{l} u = a_1 x^s f'(\xi),\ v = -\frac{u_w}{n+1} Re_b^{\frac{-1}{n+1}}[(s(2n-1)+1)f(\xi) + (s(2-n)-1)\xi f'(\xi)], \\ \xi = \frac{y}{x} Re_b^{\frac{1}{n+1}}, \\ \theta(\xi) = \frac{T - T_\infty}{T_w - T_\infty},\ \phi = \frac{C_1}{C_\infty^*},\ \chi = \frac{C_2}{C_\infty^*}. \end{array}\right\} \tag{7}$$

Eqs. (2)–(6) give

$$Af''' - n(-f'')^{n-1}f''' + \frac{(s(2n-1)+1)}{n+1}ff'' - sf'^2 + A_1^2 s - M(f' - A) = 0, \tag{8}$$

$$\frac{\theta''}{Pr} + Q\theta + Nb(\theta'\phi' + \theta'\chi') + Nt\theta'^2 + \frac{(s(2n-1)+1)}{n+1}f\theta' = 0, \tag{9}$$

$$\frac{\phi''}{Sc} + f\phi'(s(2n-1)+1) + \left(\frac{Nt}{Nb}\right)\frac{1}{Sc}\theta'' - K_1\phi\chi^2 = 0 \tag{10}$$

$$\frac{\delta\chi''}{Sc} + f\chi'(s(2n-1)+1) + \left(\frac{Nt}{Nb}\right)\frac{1}{Sc}\theta'' + K_1\phi\chi^2 = 0 \tag{11}$$

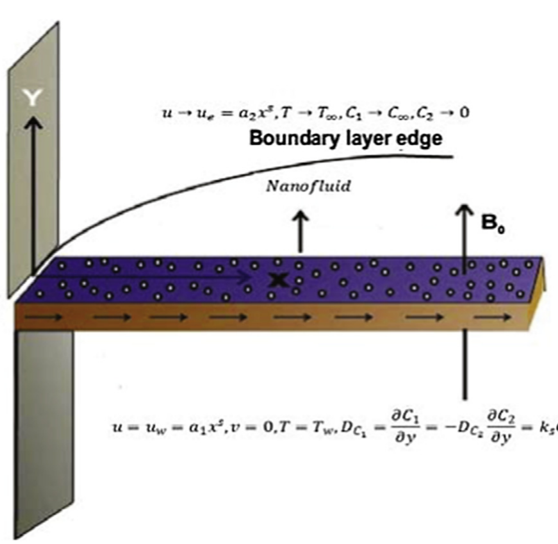

Fig. 1. Flow model.