International Communications in Heat and Mass Transfer 91 (2018) 216–224

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Activation energy impact in nonlinear radiative stagnation point flow of Cross nanofluid

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ARTICLE INFO

Keywords:
Activation energy
Brownian movement and thermophoresis
Nonlinear thermal radiation
Heat absorption/generation
Chemical reaction
Cross fluid model

ABSTRACT

Here modeling and computations are presented to introduce the novel concept of activation energy in mixed convective magnetohydrodynamic (MHD) stagnation point flow towards a stretching surface. Chemical reaction at the surface is implemented. Nanofluid aspects for thermophoresis and Brownian motion have been considered. Nonlinear thermal radiation and heat absorption/generation are presented. Nonlinear computations have been presented using Runge–Kutta–Fehlberg (RKF) Numerical Method. Main focus in this study for the description of velocity, temperature and nanoparticle concentration. Skin friction coefficient, Nusselt and Sherwood numbers are computed and discussed in Tables. Our investigations reveal that species concentration enhances for higher estimation of activation energy variable. Nusselt and Sherwood numbers show similar behavior for rising values of Weissenberg number.

1. Introduction

Many biological fluids like printer inks, detergents, animal blood, paint, polymer liquids, food stuff *etc.* modify their flow properties subjected to operated shear stress and therefore deviate from viscous liquids. Such liquids are characterized as non-Newtonian materials. Researchers have accounted numerous non-Newtonian liquid flow models for illustration. These include Casson, micropolar, Maxwell, Oldroyd-B, Burgers, generalized Burgers, Jeffrey, Sisko and Cross *etc.* Here we accounted the Cross [1] fluid model which expresses the yield stress features. This model also adequately characterizes the flow in power-law region and regions of low and high shear rates. Different from the power-law liquid we firstly here attain a finite viscosity as the shear rate evaporates *i.e.* ($\dot{\gamma} = 0$). Secondly it contains a time constant due to which this model is valuable for several engineering and industrial computations. Industrial utilization of this model comprises the blood and aqueous solution of polymer latex sphere and synthesis of the polymeric solutions [2–5].

Tnvestigation of flow and heat transport induced by moving surface has inspired numerous researchers on account of its various useful applications like polymer extrusion, wire drawing, rapid spray cooling, chilling of microelectronics, glass blowing and extinguishing in metal foundries *etc.* Crane [6] initially investigated the boundary layer flow over stretched surface. Since then, several investigators [7–15] delivered their research contributions considering distinct features of flow and heat transport problems comprising moving surfaces. Besides this the consideration of magnetic field in thermal process is important because it control both heat and liquid flow. MHD with heat transfer has ample utilizations in MHD peristaltic compressor, blood flows, wound treatments, pumping machines, turbo machinery, optical modulators, heat exchangers, optical switches, cooling of nuclear reactors and various other fields. Many scientists [16–23] have addressed MHD flow problems in various flow fields.

The consideration of thermal radiation is significant in heat exchangers, power plants, safety of nuclear reactors, furnace design, solar technology, power technology *etc.* The process of thermal radiation comprises the emanation of electromagnetic radiations in every direction by heated body. Infrared part of electromagnetic spectrum includes the radiation for most objects on this earth. That's why the consideration of radiation is noteworthy in describing the thermal characteristics of conversation systems. Furthermore thermal radiation has momentous applications in space technology where large thermal efficiency is achieved of the devices that are operated at large temperature levels [24–30].

Our main interest here is to analyze two-dimensional flow of Cross fluid towards stretchable sheet. Chemical reaction at the surface is

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https://doi.org/10.1016/j.icheatmasstransfer.2017.11.001

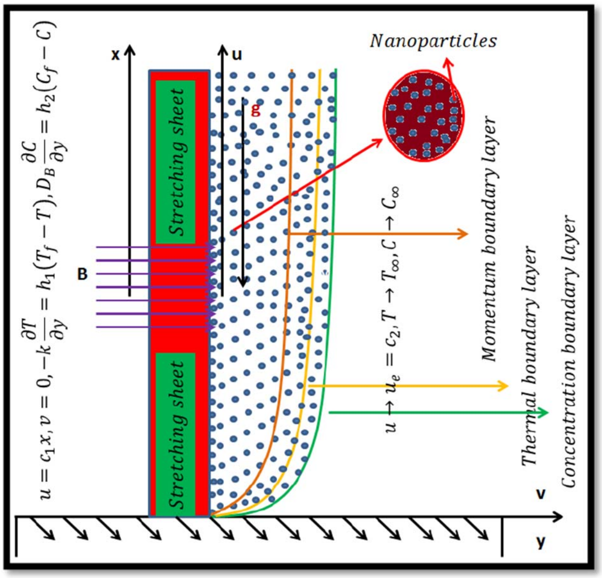

Fig. 1. Flow diagram.

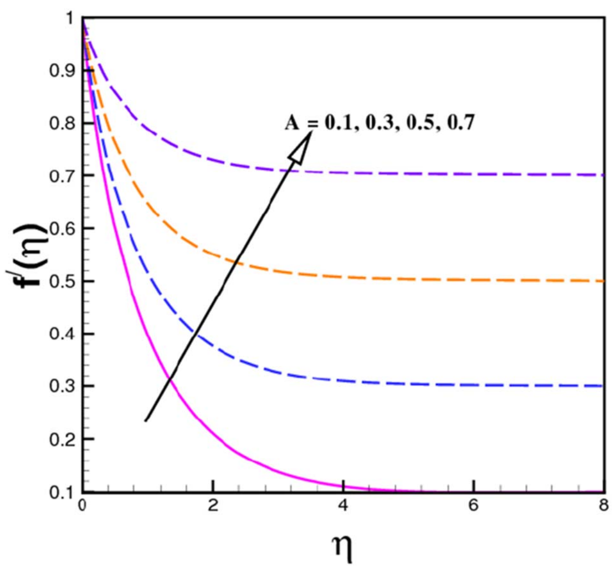

Fig. 2. f′(η) *via A*.

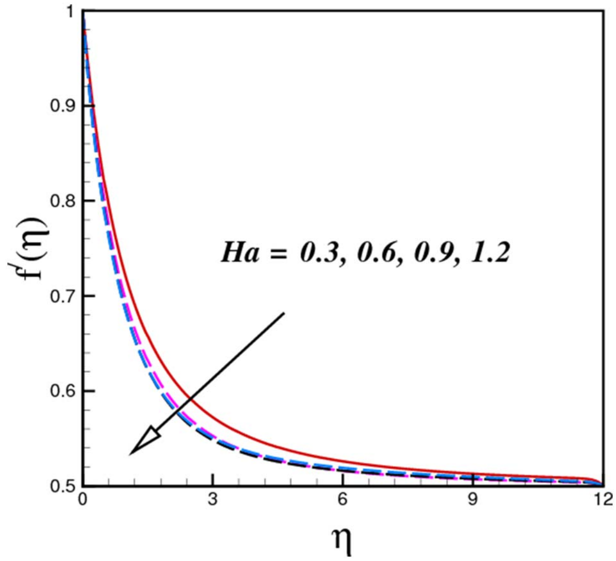

Fig. 3. f′(η) against *Ha*.

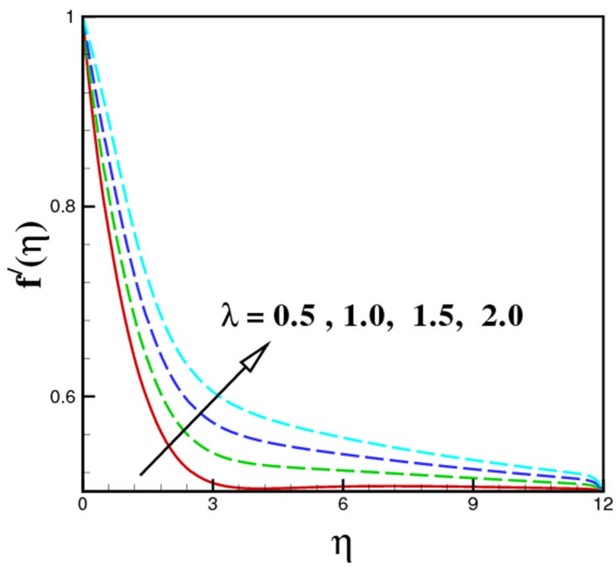

Fig. 4. f′(η) *via* λ.

implemented. Nonlinear thermal radiation and heat absorption/generation are presented. Nanofluid aspects for thermophoresis and Brownian motion have been considered. Fluid is electrically conducted in absence of induced magnetic field. Nonlinear computations have been presented using Runge–Kutta–Fehlberg (RKF) Method. The obtained consequences are comprehensively discussed with the help of graphs.

2. Modeling

Here two-dimensional (2D) incompressible mixed convective flow of magneto Cross liquid is modeled. Heat transfer modeling is performed by considering nonlinear thermal radiation and heat generation/absorption aspects. Chemical reaction at the surface is implemented to maintain the surface temperature. Activation energy is also taken into account. Brownian movement and thermophoresis have been considered. Fluid is electrically conducting. Magnetic field of B_0, is applied along y-direction. Physical configuration analyzed in present work is depicted in Fig. 1. The governing flow expressions for Cross liquid are.

$$div\boldsymbol{V} = 0, \tag{1}$$

$$\rho\frac{d\boldsymbol{V}}{dt} = div\tau + \boldsymbol{J} \times \boldsymbol{B}, \tag{2}$$

$$V = [u(x, y),\ v(x, y),\ 0], \tag{3}$$

$$\tau = -p\boldsymbol{I} + \eta^*\boldsymbol{A}_1, \tag{4}$$

$$J = \sigma(\boldsymbol{V} \times \boldsymbol{B}), \tag{5}$$

$$\eta^* = \eta_\infty + (\eta_0 - \eta_\infty)\left[\frac{1}{1 + (\Gamma\dot{\gamma})^n}\right], \tag{6}$$

$$\boldsymbol{A}_1 = \boldsymbol{L} + \boldsymbol{L}^T,\ \ \pi = tr(\boldsymbol{A}_1)^2, \tag{7}$$

$$\dot{\gamma} = \left[4\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y} + \left(\frac{\partial v}{\partial x}\right)^2\right)\right]^{1/2}. \tag{8}$$

Following [4] we put $\eta_\infty = 0$ then Eq. (6) reduces to