



## Chemically reactive flow of Maxwell liquid due to variable thicked surface



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### ABSTRACT

A new chemical reaction model comprising both heat and mass transfer expressions simultaneously is introduced in this communication. Rheological relations of Maxwell fluid model are utilized in the mathematical modeling. Flow caused here is in the region of stagnation point due to a variable sheet. It is supposed that the homogeneous process in the ambient liquid is governed by the first order kinetics whereas the heterogeneous processes on the wall surface are given through isothermal cubic autocatalator kinetics. Appropriate transformations are implemented to achieve the nonlinear differential systems. Intervals of convergence for the obtained series solutions are explicitly determined. Characteristics of influential variables on the physical quantities are interpreted. Our analysis reveals that velocity distribution is decreasing function of larger Deborah number.

### 1. Introduction

Scientists in modern research era are interested to scrutinize the flow phenomenon of non-Newtonian liquids persuaded by stretchable surfaces. Such importance is due to their useful applications in technology and industry. Majority of liquids like sugar solution, apple sauce, shampoo, mud, soap, tomato ketchup and condensed milk exhibiting the properties of non-Newtonian liquids are used as a part of our routine. Flows of non-Newtonian materials via moving surface have broad utilizations in manufacturing of plastic sheets, petroleum drilling, fiber spinning, glass blowing, aerodynamic manufacturing of plastic films, continuous casting etc. These materials cannot be analyzed through single constitutive relation. Therefore several models through their distinct characteristics have been introduced for different non-Newtonian liquids. In general these materials are classified into integral, rate and differential types. Here we intend to utilize the Maxwell liquid (a subclass of rate type liquid) for the modeling. This model is predominantly effective for polymers allowing lower molecular weight. Several attempts have been presented considering Maxwell liquid model. For illustration, Wang and Tan [1] discussed Maxwell liquid flow occupying porous medium. Jamil and Fetecau [2] computed helical flows considering Maxwell liquid. Here flow is caused by applied shear stress at plate. Zierep and Fatecau [3] described Rayleigh-Stokes relation for the flow of Maxwell liquid. Hayat et al. [4,5] investigated the impact of thermal radiation in convective flow of Maxwell liquid due to a stretched surface. Hayat et al. [6] considered flow of Maxwell

nanoliquid via unsteady stretchable surface. Mustafa [7] modeled the flow of Maxwell liquid considering non-Fourier heat flux model. Flow analysis of Mustafa [7] is extended by Abbasi and Shehzad [8] by considering temperature dependent thermal conductivity and heat absorption/generation. Stretched flow of Maxwell liquid for homogeneous/heterogeneous reactions is explored by Khan et al. [9]. Hayat et al. [10] studied two-dimensional stagnation point flow of Maxwell liquid considering non-Fourier heat flux and homogeneous/heterogeneous reactions.

The interest of recent researchers in stagnation point flows towards stretching surface is growing considerably owing to involvement in glass blowing, continual forming of metals and melt-spinning processes. Hiemenz [11] initially studied the problem of two-dimensional (2D) stagnation-point flow. Afterwards the investigators [12–16] continued research work by considering different fluid flow models. Besides this the stretchable flows in the presence of homogeneous/heterogeneous reactions have been the focus of recent researchers. Reactions are categorized through homogeneous and heterogeneous types. The catalyst in identical phase (homogeneous) or in reverse phase (heterogeneous) where the reaction happens. Usually the homogeneous-catalyst develops in gaseous state however heterogeneous catalyst develops in solid state. There are also several chemically reacting configurations comprising equally the homogeneous and heterogeneous reactions for illustration catalysis, biochemical reacting systems and combustion. Furthermore the association between homogeneous and heterogeneous reactions related with improvement and application of reactant species

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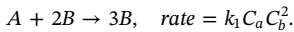
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at numerous rates both inside the liquid and on the catalytic surfaces is generally sophisticated. Keeping such in mind, Merkin [17] described the viscous liquid flow through homogeneous/heterogeneous reactions. Khan and Pop [18] discussed inside liquid and on catalyst surface flow of viscoelastic fluid bounded by a surface with chemical reactions. Kameswaran et al. [19] reported the effectiveness of homogeneous/heterogeneous version of reactant in nanoliquid flow due to porous stretched surface. Few representative studies on the topic can be further seen in the attempts [20–25].

No doubt when chemical reaction processes maneuver in the amalgamated forced and free convective flow systems, the general mass and heat transport rates could be impacted automatically or vice versa. The common reactant transfiguration rates might be inspired fundamentally by the transport phenomena. Thus a comprehensive analysis for precise assessment of the transport characteristics on execution of several procedures in presence of heterogeneous and homogeneous reactions is challenged. Prime target here is to investigate heat transfer mechanism in the stagnation point flow towards a stretching surface of variable thickness. Material under observation obeys the constitutive relations of Maxwell liquid. Homogeneous-heterogeneous processes are used to report the salient characteristics of heat and mass transfer expression. Homotopic algorithm has been invoked concerning establishment of convergent series solutions [25–33]. Impacts of arising variables on velocity, temperature, concentration and Nusselt number are addressed. It is worth mentioning that the present consideration is significant not only through academic curiosity but also of practical relevance. Particularly such consideration is noteworthy in hydrogenation of certain unsaturated macromolecules.

**2. Mathematical description**

Let us investigate the stagnation point flow of an incompressible Maxwell liquid induced by a sheet at  $y = \delta(x + b_1)^{\frac{1-n}{2}}$ . Time-dependent contribution is ignored. Two-dimensional analysis is performed. Stretching and free stream velocities are nonlinear i.e.  $(U_w(x) = U_0(x + b_1)^n, U_e(x) = U_\infty(x + b_1)^n)$ . Energy expression is analyzed in the absence of viscous dissipation and thermal radiation effects. Detailed flow assumptions can be seen through Fig. 1. We assume that the reaction in the isothermal cubic autocatalytic is [13]:



In isothermal reaction the temperature of a system remains

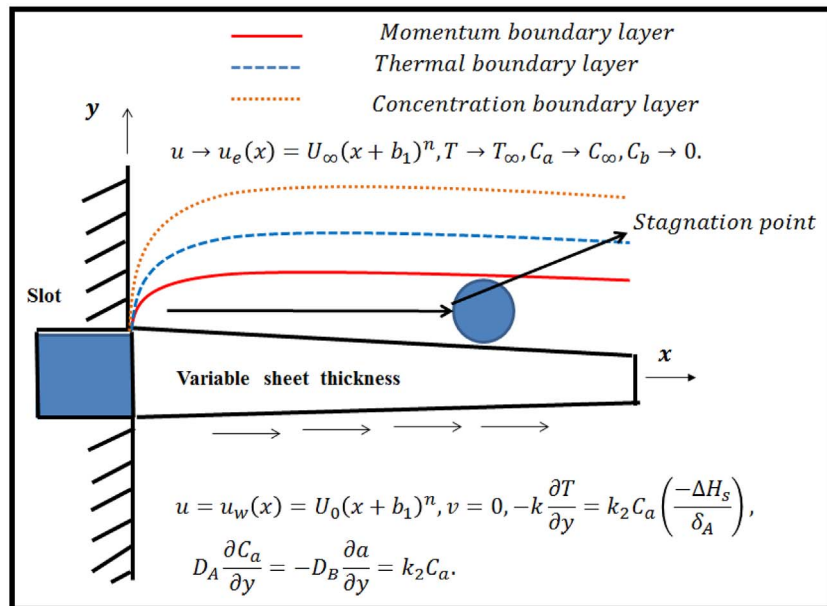


Fig. 1. Geometry of flow problem.

constant. On catalytic surface the isothermal reaction of first order is  $A \rightarrow B, \quad \text{rate} = k_2 C_a,$

where  $(A, B)$  stipulate two different kinds of autocatalysts and concentrations of the chemical reaction respectively are indicated by  $(C_a, C_b)$ . The rate constants  $(k_1, k_2)$  are associated with the homogeneous-heterogeneous process. Moreover it is anticipated that reactant  $(B)$  does not occur in the external/outer flow and the reactant  $(A)$  has a uniform concentration  $(C_{a_0})$ . Since reaction rate at far field is zero so does it at the external edge of related layer. Therefore we suppose that the chemical reactions produce heat release which indicates that influence of thermal expansion cannot be ignored in the boundary layer due to the reactions. The principles of mass, momentum and concentration yield:

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

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} + U_e \frac{dU_e}{dx} + \lambda U_e^2 \frac{\partial^2 U_e}{\partial x^2} - \lambda \left( u^2 \frac{\partial^2 u}{\partial x^2} + v^2 \frac{\partial^2 u}{\partial y^2} + 2uv \frac{\partial^2 u}{\partial x \partial y} \right), \tag{2}$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \left( \frac{-\Delta H_h}{\delta_A} \right) \left( \frac{k_1 C_a C_b^2}{\rho C_p} \right), \tag{3}$$

$$u \frac{\partial C_a}{\partial x} + v \frac{\partial C_a}{\partial y} = D_A \left( \frac{\partial^2 C_a}{\partial x^2} + \frac{\partial^2 C_a}{\partial y^2} \right) - k_1 C_a C_b^2, \tag{4}$$

$$u \frac{\partial C_b}{\partial x} + v \frac{\partial C_b}{\partial y} = D_B \left( \frac{\partial^2 C_b}{\partial x^2} + \frac{\partial^2 C_b}{\partial y^2} \right) + k_1 C_a C_b^2, \tag{5}$$

with the subjected conditions

$$u = U_w(x) = U_0(x + b_1)^n, \quad v = 0, \\ -k_T \frac{\partial T}{\partial y} = k_2 C_a \left( \frac{-\Delta H_s}{\delta_A} \right), \quad D_A \frac{\partial C_a}{\partial y} = -D_B \frac{\partial C_b}{\partial y} = k_2 C_a \text{ at } y = \delta(x + b_1)^{\frac{1-n}{2}}, \tag{6}$$

$$u \rightarrow U_e(x) = U_\infty(x + b_1)^n, \quad T \rightarrow T_\infty, \quad C_a \rightarrow C_\infty, \quad C_b \rightarrow 0 \text{ as } y \rightarrow \infty. \tag{7}$$

Here  $(u, v)$  are the velocity components along the  $x$  – and  $y$  – axes,  $u_\infty$  free stream velocity,  $\nu$  the kinematic viscosity,  $(U_w(x), U_e(x))$  the (stretching, free stream) velocities,  $\lambda$  the relaxation time of fluid,  $T$  the fluid temperature,  $\alpha = \frac{k_T}{\rho C_p}$  the thermal diffusivity,  $\Delta H_h$  the

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