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Unsteady squeezing flow of a radiative Eyring-Powell fluid channel flow with chemical reactions

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ABSTRACT

This paper studied the transient squeezing flow of a radiative magnetohydrodynamics (MHD) Eyring-Powell fluid through an infinite channel. The present analysis includes internal heat generation/absorption effects associated with exothermic or endothermic nature of the reaction. Appropriate equations governing the flow problem are formulated with detailed mathematical analysis by using suitable simplifying assumptions. Approximate solutions of the resulting nonlinear boundary-value problems are obtained via Adomian decomposition method (ADM) and validated numerically with the Runge-Kutta Shooting Method (RKSM). The result of the computation shows that the transverse magnetic field decreases both the flow velocity and wall shear stress when the walls are expanded. Also, contraction of the channel walls, heat generation, and radiation parameters enhances the wall Nusselt number while chemical reaction, Schmidt and compressed channel parameters decrease the wall Sherwood number.

1. Introduction

The last few decades have witnessed a tremendous increase in studies related to squeeze flow due to its importance in several technological and engineering processes. For instance, the study is useful in understanding the arterial blood flow due to the squeezing action of the heart; it is also relevant to the study of lubricating fluids used for dampening shocks, several polymer processes and many more applications in which the solid boundaries are compressed to squeeze out fluid. As reported in the pioneering work by Stefan [1] in which squeezing flow dynamics was reported by invoking lubrication approximations. Following this, Siddiqui et al. [2] reported the transient MHD squeezing flow through a channel. Sweet et al. [3] discussed the impact of magnetic field on the squeezing flow problems through an infinite channel. In a similar study, Mustafa et al. [4] reported the heat and mass transfer in the squeezing channel flow. Petrov and Kharlamove [5] investigated the squeezing flow of viscous Newtonian fluid through a channel. Khan et al. [6] addressed the magnetohydrodynamic unsteady squeezing flow of Casson fluid passing through a channel filled with a porous medium. Mohyud-Din et al. [7] obtained the homotopy semi-analytical solutions to study the force convective squeezing flow of nanofluid in a leaking disks. Also, Sobamowo and Akinshilo [8] discussed the MHD squeezing nanofluid flow. Furthermore, Khan et al. [9] discussed the squeezing flow of a Casson fluid via parallel circular plates. Vajravelu et al. [10] analyzed the influence of variable properties, temperature and velocity slip on unsteady magnetohydrodynamic squeezed nanofluid flow of between parallel disks with transpiration. Interested readers can see the following references for further results on the squeezed flow problems [11–17].

In practice, the complex nature of real fluid cannot be explained by the simple Newtonian constitutive relation that is based on a linear shear stress and strain relationship. This deficiency has led to a departure from the Newtonian class to non-Newtonian constitutive models. In recent times, several non-Newtonian models have been used when dealing with fluids with industrial and engineering applications. Of interest, in this study is the Eyring-Powell(E-P) model derived from the molecular theory of liquids and gases, the viscoelastic model breaks down to the Newtonian class in both high and low shear rates. The E-P model has a clear advantage over other constitutive models that were derived based on empirical relations. Recently, Agbaje et al. [18] explained the transient developing flow of E-P nanofluid over a shrinking plane. Hayat et al. [19] presented an analysis on convective hydromagnetic developing flow of E-P fluid taking the thermophoresis effect and Brownian motion into consideration. Also, in Ref. [20], Hayat et al. presented the Hall current effect on the peristaltic E-P fluid flow down

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Nomenclature			
p	Pressure	Q^*	Uniform volumetric heat generation/absorption coefficient
μ	Fluid dynamic viscosity	C	Concentration species of the fluid
t	Time (s)	D_m	Mass diffusion
l	Distance between the plates at time t	k_1	Reaction rate
α	Characteristic parameter of the squeezing motion of the plate (s^{-1})	T_0	reference temperature
B_0	Uniform magnetic field	C_0	Reference concentration
u, v	Axial and transverse velocity component (ms^{-1})	Γ, δ	Fluid parameters
ν	Kinematic viscosity	S	Squeezing number
ρ	Fluid density	M	Hartmann number
σ	Electrical conductivity of the fluid	R	Thermal radiation parameter
T	Fluid temperature	Pr	Prandtl number
κ	Thermal conductivity	Q	Heat generation/heat absorption parameter
C_p	Specific heat capacity	Sc	Schmidt number
σ^*	Stefan-Boltzman constant	γ	Chemical reaction parameter
κ^*	Coefficient of mean absorption	C_f	Skin friction
		Nu	Local Nusselt number
		Sh	Local Sherwood number

an inclined channel. Abegunrin et al. [21] reported the double diffusivity problem in the flow of E-P fluid undergoing a destructive chemical reaction. Khan et al. [22] investigated E-P fluid flow over a rotating disk. Hayat et al. [23] used the E-P nanofluid model to examine the MHD effects over a nonlinear stretching sheet. Similarly, Hina [24] discussed the heat and mass transfer analysis of MHD peristaltic slip flow of E-P fluid. In the work of Nadeem and Saleem [25], the transient developing flow of reacting E-P fluid in a rotating cone was analyzed. Tanveer [26] analyses the reacting flow of peristaltic E-P nanofluid in a curved passage. Khalil-Ur-Rehman [27] addressed the stagnation point flow in MHD E-P fluid with double diffusivity. Other related studies on E-P fluid flow under different geometries are not limited to the studies reported in Refs. [28–31] and references therein.

Motivated by the results described earlier on squeezing flows, the main aim of the current work is focused on the heat and mass transfer analysis of an electrically conducting radiative squeezing flow of internal heat generating E-P fluid which has not been reported in earlier studies to the best of our knowledge. This in view of the fact that magnetic field has been shown to play a vital role in the flow and heat transfer processes in the literature. For instance, in the dampening of shocks, flow control, agglomeration and polymer processing due to expansion and contraction of channel walls in most engineering and thermal procedures. As a result, a huge number of works have been done on the theory and application of magnetohydrodynamics by taking the of magnetic field into consideration. For example, Sheikholeslami and Ganji [32] reported the nanofluid flow through a leaky semi annulus. Also, Mahanthesh et al. [33] developed a three dimensional model for studying the developing non-Newtonian fluid flow. Gireesha et al. [34] analyzed the E-P nanofluid flow over a stretching surface. Mahanthesh et al. [35] investigated the nanofluid flow over a vertical stretching surface. Hatami et al. [36], presented a numerical investigation on Couette flow with suspended fluid particles. Gireesha et al. [37] considered the stagnation point flow with melting heat transfer effect. In the work of Gireesha et al. [38], the dusty fluid flow through a stretching surface filled with porous particles was reported while Ghadikolaei et al. [39] considered the radiative micropolar nanofluid flow through a stretching surface with porous materials.

The work is arranged in the following way: Section 2 explains the mathematical formulation and analysis of the problem, Section 3 describes Adomian decomposition method, while in Section 4, semi - analytical solutions of the problem are obtained. Section 5 discusses the results. While in Section 6, we presents main contributions to knowledge.

2. Mathematical formulation

For an incompressible non-Newtonian E-P fluid, the constitutive equation is given by Ref. [40] as

$$\mathbf{T} = -p\mathbf{I} + \mu\mathbf{A}_1 + \left[\frac{1}{\beta|\mathbf{A}_1|}\sinh^{-1}\left(\frac{1}{c}\left|\mathbf{A}_1\right|\right)\right]\mathbf{A}_1 \tag{1}$$

where $\mathbf{T}$ stands for the Cauchy stress tensor, p is the fluid pressure, $\mathbf{I}$ denotes the unit tensor, μ is the dynamic viscosity, β and c are characteristics of the E-P fluid with dimensions pascal^{-1} and second^{-1}, respectively. Further, $\mathbf{A}_1$ represents the Rivlin-Ericksen tensor given by

$$\mathbf{A}_1 = (\nabla\mathbf{V}) + (\nabla\mathbf{V})^T \tag{2}$$

and

$$\left|\mathbf{A}_1\right| = \sqrt{\frac{1}{2}\mathrm{tr}(\mathbf{A}_1^2)} \tag{3}$$

where $\nabla = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$, $\mathbf{V}$ is the velocity of the flow field and T denotes the matrix transpose. Taking the second-order approximation of $\sinh^{-1}$ function and neglecting higher term we have

$$\sinh^{-1}\left(\frac{1}{c}\left|\mathbf{A}_1\right|\right) \cong \frac{|\mathbf{A}_1|}{c} - \frac{|\mathbf{A}_1|^3}{c^3}, \quad \left|\frac{|\mathbf{A}_1|}{c}\right| \ll 1 \tag{4}$$

Consider the unsteady two-dimensional squeezing flow of a E-P fluid through an infinite channel that is separated by a distance $a(t) = \pm l(1-\alpha t)^{\frac{1}{2}}$ apart. Here l is the initial distance between two plates at time t and α is the characteristic parameter of the squeezing motion of the plate with dimension of the inverse time. Then $\alpha > 0$, implies that the two plates squeezes until they meet at $t = 1/\alpha$ on the other hand, $\alpha < 0$ means separated plates. A constant magnetic intensity $B_0(1-\alpha t)^{-\frac{1}{2}}$ is applied normally to the plate, with negligible magnetic field, due to low Reynolds numbers. Choosing a Cartesian coordinate system with (x, y), the equations governing the unsteady two dimensional flow of a E-P fluid are as follow [4]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{5}$$