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Entropy analysis of convective MHD flow of third grade non-Newtonian fluid over a stretching sheet

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Abstract The purpose of this article is to study and analyze the convective flow of a third grade non-Newtonian fluid due to a linearly stretching sheet subject to a magnetic field. The dimensionless entropy generation equation is obtained by solving the reduced momentum and energy equations. The momentum and energy equations are reduced to a system of ordinary differential equations by a similarity method. The optimal homotopy analysis method (OHAM) is used to solve the resulting system of ordinary differential equations. The effects of the magnetic field, Biot number and Prandtl number on the velocity component and temperature are studied. The results show that the thermal boundary-layer thickness gets decreased with increasing the Prandtl number. In addition, Brownian motion plays an important role to improve thermal conductivity of the fluid. The main purpose of the paper is to study the effects of Reynolds number, dimensionless temperature difference, Brinkman number, Hartmann number and other physical parameters on the entropy generation. These results are analyzed and discussed.

1. Introduction

The efficient use of energy and optimal consumption of resources has motivated research into improving the efficiency of industrial processes. Research on the improvement in heat transfer as one of the most influential factors in energy consumption has been the main focus. Evaluation of entropy generation and the use of special fluids like non-Newtonian fluids are important and efficient methods for achieving optimal heat transfer.

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Nomenclature

A	constant	T_∞	temperature at infinity (K)
B	magnetic induction vector (kg s^{-2} A^{-1})	T_w	wall temperature (K)
B_0	constant magnetic flux density (kg s^{-2} A^{-1})	u, v	components of velocity (m s^{-1})
Be	Bejan number	U_∞	free-stream velocity (m s^{-1})
Br	Brinkman number	V	velocity vector (m s^{-1})
E_1	fluid parameter	v_w	uniform surface suction/blowing
E_2	fluid parameter	Ω	dimensionless temperature difference
E_3	fluid parameter	θ	dimensionless temperature
E_4	Reynolds number	ΔT	temperature difference
Ha	Hartmann number	μ	viscosity (kg m^{-1} s^{-1})
k	thermal conductivity (kg ms^{-3} K^{-1})	α	equivalent thermal diffusivity (m^2 s^{-1})
M	Hartmann number	ρ	density of the fluid (kg m^{-3})
N_G	entropy generation number	v	kinematic viscosity (m^2 s^{-1})
P	pressure (kg m^{-1} s^{-2})	σ	electric conductivity
Pr	Prandtl number		
Re	Reynolds number	*Subscripts*	
S_0'''	characteristic entropy generation rate (kg m^{-1} K^{-1} s^{-3})	tot	total
$\dot{S}_{gen}'''$	rate of entropy generation (kg m^{-1} K^{-1} s^{-3})	∞	infinity condition
T	temperature (K)	0	plate

With the advancement of industry and improved engineering expertise, entropy generation is seen as an appropriate solution to improve efficiency in industrial processes. Bejan was the first researcher to introduce this concept by means of entropy generation minimization (EGM) [1]. EGM is also known as second law analysis and thermodynamic optimization. In recent years much research has been done on this topic in different geometries. Analysis of the second law of thermodynamics applied to an electrically conducting incompressible nanofluid fluid flowing over a porous rotating disk with an externally applied uniform vertical magnetic field has been considered by Rashidi et al. [2]. Rashidi et al. [3] extended the analysis from [2] by considering entropy generation in MHD and slip flow over a rotating porous disk [3]. Entropy generated inside the boundary-layer of nanofluids over a flat plate is studied analytically by Malvandi et al. [4]. Second law analysis of a viscoelastic fluid over a stretching sheet influenced by a magnetic field with heat and mass transfer was studied by Aïboud and Saouli [5]. Kummer's functions were used to analyze the model and show the influence of physical parameters on entropy generation.

In this article the effects of a stretching sheet due to convective MHD flow of third grade non-Newtonian fluid were investigated. In the same way a stretching sheet plays an important role in industry. It can be used in industrial applications such as metal spinning, hot rolling and extrusion. The rates of stretching and cooling have significant influence on the quality and properties of the final product [6]. Chang et al. have studied the flow of a non-Newtonian fluid over a stretching sheet by determining explicit solutions [7]. Anderson et al. investigated the flow of a non-Newtonian power-law fluid over a stretching sheet influenced by a magnetic field [8]. Chakrabarti and Gupta studied hydromagnetic flow and heat transfer due to a stretching sheet [9]. Abel et al. studied magnetohydrodynamic flow due to a stretching surface with heat and mass transfer of a non-Newtonian fluid [10].

Sarpakaya was the first researcher to study the effect of magnetic field on flows of non-Newtonian fluids [11]. Siddappa and Subhas investigated the flow of a viscoelastic non-Newtonian fluid due to a stretching plate [12]. Qasim et al. investigate the steady flow of a micropolar fluid over a stretching surface with heat transfer in the presence of Newtonian heating [13]. Nadeem et al. consider the steady flow of a Jeffrey fluid on a stretching sheet [14]. Prasad et al. investigate MHD over a nonlinear stretching sheet of a power law fluid [15]. Kishan and Reddy include the effects of suction/injection to the problem considered by Prasad et al. [15] to investigate a more complicated system of ordinary differential equations [16]. Abel and Mahesha consider the effects of variable thermal conductivity and non-uniform heat source on heat transfer in a viscoelastic NHD fluid on a stretching sheet [17]. Javeda et al. devote their paper to the study of an Eyring–Powell fluid over a stretching sheet [18]. Mahmoud and Megahed investigate MHD flow of a power law fluid on an unsteady stretching sheet [19]. Mukhopadhyay considers the flow of a Casson fluid on a nonlinearly stretching sheet [20]. Prasad et al. extend the work of Javeda et al. [18] by considering the flow of an Eyring–Powell fluid over a non-isothermal stretching sheet [21]. Bhattacharyya extends the work of Mukhopadhyay [20] by considering the flow of a Casson fluid over a stretching sheet with thermal radiation [22]. Boundary-layer flow and heat transfer of non-Newtonian fluids in porous media are investigated by Chaoyang and Chuanjing [23]. In another studies, Nadeem et al. [24–26] studied the oblique stagnation-point flow of viscoelastic and Casson fluids numerically and analytically using midpoint integration scheme with Richardson's extrapolation and HAM. Further, Akbar et al. [27] discussed the two dimensional stagnation-point flow of carbon nanotubes toward a stretching sheet with water as the base fluid under the influence of slip effects and convective boundary condition using a homogeneous model. Moreover, Noreen and