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Impacts of binary chemical reaction with activation energy on unsteady flow of magneto-Williamson nanofluid

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ABSTRACT

The current review aims to study the combined effects of variable magnetic field and heat generation/absorption on unsteady flow of non-Newtonian Williamson fluid generated by a stretching cylinder in the presence of nanoparticles. An important prospective of this endeavour is to incorporate the impacts of binary chemical reaction and activation energy for revised Buongiorno's model of nanofluid in view of their improved heat transfer. The notion of Boussinesq-approximations is utilized to model the leading equations of momentum, thermal energy and nanoparticle concentration for Williamson fluid. We have employed suitable non-dimensional quantities to alter the leading partial differential equations (PDEs) into a set of ordinary differential equation (ODEs). The numerical simulation is conducted with the help of Runge-Kutta Fehlberg scheme coupled with shooting iteration procedure. The analysis of the obtained results revealed that the assumed physical model is significantly influenced by the key physical parameters, like, magnetic parameter, chemical reaction parameter, activation energy parameter, heat generation/absorption parameter, Brownian motion and thermophoresis parameter. The physical significance of above-mentioned physical parameters on nanofluid velocity, temperature and concentration is argued and exhibited through graphs. The cardinal physical intimation of obtained results is that the nanoparticles concentration enhances with higher activation energy parameter. Further, it is perceived from these results that the rate of heat transfer over the cylinder surface de-escalates with an increase in the reaction rate parameter. It is noted that an augmentation in thermophoresis parameter leads to a rise in nanofluid temperature.

1. Introduction

Due to complexity following the consideration of all the chemical reactions of a system, it becomes more convenient and simplistic to limit to binary type only. A chemical reaction needs activation energy which is an amount must be available to start off. The activation energy for a reaction can be determined using Arrhenius equation that describes how the rate constant changes with temperature. Chemical reactions are characterized by a chemical change and one or more products are yielded that have properties different from the reactants. As a fundamental step in the process of manufacturing, many industrial applications need some form of chemical reaction. These types of reactions are conventionally carried out in chemical reactors and often limited by the degree of mass transfer achieved. It is essential to make the reaction efficient, minimizing the number of reagents, energy inputs and waste while maximizing the yield. Bestman [1] have studied the impact of chemical reaction for binary reaction model with Arrhenius activation energy. Latterly, Kandasamy et al. [2] investigated the combined effects of chemical reaction, heat and mass transfer analysis along a wedge-shaped geometry with generation/absorption. They found that an enhancement in chemical reaction parameter causes a reduction in momentum, thermal and concentration profiles. Makinde et al. [3] analyzed the effects of chemical reaction and radiative heat transfer induced by a permeable flat plate. They revealed that the fluid velocity declines with higher values of buoyancy forces and wall suction parameter. Maleque [4] elaborated the effects of binary chemical reaction and activation energy on boundary layer flow in the presence of viscous dissipation. He reported that an increase in activation energy causes a rise in velocity, temperature and concentration profiles. Wahiduzzaman et al. [5] have considered the impacts of heat generation, chemical reaction and thermal radiation on stagnation-point flow of nanofluid past a shrinking surface. The radiative heat transfer during the MHD flow of nanofluids generated by a flat plate with chemical reaction is investigated by Zhang et al. [6]. They implemented the differential transformation method (DTM) to acquire the approximate solutions for their problem. After that, Mabood et al. [7] presented a numerical study for stagnation-point flow of nanofluid in the presence of viscous dissipation and chemical reaction. In their analysis, they

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Nomenclature

u, v	velocity components
x, r	cylindrical coordinates
n	fitted rate constant
T	fluid temperature
T_w	surface temperature
T_∞	ambient temperature
C	fluid concentration
C_w	concentration at the surface
C_∞	ambient concentration
D_B	Brownian diffusion coefficient
D_T	thermophoresis diffusion coefficient
u_w	stretching velocity
k	thermal conductivity
B_0	magnetic parameter
σ^*	electrical conductivity
c_p	specific heat
β^*	ratio of viscosities
Γ	relaxation time
a, c	constants
$(\rho c)_p$	effective heat capacity of a nanoparticle
$(\rho c)_f$	heat capacity of the base fluid
ρ	fluid density
ν	kinematic viscosity
τ	parameter defined by the ratio $\frac{(\rho c)_p}{(\rho c)_f}$
τ_w	surface shear stress
q_w	surface heat flux
C_f	skin friction coefficient
Nu	local Nusselt number
Re	local Reynolds number
η	dimensionless similarity variable
ψ	stream function
f	dimensionless stream function
θ	dimensionless temperature
ϕ	dimensionless concentration function
We	local Weissenberg number
Sc	Schmidt number
Nb	Brownian motion parameter
Nt	thermophoresis parameter
σ	reaction rate parameter
Pr	Prandtl number
β	heat generation/absorption parameter
γ	curvature parameter
δ	temperature difference parameter
E	activation energy

exhibited that nanoparticle concentration declines with an increment in chemical reaction parameter. Makinde and Animasaun [8] analyzed the influence of thermophoresis diffusion and Brownian motion on bioconvection of nanofluid with thermal radiation and chemical reaction. They explained that concentration of bulk fluid upgrades with Brownian diffusion while an opposite behaviour is seen for thermophoresis parameter. In another paper, Eid [9] illustrated the influence of chemical reaction and heat generation/absorption on mixed convective flow of nanofluid past an exponentially stretched surface. He utilized the shooting technique along with Runge-Kutta Fehlberg method to get the numerical solutions. Afify and Elgazery [10] numerically analyzed the impact of chemical reaction on magnetohydrodynamic flow of Maxwell fluid generated by a stretching surface. They observed that nanoparticles concentration reduces with higher chemical reaction parameter whereas a reverse pattern is noted for temperature. A theoretically review on the boundary layer flow of nanofluid over a rotating disk with chemical reaction and partial slip is given by Reddy et al. [11]. Chemical reaction and activation energy aspects in nanofluid past a vertical plate in the presence buoyancy effects are considered by Mustafa et al. [12]. Their results show that nanoparticle concentration is higher when activation energy for chemical reaction is higher. Ullah et al. [13] investigated the impact of chemical reaction on time-dependent flow of Casson nanofluid over a wedge-shaped geometry using Keller-box method. They perceived that local Nusselt number is a decreasing function of thermophoresis and Brownian motion parameter. Anuradha and Yegammai [14] examined the effects of activation energy and binary chemical reaction on radiative flow of nanofluid over a vertical plate in the presence of ohmic dissipation. Their results investigate that reaction rate rises the temperature and velocity distributions. Hsiao [15] applied the controlling method to promote the radiative activation energy of a manufacturing system of Carreau-nanofluid. He utilized the finite difference technique to obtain the convergence and stability of the problem. Zeeshan et al. [16] discussed the impact of chemical reaction and activation energy on Couette-Poiseuille flow in horizontal channel along convective boundary conditions. Khan et al. [17] examined the MHD radiative flow of Casson fluid over a stretched surface in the presence of chemical reaction.

Nanotechnology alludes to be an emerging field of science that incorporates synthesis and advancement of different nanomaterials. Nanoparticles can be characterized as objects ranging in size from 1 to 100 nm because of their size may differ from the bulk material. Presently, different metallic nanomaterials are being provided using copper, magnesium, zinc, gold, titanium, and silver. These particles are finding their applications from medical treatments, using in various branches of industrial production, for example, solar and oxide fuel batteries for energy storage, to wide fuse into assorted materials of ordinary use. Nanoparticles have a surrounding interfacial layer which is a basic part of nanoscale matter, fundamentally affecting majority of its properties. It typically comprises of particles, inorganic and organic molecules. Organic molecules coating inorganic nanoparticles are known as stabilizers, capping and surface ligands, or passivating agents. The particles are further classified according to diameter. The ultrafine particles are the same as nanoparticles while fine particles are between 100 and 2500 nm. In addition, coarse particles cover a range in the vicinity of 2500 and 10,000 nm. Nanofluids are manufactured by doping working fluids with nanoparticles [18,19]. It has been verified that this innovation aims at improving the physical characteristics of working fluids, like, thermal conductivities and the convective heat transfer. Boungiorno [20] proposed a model for nanofluids which depict the effects of Brownian motion and thermophoresis. Nield and Kuznetsov [21] explored the impact of nanoparticles on free convection boundary layer flow induced by a vertical plate. They further incorporated the effects of Brownian motion and thermophoresis in this study. A numerical investigation for two-dimensional flow of nanofluid caused by a stretching surface with heat and mass transfer was made by Khan and Pop [22]. They noted that the rate of heat transfer was significantly reduced by the higher Brownian motion parameter. The numerical scrutiny of blood flow of Jeffrey nanofluid in tapered artery with stenosis is examined by Rahman et al. [23]. A decent literature survey on nanofluids transport problems and their different applications can be found in the review articles by Akbarzadeh et al. [24], Rehman et al. [25], Atlas et al. [26], Shehzad et al. [27], Hashim and Khan [28], Shirvana et al. [29], Esfahani et al. [30], Rehman et al. [31], Rashidi et al. [32], Prabhakar et al. [33] and Hashim et al. [34], etc.

Activation energy along with binary chemical reaction plays a significant role in technology and industrial processes. A careful view of the existing literature demonstrates that, to the best of our insight, nobody has considered the impacts of binary chemical reaction with activation energy for the time-dependent flow of Williamson nanofluid. Further, the flow is generated by a stretching cylinder under the influences of heat generation/absorption and magnetic field. Brownian diffusion