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Double diffusive unsteady convective micropolar flow past a vertical porous plate moving through binary mixture using modified Boussinesq approximation

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Variable viscosity;
Vertical surface through binary mixture

Abstract The problem of unsteady convective with thermophoresis, chemical reaction and radiative heat transfer in a micropolar fluid flow past a vertical porous surface moving through binary mixture considering temperature dependent dynamic viscosity and constant vortex viscosity has been investigated theoretically. For proper and correct analysis of fluid flow along vertical surface with a temperature lesser than that of the free stream, Boussinesq approximation and temperature dependent viscosity model were modified and incorporated into the governing equations. The governing equations are converted to systems of ordinary differential equations by applying suitable similarity transformations and solved numerically using fourth-order Runge–Kutta method along with shooting technique. The results of the numerical solution are presented graphically and in tabular forms for different values of parameters. Velocity profile increases with temperature dependent variable fluid viscosity parameter. Increase of suction parameter corresponds to an increase in both temperature and concentration within the thin boundary layer.
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1. Introduction

Non-Newtonian fluids are common fluids in industrial and engineering processes in which there is no linear relationship between stress and deformation rate as such fluid flows along horizontal or vertical surface. Within the past few years, the dynamic and behavior of non-Newtonian fluid have received considerable attention in the field of heat and mass transfer and thermal science owing to their great applications in the industrial production of molten polymers, pulps, fossils fuels and fluids containing certain additives. Immense contributions to the body of knowledge (i.e. toward the understanding of the dynamics of non-Newtonian fluids) can be found in Refs. [1–8]. Gebhart et al. [9] focused on the physics of a flow along vertical surface and explained extensively how fluid flows along vertical surface. In natural convection, fluid surrounding a

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Nomenclature

(x, y)	cartesian coordinates
t	time
T	temperature of the fluid
N	angular velocity
j	micro-inertia density
T_∞	dimensional free stream temperature
Q	activation enthalpy
E_A	activation energy
C_p	specific heat at constant pressure
R_G	universal gas constant
S_c	schmidt number
V_T	thermophoretic velocity
K_r	chemical reaction rate
$h(\eta)$	dimensionless microrotation
L_1	time dependent microrotation parameter
R_a	radiation number
G_r	modified thermal Grashof number
$f(\eta)$	velocity profile
(u, v)	velocity components along x, y directions respectively
g	acceleration due to gravity
C	concentration of the fluid
T_w	dimensional surface temperature
C_w	dimensional surface concentration
C_∞	dimensional free stream concentration
c	suction
h_q	heat generation parameter
U_o	uniform velocity at free stream
n	order of the chemical reaction
ΔH	enthalpy change
D_m	coefficient of mass diffusivity
R_A	arrhenius term
K_1	microrotation parameter
D_a	Damkholer number
G_c	modified solutal Grashof number
P_r	Prandtl number

Greek symbols

ξ	variable viscosity parameter
ϑ	kinematic viscosity
κ	thermal conductivity
τ	vortex viscosity
μ	dynamic viscosity
ω	activation energy
θ	dimensionless temperature
β	volumetric thermal-expansion coefficient
ψ	stream function
α	absorption coefficient
σ	Stefan–Boltzmann constant
ρ	fluid density
η	similarity variable
θ_w	dimensionless wall temperature
ϕ_w	dimensionless wall concentration
λ	thermophoretic parameter
ϕ	dimensionless concentration
β^*	volumetric solutal-expansion coefficient
γ^*	spin gradient viscosity

heat source receives heat energy; the fluid tends to becomes less dense and rises. The surrounding cooler fluid moves to replace it [9]. Bird et al. [10] reported that this cooler fluid is heated and the process continues forming convection current; this process transfers heat energy from the hot region to cool region. The driving force for free convective is buoyancy, a positive differences in fluid density. According to all the previous published articles on fluid flow along vertical surface, it is worth noticing that existence of buoyancy in the fluid domain is incorporated into the momentum equation based on the fact that wall temperature is greater than free stream temperature and the temperature decreases from the wall to the free stream. Because of this, a correct and accurate pressure gradient term is required to account for the convection term in momentum equation.

Emulsion on the other side can be described as a mixture of two liquids that would ordinarily not mix together. Two types of emulsion are temporary and permanent. An example of temporary emulsion is found in the industrial production of simple vinaigrette (mixture of oil and vinegar) and mixture of oil and water. When stirred or shaken vigorously, the two liquids tend to form temporary emulsion which comes together for a short time. In industry, Hollandaise sauce is another permanent emulsion which is made of egg yolks and clarified butter. These can be explained as good examples of a binary mixture of fluids. Fluid flow past a plate moving through a binary mixture has been investigated due to its importance in industry. Makinde et al. [11] carried out a research on unsteady convection with chemical reaction and radiative heat transfer past a flat porous plate moving through a binary mixture using the classical Boussinesq approximation. They assumed constant fluid viscosity within the thin boundary layer formed on vertical surface. The effects of increasing magnitude of thermal Grashof number, solutal Grashof number and other important parameters over velocity, temperature and concentration profiles were reported extensively. Makinde and Olanrewaju [12] went further to consider the flow of a viscous incompressible fluid flow past a vertical porous plate moving through a binary mixture with the influences of energy flux caused by a composition gradient and mass flux caused by a temperature gradient. They extensively reported the effect of the new parameters (i.e. Dufour and Soret parameter). Sastry and Murti [13] were motivated by the research and assumed that the fluid in question is electrically conducting and reported the effect of magnetic field parameter.

In view of these ideas, it is of importance to investigate the dynamics of fluids which contains microstructure as it flows past a vertical porous plate moving through a binary mixture as well (i.e. study fluid which contains particles that may undergo translations and rotations as it flows through a binary mixture). This kind of fluids belongs to a class of fluid with non-symmetric stress tensor that are called polar fluids. Physically, micropolar fluids consist of rigid, randomly oriented (or spherical) particles suspended in a viscous medium

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