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Unsteady Casson nanofluid flow over a rotating cone in a rotating frame filled with ferrous nanoparticles: A numerical study

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ABSTRACT

In this study, we investigated the momentum and heat transfer characteristics of Casson nanofluid flow over a rotating cone in a rotating frame filled with water based $CoFe_2O_4$ nano particles. Heat flux conditions and wall temperature conditions are very important in controlling of up and down heat transport phenomena's in industrial as well as engineering application. Resulting set of coupled nonlinear governing equations are solved numerically using Runge–Kutta based shooting technique. In graphical results we presented dual solutions for the prescribed wall temperature (PWT) and prescribed heat flux (PHF) cases. The effect of governing parameters on velocity and temperature fields along with the skin friction coefficient and the heat transfer rate are presented with the help of graphs and tables. Results indicate that the rising values of the volume fraction of ferro particles and buoyancy parameter have tendency to improve the skin friction coefficient as well as the heat transfer rate for both the prescribed wall temperature (PWT) and prescribed heat flux (PHF) cases.

1. Introduction

Ferro fluids are widely used in rotating X-ray tubes, sealing of hard disk drives, rods separation system, oil lubricant bearing and dampers processes and rotating shafts. These are also used as a controller in electric motors and Wi-Fi speaker systems without use of change in their geometrical shape. Ferrous based nano particles are greatly used in MHD based fluid devices like sensor systems, pressure transducers, acidometer, densitometers, electro mechanical converters, inexpensive and silent printers etc. Keeping view into this importance the revolution of ferro fluid was initiated by [1] and Guptha and Guptha [2]. Rotation effect on MHD ferro fluid flow along a rotating disk was analyzed by Ram and Sharma [3]. Sheikholeslami and Bandpy [4] discussed the external magnetic field effect on convection flow of heated cavity filled ferrofluid. A space and time dependent heat source/sink effect on MHD radiative ferro fluid flow along a plate was investigated by Raju et al. [5]. Qasim et al. [6] illustrated the prescribed heat flux condition and slip effects on ferro fluid flow over a stretching cylinder. Convection analysis of ferro fluid flow past a stretching surface in the presence of radiation was considered by Rani Titus et al. [7].

The recent growths of progressive technologies have stimulated excitement in fluid flows through a cone. It has advanced applications in many of the real world systems like industrial engineering applications, solar collectors, hydrology, geosciences, preparation of transmission missile gun operations, aeronautical engineering, development of electronic chips, homeo-therapy treatment, , astro-physics, endoscopy scanning, radiology treatment, nuclear safety and cleaning management systems, dental applications paper production industries, lubricating grease for seals, valves, and threaded connections. Flow over a cone with unsteadiness with non-uniform heat source/sink also plays an importance in many of science and medical engineering processes like petroleum industries, pharmaceutical chemistry, environmental controlling, inverting solar pumps and plantation. Due this important the pioneering work of convection flow past vertical cone discussed by Kumari et al. [8]. In continuation of this the researchers [9], Nadeem and Saleem [10], Sheikholeslami et al. [11], Raju and Sandeep [12] are discussed by considering various boundary conditions with various effects like radiation, magnetic field, Soret and Dufour effects, Brownian motion and thermophoretic effects etc. Saleem and Nadeem [13] investigated an unsteady nanofluid flow over a vertical rotating cone in the presence of buoyancy effect. Raju and Sandeep [14] discussed the non-Newtonian flow over a cone in the presence of chemical reaction and thermal radiation. Recently, the magneto hydrodynamic 3D flow of non-Newtonian nanofluid over a thermally radiative sheet in the presence of heat generation was examined by Shehzad et al. [15]. Pesso and Piya [16] investigated the convection flow in pipe in the presence of heat generation. The

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Nomenclature

v_e	Free stream velocity
g_e	Acceleration due to gravity (m/s^2)
υ	Kinematic viscosity (m^2/s)
ρ_{nf}	Density (Kg/m^3)
μ_{nf}	Dynamic viscosity (Ns/m^2)
α^*	Semi vertical angle
A^*, B^*	Heat generation or absorption coefficient
α_1	Ratio of angles
x	Distance along the surface (m)
y	Distance normal to the surface (m)
S	Unsteadiness parameter
u, v, w	Velocity components in x, y *and* $z$directions respectively (m/s)
c_p	Specific heat capacity at constant pressure (J/KgK)
k_{nf}	Thermal conductivity (W/mK)
Ω	Composite angular velocity
$(\rho c_p)_{nf}$	Effective heat capacity(Kg/m^{3}K)
$(\rho c_p)_p$	Effective heat capacity of the particle medium (Kg/m^3K)
λ	Buoyancy parameter
β_T	Volumetric thermal expansion (K^{-1})
Pr	Prandtl number
α_{nf}	Diffusion coefficient (m^2/s)
σ^*	Stefan-Boltzmann constant (W m/K^4)
k^*	Mean absorption coefficient
η	Similarity variable
T	Temperature (K)
ν_{nf}	Kinematic viscosity (m^2/s)
Cf_x	Skin friction coefficient in x-direction
Cf_y	Skin friction coefficient in y-direction
Nu_x	Local Nusselt number
Re_L	Local Reynolds number
ϕ	Nano particle volume fraction
Gr	Grashof number
f, g	Dimensionless velocities
θ	Dimensionless temperature (K)
q_w	Wall heat flux (W/m^2)
σ	Electrical conductivity (S/m)

Subscripts

f	Fluid
w	Condition at the wall
∞	Condition at the free stream
nf	Nano fluid

temperature dependent transport of mixed convection flow past vertical channels was considered by Prasad et al. [17].

Due to the diversity of the nature flow, it develops the different nature of characteristics. For example rheological fluids, power-law fluids, Jeffrey fluid and Eyring–Powell fluid etc. The Casson fluid is a closed with rheological fluid flow model for expressing the non-Newtonian fluid flow properties with a yield stresses. This model was developed due to viscous suspension of cylindrical shaped particles in a fluid flow. Despite of few fluids are report well due to their nonlinearity in the fluid flow, pseudo plasticity and yielding stresses in nature. It is a special case of power-law model. For example slurries, blood, chocolate, waxy crude oil, waste water sludge's and gum solutions. Casson model is a suitable for the nonlinear reaction of pseudo plastic-yield stress fluids quite well and due to this importance it has initiated in Wilkinson [18]. It has profited in many industrial processes like pharmaceutical engineering industries, aerospace technology, food processing technology and polymer production. The Casson flow with various dimensions and influences are given by Walwander et al. [19,20], Raju et al. [21]. [22] Discussed an unsteady MHD flow along vertically moving an impulsive plate in the presence of radiation and inclined magnetic field effect. An unsteady magnetohydrodynamic asymmetric flow of a third grade fluid with buoyancy forces and convective cooling was investigated by Chinyoka and Makinde [23]. Raju et al. [24] analyzed the non-uniform heat generation/absorption coefficients on Nanofluid flow along a permeable vertically moving plate. An unsteady convection flow of a micropolar fluid along a stretching/shrinking sheet in the presence of non-uniform heat source/sink and magnetic field effect was considered by Sandeep and Sulochana [25]. Jayachandrababu et al. [26] investigated the cross diffusion effects on Eyring–Powell nanofluid flow over a permeable cone with magnetic field effect. Recently, the researchers [28–30] studied the mass and heat transfer characteristics of non-Newtonian fluid with various effect and geometries.

Heat flux conditions as well as wall temperature conditions are very important in controlling of up and down heat transport phenomena's in industrial as well as engineering application. Motivations of the above studies, the present paper address the heat transfer characteristics of Casson fluid flow over a rotating cone in a rotating frame filled with water based $CoFe_2O_4$ nano particles. Resulting set of coupled non-linear governing equations are solved numerically using Runge–Kutta based shooting technique. In this study we presented dual solutions for the prescribed wall temperature (PWT) and prescribed heat flux (PHF) cases over a rotating cone. The effect of flow governing parameters on velocity and temperature fields along with the skin friction coefficient and the heat transfer rate are presented with the help of graphs and tables.

2. Formulation of the problem

In this study, we consider an unsteady ferro fluid flow on a rotating cone in rotating frame with non-uniform heat source/sink. We consider the rectangular curvilinear fixed coordinate system. The geometry of the problem is shown in Fig. 1. Let x, y

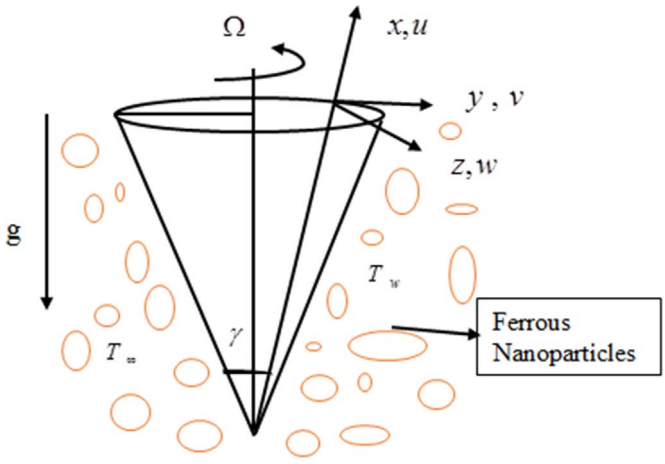

Fig. 1. Physical model of the problem.