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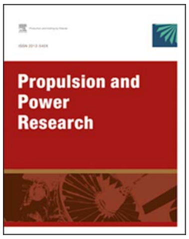

ORIGINAL ARTICLE

A mathematical analysis of time dependent flow on a rotating cone in a rheological fluid

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Abstract In the present study we have explored the time dependent combined convectional flow on a rotating cone in a rotating Jeffrey fluid with the combined effects of heat and mass transfer. The governing equations of motion, energy and mass transfer for unsteady flow are presented and simplified using similar variables. The reduced coupled nonlinear differential equations are solved analytically with the help of strong analytical technique homotopy analysis method. The heat transfer analysis for prescribed wall temperature is considered. Numerical results for Nusselt number and Sherwood number have computed and discussed. The physical features of pertinent parameters are discussed by plotting the graphs of velocity, heat transfer, concentration, skin friction, Nusselt number and Sherwood number.

1. Introduction

Recently, the study of non-Newtonian fluids has found much importance due to their extensive use in many real world applications. Such application include food mixing and chyme movement in the intestine, polymer solutions, paint, flow of plasma, flow of blood, flow of nuclear fuel slurries, flow of liquid metals and alloys, flow of mercury amalgams and lubrications with heavy oils and greases. In the history of fluid mechanics there is not a single model which exhibits all the properties of non-Newtonian fluids therefore, many mathematical models possessed different physical characteristics exist. However, Jeffrey fluid model is a simple non-Newtonian fluid model which present the relaxation and retardation effects. Some studies on the Jeffrey fluid models are given in the Refs. [1–7].

Mixed convection flow is another important subject which has attracted the attention of various researchers due to its fundamental applications. Solar central receivers exposed to

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Nomenclature

T, C, D	temperature, concentration and mass diffusivity, respectively
C_{fx}, C_{fy}	local skin friction coefficients in the x and y directions, respectively
f, g	dimensionless stream function, velocity components in x- and y-directions, respectively
Gr_1, Gr_2	Grashof numbers due to temperature and concentration distributions, respectively
K, L	thermal conductivity and characteristic length respectively
N	ratio of the Grashof number
Nu_x	local Nusselt number
Pr, Sc	Prandtl and Schmidt numbers respectively
Re_L, Re_x	Reynolds number based on length L and x respectively
Sh_x	local Sherwood number
t, t^*	dimensional and dimensionless times, respectively
u, v, w	velocity components in the x, y and z- directions, respectively
$x,\ y,\ z$	distances measured along meridional section circular section and normal to the cone surface, respectively
α^*	semi-vertical angle of the cone
ξ, ξ^*	volumetric coefficients of the thermal and concentration expansions, respectively
η	similarity variable
θ, ϕ	dimensionless temperature and concentration, respectively
γ_1, γ_2	buoyancy parameters due to the temperature and concentration gradients, respectively
υ, μ	dynamic and kinematic viscosity respectively
ρ	density
A, λ_1	Deborah number and ratio of relaxation to retardation time, respectively.

wind currents, electronic devices cooled by fans, nuclear reactors cooled during emergency shutdown, heat exchangers placed in a low velocity environment are some of the applications of mixed convection flow [8]. The study of convective heat transfer in a rotating flows over a rotating cone is also very important phenomena for the thermal design of various types of equipment's such as rotating heat exchanger, spin stabilized missiles, containers of nuclear waist disposal and geothermal reservoirs. In the existing work, a vertical cone is placed in a non-Newtonian fluid with the axis of the cone being in line with the external flow is explored.

Initially Hering and Grosh [9] have discussed a number of similarity solutions for cones. Himasekhar et al. [10] presented the similarity solution of the mixed convection flow over a vertical rotating cone in a fluid for a wide range of Prandtl numbers. All the above mentioned works refer to steady flows. In many practical problems the flows are unsteady due to the angular velocity of the spinning body which varies with time or due to the free stream angular velocity which varies with time. Ece [11] develops the solution for small time for unsteady boundary layer flow of an impulsively started translating a spinning rotational symmetric body. Roy and Anilkumar [12,13] have investigated the self and semi-similar solutions of an unsteady mixed convection flow over a rotating cone in a rotating viscous fluid.

Boundary layer on a rotating cones, discs and axisymmetric surfaces with a concentrated heat surface has been given by Wang [14]. Mixed convection flow about a cone in a porous medium has been discussed by Yih [15]. Further, Chamkha and Rashad [16] discussed unsteady heat and mass transfer by MHD mixed convection flow from a rotating vertical cone with chemical reaction and soret and dufour Effects.

In general it is challenging to handle nonlinear problems, especially in an analytical way. Perturbation techniques like Variation of iteration method (VIM) and homotopy perturbation method (HPM) [17,18] were frequently used to get solutions of such mathematical investigation. These techniques are dependent on the small/large constraints, the supposed perturbation quantity. Unfortunately, many nonlinear physical situations in real life do not always have such nature of perturbation parameters. Additional, both of the perturbation techniques themselves cannot give a modest approach in order to adjust or control the region and rate of convergence series. Liao [19] presented an influential analytic technique to solve the nonlinear problems, explicitly the homotopy analysis method (HAM) [17–28]. It offers a suitable approach to control and regulate the convergence region and rate of approximation series, once required.

The objective of the present paper is to discuss the analytical study of unsteady mixed convection flow of a rotating Jeffrey fluid in a rotating cone. The highly nonlinear coupled partial differential equations of Jeffrey fluid model along with heat and mass transfer are simplified by using suitable similarity

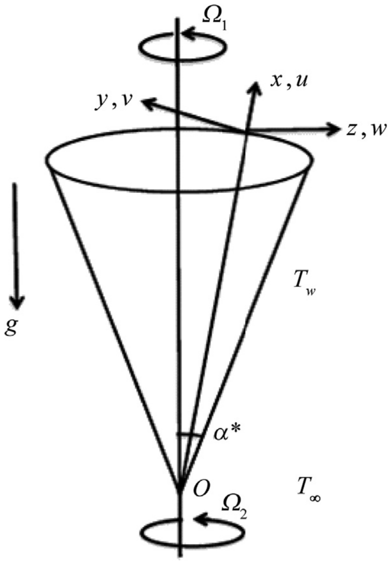

Figure 1 Physical model and coordinate system.

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