Applied Mathematics and Computation 293 (2017) 480–492

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Unsteady mixed convection dusty fluid flow past a vertical wedge due to small fluctuation in free stream and surface temperature

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ARTICLE INFO

Keywords:
Unsteady
Mixed convection
Boundary layer flow
Dusty fluid
Vertical wedge

ABSTRACT

We examine the unsteady characteristics of the mixed convection boundary layer flow of dusty fluid past a vertical wedge. The free stream and surface temperature are assumed to be fluctuating with small amplitude in time about a steady non-zero mean surface temperature and free stream velocity. The set of governing equations has been solved by two distinct methods, namely, the straightforward finite difference method for the entire frequency range, and the extended series solution for low frequency range and the asymptotic series expansion method for high frequency range. The effects of varying the ratio of the particle density to the gas density, κ, and Richardson's number, *Ri*, are discussed in terms of the amplitudes and phase angles of the skin friction and heat transfer and the transient skin friction and heat transfer. The unsteady behaviors of streamlines and isolines of temperature are also observed with the change of these physical parameters as well as of the amplitude of oscillation, ϵ. The results show that the presence of particle into the fluid, buoyancy caused mixed convection and fluctuations of free stream and surface temperature significantly enhance the time-dependent skin friction and heat transfer.

1. Introduction

Due to importance of dusty viscous flows in petroleum industry, in the purification of crude oil, in physiological flows and other technological fields, various studies have appeared in the literature. Other important applications involving dust particles in boundary layers include soil salvation by natural winds, lunar surface erosion by the exhaust of a landing vehicle and dust entrainment in a cloud formed during a nuclear explosion. Saffman [1] has formulated the basic equations, for the flow of dusty fluid. Since then many researchers have discussed the problem of dusty fluid. Marble [2] studied the problem about the dynamic of a gas containing small solid particles. It was shown that for gas-particle flow systems, the particle clouds are governed by four similarity parameters each of which has a simple physical significance. Micheal and Miller [3] studied the flow of dusty gas past an impulsively started infinite horizontal plate using the Laplace transform technique. Micheal [4] considered the effect on the steady flow past a sphere of a uniform upstream distribution of dust particles having a small relaxation time. Singh and Ram [5] presented the unsteady two dimensional laminar flow of an

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http://dx.doi.org/10.1016/j.amc.2016.08.048
0096-3003/

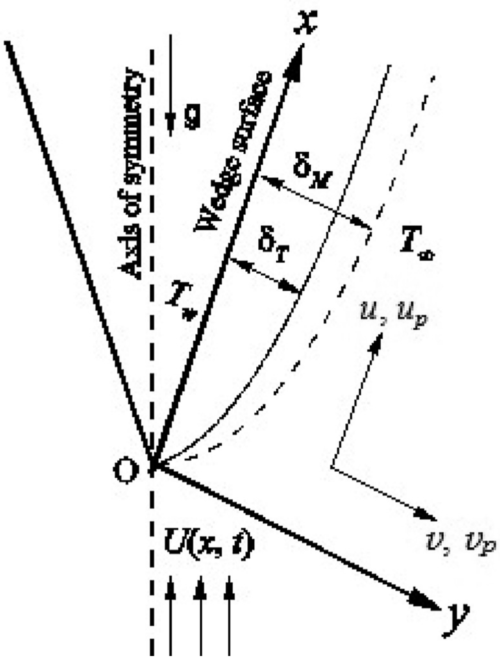

Fig. 1. Physical configuration and coordinate system.

electrically conducting dusty viscous liquid through a channel in the presence of a transverse magnetic field. Soundalgekar and Gokhale [6] studied the flow of a dusty gas past an impulsively started infinite vertical plate by employing an implicit finite difference technique. The non-dimensional governing equations were studied by finite-difference method. An explicit finite-difference solution of flow of a dusty gas past a uniformly accelerated horizontal plate in a viscous incompressible gas was presented by Das et al. [7]. Gas-velocity, dust-velocity and the skin friction were shown graphically. The review of state-of-the-art mathematical modeling of dusty gas laminar boundary layers in the framework of the two-fluid approach and the formulation of the two-phase boundary layers approximations, using the matched asymptotic expansion method was studied by Osiptsov [8]. The low and high-velocity boundary layers both on curve and flat surfaces are considered. Ganesan and Palani [9] studied numerical solution of unsteady free convection flow of a dusty gas past a semi-infinite inclined plate with constant heat flux using an implicit finite difference method. The effect of heat transfer on the flow of dusty gas past a semi-infinite isothermal inclined plate has been studied by Palani and Ganesan [10].

Due to importance of dusty viscous flows in various technological fields, many studies have been published in the literature. The dispersion and fall out of pollutants in air or water has necessitated the study of dusty fluids. With understanding, here we aim to investigate the effect of dust particle on the mixed convection flow of viscous incompressible fluid past a vertical wedge.

2. Formulation of the problem

A two dimensional fluctuating mixed convection flow of a viscous incompressible dusty fluid flow along a vertical wedge plate in the presence of solid dust particles is considered. The flow configuration and coordinate system are shown in Fig. 1. Here δ_M and δ_T are the momentum and thermal boundary layers. It has been assumed that both the surface temperature and free stream exhibit small amplitude oscillations in time about a steady non-zero mean temperature and free stream velocity. The ambient fluid temperature is taken as T_∞.

Under the usual boundary layer approximation for two dimensional flow the equations appropriate for the flow of dusty fluid given by Dalal et al. [11] can be written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\frac{\partial^2 u}{\partial y^2} + \rho g\beta\cos(\pi/4)\bar{T} + \frac{\rho_p}{\tau_m}(u_p - u), \tag{2}$$

$$\rho C_p\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \lambda\frac{\partial^2 T}{\partial y^2} - \frac{\rho_p C_s}{\tau_T}(T_p - \bar{T}), \tag{3}$$