ABSTRACT

Two phase flows are of fundamental interest from the fluid mechanics standpoint of view and also of great economic, social and environmental importance due to their application in many practical fields of science and technology. The industrial applications of these flows encompass weather prediction, earth quake, cyclone and cloud computing etc. The disposal of waste water borne particulate in the coastal zone, prediction of particulate deposition from urban atmospheric gas emissions etc. also are examples of such flows. Problems concerned with atmospheric fall out, batch settling, rain erosion of guided missiles and aircraft icing are some of the areas where the dynamics of dusty fluids play a prominent role. The flow and heat transfer along a stretching sheet has very vast applications in prediction of flow over a helicopter rotor blades, nuclear cooling system, nuclear waste disposal and aero foil lift hysteretic at the stall etc. Besides all these examples drawn from nature, science, technology and biology, recent space-craft observations have confirmed that dust particles play a prominent role in the dynamics of Martian atmosphere. A general terminology given to such flows where solid particles move in suspension in a fluid media is “flow of fluid-particle suspension”. The literature on the flow and heat transfer characteristics from the boundary to both the solid and fluid phases is scanty and many gaps do exist in the literature. To cite a few the effect of different boundary shapes on the characteristics of flow of fluid-particle suspension is still unexplored to the fullest extent. Further, the effect of electrification of SPM, radiation and the buoyancy parameters are some aspects which have not been attempted for analysis. The present in investigation is an attempt to probe and understand characteristics of flow in thermal boundary layer.

The pioneering work done by Soo[10], Batchelor[4], Marbel[9], Saffmann[3] in the field of dynamics of two phase flow demands a special consideration as a branch of fluid mechanics. Heat transfer between a particulate suspension and a solid body is a problem, the solution of which involves the consideration of the equations of motion of a two-phase system. Both Marble[2] and Soo[13]have developed the conservation laws of mass, momentum and energy for two-phase flow. Singleton[10] has considered compressible laminar boundary-layer flow of a dusty gas over a semi-infinite flat plate. Tabakoff & Hamed[16,17], Jain & Ghosh[111], Dutta and Mishra[18,19], Wang & Glass [34], Aziz[142], Nandekeyyar & Das[50], Mishra & Tripathy[30], Chamkha et. al.[126], Palani & Ganesan[26], Tripathy & Mishra[38] have studied the laminar boundary-layer
flow characteristics either with or without heat transfer aspects over semi-infinite/infinite flat plates. The boundary layer flow on a continuously solid stretching surface with various aspects was first investigated by Sakiadis[42,114]. It is a different type of boundary layer problem having solution substantially different from that of boundary layer flow over semi-infinite flat plate. Subsequently, many investigators like Crane[49], Gupta and Gupta[115], Dutta et. al.[117], Vajravelu et. al.[70], Grubka & Bobba [44], Pal & Mondal[118], Sharidan S. et.al.[45], Chen[47], Nandkeolyar & Sibanda[127], Gireesha et. al.[52, 53, 54,55,56], Mukhopadhyay[132], Gorder & Vajravelu[65], Barik et.al.[72], Pavithra & Gireesha[136] have extended the work of Sakiadis with the inclusion of several heat transfer characteristics. The interaction of radiation with laminar free convection heat transfer from a vertical plate was investigated by Cess[119] for an absorbing, emitting fluid in the optically thick region. Subsequently, many investigators like Arpaci[120], Cheng & Ozisik[121], Hossain & Takhar[123], Raptis & Perdikis[124], Das et.al[125], Chamkha et.al.[126], Makinde & Olanrewaju[143], England & Emery [145] have either extended or studied the related problems with different flow situations. Falkner & Skan[80] have studied some approximate solutions of the boundary layer equations past a wedge. Hartee[81], Watkins[82], Foster et.al.[141], Martin & Boyd[138], Chandrasekar & Shamugapriya[139], Mukhopadhyay[63], Sheddeek et. al.[84], Mishra & Tripathy[39, 112] have formulated variety of problems with regard to the Falkner-Skan flow with or without SPM past a wedge with heat transfer aspects. A critical review of the works cited above and other investigations indicated that the flow dynamics and heat transfer characteristics of flow of fluid-particle suspension have been analyzed by various investigators considering the influencing parameters in an isolated situation. No substantiate effort has been put by researchers to consider the influencing parameters simultaneously and develop a mathematical model and the present study is such an attempt to advance the state-of-the-art of knowledge of flow of fluid-particle suspension.

Considering the fact that a good understanding of two phase boundary layer flow is essential to study the impact of presence of SPM on boundary layer characteristics like skin friction coefficient, rate of heat transfer, particulate velocity, particulate temperature and density variation on the surface etc., this investigation is aimed to provide answers to some of the questions that the research community is facing. In the present analysis, the aspects like volume fraction, diffusion of SPM through carrier fluid, electrification of
SPM, buoyancy force, the terms related to the heat added to the system to slip-energy flux in the energy equation of particle phase, the momentum equation for particle phase in normal direction, heat due to conduction, viscous dissipation, thermal radiation and internal heat generation/absorption in the energy equations of both fluid & particle phases have been considered to fulfill the inadequacies of the previous investigations. Towards obtaining a solution to the two phase flow problems, the flows past some standard cases of boundaries have been considered here. These include:

a) Flow past a flat plate,
b) Flow over a stretching sheet and
c) Flow past a wedge.

Thermal mixed boundary layer flow of fluid-particle suspension over a semi-infinite flat plate with particle electrification is considered in the first phase of this investigation. Profiles of non-dimensional velocities and temperature for both fluid and particle media are generated by solving the governing equations through momentum integral method followed by Range-Kutta 4th order scheme. The solution obtained in the present investigation is noted to be valid throughout the entire length of the plate, which was a limitation in earlier reported investigations. From this study it is identified that the electrification of SPM enhances the heat transfer rate along the length of the plate. It is further seen from the analysis carried out for this case of flow that the normalized temperature of particle phase has an increasing trend with increase of electrification parameter and dropping slowly across the boundary layer for any particular value of this parameter.

The second case considered in this study is consideration of the effects of viscous dissipation, thermal conductivity and thermal radiation of convective flow of a fluid-particle suspension past a vertical stretching sheet. By reducing the governing partial differential equations of flow field into a set of non-linear ordinary differential equations and solving them numerically again through Range-Kutta fourth order method adopting shooting technique, results corresponding to non-dimensional boundary layer profiles as well as shear stress and rate of wall heat transfer have been developed. It is found that for this case of flow, the normalized temperature of fluid phase increases, whereas the normalized particle temperature decreases across the boundary layer when radiation is more. For this boundary it is noted that the rate of wall heat transfer significantly increases with increase of diffusion parameter, Grashoff number & Prandtl number while the heat transfer rate decreases with increase of Eckret number and radiation parameter.
Thermal radiative boundary layer flow of fluid-particle suspension due to an exponential stretching sheet in presence of electrification of particles and internal heat source/sink is another case of two phase flow considered in this study. Similarity transformation followed by shooting technique using Runge-Kutta4th order method is adopted for analyzing this problem. Particle electrification and the effect of a heat source/sink are included in the set of influencing parameters to understand the flow characteristics. From this investigation it is observed that the higher electrification parameter is to reduce the normalized fluid temperature and to enhance the normalized particle temperature in the presence of heat source, whereas the trend is reversed in the presence of heat sink.

Analysis of the boundary layer flow of particulate suspension and heat transfer past a wedge with electrification of particles is an area where much work has not been reported in the literature. The present study is almost first of its kind in exploring the flow dynamics of SPM past a wedge considering different wedge angles with particle electrification. The problem is solved by employing finite difference using non-uniform grid. The analysis has shown that the generation of resistive (Lorentz) forces due to particle electrification for flow with SPM which reduces the effect of drag forces indicating to increase the carrier fluid velocity. Further, the temperature of the particle phase at any point away from the boundary of the wedge is found to increase with the increase of electrification of particles. More conclusions are drawn regarding the impact of other influencing parameters and the same are included at appropriate location in this volume.

The investigation on steady laminar boundary layer flow with SPM over a semi-infinite flat plate in presence of thermal radiation and heat generation/absorption marks the final stage of the present work. The governing equations have been solved numerically with the help of finite difference technique using non-uniform grid. From the analysis made in this part of the study it is concluded that the normalized temperatures of both fluid and particle phases decrease with increase of radiation parameter while the local heat transfer rate increases. It is also observed there upon that an increase in the heat generation/absorption parameter results in an increase in temperature of both the fluid and particle phases across the boundary layer.

Sujata Panda