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Velocity Profile of Fluid Particle Suspension over a Horizontal Plate with Electrification of Particles

Tumbanath Samantara

Abstract: The modelling of electrified flow over a horizontal plate is considered. Here the fluid is of Newtonian type and fluid-fluid, fluid- particles collisions are accounted. The effective volumetric force, viscous dissipation, browanion diffusion, in fluid phase as well as particle phase has been considered. In this paper we considered the generation of electricity due to hitting of particles with each other and with the wall of the flow and its impact on motion of flow particles. The systems of equations representing the flow are solved by finite difference method. It concludes from outcome of computation that the particle velocity rises with rise of electricity generation and increasing size of particles.

Keywords: Electricity generation, viscous dissipation, browanion diffusion

I. INTRODUCTION

Investigations of two-phase flow and transfer of heat over a horizontal plate whose starting end is fixed, where as other end is elongated infinitely. Consideration of this type of geometrical figure is very much important for its over rising applications in industry and environmental phenomena. Researchers encounter problems having this type geometry, starting from very simple case to very complicated one. The complex type of problems can be handled by using advanced numerical methods as well as high speed computers to get desirable accuracy of the result. The studies and investigations are available for pure fluids. The approximated result of the fluid with particles with low density is manageable up to some extent. But is not valid for all the cases when the presence of particle ratio is high and the characteristic of the particles plays vital role in flow and heat transfer. This type of two phase flows severally occurred in waste processing and recycling industries, direct fuel ignition for spark and diesel ignition and many more. Hence the study of two-phase flows plays an important role as compared to pure fluid.

Starting with Soo[13] and several others[2,3, 12] have developed theories and mathematical approach i.e. governing equations of two-phase flow. Several efforts have been made in recent times to theorize these phenomena. Otterman [8, 9] has justified that boundary layer approximation for clear fluid is also valid for two phase fluid, provided both of them have density of same order .Further the fluid phase momentum equation in vertical direction has not been taken account for very small deviations, but that of the particle phase cannot be neglected as have considerable boundary layer.

Tripathy and Mishra [4, 6, 7, 14, 15] have formulate the problem for two-phase flow including the forces due to fluid-particle, particle-particle and particle-wall interaction in both the phases for momentum and energy equations. The governing flow field equations are solved by using numerical scheme in finite difference methods with non-uniform grid to obtain the accuracy and boundary layer characters are analyzed. Panda and Mishra [10] have analysed the flow dynamics and temperature distrubution of dusty fluid over a horizontal plate to investigate the flow characteristics. Samantara et. al. [11, 16] have studied the two-phase flow with electrification of particles and through a wall jet.

In this analysis, as the particles are very small in size, the brownian motion of particles should be considered. Particle cloud is treated as a fluid and it's concentration can be calculated in terms of diffusion equation in place of particle continuity equation. Though the considered fluid is neither electrically conducted nor there is supply of any electric force from outside but there is generation of electricity due to contact and separation of solid particles among themselves and with the wall.. Hence, an effective electric drag force [13] is exerted , which imparts a reacting force of equal magnitude and acting in opposite direction, which is transmitted to the fluid medium. Hence, this plays a significant role in both the fluid and particle phase momentum and energy equation, which is hardly investigated previously. Again, probably no literature available about consideration of momentum equation of particle phase in vertical direction of horizontal direction flow along with volumetric force and viscous dissipation.

II. MATHEMATICAL FORMULATION

The derivation of the mathematical equations for the boundary layer flow of laminar type in two dimensional Cartesian frames with the characteristics of steady ,incompressible and viscous fluid with suspended particle is carried out. The flow is occurred over a flat plate whose one end is the origin of flow and another end extended infinitely in x direction. It is assumed that the dust particles are distributed uniformly throughout the fluid flow. Cartesian coordinate system is introduced with *x*-axis along the surface of the plate from its leading edge, where the flow of free stream is maintained in a uniform velocity *U* and *y*-axis is perpendicular to it.

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*****Correspondence Author(s)
Tumbanath Samantara, Department of Mathematics, Centurion University of Technology and Management, Odisha, India, tnsamantara@gmail.com

The dust particles collide each other and with the wall generate electricity .

Let the electric force $\vec{E}$ arises due to particle-particle and particle-wall interaction is uniform throughout the flow field.

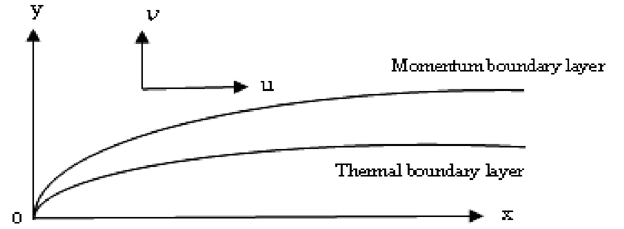

Fig. 1 : Schematic diagram of the problem

The temperature of the plate is assumed to be a function of the distance along the wall. Since the plate is insulated, the boundary condition $\frac{\partial T}{\partial y} = 0$ is satisfied on the wall of the plate i.e. at $y = 0$, which is the condition of an adiabatic wall, is significant only when the frictional heat is taken into consideration. The free stream temperature is denoted by T_∞ .As the plate is extended infinitely, the fluid as well as particle velocity are considered parallel to the plate.

By considering above assumptions, the two-phase boundary layer flow equations are given as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

$$\frac{\partial}{\partial x}(\rho_p u_p) + \frac{\partial}{\partial y}(\rho_p v_p) = 0$$

(2)

$$(1-\varphi)\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = (1-\varphi)\mu\frac{\partial^2 u}{\partial y^2} - \frac{1}{\tau_p}\varphi\rho_s(u - u_p) + \varphi\rho_s\left(\frac{e}{m}\right)E$$

(3)

$$\varphi\rho_s\left(u_p\frac{\partial u_p}{\partial x} + v_p\frac{\partial u_p}{\partial y}\right) = \varphi\mu_s\frac{\partial^2 u_p}{\partial y^2} + \frac{1}{\tau_p}\varphi\rho_s(u - u_p) + \varphi\rho_s\left(\frac{e}{m}\right)E$$

(4)

$$\varphi\rho_s\left(u_p\frac{\partial v_p}{\partial x} + v_p\frac{\partial v_p}{\partial y}\right) = \varphi\mu_s\frac{\partial^2 v_p}{\partial y^2} + \frac{1}{\tau_p}\varphi\rho_s(v - v_p)$$

(5)

$$u_p\frac{\partial \rho_p}{\partial x} + v_p\frac{\partial \rho_p}{\partial y} = \nu_p\frac{\partial^2 \rho_p}{\partial y^2} \qquad (6)$$

Subject to the boundary condition

At $y = 0 : u = v = 0, u_p = u_{pw}(x), v_p = 0, \rho_p = \rho_{pw}(x),$ (7)

At $y = \infty : u = u_p = U,\ \rho_p = \rho_{p_\infty},\ v_p = 0,$ (8)

Where (u, v) and (u_p, v_p) are the velocity components of the fluid and particle phases along the x and y directions respectively .

$(\rho,\ \rho_p),\ (\mu,\ \mu_s)$,and (ν, ν_p) are the density, coefficient of viscosity, and kinematic coefficient of viscosity of the fluid and particle phase respectively.

φ is the finite volume fraction,

ρ_s is the material density of the particle.

ρ_{p_∞} is the particle density of the particle ,

e is the charge per particle and m is the mass of electron.

Introducing the non- dimensional variables

$x^* = \frac{x}{L}, y^* = \frac{y}{L}\sqrt{Re}\ , u^* = \frac{u}{U}, v^* = \frac{v}{U}\sqrt{Re}, u_p^* = \frac{u_p}{U},$

$v_p^* = \frac{v_p}{U}\sqrt{Re}\ , \rho_p^* = \frac{\rho_p}{\rho_{p_0}},$ (9)

and after dropping stars, the equations (1) to (6) can be written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (10)$$

$$\frac{\partial}{\partial x}(\rho_p u_p) + \frac{\partial}{\partial y}(\rho_p v_p) = 0 \qquad (11)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \alpha\frac{1}{1-\varphi}\frac{FL}{U}\rho_p(u - u_p) + \frac{1}{1-\varphi}\alpha\rho_p M \qquad (12)$$

$$u_p\frac{\partial u_p}{\partial x} + v_p\frac{\partial u_p}{\partial y} = \epsilon\frac{\partial^2 u_p}{\partial y^2} + \frac{FL}{U}(u - u_p) + M \qquad (13)$$

$$u_p\frac{\partial v_p}{\partial x} + v_p\frac{\partial v_p}{\partial y} = \epsilon\frac{\partial^2 v_p}{\partial y^2} + \frac{FL}{U}(v - v_p) \qquad (14)$$

$$u_p\frac{\partial \rho_p}{\partial x} + v_p\frac{\partial \rho_p}{\partial y} = \epsilon\frac{\partial^2 \rho_p}{\partial y^2} \qquad (15)$$

With the conditions

$y = 0$: u =0, v = 0, $u_p = u_{pw}(x)$, $v_p = 0$, $\rho_p = \rho_{pw}(x)$,

$\frac{\partial T}{\partial y} = 0, \frac{\partial T_p}{\partial y} = 0$ (16)

$y = \infty$: $u = u_p = \rho_p = 1,\ v_p = 0,\ T = 0, T_p = 0$ (17)

Where

$M = \left(\frac{e}{m}\right)E$, is the electrification parameter

$\alpha = \frac{\rho_{p0}}{\rho}$, is the loading ration

$\epsilon = \frac{\nu_s}{\nu}$, is the diffusion parameter

$Re = \frac{UL}{\nu}$,

$F = \frac{18\mu}{\rho_p D^2}$, is the fluid-particle interaction parameter,

and D is the diameter of particle and L is the characteristics length of the plate.

III. METHOD OF SOLUTION

The above systems of equations are solved by using finite difference method using non uniform grid..The derivatives of a physical quantities W at the node (n, j) are expressed in terms of the values of the above said variables nearby nodes by using Taylor series expansions such as

$$W_{j+1}^{n+1} = \sum_{m=0}^{\infty}\frac{(y_{j+1} - y_j)^m}{m!}\left(\frac{\partial^m W}{\partial y^m}\right)_j^{n+1}$$

(18)

$$W_{j-1}^{n+1} = \sum_{m=0}^{\infty}\frac{(y_{j-1} - y_j)^m}{m!}\left(\frac{\partial^m W}{\partial y^m}\right)_j^{n+1}$$

(19)

Where $y_{j+1} - y_j = r_y(y_j - y_{j-1}) = r_y\Delta y_j$ (20)

The expression (18) and (19) represents corresponding finite difference expressions for $\frac{\partial W}{\partial x}, \frac{\partial W}{\partial y}$ and $\frac{\partial^2 W}{\partial y^2}$ as

$$\left(\frac{\partial W}{\partial y}\right)_j^{n+1} = \frac{W_{j+1}^{n+1} - (1 - r_y^2)W_j^{n+1} - r_y^2 W_{j-1}^{n+1}}{r_y(r_y + 1)\Delta y_j} + O(\Delta y^2)$$

(21)

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$$\left(\frac{\partial^2 w}{\partial y^2}\right)_j^{n+1} = 2\frac{W_{j+1}^{n+1} - (1+r_y)\, W_j^{n+1} + r_y\, W_{j-1}^{n+1}}{r_y(r_y+1)\Delta y_j^2} + O(\Delta y^2)$$

(22)

and $$\left(\frac{\partial w}{\partial x}\right)_j^{n} = \frac{1.5W_j^{n+1} - 2W_j^{n} + 0.5W_j^{n-1}}{\Delta x} + O(\Delta x^2)$$

(23)

Where r_y is the grid growth ratio.

To maintain the linearity of system of equations ,the undifferentiated components W_j^{n+1} present on the left hand side of the momentum, and continuity equations of both phases are extrapolated as follow.

$$W_j^{n+1} = 2\, W_j^n - W_j^{n-1} + O(\Delta y^2)$$

(24)

Proceeding as above the discretised equations for (9) to (15) are reduced to a form,

$$a_j W_{j-1}^{n+1} + b_j W_j^{n+1} + c_j W_{j+1}^{n+1} = d_j$$

(25)

and the continuity equation (12) is integrated across the boundary layer to give v_j^{n+1} by using,

$$v_j^{n+1} = v_{j-1}^{n+1} - \frac{1}{2}\frac{\Delta y}{\Delta x}\,[A+B]$$

(26)

Where $A = 1.5u_j^{n+1} - 2u_j^n + 0.5u_j^{n-1}$ and
$B = 1.5u_{j-1}^{n+1} - 2u_{j-1}^n + 0.5u_{j-1}^{n-1}$

and W stands for either u or v or u_p or v_p or ρ_p

The detail of computation will be explained by considering a rectangular – grid system with J lines in the y-direction which is normal to the plate and the *n*-lines in the *x*- direction i.e., parallel to the plate. In other words Y-axis is the initial line of J lines and the X-axis is the initial line of n-lines.

In the finite-difference scheme, the flow profiles along some *n*-line, say, the initial line $n = n - 1$ and $n = n$ are known and the flow parameters along the $(n+1)$ line have to be calculated.

The computation is started from $(n+1)^{th}$ line to $(n+2)^{th}$ line by repeating the above steps. The calculation is continued till getting the value of x of desired accuracy.

IV. RESULT AND DISCUSSION

To examine the characteristics of the flow field, a study is organised. The property of different parameters of the flow and the results obtained after numerical calculation are expressed by graphs.

Fig-2 depicts the variation of fluid phase velocity 'u' with electrification parameter M. The conclusion drawn is, that the value of the fluid phase velocity rises with the rise of electrification parameter M.

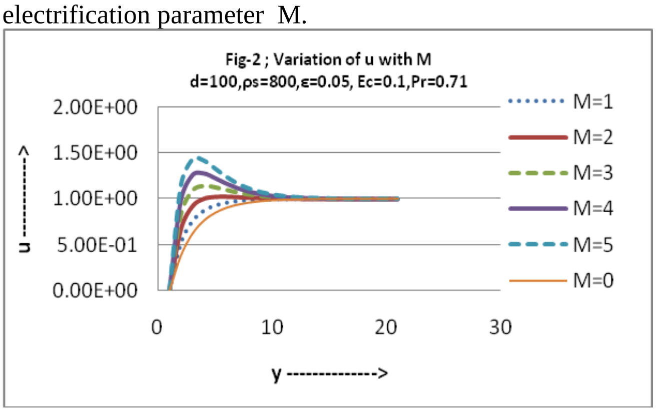
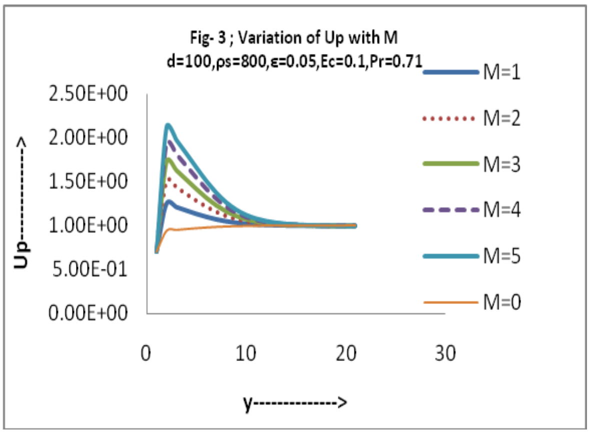


Fig- 3 demonstrates the variation of particle phase velocity 'u_p' with electrification parameter M. It is concluded that the value of the particle phase velocity goes up as the rise of electrification parameter M.



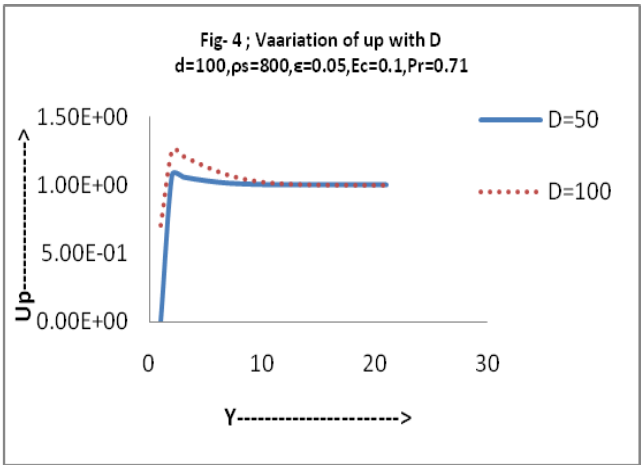


Fig.- 4 depicts the variation of particle phase velocity 'u_p' with the size of the particle. It is concluded that, the value of u_p goes up with increasing the size of the particle.

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AUTHORS PROFILE

Dr Tumbanath Samantara, had obtained his M.Phil and PhD degree from Utkal University.He has !9 year of teaching experience in teaching B.Tech, B.Sc, M.Sc,and M.Phil students.Presently he is working as Associate Professor in Centurion university of technology and Management, Odisha, India.He has guided 06 number of M.Tech/M.Phil students and has published 10 papers in national as well as international journal of repute .Computational Fluid Dynamics, Numerical Analysis and soft Computing are the areas of his research interest.

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