J. Appl. Math. & Informatics Vol. **41***(2023), No. 2, pp. 401 - 411*
https://doi.org/10.14317/jami.2023.401

EFFECT OF MAGNETIC FIELD ON LONGITUDINAL FLUID VELOCITY OF INCOMPRESSIBLE DUSTY FLUID†

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Abstract. The effects of longitudinal velocity dusty fluid flow in a weak magnetic field are investigated in this paper. An external uniform magnetic field parallel to the flow of dusty fluid influences the flow of dusty fluid. Besides that, the problem under investigation is completely defined in terms of identifying parameters such as longitudinal velocity (u), Hartmann number (M), dust particle interactions β, stock resistance γ, Reynolds number (Re) and magnetic Reynolds number (Rm). While using suitable transformations of resemblance, The governing partial differential equations are transformed into a system of ordinary differential equations. The Hankel Transformation is used to solve these equations numerically. The effects of representing parameters on the fluid phase and particle phase velocity flow are investigated in this analysis. The magnitude of the fluid particle is reduced significantly. The result indicates the magnitude of the particle reduced significantly. Although some of our numerical solutions agree with some of the available results in the literature review, other results differs because of the effect of the introduced magnetic field.

AMS Mathematics Subject Classification : 76A05, 76D10, 76M12, 76N20.
Key words and phrases : Induced Magnetic field, differential equations, dusty fluid flow, incompressible fluid, multi-step iterative method.

Nomenclature

f - Dimensionless stress functions
M - Magnetic parameter
P_r - Prandtl number
B_0 - Magnetic field intensity
C_r - Local skin friction coefficient
R_e - Reynolds number
T - Fluid temperature

Received Received June 28, 2022. Revised October 20, 2022. Accepted November 17, 2022.
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†This work is for my reseach work in GIET University, Gunpur-765022, Odisha.

u - Fluid velocity along x-axis
U_0 - Reference velocity
v - Fluid velocity along y-axis

1. Introduction

The boundary layer problem of dusty fluid flow has been under investigation over many years ago. Both unsteady and steady incompressible fluid flow has been studied by different researchers such as Sakiadies (1961), Girresha (2012) and Mudassar (2017) amongst others[1]. Recently, the study of steady dusty fluid flow under fluid flow has become a subject to the field of applied mathematics and above all with an introduction of magnetic field. This has enabled numerous researchers to study the effect of physical characterizing parameters such as magnetic parameter, fluid particles parameters and dust particles parameters amongst others on dust fluid flow velocity profile, heat transfer, temperature and pressure profile.[2,3].

These researchers limited themselves on the influence of applied external magnetic field to fluid flow at different angles without dwelling in any way with the effect of induced magnetic field on the fluid flow nor on the skin friction moreover, despite the efforts of those researcher, no one attempted to carry out an investigation on the effects of physical characterizing parameters on induced magnetic profile such as magnetic Reynolds number (Rm) [4, 5].

To fill this void, the current research looks into the effect of an induced magnetic field on the boundary layer in an axi-symmetric jet mixing of incompressible dusty fluid in cylindrical polar coordinate[7,8].

As different researchers have investigated the problem of boundary layer fluid flow in this paper presents a few of their findings in order to establish the gap between them and the current study. By evaluating their investigations, this study aims at bringing more light to their investigations by introducing magnetic induction equation on the governing equations of the boundary layer steady incompressible dusty fluid flow, a key field of study which has drawn numerous interests to current mathematicians[6].

Initially, boundary layer fluid flow was began by Prandtl (1904) and Sakiadies (1961) who looked at boundary layer flow and travel at a constant speed He designed a boundary layer equation for two-dimensional and axisymatic flow by using both exact and numerical methods through which he obtain the results.

Through this investigation, the studied effect of physical parameter such as fluid particles interaction On the flow and heat transfer characteristics, consider the pressure parameter, suction parameter, Prandtl number, and Eckert number.

This allowed him to discover that the fluid phase velocity (U) did not change significantly, while the particles phase velocity (U_p) changed as the fluid particle interaction parameters increased. In addition, for fluids with a higher Prandtl number, had a thinner thermal boundary layer which increased the gradient of temperature and the surface heat transfer. Consequently he noted that fluid velocity (U) decreased asymptotically thought with a significant increase in dust particle phase velocity (U_p) due to increase of suction parameter f_o. Recently, Mudassar J. et al. (2017) in view of the above previous studies carried out a study on an exact solution of boundary flow of dusty fluid flow in the presence of applied magnetic field. By specifying his problem in terms of characterizing parameters known as fluid particles interaction parameters, (β) Magnetic field parameter (M) and mass concentration of dust particles parameter, (γ) he observed that both fluid and dust particles velocities decreased with an increase of magnetic parameter which increased Lorentz force resulting to the decrease of fluid velocity.

As noted early, within the course of time the study of two-dimensional boundary layer dusty fluid flow where solid spherical particles are distributed in a fluid has become of great interest in a wide range of technical problems such as fluid flow through packed beds, sedimentation and centrifugal separations of particles. Mainly, this has been enhanced by two phase nature of dusty fluid flow whose occurrence contains the distribution of particles. Consequently, animated by the interest of two-dimensional boundary layer dusty fluid flow; researchers also worked out the dusty model for various flow configuration under the boundary layer fluid flow conditions by using different physical characterizing parameters.

2. General Governing Equations and Mathematical Formulation

In order to derive our fluid flow equations, we must take into account the following assumptions.
The following are the fluid flow equations:
The following assumptions are taken into account when calculating our fluid flow equations. These assumptions are:

(1) The flow is steady and incompressible.
(2) Pressure gradient is negligible.
(3) The number density is constant.
(4) External electrical field (E) is negligible.
(5) The dust particles are thought to be uniformly sized and spherical in shape.

On the other hand, in order to derive the dust particle momentum equations, the following assumptions were taken into account.
These assumptions are:

(1) The flow is steady and incompressible.

(2) There is no viscous force.
(3) The magnetic field effect is negligible.
(4) The pressure gradient is constant and negligible.

Non-Newtonian fluid activity can be found in a variety of industrial fluids, including Foods, liquid plastics, polymers, pulps, and molten plastics Because of the growing use of non-Newtonian materials in various manufacturing and processing industries, a lot of research has gone into figuring out how they flow.

In cylindrical polar coordinates, the equation of governing is the study of two-phase boundary layer flow in the axi-symmetric case:

Continuity Equation in fluid phase

$$\frac{\partial}{\partial z}(ru) + \frac{\partial}{\partial z}(rv) = 0 \tag{1}$$

In fluid phase the Equation of Motion

$$(1-\phi)\rho\left(u\frac{\partial u}{\partial z} + v\frac{\partial u}{\partial r}\right) = \frac{\mu}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) + \frac{\rho_p}{\tau_m}(u_p - u) \tag{2}$$

Equation of Continuity in particle phase

$$\frac{\partial}{\partial z}(r\rho_p u_p) + \frac{\partial}{\partial r}(r\rho_p v_p) = 0 \tag{3}$$

In particle phase the equation of Motion is

$$\rho_p\left(u_p\frac{\partial u_p}{\partial z} + v_p\frac{\partial u_p}{\partial r}\right) = -\rho_p\left(\frac{u_p - u}{\tau_m}\right) \tag{4}$$

$$\rho_p\left(u_p\frac{\partial v_p}{\partial z} + v_p\frac{\partial v_p}{\partial r}\right) = -\rho_p\left(\frac{v_p - v}{\tau_m}\right) \tag{5}$$

The dimensionless variables are introduced to analyze the boundary layer flow are

$$\overline{z} = \frac{z}{\lambda},\ \overline{r} = \frac{r}{(\tau_m\nu)^{(1/2)}},\ \overline{u} = \frac{u}{U},\ \overline{v} = v\left(\frac{\tau_m}{\nu}\right)^{1/2},\ \overline{u}_p = \frac{u_p}{U},$$
$$\overline{v}_p = v_p\left(\frac{\tau_m}{\nu}\right)^{1/2},\ \alpha = \frac{\rho_{p_0}}{\rho} = const.,\ \overline{\rho}_p = \frac{\rho_p}{\rho_{p_0}},\ \overline{T} = \frac{T}{T_0},$$
$$\overline{T}_p = \frac{T_p}{T_0},\ \lambda = \tau_m U,\ \tau_m = \frac{2}{3}\frac{C_p}{C_s}\frac{1}{P_r}\tau_T,\ P_r = \frac{\mu C_p}{K}.$$

We can now claim that the pressure in the mixing area is roughly constant when the flow from the orifice is partially extended. As a consequence, the pressure at the outlet is the same as the pressure in the surrounding stream. As a result, the jet's velocity and temperature are only marginally different from the stream that runs through it Thermal conductivity and viscosity coefficient Then you'll be able to write.

$$u = u_0 + u_1,\ v = v_1,\ u_p = u_{p_0} + u_{p_1},\ v_p = v_{p1},$$
$$\rho_p = \rho_{p1},$$

where the subscripts 1 denote perturbed values that are far smaller than the basic values of the surrounding stream with subscripts 0, i.e, the non linear equations (1) to (5) can be written using the dimensionless variable and perturbation form after lowering the bar.

$$\frac{\partial}{\partial z}(ru_1) + \frac{\partial}{\partial r}(rv_1) = 0 \tag{6}$$

$$(1-\phi)u_0\frac{\partial u_1}{\partial z} = \frac{1}{r}\frac{\partial u_1}{\partial r} + \frac{\partial^2 u_1}{\partial r^2} + \alpha\rho_{p_1}(u_{p_0} - u_0) \tag{7}$$

$$\rho_{p_1} = \rho_{p_1}(r) \tag{8}$$

$$u_{p_0}\frac{\partial u_{P_1}}{\partial z} = (u_0 - u_{p_0}) + (u_1 - u_{p_1}) \tag{9}$$

$$u_{p_0}\frac{\partial v_{P_1}}{\partial z} = (v_1 - v_{p_1}) \tag{10}$$

The boundary conditions for u_1,v_1,u_{p_1},v_{p_1} are

$$u_1(0,r) = \begin{cases} u_{10} & r \leq 1 \\ 0 & r > 1 \end{cases} \tag{11}$$

$$\frac{\partial u_1}{\partial r}(z,0) = 0, \quad u_1(z,\infty) = 0 \tag{12}$$

$$v_1(0,r) = 0 \tag{13}$$

$$u_{p1}(0,r) = \begin{cases} u_{p10} & r \leq 1 \\ 0 & r > 1 \end{cases} \tag{14}$$

$$v_{p1}(0,r) = 0 \tag{15}$$

The particle density boundary conditions ρ_{p_1} are

$$\rho_{p1}(0,r) = \begin{cases} \rho_{p10} & r \leq 1 \\ 0 & r > 1 \end{cases} \tag{16}$$

3. Method of Solution

We solved the governing linearized equations (7) and (9) using the Hankel transform technique and the related conditions , then Hankel transform of

$$(1-\phi)u_0\frac{\partial u_1}{\partial z} = \frac{1}{r}\frac{\partial u_1}{\partial r} + \frac{\partial^2 u_1}{\partial r^2} + \alpha M\rho_{p_1}(u_{p_0} - u_0)$$

i.e.

$$H\left((1-\phi)u_0\frac{\partial u_1}{\partial z}\right) = H\left(\frac{1}{r}\frac{\partial u_1}{\partial r} + \frac{\partial^2 u_1}{\partial r^2} + \alpha M\rho_{p_1}(u_{p_0} - u_0)\right)$$

$$\implies (1-\phi)u_0 H\left(\frac{\partial u_1}{\partial z}\right) = H\left(\frac{1}{r}\frac{\partial u_1}{\partial r} + \frac{\partial^2 u_1}{\partial r^2}\right) + MH(\alpha\rho_{p_1}(u_{p_0} - u_0))$$

let

$$u_1^*(p) = H(u_1(r)) = \int_0^\infty u_1(r) r J_0(pr) dr$$

also

$$H\left(\frac{\partial u_1}{\partial z}\right) = \int_0^\infty \frac{\partial u_1}{\partial z} r J_0(pr) dr$$
$$= \frac{\partial}{\partial z} \int_0^\infty u_1(r) r J_0(pr) dr = \frac{\partial u_1^*}{\partial z}$$

and

$$H(\alpha \rho_{p_1}) = \int_0^\infty \alpha \rho_{p_1}(r) r J_0(pr) dr = \alpha \rho_{p_1}^*(p)$$

then we have

$$(1-\phi) u_0 \frac{\partial u_1^*}{\partial z} = -p^2 u_1^* + \alpha M \rho_{p_1}^* (u_{p_0} - u_0)$$

or

$$\frac{\partial u_1^*}{\partial z} + \frac{p^2}{(1-\phi)u_0} u_1^* = \alpha M \frac{(up_0 - u_0)}{(1-\phi)u_0} \rho_{p_1}$$

or

$$\frac{\partial u_1^*}{\partial z} + A p^2 u_1^* = \alpha E \rho_{p_1}^*$$

where

$$A = \frac{1}{(1-\phi)u_0}$$

and

$$E = \frac{(up_0 - u_0)M}{(1-\phi)u_0}$$

$$u_1^* = e^{-\int AP^2 dr} \left[\left(\int \alpha E \rho_{p_1} * e^{\int AP^2 dz} \right) + B \right]$$

or

$$u_1^*(z,p) = \frac{\alpha E}{AP^2} \rho_{p_1}^* + B e^{-AP^2 z}$$

now for z=0

$$u_1^*(0,p) = \frac{\alpha E}{AP^2} \rho_{p_1}^*(0,p) + B$$
$$B = u_1^*(0,p) - \frac{\alpha E}{AP^2} \rho_{p_1}^*(0,p)$$

but

$$\rho_{p_1}^*(0,p) = \int_0^\infty \rho_{p_1}(0,r) J_0(pr) dr$$
$$\frac{\rho_{p_{10}}}{P} [r J_1(pr)]_0^1 = \frac{\rho_{p_{10}}}{P} J_1(P)$$

and

$$u_1^*(0,p) = \int_0^\infty u_1(0,r) r J_0(pr) dr$$
$$= u_{10} \int_0^\infty r J_0(pr) dr = u_{10} \frac{J_1(P)}{P}$$

therefore we have

$$B = \frac{u_{10} J_1(P)}{P} - \frac{\alpha E}{AP^2} \frac{\rho_{10} J_1(P)}{P}$$

using above equation we get

$$u_1^* = \left(u_{10} - \frac{\alpha E \rho_{p_1 0}}{AP^2} \right) \frac{J_1(P)}{P} e^{-AP^2 z} + \frac{\alpha E \rho_{p_1 0}}{AP^2} \frac{J_1(P)}{P}$$

Hankels transform of

$$u_{p_0} \frac{\partial u_{P_1}}{\partial z} = (u_0 - u_{p_0}) + (u_1 - u_{p_1})$$

is

$$H \left(u_{p_0} \frac{\partial u_{P_1}}{\partial z} \right) = H \left((u_0 - u_{p_0}) + (u_1 - u_{p_1}) \right)$$

let

$$u_{p_1}^* = H(u_{p_1}(r)) = \int_0^\infty u_{p_1}(r) r J_0(pr) dr$$

now

$$H \left(\frac{\partial u_{P_1}}{\partial z} \right) = \int_0^\infty \frac{\partial u_{P_1}}{\partial z} r J_0(pr) dr = \frac{\partial}{\partial z} \int_0^\infty u_{P_1} r J_0(pr) dr = \frac{d u_{P_1}}{dz}^*$$

then we have

$$\frac{d u_{P_1}}{dz}^* = \frac{u_1^* - u_{p_1}^*}{u_{p_0}}$$

Where $H(1) = 0$

$$\implies \frac{d u_{P_1}}{dz}^* + \frac{u_{p_1}^*}{u_{p_0}} = \frac{u_1^*}{u_{p_0}}$$

$$u_{p_1}^* = \frac{1}{u_{p_0}} \left(u_{10} - \frac{\alpha E \rho_{p_{10}}}{Ap^2} \right) \frac{J_1(p)}{p} \frac{e^{-Ap^2}}{\frac{1}{u_{P_0}} - Ap^2} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} \frac{J_1(p)}{p} + G e^{-\frac{z}{u_{p_0}}}$$

$$G = u_{p_{10}} \frac{J_1(p)}{p} - \frac{1}{u_{p_0}} \left(u_{10} - \frac{\alpha E \rho_{p_{10}}}{Ap^2} \right) \frac{J_1(p)}{p} \frac{1}{\frac{1}{u_{P_0}} - Ap^2} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} \frac{J_1(p)}{p}$$

$$G e^{-\frac{z}{u_{p_0}}}$$
$$= u_{p_{10}} \frac{J_1(p)}{p} e^{-\frac{z}{u_{p_0}}} - \frac{1}{u_{p_0}} \left(u_{10} - \frac{\alpha E \rho_{p_{10}}}{Ap^2} \right) \frac{J_1(p)}{p} \frac{1}{\frac{1}{u_{P_0}} - Ap^2} e^{-\frac{z}{u_{p_0}}} - \frac{\alpha E \rho_{p_0}}{Ap^2} \frac{J_1(p)}{p} e^{-\frac{z}{u_{p_0}}}$$

$$u_{p_1}^*$$
$$= \left[\left(u_{p_1 0} + \frac{\alpha E \rho_{p_1 0} - u_{10}}{1 - Ap^2 u_{p_0}} \right) e^{-\frac{z}{u_{p_0}}} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} + \frac{\left(u_{10} - \frac{\alpha E \rho_{p_1 0}}{Ap^2} \right)}{(1 - Ap^2 u_{p_0})} e^{-Ap^2 z} \right] \frac{J_1(p)}{p}$$

Where J0, J1 are the zero-order and first-order Bessel functions respectively. Now the equations are

$$u_1^* = \left(u_{10} - \frac{\alpha E \rho_{p_1 0}}{Ap^2}\right) \frac{J_1(p)}{p} e^{-Ap^2 z} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} \frac{J_1(p)}{p} \tag{17}$$

$$u_{p_1}^* = \left[\left(u_{p_0} + \frac{\alpha E \rho_{p_1 0} - u_{10}}{1 - Ap^2 u_{p_0}}\right) e^{-\frac{z}{u_{p_0}}} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} + \frac{\left(u_{10} - \frac{\alpha E \rho_{p_1 0}}{Ap^2}\right)}{(1 - Ap^2 u_{p_0})} e^{-Ap^2 z} \right] \frac{J_1(p)}{p} \tag{18}$$

$$u_1^* = \int_0^\infty r u_1 J_0(pr) dr$$

$$A = \frac{1}{(1-\phi)u_0}, E = \frac{M u_{p_0} - u_0}{u_0}, C = \frac{2}{3 P_r U_{p_0}} and (18) gives \rho_{p_1}^* = \rho_{p_1 0} \frac{J_1(p)}{p} \tag{19}$$

Hankel inversion of (17) to (18) gives

$$u_1 = \int_0^\infty \left[\left(1 - e^{-Ap^2 z}\right) \alpha E \rho_{p_{10}} + A u_{10} P^2 e^{-Ap^2 z} \right] \frac{J_0(pr) J_1(p)}{Ap^2} dp \tag{20}$$

$$u_{p_1} = \int_0^\infty \left[\left(u_{p_0} + \frac{\alpha E \rho_{p_1 0} - u_{10}}{1 - Ap^2 u_{p_0}}\right) e^{-\frac{z}{u_{p_0}}} + \frac{\alpha E \rho_{p_1 0}}{Ap^2} + \frac{\left(u_{10} - \frac{\alpha E \rho_{p_1 0}}{Ap^2}\right)}{(1 - Ap^2 u_{p_0})} e^{-Ap^2 z} \right] J_0(pr) J_1(p) dp \tag{21}$$

Where J_0, J_1 are indeed the zero-order and first-order Bessel functions, respectively.

4. Conclusion and discussion of the result

Taking into account the following factors, numerical computations have been made $P_r = 0.72$, $u_{10} = u_{p_{10}} = T_{10} = T_{p_{10}} = \rho_{p_{10}} = 0.1$, $\phi = 0.01$. The velocity and temperature at the exit are taken nearly equal to unity.

Figure (4.1) shows the profiles of longitudinal perturbation fluid velocity u_1 for $u_1 = 0.1, 0.2$, for different Z values. It has been observed that as the magnetic field is increased, the magnitude of dust particles decreased.

Profiles of longitudinal perturbation particle velocity u_{p_1} for 0.1,0.2 and different Z values are shown in Figure 4.2. It has been observed that the magnetic field of dust parameters increases, the magnitude of u_{p_1} decreases.

It is observed that the magnetic field increases along the fluid velocity then the dust particles will attract towards the magnetic field and it improves the quality of purification of water and dust particle is reduced significantly.

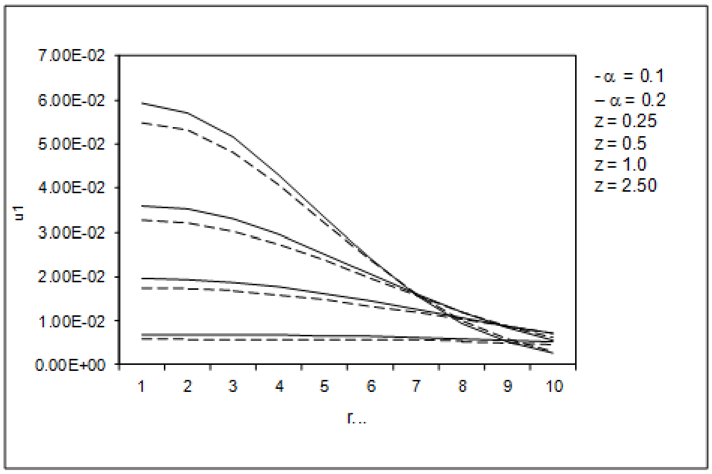

FIGURE 1. 4.1 Profiles of longitudinal perturbation fluid velocity with magnetic field

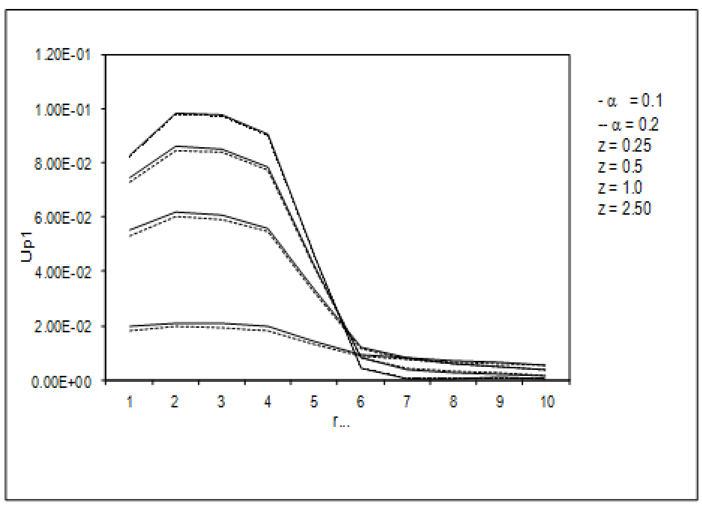

FIGURE 2. 4.2 Profiles of longitudinal perturbation particle velocity with magnetic field

Conflicts of interest : No conflict of interest among authors.

Data availability : Not applicable

Acknowledgments : One of the authors(N Jagannadham)is thankful to Dr.Srinivas, Associate Professor, SR University, Warangal for fruitful discussion in the result of manuscript.

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