MHD FLOW OF A NON – NEWTONIAN FLUID THROUGH AN ISOCELES TRIANGULAR CHANNEL

SANA AHSAN

Sam Higginbottom Institute of Agriculture, Technology and Sciences (Deemed to be University), Allahabad India (Email:sana.ahsan87@gmail.com)

Dr. R. K. KHARE

Sam Higginbottom Institute of Agriculture, Technology and Sciences (Deemed to be University), Allahabad India (Email:drrajeevkhare@gmail.com)

Dr.AJIT PAUL

Sam Higginbottom Institute of Agriculture, Technology and Sciences (Deemed to be University), Allahabad, India (Emai:paulajit1969@yahoo.co.in)

Abstract: Magnetohydrodynamic flow of dusty fluids through channels is of great importance in various industries manufacturing metallic items as they involve the flow of molten metals in pipes. In this paper, the flow of an incompressible dusty fluid through an isosceles triangular channel under the influence of transversely applied magnetic field has been studied. The related mathematical equations have been formed on the basis of the physical nature of the motion and they have been solved using Fourier Transformation to find the expression for velocity and by giving suitable values to the parameters involved in the equation, graphs have been drawn for different values of magnetic field parameter and velocity. It has been observed that the velocity of both phases decreases with increasing magnetic field which may be used to control the movement of dusty particles in channels.

Introduction

The study of the flow of a dusty incompressible and electrically conducting fluid through tube of different cross sections in presence of magnetic field is very useful in industries and engineering sciences because the efficiency and performance of many devices are affected by the presences of suspended solid particles contained by the fluid in magnetic field.

Different scientists have made great efforts to understand the interaction between dusty fluid and magnetic field .Saffman (1962) investigated the effect of stability of laminar flow of dusty gas. Dube and Srivastava (1972) derived the expression for the unsteady flow of a dusty viscous fluid, they assumed the uniform distribution of dust particle in a channel bounded by two parallel flat plates. Das and Gupta (1991) investigated the unsteady viscous flow of an incompressible fluid viscous liquid through an equilateral triangular channel in the presence of magnetic field.

In the present study we have taken an isosceles triangular channel through which the flow of fluid has been considered .The fluid assumed to be dusty, viscous, and incompressible and electrically conducting on the other hand the particle phase is assumed to be incompressible and electrically nonconducting. Dust particle are assumed to be spherical in shape and equal in size and mass. The flow is induced by decaying pressure gradient and other forces of interaction have been ignored

The magnetic field applied id transverse in nature and induced magnetic field is neglected because we have assumed the Reynolds number to be very small. The differential equations so formed have been solved analytically under the boundary condition and the expression for velocity has been derived. The graphs are formed using different parameters to explain the result which is thus explained theoretically also.

Formulation of problem

Consider the flow of a dusty viscous incompressible fluid through an isosceles triangular channel placed under transverse magnetic field. Flow of fluid is assumed to be in the direction along the axis of the channel.

The governing equations of motion are

$$(1-\varphi)\frac{\partial u'}{\partial t'} + (u'\nabla)u' = -\frac{\nabla p\prime}{\rho} + v\nabla^2 u' + \frac{KN}{\rho}(v'-u') + \mu\frac{J\times H}{(1+c^2)} \quad (1)$$

$$\mathrm{m}[\frac{\partial v'}{\partial t'} + (v'\nabla)\nabla] = k(v'-u')$$
(2)

$$\nabla . u' = \nabla . v' = 0$$
(3)

$$\frac{\partial N}{\partial t} + \nabla(Nv') = 0$$
(4)

Where,

u: Axial velocity of fluid,

v: Axial velocity of dust particle,

p: Pressure,

K: Stokes's resistance coefficient,

m: mass of each particle,

N: number density of the particle,

v : Kinematic viscosity,

ρ: density of the fluid,

μ_e: Permeability,

σ: electrical conductivity,

H: strength of magnetic field,

B_0: magnetic field,

j: Current density,

τ: Relaxation time,

f: Mass concentration,

After simplifying the equation (1) we get

$$(1-\varphi)\frac{\partial u'}{\partial t'} = \frac{1}{\rho}\left(\frac{-\partial p\prime}{\partial z}\right) + v\left(\frac{\partial^2 u'}{\partial x^2} + \frac{\partial^2 u'}{\partial y^2}\right) + \frac{KN}{\rho}(v'-u') - \frac{\sigma(B_0^2 u\prime)}{\rho(1+c^2)} \quad (5)$$

$$\frac{\partial v\prime}{\partial t\prime} = \frac{1}{\tau}(u'-v')$$
(6)

The boundary conditions are $u' = 0$ and $v' = 0$ on the boundary of the channel. The flow is induced by a pressure gradient of the form

$$\frac{-1}{\rho}\frac{\partial p}{\partial z} = A(1+\varepsilon e^{i\omega t})$$
(7)

Where A is the constant and ε is a dimensionless small quantity

Now the non dimensional variables are

$u = u_1 u'$,$v = v_1 v'$, $x = ax'$,$y = ay'$,$z = az'$, $\tau = \frac{a}{u_1}\tau'$, $p = \rho u_1^2 p'$,

$R = \frac{au_1}{v}$,$t = \frac{au_1}{v}$,$M = B_0 a\sqrt{\frac{\sigma}{\rho v}}$

,$f = \frac{mN}{\rho}$,$\tau = \frac{m}{k}$,$\omega' = \frac{\omega a}{u_1}$,$A' = \frac{Aa}{u_1^2}$ (8)

Putting these in the above equations we get

$$(1-\varphi)\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial z} + \frac{1}{R}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{f}{\tau}(v-u) - \frac{M^2 u}{R(1+c^2)} \quad (9)$$

$$\tau\frac{\partial v}{\partial t} = (u - v) \quad (10)$$

$$-\frac{\partial p}{\partial z} = A(1 + \varepsilon e^{i\omega t}) \quad (11)$$

Corresponding non dimensional initial and boundary conditions become $t \le 0$,$u(x,y,t) = 0$, $v(x,y,t) = 0$ every where in the channel and

$t > 0$,$u(x,y,t) = 0$, $v(x,y,t) = 0$ on the boundary of the channel.

We transform equation no. (9) into trilinear co-ordinate system. Let XYZ be an isosceles triangular tube and p is its centroid which is taken as origin. The lines perpendicular to XY is taken as x-axis and perpendicular to it is y-axis .Let us we consider the sides of the triangle are 3a, 3a and 4a.Consider the perpendiculars on sides of the triangle from any point within the triangle be $p_{1,}$ p_2 *and* p_3.

By the theorem we know that $p_1 + p_2 + p_3 = \sqrt{5}a$ (12)

Now we can write

$$\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} = \frac{\partial^2}{\partial {p_1}^2} + \frac{\partial^2}{\partial {p_2}^2} + \frac{\partial^2}{\partial {p_3}^2} - \frac{\partial^2}{\partial p_1 \partial p_2} - \frac{\partial^2}{\partial p_2 \partial p_3} - \frac{\partial^2}{\partial p_1 \partial p_3} \quad (13)$$

Under the transformation (13) equation (9) becomes

$$(1-\varphi)\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial z} + \frac{1}{R}\left(\frac{\partial^2}{\partial {p_1}^2} + \frac{\partial^2}{\partial {p_2}^2} + \frac{\partial^2}{\partial {p_3}^2} - \frac{\partial^2}{\partial p_1 \partial p_2} - \frac{\partial^2}{\partial p_2 \partial p_3} - \frac{\partial^2}{\partial p_1 \partial p_3}\right) + \frac{f}{\tau}(v-u) - \frac{M^2 u}{R(1+c^2)} \quad (14)$$

And the boundary conditions are

$t \le 0$, $u = v = 0$ Everywhere in the channel and

$t > 0$, $u = v = 0$, at the points p_1, p_2 *and* p_3.

Now we can assume the solution as

$$u(p_1,p_2,p_3,t) = A\{u_0(p_1,p_2,p_3) + \varepsilon u_1(p_1,p_2,p_3)e^{i\omega t}\} \quad (15)$$

$$v(p_1,p_2,p_3,t) = A\{v_0(p_1,p_2,p_3) + \varepsilon v_1(p_1,p_2,p_3)e^{i\omega t}\} \quad (16)$$

Where $u_0$and v_0 are the steady parts and $u_1$and v_1 are the unsteady parts.

Now the boundary conditions changes to

$u_0 = 0$, $v_0 = 0$ and $u_1 = 0, v_1 = 0$ at $p_1 = 0, p_2 = 0$ and $p_3 = 0$

Putting the values of different derivatives of u from (15) and (16) in equation (14) and equating separately the terms free from $\varepsilon e^{i\omega t}$ and the coefficients of $\varepsilon e^{i\omega t}$.

We get the following

$$\left(\frac{\partial^2 u_0}{\partial {p_1}^2}+\frac{\partial^2 u_0}{\partial {p_2}^2}+\frac{\partial^2 u_0}{\partial {p_3}^2}-\frac{\partial^2 u_0}{\partial p_1 \partial p_2}-\frac{\partial^2 u_0}{\partial p_2 \partial p_3}-\frac{\partial^2 u_0}{\partial p_1 \partial p_3}\right)+\frac{Rf}{\tau}(v_0-u_0)-\frac{M^2 u_0}{R(1+c^2)}+R=0$$

(17)

$$\left(\frac{\partial^2 u_1}{\partial {p_1}^2}+\frac{\partial^2 u_1}{\partial {p_2}^2}+\frac{\partial^2 u_1}{\partial {p_3}^2}-\frac{\partial^2 u_1}{\partial p_1 \partial p_2}-\frac{\partial^2 u_1}{\partial p_2 \partial p_3}-\frac{\partial^2 u_1}{\partial p_1 \partial p_3}\right)+\frac{Rf}{\tau}(v_1-u_1)-\frac{M^2 u_1}{R(1+c^2)}+R-Ru_1 i\omega(1-\varphi)=0$$

(18)

Again putting the value of u and v and different derivatives of v from equation(15) and (16) in equation (10) and equating separately the terms free from $\varepsilon e^{i\omega t}$ and the coefficients of $\varepsilon e^{i\omega t}$ we get

$$\tau\frac{\partial v}{\partial t}=(u_0-v_0)=0$$

This means $u_0=v_0$ (19)

So the steady parts of the velocities are same.

And we also get $v_1=\frac{1}{(1+i\omega\tau)}u_1$ (20)

Now putting equation (20) in equations (18)

$$\left(\frac{\partial^2 u_1}{\partial {p_1}^2}+\frac{\partial^2 u_1}{\partial {p_2}^2}+\frac{\partial^2 u_1}{\partial {p_3}^2}-\frac{\partial^2 u_1}{\partial p_1 \partial p_2}-\frac{\partial^2 u_1}{\partial p_2 \partial p_3}-\frac{\partial^2 u_1}{\partial p_1 \partial p_3}\right)+\frac{Rf}{\tau}\left(\frac{1}{(1+i\omega\tau)}u_1-u_1\right)-\frac{M^2 u_1}{R(1+c^2)}+R-Ru_1 i\omega(1-\varphi)=0$$

Or

$$\left(\frac{\partial^2 u_1}{\partial {p_1}^2}+\frac{\partial^2 u_1}{\partial {p_2}^2}+\frac{\partial^2 u_1}{\partial {p_3}^2}-\frac{\partial^2 u_1}{\partial p_1 \partial p_2}-\frac{\partial^2 u_1}{\partial p_2 \partial p_3}-\frac{\partial^2 u_1}{\partial p_1 \partial p_3}\right)+\frac{Rf}{\tau}\left(\frac{i\omega\tau}{(1+i\omega\tau)}\right)u_1-\frac{M^2 u_1}{R(1+c^2)}+R-Ru_1 i\omega(1-\varphi)=0$$

Or

$$\left(\frac{\partial^2 u_1}{\partial {p_1}^2}+\frac{\partial^2 u_1}{\partial {p_2}^2}+\frac{\partial^2 u_1}{\partial {p_3}^2}-\frac{\partial^2 u_1}{\partial p_1 \partial p_2}-\frac{\partial^2 u_1}{\partial p_2 \partial p_3}-\frac{\partial^2 u_1}{\partial p_1 \partial p_3}\right)+R\left(\frac{fi\omega\tau}{(1+i\omega\tau)}-\frac{M^2}{R(1+c^2)}-i\omega(1-\varphi)\right)u_1+R=0$$

Or

$$\left(\frac{\partial^2 u_1}{\partial {p_1}^2}+\frac{\partial^2 u_1}{\partial {p_2}^2}+\frac{\partial^2 u_1}{\partial {p_3}^2}-\frac{\partial^2 u_1}{\partial p_1 \partial p_2}-\frac{\partial^2 u_1}{\partial p_2 \partial p_3}-\frac{\partial^2 u_1}{\partial p_1 \partial p_3}\right)+R(C_1)u_1+R=0$$

(21)

Where,

$$C_1=\frac{M^2}{R(1+c^2)}-\frac{fi\omega\tau}{(1+i\omega\tau)}+i\omega(1-\varphi)$$

Similarly using equation (19) in (17) we get

$$\left(\frac{\partial^2 u_0}{\partial {p_1}^2}+\frac{\partial^2 u_0}{\partial {p_2}^2}+\frac{\partial^2 u_0}{\partial {p_3}^2}-\frac{\partial^2 u_0}{\partial p_1 \partial p_2}-\frac{\partial^2 u_0}{\partial p_2 \partial p_3}-\frac{\partial^2 u_0}{\partial p_1 \partial p_3}\right)+\frac{Rf}{\tau}(u_0-u_0)-\frac{M^2 u_0}{R(1+c^2)}+R=0$$

Or

$$\left(\frac{\partial^2 u_0}{\partial {p_1}^2}+\frac{\partial^2 u_0}{\partial {p_2}^2}+\frac{\partial^2 u_0}{\partial {p_3}^2}-\frac{\partial^2 u_0}{\partial p_1 \partial p_2}-\frac{\partial^2 u_0}{\partial p_2 \partial p_3}-\frac{\partial^2 u_0}{\partial p_1 \partial p_3}\right)-\frac{M^2 u_0}{R(1+c^2)}+R=0$$

(22)

Now let us assume the solution of (21) and (22) satisfying the boundary conditions

$u_0=0,\quad v_0=0$ and $u_1=0, v_1=0$ at $p_1=0, p_2=0$ and $p_3=0$

$$u_0=\sum_{n=1}^{\infty}\alpha_n\left(\sin\frac{2n\pi}{\sqrt{5}a}p_1+\sin\frac{2n\pi}{\sqrt{5}a}p_2+\sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \quad (23)$$

$$u_1=\sum_{n=1}^{\infty}\beta_n\left(\sin\frac{2n\pi}{\sqrt{5}a}p_1+\sin\frac{2n\pi}{\sqrt{5}a}p_2+\sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \quad (24)$$

Now substituting the values of u_0 and u_1 and different derivatives of u_0

And u_1 from equation (23) and (24) in (21) and (22) we get

$$\frac{M^2}{1+c^2}\left\{\sum_{n=1}^{\infty}\alpha_n\left(\sin\frac{2n\pi}{\sqrt{5}a}p_1+\sin\frac{2n\pi}{\sqrt{5}a}p_2+\sin\frac{2n\pi}{\sqrt{5}a}p_3\right)\right\}=R \quad (25)$$

$$R\left\{\sum_{n=1}^{\infty}\beta_n\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)\right\}(-C_1)=-R$$

Or

$$\left\{\sum_{n=1}^{\infty}\beta_n\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)\right\}=1 \qquad (26)$$

Now since we know that

$$p_1+p_2 + p_3=\sqrt{5}a$$

We can write

$$R=\frac{R}{\sqrt{5}a}\left\{\left(\sqrt{5}a-2p_1\right)+\left(\sqrt{5}a-2p_2\right)+\left(\sqrt{5}a-2p_3\right)\right\} \qquad (27)$$

Expressing

$\left(\sqrt{5}a-2p_1\right),\left(\sqrt{5}a-2p_2\right) and \left(\sqrt{5}a-2p_3\right)$ as the Fourier's sine series, we get

$$\left\{\sum_{n=1}^{\infty}\beta_n\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)\frac{2}{\pi}\right\}=1 \qquad (28)$$

We get

$$\frac{M^2}{1+c^2}\left(\alpha_n\frac{\pi}{2}\right)=R$$

Or,

$$\alpha_n=\frac{2R(1+c^2)}{M^2\pi n} \qquad (29)$$

And

$$\beta_n=\frac{2}{\pi n C_1} \qquad (30)$$

Hence the solution becomes

$$u_0=\sum_{n=1}^{\infty}\frac{2R(1+c^2)}{M^2\pi n}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \qquad (31)$$

So

$$v_0=\sum_{n=1}^{\infty}\frac{2R(1+c^2)}{M^2\pi n}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \qquad (32)$$

$$u_1=\sum_{n=1}^{\infty}\frac{2}{\pi n C_1}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \qquad (33)$$

$$v_1=\frac{1}{1+i\omega\tau}\sum_{n=1}^{\infty}\frac{2}{\pi n C_1}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right) \qquad (34)$$

So the solution becomes

$$u=A\left\{\sum_{n=1}^{\infty}\frac{2R(1+c^2)}{M^2\pi n}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)+\varepsilon\sum_{n=1}^{\infty}\frac{2}{\pi n C_1}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)e^{i\omega t}\right\} \qquad (35)$$

$$v=A\left\{\sum_{n=1}^{\infty}\frac{2R(1+c^2)}{M^2\pi n}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)+\varepsilon\frac{1}{1+i\omega\tau}\sum_{n=1}^{\infty}\frac{2}{\pi n C_1}\left(sin\frac{2n\pi}{\sqrt{5}a}p_1+sin\frac{2n\pi}{\sqrt{5}a}p_2+sin\frac{2n\pi}{\sqrt{5}a}p_3\right)e^{i\omega t}\right\} \qquad (36)$$

Table 1

Velocity of Fluid (u) vs. Magnetic Field (M)

($n = 1\ldots\ldots9$, $a=1$, $p_1=1$, $p_2=1.1$, $p_3=0.1$, $R=1$, $\omega=0.1$, $\varepsilon=0.1$, $t=1$, $\tau=0.1$, $\varphi=0.1$, $f=0.1$)

Sr. no	Magnetic Field (M)	Velocity of fluid(u)		
		non Newtonian factor(c)=1.0	non Newtonian factor(c)=1.3	non Newtonian factor(c)=1.5
1	1.0	0.519618360	0.696949340	0.839771246
2	1.5	0.231616304	0.311338530	0.375925303
3	2.0	0.130350595	0.175287940	0.211737612
4	2.5	0.083436136	0.112212713	0.135561989
5	3.0	0.057944718	0.077932646	0.094152836
6	3.5	0.042572569	0.057258906	0.069177496
7	4.0	0.032594975	0.043839699	0.052965510
8	4.5	0.025754204	0.034639134	0.041849923
9	5.0	0.020860975	0.028057867	0.033898732
10	5.5	0.017240511	0.023188405	0.028015629
11	6.0	0.014486837	0.019484747	0.023540990
12	7.0	0.010643407	0.014315362	0.017295487
13	9.0	0.006438611	0.008659928	0.010462732
14	12	0.003621721	0.004871213	0.005885294

Table 2

Velocity of particle (v) vs. Magnetic Field (M)

($n = 1\ldots\ldots9$, $a=1$, $p_1=1$, $p_2=1.1$, $p_3=0.1$, $R=1$, $\omega=0.1$, $\varepsilon=0.1$, $t=1$, $\tau=0.1$, $\varphi=0.1$, $f=0.1$)

Sr. no	Magnetic Field (M)	Velocity of particle(v)		
		non Newtonian factor(c)=1.0	non Newtonian factor(c)=1.3	non Newtonian factor(c)=1.5
1	1.0	0.519523429	0.696784489	0.839538761
2	1.5	0.231595799	0.311302654	0.375873970
3	2.0	0.130343537	0.175275766	0.211720289
4	2.5	0.083432957	0.112207332	0.135554408
5	3.0	0.057943017	0.077929824	0.094148903
6	3.5	0.042571544	0.057257239	0.069175199
7	4.0	0.032594302	0.043838624	0.052964046
8	4.5	0.025753733	0.034638395	0.041848926
9	5.0	0.020860629	0.028057331	0.033898016
10	5.5	0.017240246	0.023188001	0.028015094
11	6.0	0.014486628	0.019484432	0.023540577
12	7.0	0.017295220	0.014315156	0.017295220

13	9.0	0.010462596	0.008659820	0.010462596
14	12	0.005885226	0.004871159	0.005885226

Figure 1

Velocity of Fluid (u) vs. Magnetic Field (M)

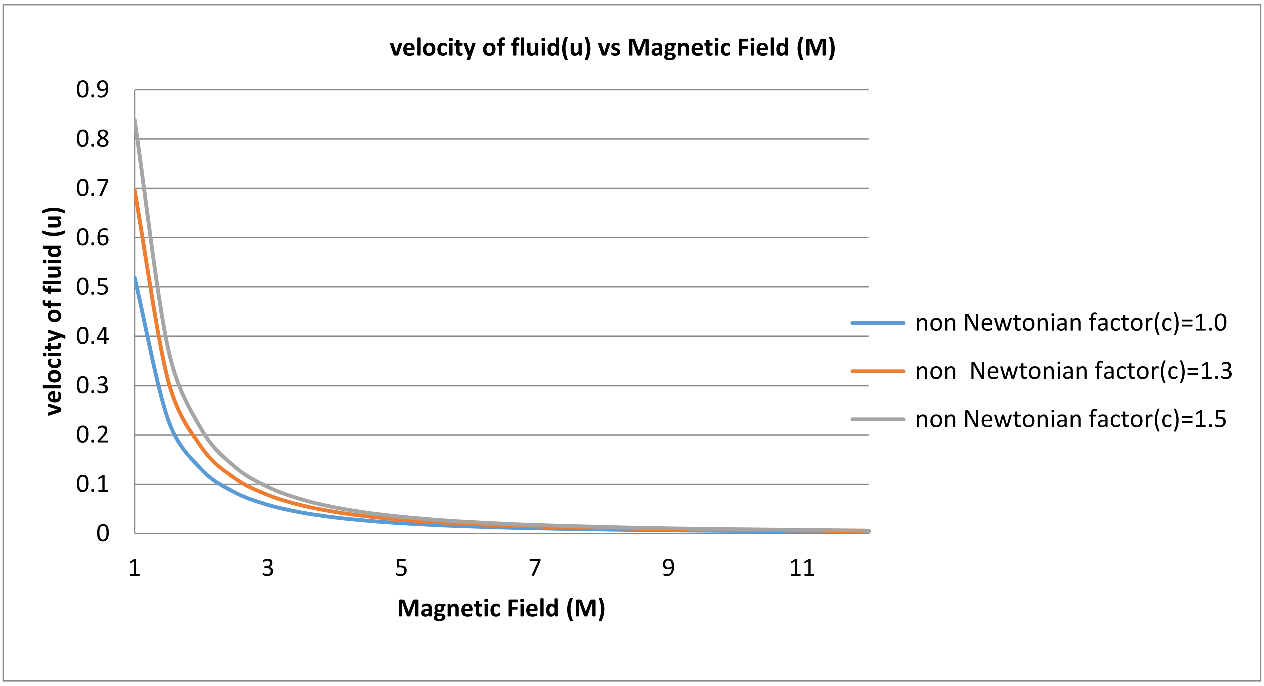
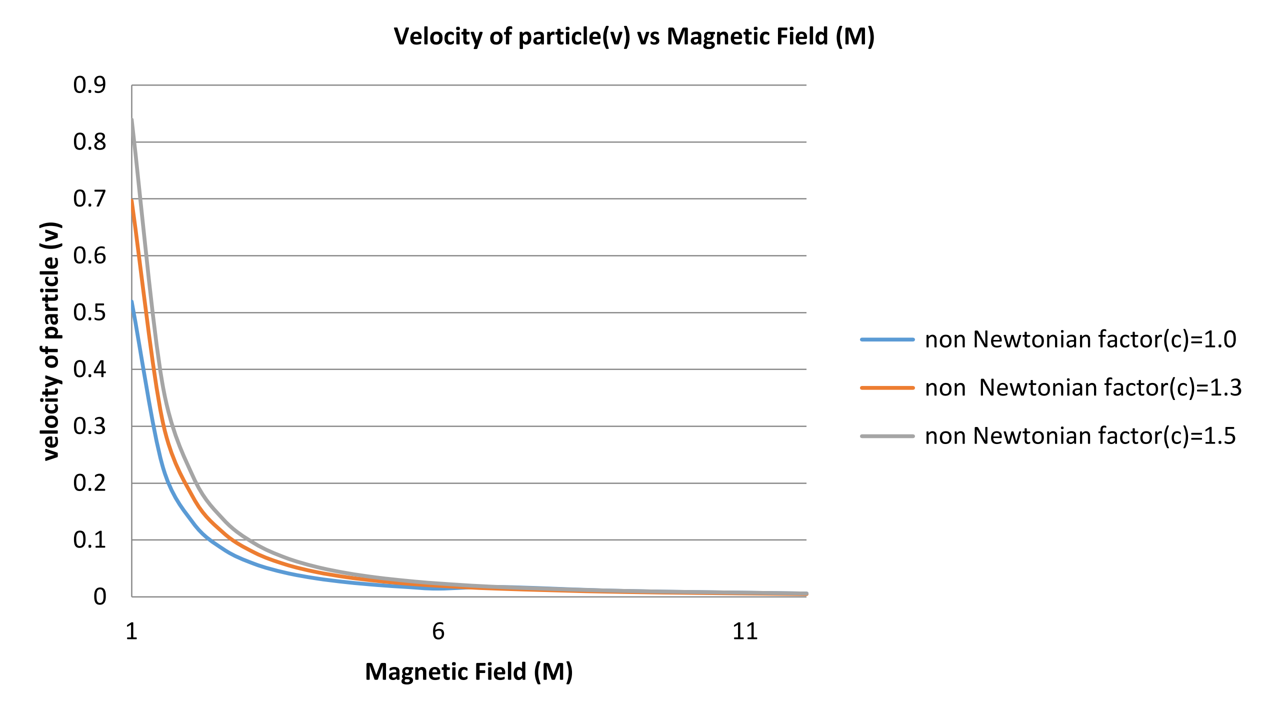


Figure 2

Velocity of particle (v) vs. Magnetic Field (M)



Result and Discussion

The graphs in the above presentation show the change in velocity profiles of fluid and dust while changing the values of magnetic field parameter, under the influence of non Newtonian factor of the fluid

Figure 1 shows the change in the velocity of the fluid with changes in magnetic field parameter. It is observed from the graph that on increasing the value of magnetic field parameter the graph of velocity first decreases exponentially then becomes parallel to the axis of magnetic field and the finally merges with the axis of magnetic field. This is due to Lenz Law. It has also been observed on increasing the value of nonNewtonian factor the initial velocity of the fluid also increases. The results observed above have been verified mathematically.

Figure 2 shows the graph of particle velocity with respect to the changes in the magnetic field and non Newtonian factor of the fluid. Physically it can be interpreted that decreases in velocity on increasing magnetic field parameter is due to Lenz Law. It is found mathematically and graphically that the magnetic field parameter has the decreasing effect on the velocity of the particle. It has also been shown that increasing nonNewtonian factor decreases the initial velocity of the particle.

Thus we can conclude that in both the phases the effect of magnetic field parameter and nonNewtonian factor is same. The graph in both the cases is exponentially decreasing in the beginning turns from the origin becomes parallel to axis of magnetic field and then finally merges with the axis. The result is obvious from the mathematical calculations also. The square of magnetic field parameter comes in the denominator of the expressions of fluid and dust particle, because of which the graph decreases in such a manner.

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