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Examining The Effect of The Magnetic Field on Free Convection Flows in Liquid Metals, Electrolytes and Ionized Gases

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Abstract

This paper present research result of the behavior of unsteady free convection flow of a visco-elastic fluid past an infinite porous plate with constant suction under the action of the time depend plate temperature. A uniform magnetic field is applied transversely to the porous plate and the magnetic lines of forced are taken to be fixed relative to the fluid. It is assumed that the plate temperate fluctuates about a constant mean, in the magnitude but not in direction. The numerical results of the real part M^r and imaginary part M^i of the fluctuating part of the velocity are tabulated. It is determined that the velocity distribution inside the boundary layer lags behind the wall fluctuation by the constant angle ϕ. The results obtained in the paper are useful in analyzing the effect of the magnetic field on free convection flows in liquid metals, electrolytes, and ionized gases.

Keywords : Visco-Elastic, Magnetic field, Porous Plate, Free Convection, Visco-elastic jetting.

I. INTRODUCTION

In the recent years the non-Newtonian fluids finds an increasing interest in industry and technology due to growing use of such fluids in many activities. The objective of this work is to analyze the flow of an elastico-viscous fluid in a compliant annulus.

Bikesh Chandra Ghosh, N. C. Ghosh has studied the MHD flow of a visco-elastic fluid through porous medium and he found analytical expression velocity profiles of the fluid and dust particles using the Laplace transform technique [6]. Ignacio Lira studied scales of free convection around a vertical cylinder and he showed that non dimensionalizing the momentum and energy equations in the terms of the Rayliegh or Boussinesq numbers allows the use of the Prandtl number as a criterion to establish whether the motive buoyancy force is the mainly balanced by inertia or by friction [11]. O Anwar et al have studied numerical study of heat transfer of a third grade visco-elastic fluid in non-Darcy porous media with thermo physical effects and a numerical solution is presented for natural convective dissipative heat transfer of the an incompressible, third grade, non-Newtonian fluid flowing past an infinite porous plate. The mathematical model is developed in an (x-y) co-ordinate system. Using a set of transformations the momentum equation is rendered one-dimensional and a partly linearized heat conservation equation is derived [10].

Hall Effect on magneto-hydrodynamic free-convection flow at a stretching surface with a uniform free stream presented by Emad M Abo-Eldahab and found that the free convection flow of a conducting fluid near an isothermal sheet with a uniform free stream of constant velocity and temperature is investigated. The effects of the magnetic field, the hall and the hear source/sink parameters on these functions are discussed [7].

Dynamics wetting with viscous Newtonian and non-Newtonian fluid has been studied by Y Wei et al and he examined various aspects of dynamic wetting with viscous Newtonian and Non-Newtonian fluids [12].

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Rita Choudary and Alok Das has investigated elastico-visous flow in a compliant annulus[5] Highly efficient lattice Blotzmann model for compressible fluids: two dimensional case presented by Chen Feng et al. He analyzed the (i) shock tube such as the sod, Lax, Sjogreen, Colella explosion wave and collision of two strong shocks. (ii) Regular and Mach shock reflection and (iii) shock wave reaction on cylindrical bubble problems. [13]

Yadav and Ray studied the unsteady flow of an-immiscible visco-elastic fluid through porous medium between two parallel plates in the presence of a transverse magnetic field. These studies have been carried for inviscid fluid [1] Srivastava and Khare have investigated the Ralyelgh-Taylor instability of two viscous superposed conducting fluids on a vertical magnetic field [2] Gravity field in porous medium has been given by Veena Sharma and Gin Chand Rana [8].

P Kumar has studied the instability if the visco-elastic superposed fluids with the suspended particles and variable magnetic field in porous medium porosity and found that the stability criterion is independent of the effects of visco-elastic medium porosity and suspended particles but is dependent on the orientation and magnitude of the magnetic field [3]

R. C. Sharma and S K Kango, studied the stability of two superposed Walter B' visco-elastic fluids in the presence of suspended particles and variable magnetic filed in porous medium [4] Yu, J.D., et al studies Two-Phase Viscoelastic Jetting [9]

In the present Paper we derive the separate expressions for the real part M_r and imaginary part M_i of the fluctuating part of the velocity and their Numerical study has been presented.

The phase angle ϕ and $M = \sqrt{M_r^2 + M_i^2}$ are calculated and tabulated.

II. NOMENCLATURE

U = is the velocity in the direction of x – axis,
V = is the velocity normal to the plate
T = time variable
η_o = The limiting viscosity at small rate of shear
K_0 = Elastic constant
f_x = acceleration due to gravity.
β = Thermal Conductivity
T = Temperature in the boundary layer.
T_∞ = Temperature far away from the plate

III. FORMULATION OF THE PROBLEM AND PERTURBATION EQUATIONS

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

$$\rho\frac{\partial u}{\partial t} + \rho v\frac{\partial u}{\partial y} = \rho f_x \beta(T - T_\infty) + \eta_o\frac{\partial^2 u}{\partial y^2} - K_o\{\frac{\partial^3 u}{\partial y^2 \partial t} + v\frac{\partial^3 u}{\partial y^3}$$
$$-3\frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2} - 2\frac{\partial v}{\partial y}\frac{\partial^2 u}{\partial y^2}\} - \sigma B_o^2 u \qquad (2)$$

$$\rho\frac{\partial v}{\partial t} + \rho v\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} + 2\eta_o\frac{\partial^2 v}{\partial y^2} - 2K_o(\frac{\partial^3 v}{\partial y^2 \partial t}$$
$$+ v\frac{\partial^3 v}{\partial y^3} - 3\frac{\partial v}{\partial y}\frac{\partial^2 v}{\partial y^2}) \qquad (3)$$

$$\rho c_p\left\{\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y}\right\} = \lambda\frac{\partial^2 T}{\partial y^2} \qquad (4)$$

The origin is taken at any point of a flat vertical porous infinite plate. The X-axis is chosen along the plate vertically upwards and Y-axis perpendicular to it.

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In the equation(4) terms representing viscous and elastic dissipation are assumed to be neglected.- $\frac{\sigma B_0^2 u}{\rho}$ is the value of $\vec{J} * \vec{B}$, $\vec{J}$ and $\vec{B}$ being given by Maxwell's equation in ohm's law namely:-

$$\nabla \times H = 4\pi \vec{J}$$
$$\nabla . B = 0$$
$$\nabla \times B = \frac{\partial \vec{B}}{\partial t}$$
$$where \vec{J} = \sigma\left[\vec{B} + \left(\vec{u} \times \vec{B}\right)\right]$$

from (1) for constant suction velocity v_0

$$v = -v_0 \qquad (5)$$

applying (5) in equations (2) and (3)

$$\frac{\partial u}{\partial t} - v_o \frac{\partial u}{\partial y} = f_x(T - T_\infty) + \gamma \frac{\partial^2 u}{\partial y^2} - k\left(\frac{\partial^3 u}{\partial y^2 \partial t} - v_o \frac{\partial^3 u}{\partial y^3}\right) - \frac{mu}{\rho} \qquad (6)$$

where $\nu = \frac{\eta_o}{\rho}$, $K^o = \frac{k_o}{\rho}$ and $m = \sigma B_o^2$

$$\frac{\partial v}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial y} \qquad (7)$$

The boundary conditions are

$$\left.\begin{array}{l} u = 0 \text{ and } T = Tw(t) \text{ at } y = 0 \\ u = 0 \text{ and } T = 0 \text{ at } y \to \infty \end{array}\right\} \qquad (8)$$

Introducing the following non-dimensional quantities.

$$\left.\begin{array}{l} \eta = \frac{y v_o}{\nu} \\ t = \frac{v_o^2 t}{u \nu} \\ u = \frac{u}{G v_o} \\ K = K^o \frac{v_o^2}{\nu^2} \\ T = \frac{T - T_\infty}{T_w - T_\infty} \\ G = \frac{\nu f_x \beta(T_w - T_\infty)}{v_o^3} \text{ the Grashoff Number} \\ P = \frac{\eta_o c_p}{\lambda} \text{ the prandtl number} \end{array}\right\} \qquad (9)$$

Equation (6) and (4) thus reduce to

$$\frac{\partial^2 u}{\partial \eta^2} + \frac{\partial u}{\partial \eta} - \frac{1}{4}\frac{\partial u}{\partial t} - k\left[\frac{1}{4}\frac{\partial^3 u}{\partial t \partial n^2} - \frac{\partial^3 u}{\partial \eta^3}\right] - Mu = -T \qquad (10)$$

where $M = \frac{m\nu}{v_o^2 \rho}$

$$\frac{\partial^2 T}{\partial \eta^2} + \rho \frac{\partial T}{\partial \eta} - \frac{\rho}{4}\frac{\partial T}{\partial t} = 0 \qquad (11)$$

Boundary conditions (8) now reduce to

$$\left.\begin{array}{l} u = 0, T = 1 \text{ at } \eta = 0 \\ u = 0, T = 0 \text{ at } \eta \to \infty \end{array}\right\} \qquad (12)$$

let temperature and the velocity in the neighborhood of the plate be assumed.

$$T(\eta, t) = \{1 - f_1(\eta)\} + \varepsilon e^{i\omega t}\{1 - f_2(\eta)\} \qquad (13)$$

and $u(\eta, t) = g_1(\eta) + \varepsilon e^{i\omega t} g_2(\eta)$ (14)

respectively. Substituting equation (13) in equation (11) and comparing the harmonic terms. We have

$$f_1(\eta) = 1 - e^{-P\eta} \qquad (15)$$

$$f_2(\eta) = 1 - e^{-PH\eta} \quad (16)$$

where $H = \frac{1}{2}\left\{1 + \left(1 + \frac{i\omega}{P}\right)^{\frac{1}{2}}\right\}$ and f_1 and f_2 satisfy the reduced boundary conditions

$$\left.\begin{aligned} f_1 = f_2 &= 0 \ at \ \eta = 0 \\ f_1 = f_2 &= 1 \ at \ \eta \to \infty. \end{aligned}\right\} \quad (17)$$

substitution of equation (13) and equation(14) in equation(10) and comparison of harmonic terms yields to

$$kg_1^{'''} + g_1^{''} + g_1^{'} - Mg_1 = f_1 - 1 = -e^{-P\eta} \quad (18)$$

$$kg_2^{'''} + \left(1 - \frac{k}{4}i\omega\right)g_2^{''} + g_2^{'} + g_2^{'} - \frac{i\omega}{4}g_2 - Mg_2 = f_2 - 1 = -e^{-PH\eta} \quad (19)$$

The corresponding boundary conditions now become.

$$\left.\begin{aligned} g_1 = g_2 &= 0 \text{ when } \eta = 0 \\ g_1 = g_2 &= 0 \text{ when } \eta \to \infty \end{aligned}\right\} \quad (20)$$

equation (18) and (19) reduce to these governing the flow of a Newtonian fluid, if k=0

Let us assume the solution in the form given.

$$g_1 = g_{01} + kg_{11} + o(k^2) \quad (21)$$

$$g_2 = g_{02} + kg_{12} + 0(k^2) \quad (22)$$

inserting (21) and (22) in (18) and (19) and equating the coefficients of k , we obtain after substituting for f_1 and f_2 respectively from (15) and (16).

$$g_{01}^{''} + g_{01}^{'} - Mg_{01} = -e^{-\rho\eta} \quad (23)$$

$$g_{11}^{'} + g_{11}^{'} - Mg_{11} = -g_{01}^{'''} \quad (24)$$

$$g_{02}^{'} + g_{02}^{'} - \frac{i\omega}{4}g_{02} - Mg_{02} = -e^{-\rho h\eta} \quad (25)$$

$$g_{12}^{''} + g_{12}^{'} - \frac{i\omega}{4}g_{12} - Mg_{12} = -g_{02}^{'''} + \frac{i\omega}{4}g_{02}^{''} \quad (26)$$

The corresponding boundary conditions on $g_{01}, g_{11}, g_{02}, and g_{12}$ are

$$\left.\begin{aligned} g_{01} = g_{11} = g_{02} = g_{12} &= 0 at \eta = 0 \\ g_{01} = g_{11} = g_{02} = g_{12} &= 0 at \eta \to \infty \end{aligned}\right\} \quad (27)$$

on solving equation (23) to equation (26) which satisfy equation(27) the velocity field in the boundary layer is obtained for $P \neq 1$ as

$$u = g_1 + \varepsilon^{i\omega t} g_2 \quad (28)$$

where

$$g_1 = \frac{e^{\alpha_2\eta} - e^{-P\eta}}{P^2 - P - M} + kP^3\left\{\frac{e^{\alpha_2\eta} - e^{p\eta}}{(P^2 - P - M)^2}\right\}$$

$$g_2 = \frac{e^{\beta_2\eta} - e^{pH\eta}}{P^2H^2 - PH - M - \frac{i\omega}{4}} + \frac{k^2P^2H^2(e^{\beta_2\eta} - e^{-PH\eta})(PH + \frac{i\omega}{4})}{(P^2H^2 - PH - M - \frac{i\omega}{4})^2}$$

$$\beta_2 = -(A_1 + iB_1), \quad \alpha_2 = -\left\{\frac{1 + \sqrt{1 + 4m}}{2}\right\}$$

$$A_1 = \frac{1}{2}\left\{1 + (1 + 4m)^{1/2} + \frac{\omega^2}{8(1 + 4m)^{3/2}}\right\}$$

$$B_1 = \frac{\omega}{4\sqrt{1 + 4m}}, \quad H = C_1 + iD_1, \quad C_1 = 1 + \frac{1}{16}\frac{\omega^2}{P^2},$$

$$D_1 = \frac{\omega}{4P}$$

we may write

$$u = g_1 + \varepsilon(M_r \cos\omega t - M_i \sin\omega t) \quad (29)$$

(The imaginary part being neglected for obvious reasons)

where M_r *and* M_i are the real and imaginary parts of the fluctuating part of the velocity when $P \neq 1$ and are given by

$$M_r + M_i = g_2 \quad (30)$$

Equating real and imaginary parts we have:

$$M_r = \frac{E_1G_1 + F_1H_1}{G_1^2 + H_1^2} + \frac{kP^2[(E_1I_1 - F_1J_1)(G_1^2 - H_1^2) + 2G_1H_1(E_1J_1 + F_1I_1)]}{(G_1^2 + H_1^2)^2} \quad (31)$$

$$M_i = \frac{F_1G_1 - E_1H_1}{G_1^2 + H_1^2} + \frac{kP^2[(E_1J_1 + F_1I_1)(G_1^2 - H_1^2) - 2G_1H_1(E_1I_1 + F_1J_1)]}{(G_1^2 + H_1^2)^2} \quad (32)$$

where $I_1 = (C_1^2 - D_1^2)PC_1 - 2C_1D_1(PD_1 + \frac{\omega}{4})$

$$J_1 = (C_1^2 - D_1^2)(PD_1 + \frac{\omega}{4}) + 2PC_1^2D_1$$

$$G = P^2G_1^2 - P^2D_1^2 - PC_1 - M$$

$$H_1 = 2P^2C_1D_1 - PD_1 - \frac{\omega}{4}$$

$$E_1 = e^{-A_1\eta}\cos(\beta_1\eta) - e^{-PC_1\eta}\cos(PD_1\eta)$$

$$F_1 = e^{-PC_1\eta}\sin(PD_1\eta) - e^{-A_1\eta}\sin(\beta_1\eta) \quad (33)$$

$$C_1 = 1 + \frac{1}{16}\frac{\omega^2}{P^2}, \quad D_1 = \frac{1}{4}\frac{\omega}{P}$$

Equation (31) and (32) together yield

$$M = |M_r + iM_i|$$

$$= \frac{\left[(E_1^2 + F_1^2)\left\{(G_1 + KP^2I_1)^2 + (H_1 + KP^2J_1)^2\right\}\right]^{1/2}}{G_1^2 + H_1^2} \quad (34)$$

Table 1. Real part M_r when P=0.01, $\omega = 0.2$

η / k	**0**	**0.05**	**0.5**	**1**
0	0	0	0	0
0.5	.22792	.22791	.22788	.22784
1	.35114	.35113	.35108.	.35101
2	.35998	.35997	.35990	.35982
4	.27366	.27365	.27358	.27350
5	.24449	.24448	.24441	.24433

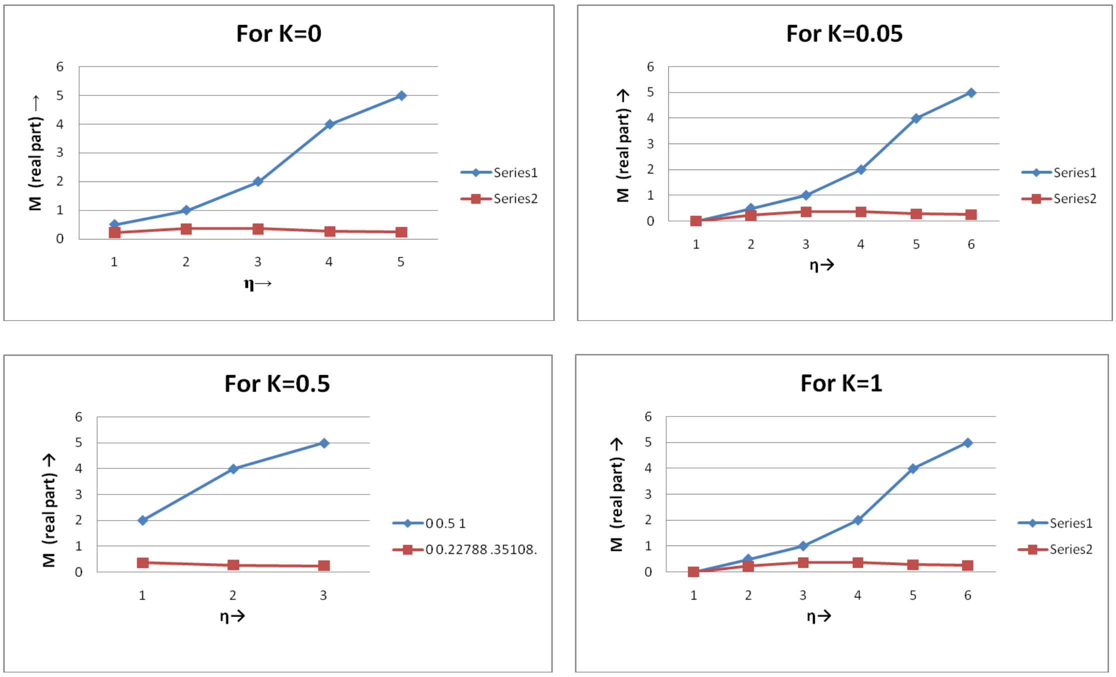


Figure 1. Graphs showing the variation in values of 'Mr' with respect to the change in value of 'η' for different values of 'K' i.e K=0, K=0.05, K=0.5 and K=1.0.

Table 2. Imaginary Part M_i when P=0.1, ω =0.2

η / k	**0**	**0.05**	**0.5**	**1.0**
0.5	-.01743	-.01744	-.01758	-.01773
1	-.03328	-.03330	-.03353	-.03378
2	-.05117	-.05119	-.05142	-.05167
4	-.06680	-.05119	-.06695	-.05167
5	-.07246	-.07247	-.07261	-.07276

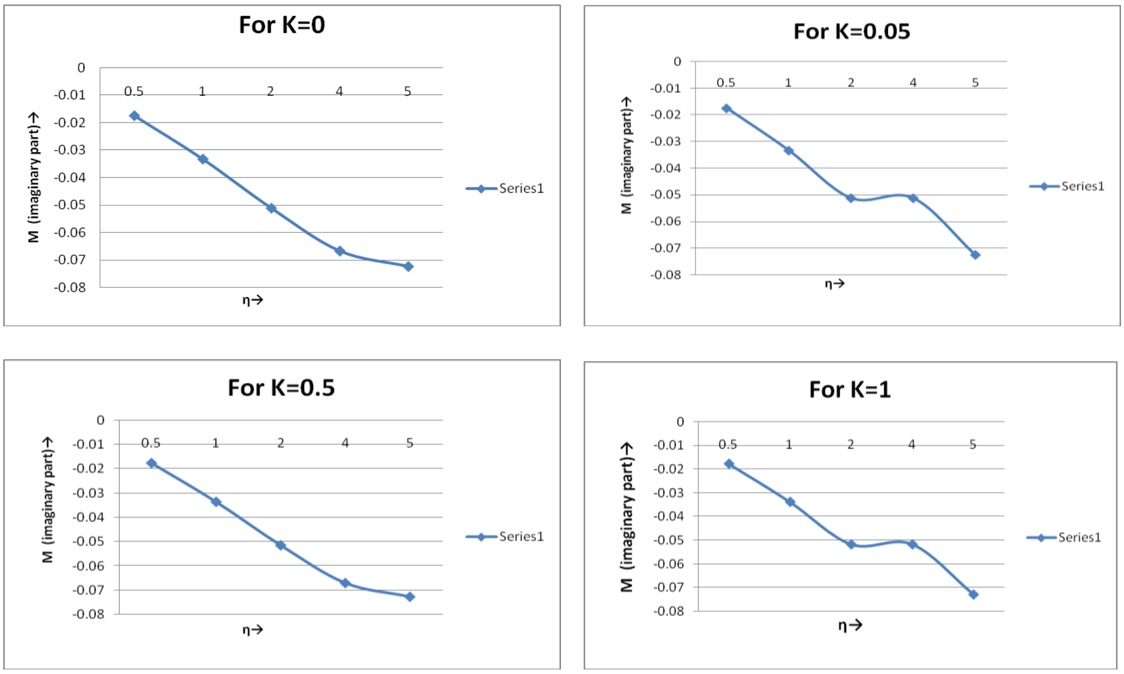
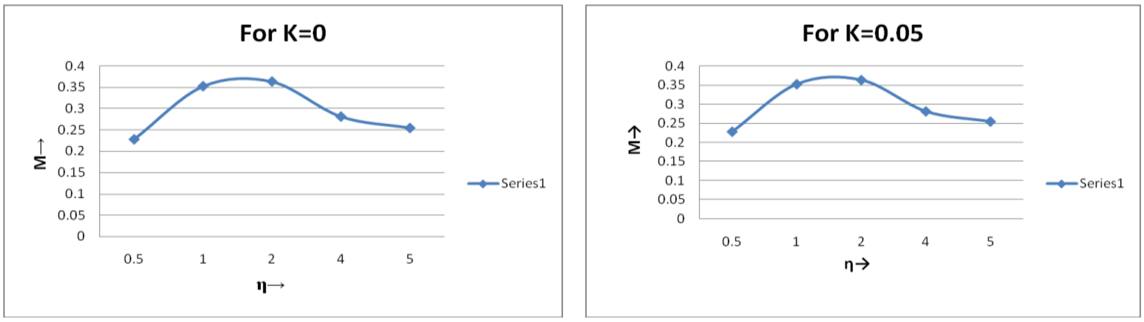


Figure 2. Graphs showing the variation in values of 'Mᵢ' with respect to the change in value of 'η' for different values of 'K' i.e K=0, K=0.05, K=0.5 and K=1.0.

Table 3. $|M_r + iM_i| = \sqrt{M_r^2 + M_i^2}$ = M

η / k	**0**	**0.05**	**0.5**	**1.0**
0.5	.22858	.22856	.22753	.22851
1	.35268	.35270	.35266	.35261
2	.36359	.36358	.36367	.36349
4	.28169	.28167	.28163	.28160
5	.25500	.25499	.25495	.25491



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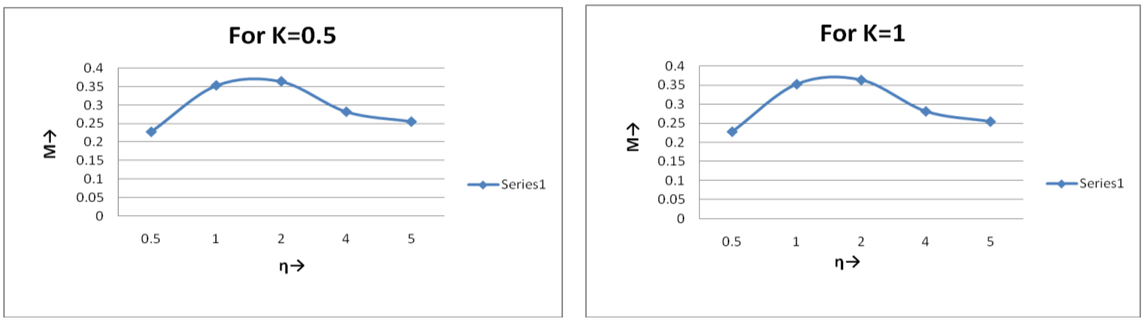

Figure 3. Graphs showing the variation in values of ‘M’ with respect to the change in value of ‘η’ for different values of ‘K’ i.e K=0, K=0.05, K=0.5 and K=1.0.

Table 4. $|\tan\phi|$ For P= 0.1 , $\omega = 0.2$

η / k	0	0.05	0.5	1.0
0.5	.07647	.07652	.07714	.07781
1	.09477	.09483	.09550	.09623
2	.14214	.14220	.14287	.014359
4	.24409	.24414	.24472	.24533
5	.29636	.29642	.29703	.29779

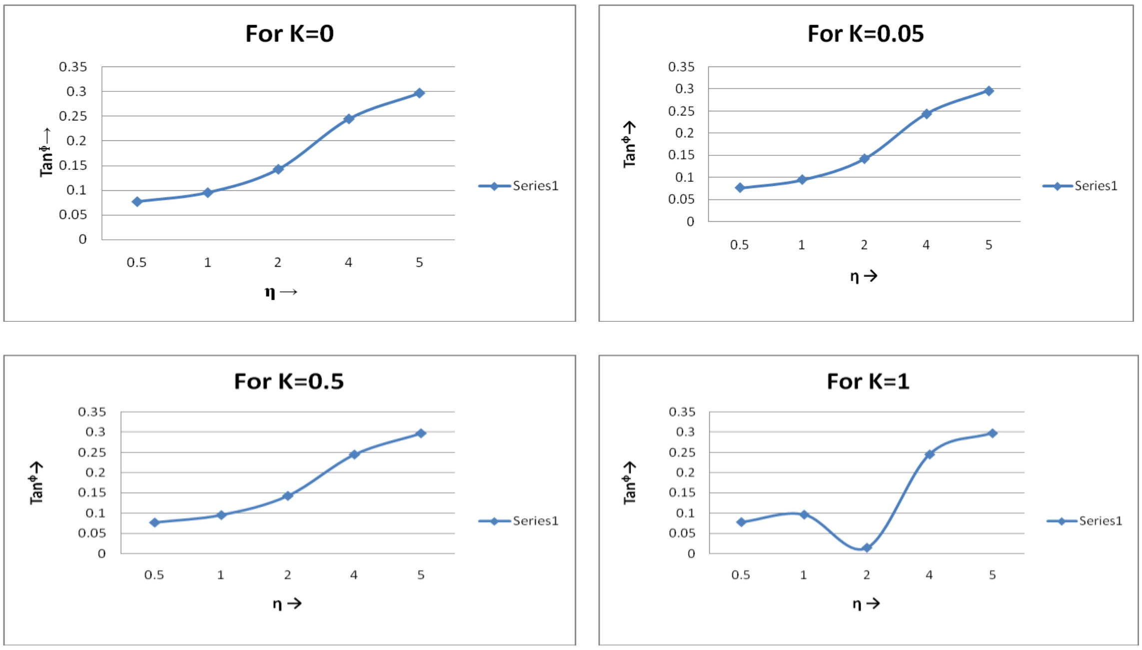

Figure 4. Graphs showing the variation in values of ‘tan ϕ’ with respect to the change in value of ‘η’ for different values of ‘K’ i.e K=0, K=0.05, K=0.5 and K=1.0.

IV. CONCLUSIONS

The effect of magnetic field on free convection flows in liquid metals, electrolytes and ionized gases has been studied, when the plate temperature oscillates about a constant mean in magnitude but not in direction. The values of M_r for different values of K_r considering $P = 0.1$ and $\omega = 0.2$ as constants are entered in Table 1. We observe from the table that M_r is positive throughout. It is zero at $\eta = 0$ for every value of K. its value is maximum a K=0, for $\eta = 0.5$ at K=0, $\eta = 0.5$ for $\eta = 1$ at K=0 for $\eta = 2$, at K=0 for $\eta = 4$ at K=0 for $\eta = 5$.

It does not show any remarkable change for any value of η in the region $0 \le K \le .05$, but shows comparatively an appreciable change in the region after it.

In table 2, M_i is entered, an examination of this table shows that M_i is negative throughout. It is zero at $\eta = 0$ for every value of K=0. Its magnitude is maximum at K=1 for $\eta = 0.5$ at K=1 for $\eta = 1$ at K=1 for $\eta = 2$, at K=1 at $\eta = 4$,at K=1 at $\eta = 5$. Its magnitude does not show an appreciable change for any value of η in the region $0 \le K \le .05$ but shows comparatively appreciable change in the region after that.

In table 3, the values of $M = \sqrt{M_r^2 + M_i^2}$ for various sets of values of η and K have been incorporated. The study of this table indicates that M is at $\eta = 0$ for every value of K. Its magnitude is maximum at K=0 for $\eta = 0.5$, at K=0.5 for $\eta = 1$ at K=0.5 for $\eta = 2$, at K=0 for $\eta = 4$, at K=0 for $\eta = 5$.

In the velocity distribution eq. 29 the coefficient of ε is $(M_r \cos \omega t - M_i \sin \omega t) = \sqrt{M_r^2 + M_i^2} \cos(\omega t + \phi)$. The term lags or leads over fluctuations by an angle ϕ. In our case ϕ is negative. The values of $|\tan \phi|$ for various K are entered in table 4.

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