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EFFECT OF MAGNETIC VISCOSITY AND SUSPENDED PARTICLES ON THERMAL INSTABILITY OF A PLASMA IN POROUS MEDIUM

KIRTI PRAKASH AND SEEMA MANCHANDA

Department of Mathematics, D.C.C., Himachal Pradesh University, Summer-Hill, Shimla 171 005

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The effect of suspended particles and magnetic viscosity is investigated on thermal instability of an infinitely conducting plasma in porous medium. It is found that the presence of each suspended particles, magnetic field and magnetic viscosity introduces oscillatory modes in the system which were, otherwise, non-existant. When instability sets in as stationary convection, the suspended particles and the magnetic viscosity are found to have destabilizing and stabilizing effects respectively on the thermal instability of the system. The medium permeability has destabilizing (or stabilizing) and the magnetic field has stabilizing (or destabilizing) effects under certain conditions in the presence of magnetic viscosity whereas in the absence of magnetic viscosity, the magnetic field succeeds in stabilizing the thermal instability of plasma-particle layer and the medium permeability and suspended particles destabilize the layer.

1. INTRODUCTION

An excellent account of the theoretical and experimental results on thermal convection in a fluid, under varying assumption of hydrodynamics and hydromagnetics, has been given in the celebrated work of Chandrasekhar[1]. The effects of the magnetic viscosity which exhibits itself in the off-diagonal elements of the pressure tensor term have been studied by many authors[2-4]. During the last decade considerable research has taken place in the study of magnetic viscosity effects on various stability problems. The stabilizing influence of magnetic viscosity has been demonstrated on thermal instability, thermosolutal instability and gravitational instability by several authors[5-10]. The medium has been considered to be non-porous in all the above studies.

The problem of thermal convection in fluids in porous medium is of considerable importance in geophysics, soil sciences, ground water hydrology and astrophysics. The development of geothermal power resources has increased general interest in the properties of convection in porous media. When a fluid slowly filters through the pores of a macroscopically homogeneous and isotropic porous medium of permeability

k_1, the gross effect is presented by the Darçy's law according to which the usual viscous term is replaced by the resistance term $-\left(\frac{\mu}{k_1}\right)\vec{u}$, where $\vec{u}$ is the filter velocity of the fluid.

In geophysical situations, more often than not, the fluid is not pure but may instead be permeated with suspended (or dust) particles. Recently dusty plasma have become the subject of intensive investigations[11-15]. In a dusty plasma the dust particles are, in general charged but we have considered only heat capacity of the suspended particles/dust without taking into consideration the charge on it. Scanlon gand Segel[16] considered the effect of suspended particles on the onset of Be'nard convection and found that the critical Rayleigh number was reduced solely because the heat capacity of pure gas was supplemented by that of the particle. The effects was thus found to destabilize the layer. The medium was non porous. The thermal instability of fluids in a porous medium in the presence of suspended particles has been studied by Sharma and Sharma[17]. The effects of suspended particles and medium permeability were found to destabilize the layer.

In the present paper we investigated the thermal instability of a plasma in porous medium including simultaneously the effect of suspended particles and the magnetic viscosity.

2. Perturbation Equations and Dispersion Relation

Consider an infinite, horizontal, incompressible, viscous and electrically conducting plasma layer of depth d, bounded by the planes $z = 0$ and $z = d$ in an isotropic and homogeneous medium of porosity ε. This layer is heated from below such that a steady adverse temperature gradient $\beta\left(= \left|\frac{dT}{dz}\right|\right)$ is maintained. Temperatures and densities, at the bottom surface $z = 0$ are T_0 and ρ_0 and at the upper surface $z = d$ are T_1 and ρ_1 respectively. The system is acted on by a uniform vertical magnetic field $\vec{H}$ (0, 0, H) and gravity force $\vec{g}$ (0, 0, $-$ g). Let p, $\rho, T, \alpha, \kappa, g, \mu_e, \mu$, $\nu\,(= \mu/\rho_0)$ η and $\overleftrightarrow{P}$ denote, respectively, the pressure, density, temperature thermal coefficient of expansion, thermal diffusivity, gravitational acceleration, magnetic permeability, viscosity, kinematic viscosity, electrical resistivity and stress tensor taking into account the magnetic viscosity. Then the equations of motion and continuity for the plasma permeated with suspended particles in a porous medium are

$$\frac{1}{\varepsilon}\left[\frac{\partial \vec{u}}{\partial t}+\frac{1}{\varepsilon}(\vec{u}\cdot\nabla)\vec{u}\right] = -\frac{1}{\rho_0}\nabla p-\frac{1}{\rho_0}\nabla\overleftrightarrow{P}+\vec{g}\left(1+\frac{\delta\rho}{\rho_0}\right)$$
$$+\frac{\mu_e}{4\pi\rho_0}(\nabla\times\vec{H})\times\vec{H}-\frac{\nu}{k_1}\vec{u}+\frac{KN}{\varepsilon}(\vec{V}-\vec{u}), \qquad \ldots (1)$$

$$\nabla\cdot\vec{u} = 0, \qquad \ldots (2)$$

where $\vec{u}(u, v, w)$, ρ and $\vec{V}(\bar{x}, t)$, $N(\bar{x}, t)$ denote, respectively, the velocity and the density of pure plasma and the velocity and the number density of the suspended particles. $K = 6\pi\mu\eta'$, η' being particle radius, is Stoke's drag coefficient and $\bar{x} = (x, y, z)$.

Assuming a uniform particle size, a spherical shape and small relative velocities between the plasma and particles, the presence of particles adds an extra force term in the equations of motion (1), proportional to the velocity difference between the particles and the plasma. Since the force exerted by the plasma on the particles is equal and opposite to that exerted by the particles on the plasma, there must be an extra force term, equal in magnitude but opposite in sign, in the equations of motion for the particles. We assume that the distances between the particles are quite large compared with their diameter so that the interparticle reactions are ignored. The effects of pressure, gravity and Darcian force on the particles are negligibly small and, therefore, ignored. Under the above assumptions, if mN is the mass of particles per unit volume, the equations of motion and continuity are

$$mN\left[\frac{\partial \vec{V}}{\partial t} + \frac{1}{\varepsilon}(\vec{V}\cdot\nabla)\vec{V}\right] = KN(\vec{u} - \vec{V}), \qquad \dots (3)$$

$$\varepsilon\frac{\partial N}{\partial t} + (\nabla\cdot N\vec{V}) = 0. \qquad \dots (4)$$

When the fluid and the particles are in thermal equilibrium, the equation of heat conduction gives

$$E\frac{\partial T}{\partial t} + (\vec{u}\cdot\nabla)T + \frac{mNC_{pt}}{\rho_0 C}\left[\varepsilon\frac{\partial}{\partial t} + \vec{V}\cdot\nabla\right]T = \kappa\nabla^2 T, \qquad \dots (5)$$

where $E = \varepsilon + (1-\varepsilon)\dfrac{\rho_s C_s}{\rho_0 C}$; ρ_0, C and ρ_s, C_s stand for the density and the heat capacity of plasma and solid matrix, respectively and C_{pt} is the heat capacity of the particles.

The equation of state is

$$\rho = \rho_0[1 - \alpha(T - T_0)],$$

where the suffix zero refers to the values at reference level $z = 0$ and $z = d$ The Maxwell's equations yield

$$\varepsilon\frac{d\vec{H}}{dt} = (\vec{H}\cdot\nabla)\vec{u} + \varepsilon\eta\nabla^2\vec{H}, \qquad \dots (6)$$

$$\nabla\cdot\vec{H} = 0, \qquad \dots (7)$$

where $\dfrac{d}{dt} = \dfrac{\partial}{\partial t} + \dfrac{1}{\varepsilon}(\vec{u}\cdot\nabla)$ stands for the convection derivative.

For the magnetic field along the z-axis, the stress tensor $\overleftrightarrow{P}$ taking into account the magnetic viscosity (Vandakurov[18]) has the components

$$\left.\begin{aligned}
P_{xx} &= -\rho_0 \nu_0 \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right), \\
P_{xy} &= P_{yx} = \rho_0 \nu_0 \left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right), \\
P_{xz} &= P_{zx} = -2\, \rho_0 \nu_0 \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right), \\
P_{yz} &= P_{zy} = 2\, \rho_0 \nu_0 \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right), \\
P_{yy} &= \rho_0 \nu_0 \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right), P_{zz} = 0,
\end{aligned}\right\} \quad \ldots (8)$$

where $\rho_0 \nu_0 = \frac{NT}{4\omega_H}$, ω_H being the ion-gyration frequency while N and T are number density and temperature of ions respectively. The steady state solution is

$$\vec{u} = (0,\ 0,\ 0), \quad \vec{V} = (0,\ 0,\ 0), \quad T = T_0 - \beta z,$$

$$\rho = \rho_0 (1 + \alpha\beta z),$$

where $\beta = \frac{T_0 - T_1}{d}$ is the magnitude of uniform temperature gradient which is maintained and is positive as the temperature decreases upwards.

Let $\delta\rho, \delta p, \theta, \vec{u}(u, v, w)$, $\vec{V}(l, r, s)$ and $\vec{h}(h_x, h_y, h_z)$ denote, respectively, the perturbations in density ρ, pressure p, temperature T, plasma velocity (initially zero), particle velocity (initially zero) and magnetic field $\vec{H}$. The change in density $\delta\rho$ caused by the perturbation θ in temperature is given by

$$\delta\rho = -\alpha\rho_0\theta. \quad \ldots (9)$$

Then the linearized perturbation equations of the plasma particle layer are

$$\frac{1}{\varepsilon} \frac{\partial \vec{u}}{\partial t} = -\frac{1}{\rho_0} \nabla \delta p - \frac{1}{\rho_0} \nabla \overleftrightarrow{P} - \left(\frac{\nu}{k_1} \right) \vec{u} + \frac{\mu_c}{4\pi\rho_0} (\nabla \times \vec{h}) \times \vec{H}$$

$$+ \vec{g} \left(\frac{\delta\rho}{\rho_0} \right) + \frac{KN}{\varepsilon\rho_0} (\vec{V} - \vec{u}), \quad \ldots (10)$$

$$\nabla \cdot \vec{u} = 0, \quad \ldots (11)$$

$$\left(\frac{m}{K} \frac{\partial}{\partial t} + 1 \right) \vec{V} = \vec{u}, \quad \ldots (12)$$

$$(E + b\varepsilon)\frac{\partial \theta}{\partial t} = \beta\,(w + bs) + \kappa\,\nabla^2\theta, \qquad \text{... (13)}$$

$$\varepsilon\frac{\partial \vec{h}}{\partial t} = (\vec{H}\cdot\nabla)\,\vec{V} + \eta \in \nabla^2\vec{h}, \qquad \text{... (14)}$$

and

$$\nabla\cdot\vec{h} = 0, \qquad \text{... (15)}$$

where $b = \dfrac{mN\,C_{pt}}{\rho_0\,C}$.

Analyzing the disturbances into normal modes, we assumed that the perturbation quantities are of the form

$$[w, h_z, \zeta, \xi, \theta] = [W(z), K(z), Z(z), X(z), \Theta(z)] \times \exp\,[ik_x x + ik_y y + nt], \qquad \text{... (16)}$$

where k_x and k_y are the wave numbers along the x and y directions, respectively. $k = (k_x^2 + k_y^2)^{1/2}$ is the resultant wave number and n is the growth rate, which is, in general, a complex constant.

$\zeta = i\,k_x\,v - i\,k_y\,u$ and $\xi = i\,k_x\,h_y - i\,k_y\,h_x$ denote, respectively, the z-components of vorticity and current density.

Using eqns. (8), (9) and expression (16), eqns. (10)-(15) in non-dimensional form become

$$\left[\left(1 + \frac{M}{\tau_1\,\sigma + 1}\right)\frac{\sigma}{\varepsilon} + \frac{1}{p_l}\right](D^2 - a^2)\,W + \left(\frac{\nu_0\,d}{\nu}\right)(2D^2 + a^2)\,DZ + \left(\frac{gd^2}{\nu}\right)a^2\,\alpha\,\Theta - \frac{\mu_e Hd}{4\pi\,\rho_0\nu}(D^2 - a^2)\,DK = 0, \qquad \text{... (17)}$$

$$\left[\left(1 + \frac{M}{\tau_1\,\sigma + 1}\right)\frac{\sigma}{\varepsilon} + \frac{1}{P_l}\right]Z = \left(\frac{\nu_0}{\nu_d}\right)(2D^2 + a^2)\,DW + \frac{\mu_e Hd}{4\pi\,\rho_0\,\nu}DX, \qquad \text{... (18)}$$

$$(D^2 - a^2 - E_1\,p_1\,\sigma)\,\Theta = -\frac{\beta d^2}{\kappa}\left(\frac{\tau_1\,\sigma + B}{\tau_1\,\sigma + 1}\right)W, \qquad \text{... (19)}$$

$$(D^2 - a^2 - p_2\,\sigma)\,K = -\left(\frac{Hd}{\eta\varepsilon}\right)DW, \qquad \text{... (20)}$$

and

$$(D^2 - a^2 - p_2\,\sigma)\,X = -\left(\frac{Hd}{\eta\varepsilon}\right)DZ, \qquad \text{... (21)}$$

where we have put $x = x^{*}d$, $y = y^{*}d$, $Z = z^{*}d$ and $D = \frac{d}{dz^{*}}$ in the new unit of length d (omitting the asterisks for simplicity),

$E_1 = E + b\varepsilon$, $B = b + 1$, $a = kd$, $\tau = \frac{m}{K}$, $\tau_1 = \frac{\tau\nu}{d^2}$, $M = \frac{m}{\rho_0}$, $\sigma = \frac{nd^2}{\nu}$, $p_1 = \frac{\nu}{\kappa}$ is the Prandtl number, $p_2 = \frac{\nu}{\eta}$ is the magnetic Prandtl number and $P_l = \frac{k_1}{d^2}$ is the dimensionless medium permeability.

We consider the case where both boundaries are free and perfect conductors of heat, while the adjoining medium is assumed to be electrically non-conducting. The appropriate boundary conditions for this case are

$$W = D^2 W = DZ = X = \Theta = 0 \text{ at } z = 0 \text{ and } z = 1 \qquad \dots (22)$$

and $\vec{h}$ is continuous.

In the absence of any surface current, the tangential components of the magnetic field are continuous. Hence the boundary conditions, in addition to (22) are

$$DK = 0 \text{ on the boundaries.} \qquad \dots (23)$$

Eliminating Θ, X, Z and K between eqns. (17)-(21), and using the proper solution $W = W_0 \sin \pi z$, W_0 being constant, we obtain the dispersion relation

$$R_1 x = \left(\frac{\tau_1 \sigma + 1}{\tau_1 \sigma + B}\right)\left[(1 + x)(1 + x + iE_1 p_1 \sigma_1)\frac{A}{\pi^2} + \frac{Q_1 (1 + x)(1 + x + iE_1 p_1 \sigma_1)}{\varepsilon (1 + x + i p_2 \sigma_1)} + \frac{U(x-2)^2 (1 + x + iE_1 p_1 \sigma_1)(1 + x + ip_2 \sigma_1)^2}{(1 + x + ip_2 \sigma_1)\left\{(1 + x + i p_2 \sigma_1)\frac{A}{\pi^2} + \frac{Q_1}{\varepsilon}\right\}}\right], \qquad \dots (24)$$

where

$$\frac{A}{\pi^2} = \left[\left(1 + \frac{M}{\tau_1 \sigma + 1}\right)\frac{i\sigma_1}{\varepsilon} + \frac{1}{P}\right],$$

$x = \frac{a^2}{\pi^2}$, $U = \frac{\nu_0^2}{\nu^2}$, $Q = \frac{\mu_e H^2 d^2}{4\pi\rho_0 \nu\eta}$ (Chandrasekhar number),

$Q_1 = \frac{Q}{\pi^2}$, $R = \frac{g\alpha\beta d^4}{\nu\kappa}$ (Rayleigh number), $R_1 = \frac{R}{\pi^4}$, $P = \pi^2 P_l$ and $i\sigma_1 = \frac{\sigma}{\pi^2}$.

3. The Stationary Convection

When the instability sets in as stationary convection, the marginal state will be characterized by $\sigma = 0$. In this case eqn. (24) reduces to

$$R_1 = \frac{1}{B}\left[\frac{(1+x)^2}{xP} + \frac{Q_1}{\varepsilon}\left(\frac{1+x}{x}\right) + \frac{U(x-2)^2(1+x)^2}{x\left(\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right)}\right]. \quad \text{... (25)}$$

To study the effects of magnetic viscosity, medium permeability, magnetic field and suspended particles on R_1; we examine the nature of $\frac{dR_1}{dU}$, $\frac{dR_1}{dP}$, $\frac{dR_1}{dQ_1}$ and $\frac{dR_1}{dB}$, respectively.

It follows from eqn. (25)

$$\frac{dR_1}{dU} = \frac{(x-2)^2(1+x)^2}{Bx\left(\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right)} > 0, \quad \text{... (26)}$$

which implies that magnetic viscosity has stabilizing effect on the system.

Also eqn. (25) yields

$$\frac{dR_1}{dP} = \frac{(1+x)^2\left[U(x-2)^2(1+x) - \left(\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right)^2\right]}{BP^2 x\left[\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right]^2}, \quad \text{... (27)}$$

and

$$\frac{dR_1}{dQ_1} = \frac{-(1+x)\left[U(x-2)^2(1+x) - \left(\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right)^2\right]}{B\varepsilon x\left[\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right]^2}. \quad \text{... (28)}$$

If $\left[\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right]^2 < U(x-2)^2(1+x)$, then $\frac{dR_1}{dP} > 0$ and $\frac{dR_1}{dQ_1} < 0$, exhibiting the stabilizing effect of medium premeability and destabilizing effect of the magnetic field.

If $\left[\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right]^2 > U(x-2)^2(1+x)$, then $\frac{dR_1}{dP} < 0$ and $\frac{dR_1}{dQ_1} > 0$, meaning thereby the destabilizing effect of medium permeability and stabilizing effect of the magnetic field.

Now

$$\frac{dR_1}{dB} = -\frac{1}{B^2}\left[\left(\frac{1+x}{xP}\right)^2 + \frac{Q_1}{\varepsilon}\left(\frac{1+x}{x}\right) + \frac{U(x-2)^2(1+x)^2}{x\left(\frac{1+x}{P}+\frac{Q_1}{\varepsilon}\right)}\right] < 0. \qquad \ldots (29)$$

Thus, the effect of suspended particles is to destabilize the plasma-layer in porous medium i.e. to lower the critical temperature gradient.

Figure 1 depicts the variations of Rayleigh number R_1, with respect to magnetic viscosity parameter U for fixed $B = 1$, $P = 1$, $\varepsilon = 1$, $Q = 5$ for a fixed wave number $x = 0.5$ and $x = 1.0$. The Rayleigh number increases with increase in magnetic viscosity parameter showing its stabilizing effects on the thermal instability. Figure 2 shows the variation of R_1 with medium permeability P. It depicts both the destabilizing (for $P = 0.2$ to 0.4) and stabilizing role (for $P = 0.4$ to 1.0) for fixed values of $U = 25$, $Q = 5$, $B = 1$, $\varepsilon = 1$ for fixed wave number $x = 0.5$ and $x = 0.6$. Figure 3 depicts the destabilizing effect for $Q = 5$ to 10 and stabilizing effect for $Q = 10$ to 20 for for the values of $U = 25$, $P = 1$, $\phi = 1$, $B = 1$ for fixed wave number $x = 0.5$ and $x = 0.6$ when R_1 is plotted against the magnetic field parameter Q. In Fig. 4 the Rayleigh number R_1 is plotted with respect to B for fixed value of $U = 25$, $P = 1$, $\varepsilon = 1$, $Q = 5$ for fixed wave numbers $x = 0.5$ and $x = 0.6$. The suspended particles have destabilizing effect.

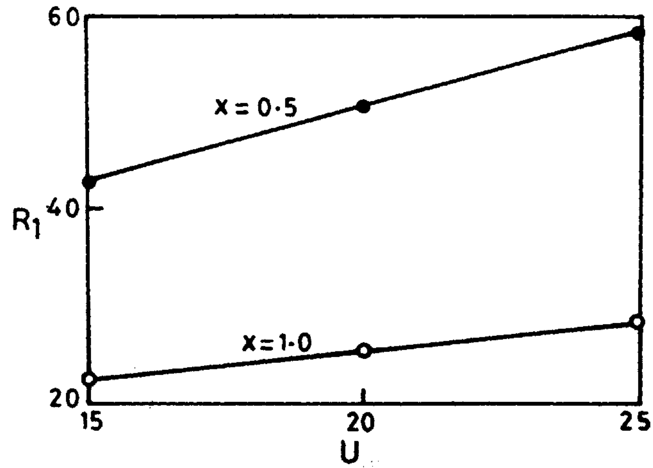

FIG. 1. The variation of R_1 with U for a fixed $B = 1$, $P = 1$, ε, $Q = 5$ for a fixed wave number $x = 0.5$ and $x = 1.0$.

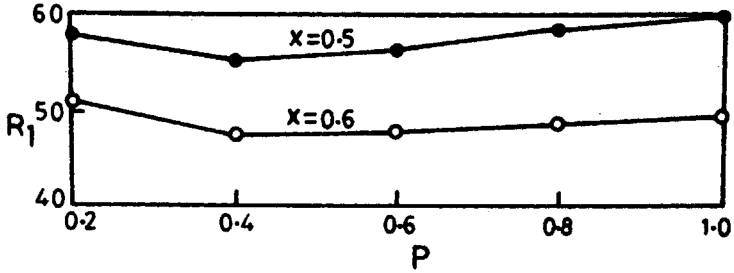

FIG. 2. The variation of R_1 with P for a fixed $U = 25$, $Q = 5$, $B = 1$, $\varepsilon = 1$ and for a fixed wave number $x = 0.5$ and $x = 0.6$.

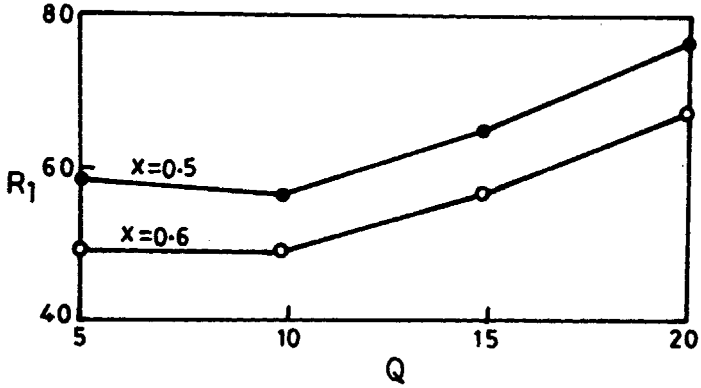

FIG. 3. The variation of R_1 with Q for a fixed $U = 25$, $P = 1$, $\varepsilon = 1$, $B = 1$ and for a fixed wave number $x = 0.5$ and $x = 0.6$.

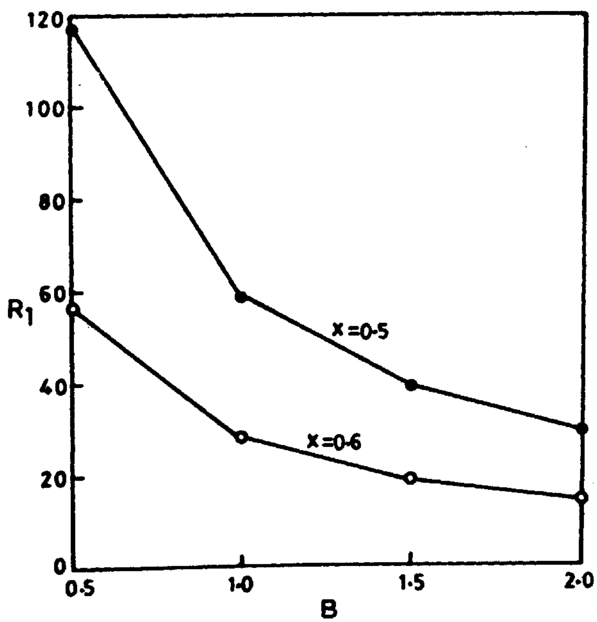

FIG. 4. The variation of R_1 with B for a fixed $U = 25$, $P = 1$, $\varepsilon = 1$, $Q = 5$ and for a fixed wave number $x = 0.5$ and $x = 0.6$.

In the absence of magnetic viscosity,

$$\frac{dR_1}{dQ_1} = \frac{1+x}{B\varepsilon x}, \quad \frac{dR_1}{dP} = -\frac{(1+x)^2}{BxP} < 0,$$

and

$$\frac{dR_1}{dB} = -\frac{1}{B^2}\left[\frac{(1+x)^2}{xP} + \frac{Q_1}{\varepsilon}\left(\frac{1+x}{x}\right)\right] < 0,$$

the medium permeability and suspended particles have destabilizing effects and the magnetic field has stabilizing effect.

4. The Oscillary Modes

Here we examine the possibility of oscillatory modes, if any, on the stability problem due to the presence of magnetic field, magnetic viscosity and suspended particles. Multiplying eqn. (17) by W^* (the complex conjugate of W), integrating over the range of z and making use of eqns. (18)-(21) together with boundary conditions (22) and (23) we obtain

$$\left[\left(1+\frac{M}{\tau_1\sigma+1}\right)\frac{\sigma}{\varepsilon}+\frac{1}{P_l}\right]I_1 - \frac{g\alpha\kappa a^2}{\nu\beta}\left(\frac{\tau_1\sigma+1}{\tau_1\sigma+\beta}\right)[I_2+E_1p_1\sigma^* I_3]$$

$$+\frac{\mu_e\eta\varepsilon}{4\pi\rho_0\nu}[I_4+p_2\sigma^* I_3]+d^2\left[\left(1+\frac{M}{\tau_1\sigma^*+1}\right)\frac{\sigma^*}{\varepsilon}+\frac{1}{P_l}\right]I_6$$

$$+\frac{\mu_e\eta\varepsilon d^2}{4\pi\rho_0\nu}[I_7+p_2\sigma I_8] = 0, \qquad \text{... (30)}$$

where
$$I_1 = \int_0^1 (|DW|^2 + a^2|W|^2)\,dz\,;\; I_2 = \int_0^1 (|D\Theta|^2 + a^2|\Theta|^2)\,dz\,,$$

$$I_3 = \int_0^1 |\Theta|^2\,dz,\; I_4 = \int_0^1 (|D^2K|^2 + 2a^2|DK|^2 + a^4|K|^2)\,dz,$$

$$I_5 = \int_0^1 (|DK|^2 + a^2|K|^2)\,dz\,,\; I_6 = \int_0^1 |Z|^2\,dz,$$

$$I_7 = \int_0^1 (|DX|^2 + a^2|X|^2)\,dz\,,\; I_8 = \int_0^1 |X|^2\,dz. \qquad \text{... (31)}$$

The integrals $I_1 - I_8$ are all positive definite. Substituting $\sigma = i\sigma_0$, where σ_0 is real, in eqn (30) and equating the imaginary parts, we obtain

$$\sigma_0 \left[\frac{1 + M + (\tau_1 \sigma_0)^2}{\varepsilon \left\{ 1 + (\tau_1 \sigma_0)^2 \right\}} (I_1 + d^2 I_6) - \frac{g\alpha\kappa a^2}{\nu\beta} \left\{ \frac{\tau_1 (B-1)}{B^2 + (\tau_1 \sigma_0)^2} I_2 \right. \right.$$

$$\left. \left. - E_1 p_1 \frac{B + (\tau_1 \sigma_0)^2}{B^2 + (\tau_1 \sigma_0)^2} I_3 \right\} - \frac{\mu_e \eta \varepsilon}{4\pi\rho_0 \nu} p_2 I_5 + \frac{\mu_e \eta \varepsilon d^2}{4\pi\rho_0 \nu} p_2 I_8 \right] = 0. \quad \text{... (32)}$$

Equation (32) yields $\sigma_0 = 0$ or $\sigma_0 \neq 0$, which means that modes may be non-oscillatory or oscillatory. In the absence of suspended particles, magnetic viscosity and magnetic field, eqn. (32) reduces to

$$\sigma_0 \left(\frac{I_1}{\varepsilon} + \frac{g\alpha\kappa a^2}{\nu\beta} E_1 p_1 I_3 \right) = 0, \quad \text{... (33)}$$

and terms in bracket are positive. Thus $\sigma_0 = 0$, which means the modes are non-oscillatory and the principle of exchange of stabilities is satisfied for a porous medium in the absence of suspended particles, magnetic viscosity and magnetic field. The presence of each, suspended particles, magnetic viscosity and magnetic field, brings oscillatory modes, which were non-existent in their absence.

5. Summary

It is found that when instability sets in as stationary convection, the magnetic viscosity has stabilizing effect on the system where as suspended particles destabilize the layer. The medium permeability and magnetic field has stabilizing or destabilizing effect under certain conditions. In the absence of magnetic viscosity both the medium permeability and suspended particles have destabilizing effect and the magnetic field have stabilizing effect. It is also observed that in the presence of suspended particles magnetic field and magnetic viscosity oscillatory modes are introduced in the system whereas in their absence, the principle of exchange of stabilities is satisfied and the modes are non-oscillatory. The effects of magnetic viscosity, medium permeability, magnetic field and suspended particles have also been shown graphically.

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