JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Thermal Convection in a Magnetic Fluid Saturated Porous Layer

Latha A L
Assistant Professor, Department of Physics
Government First Grade College for Women, Vijayanagara, Mysuru, India

ABSTRACT: In the presence of a uniform magnetic field applied vertically, a theoretical investigation on thermal convection is undertaken in an initially basic magnetic fluid horizontal porous layer. The fluid motion is described using the Brinkman extended-Darcy equation, and the start of thermomagnetic convection is predicted using linear stability theory.

Keywords: magnetic nanofluid, convection, porous medium, viscosity ratio.

1 INTRODUCTION

Magnetic nanofluids are colloidal suspensions of single-domain nano-scale magnetic particles distributed in a non-conducting carrier liquid. These fluids are also known as magnetic fluids. Since the 1960s, when these fluids were first synthesized, their technological applications have grown. These fluids have a wide range of uses, including loud speakers, rotatory exclusion seals, bearings, dampers, shock absorbers, medical medication targeting, and a variety of other thermal transport applications. Rosensweig (1985), Bashtovoy and Berkovsky (1996), and Berkovsky et al. (1993) provide extensive introductions to ferrofluids and their numerous uses.

When a horizontal ferrofluid layer is heated from below, convective motions called ferroconvection can occur, which are akin to traditional Benard convection. Ferroconvection in a horizontal layer of ferrofluid has been widely researched. Finlayson (1970) was the first to investigate the linear stability of ferrofluid convection in a horizontal layer heated from below in the presence of a uniform vertical magnetic field. Lalas and Carmi (1971) researched the thermoconvective instability of ferrofluids without taking into account buoyancy effects, whereas Shliomis (1974) examined the linear relation for magnetized perturbed quantities at the limit of instability. Gotoh and Yamada (1982) used linear stability to perform a similar analysis with fluid confined between ferromagnetic plates. The effect of magnetic field on heat and mass transport in ferrofluids has been discussed by Volker et al.(2007).

Thermal convection of ferrofluids saturating a porous medium has also received a lot of attention in the literature because of its importance in controlled emplacement of liquids or chemical treatment, emplacement of geophysically imageable liquids into specific zones for subsequent imaging, and so on. Rosensweig et al. (1978) investigated the penetration of ferrofluids in the Heleshaw cell experimentally. Zahn and Rosensweig (1980) investigate the stability of magnetic fluid penetration through a porous media in a high uniform magnetic field oblique to the interface. Vaidyanathan et al. (1991) investigate the thermal convection of a ferrofluid saturating a porous media in the presence of a vertical magnetic field. Their investigation is restricted to free-free borders and the condition where effective viscosity equals fluid viscosity. Borglin et al. (2000) recently revealed laboratory-scale experimental results on ferrofluid behavior in porous media composed of sands and sediments.
As a result, the primary goal of this study is to use a non-Darcian model to determine the criterion for the commencement of thermomagnetic convection in a high permeability ferrofluid saturated porous layer. The opportunity is being taken to review the current outcomes on free boundaries. For free-free borders, the ensuing eigenvalue issue is solved accurately.

2. Mathematical formulation

We consider an initially basic magnetic fluid in a porous layer of depth *d*. A Cartesian coordinate system (*x*, *y*, *z*) is used with the z – axis normal to the layer. The flow in the porous medium is described by Lapwood-Brinkman extended-Darcy equation and the Boussinesq approximation on the density is made.

The governing equations for the flow of an incompressible magnetic nanofluid in a porous medium are (Finlayson 1970) :

$$\left[\Lambda\left(D^2-a^2\right)-1/Da\right]\left(D^2-a^2\right)W=-a^2R\left[M_1D\Phi-\left(1+M_1\right)\Theta\right] \quad (1)$$

$$\left(D^2-a^2\right)\Theta=-W \quad (2)$$

$$\left(D^2-a^2M_3\right)\Phi-D\Theta=0\,. \quad (3)$$

Here $D=d/dz$ is the differential operator, $a=\sqrt{\ell^2+m^2}$ is the overall horizontal wavemumber, R is the thermal Rayleigh number M_1 is the magnetic number, $N=RM_1$ is the magnetic Rayleigh number, M_3 is the measure of nonlinearity of magnetization

The above equations are solved subject to appropriate boundary condition

(i) Lower and upper boundaries are free with large magnetic susceptibility (Finlayson (1970))

$$W=0=D^2W,\quad \Theta=0,\quad D\Phi=0 \qquad \text{at } z=0,\ 1. \quad (4)$$

3. Method of solution

We assume the solution satisfying the boundary conditions (4) in the form

$$W = A_0 \sin \pi z, \quad \Theta = B_0 \sin \pi z \quad \text{and} \quad \Phi = -(C_0 / \pi) \cos \pi z \tag{5}$$

where A_0, B_0 and C_0 are constants.

Substituting Eq. (5) into Eqs. (1) – (3), and eliminating A_0, B_0 and C_0 from the equations, we obtain an expression for the Rayleigh number in the form

$$R = \frac{(\Lambda\delta^2 + Da^{-1})(\pi^2 + M_3 a^2)\delta^4}{a^2(\pi^2 + M_3(1+M_1)a^2)} \tag{6}$$

where $\delta^2 = \pi^2 + a^2$ is the total wavenumber.

For very large M_1, we obtain the results for the magnetic mechanism operating in the absence of buoyancy effects. The corresponding magnetic Rayleigh number N can be expressed as follows

$$N = R M_1 = \frac{(\Lambda\delta^2 + 1/Da)(\pi^2 + M_3 a^2)\delta^4}{a^4 M_3} \tag{7}$$

4. Results and discussion

The eigenvalue is either the Rayleigh number *R* or the magnetic Rayleigh number *N*, depending on the circumstance. If the buoyancy force dominates the magnetic force, it is *R* but not $N(=R M_1)$ **which determines the system's stability, and vice versa. Figure 1 depict the critical eigenvalue** R_c and N_c **calculated free-free boundary conditions studied.** Increase in the measure of non-linearity of magnetization parameter M_3 is to decrease R_c and N_c, and thus it has a destabilizing effect on the system. This fact is clarified by plotting R_c and N_c as a function of Da^{-1} in Figs. 1 and 2, respectively for two values of $M_3 = 1$ and 2. From these two figures it is also marked that the departure in R_c and N_c values with an increase in M_3. Also, we notice that an increase in the value of Da^{-1} is to increase R_c and N_c, and thus leads to a more stable system.

5. Conclusions

The linear stability analysis is used to examine thermal convection in a magnetic fluid saturated porous layer in the presence of a uniform vertical magnetic field for free-free barriers. The ensuing eigenvalue issue is solved analytically. The system becomes destabilized as the values of M_1, M_3 and Da increase.

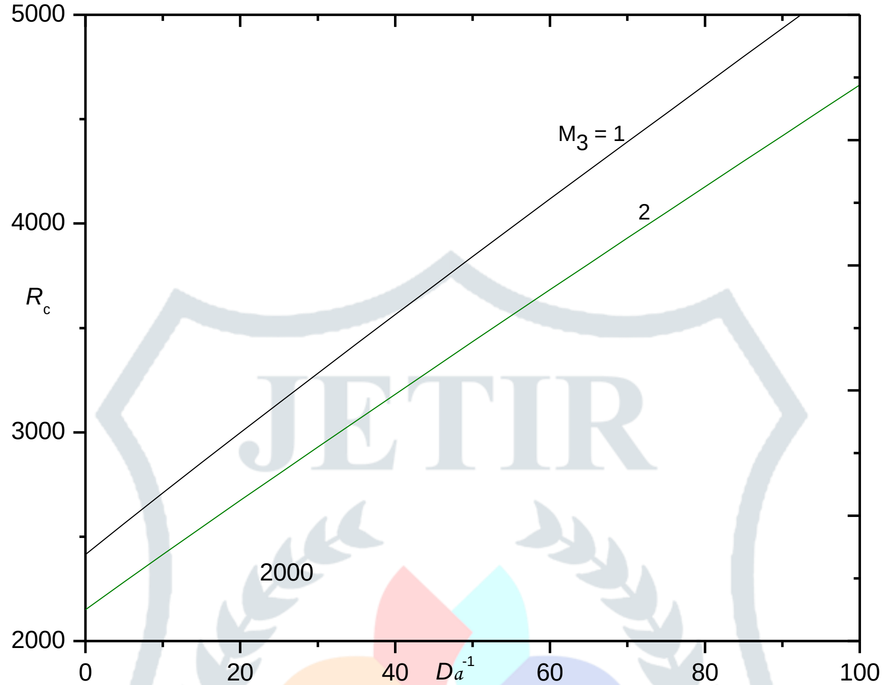

Figure 1: Variation of R_c as a function of Da^{-1} for $M_1 = 1$ with two values of M_3

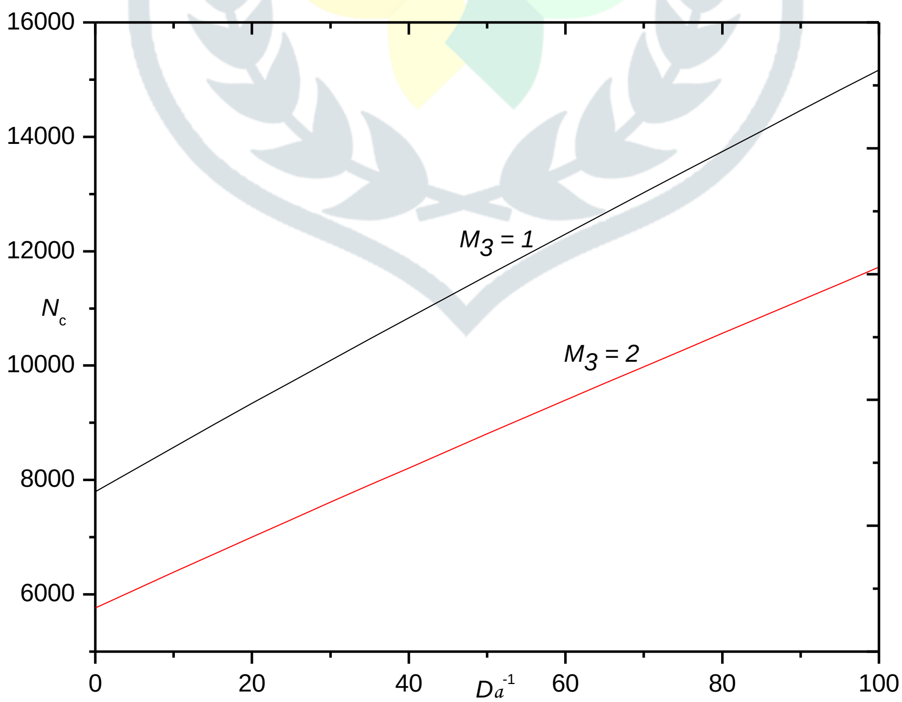

Figure 2. Variation of N_c as a function of Da^{-1} when $M_1 \to \infty$ with two values of M_3

REFERENCES

[1] Bashtovoy, V. G., Berkovsky, B. N. (1996). Magnetic fluids and applications hand book, Begell house, New York

[2] Berkovsky B. M., Medvedev V. F., Krakov M. S. (1993), Magnetic fluids, Engineering Applications, Oxford University Press, New York.

[3] Borglin S. E., Mordis G. J. Oldenburg C. M. (2000), Experimental studies of the flow of ferrofluid in porous media, *Transport in Porous Media* **41**, 61-80.

[4] Finlayson B. A. (1970), Convective instability of ferromagnetic fluids, *J. Fluid Mech*. **40(2),** 753-767.

[5] Gotoh K. M., Yamada M. (1982), Thermal convection in a horizontal layer of magnetic fluids *J. Phys. Soc*. Japan **51,** 3042-3048.

[6] Lalas D. P., Carmi S. (1971), Thermoconvective stability of ferrofluids. *Phys. Fluids* **14(2)**, 436-437.

[7] Rosensweig R. E. (1985), Ferrohydrodynamics, Cambridge University Press, London, reprinted with corrections (Dover, New York, 1997).

[8] Rosensweig R. E., Zahn M., Volger T. (1978), Stabilization of fluid penetration through a porous medium using magnetizable fluids, In: Berkovsky, B (ed.), Thermomechanics of magnetic fluids, *Hemisphere,* Washington D. C., 195-211.

[9] Shliomis M. I. (1974), Magnetic fluids, *Soviet Phys. Uspekhi* (Engl. Trans) **17(2)**, 153-169.

[10] Vaidaynathan G., Sekar R., Balasubramanian R(1991), Ferroconvective instability of fluids saturating a porous medium, *Int. J. Engng. Sci*. **29**, 1259-1267.

[11] Volker T, Blums E, Odenbach S. (2007), Heat and mass transfer phenomena in magnetic fluids, *GAMM-Mitt*, 30, No.1, 185-194.

[12] Zhan M., Rosensweig R. E. (1980), Stability of magnetic fluid penetration through a porous medium with uniform magnetic field oblique to the interface, *IEEE Transactions of Magnetics*, MAG-**16**, 275-282 .