Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/4395
DOI URL: http://dx.doi.org/10.21474/IJAR01/4395

RESEARCH ARTICLE

A REVIEW ARTICLE ON STABILITY OF FERROMAGNETIC FLUIDS.

Deepti Joshi[1], Naveen Bhagat[2] and Sumit Pant[2].

1. Department of Chemistry, M. B. Govt. P. G. College, Haldwani (Nainital), 263139, India.
2. Department of Mathematics, M. B. Govt. P. G. College, Haldwani (Nainital), 263139, India.

……………………………………………………………………………………………………....

Manuscript Info

……………………..

Manuscript History

Received: 04 april 2017
Final Accepted: 06 june 2017
Published: june 2017

Abstract

……………………………………………………………………

Magnetic fluids are basically classified into two categories; first one is ferromagnetic fluids (or ferrofluids) and another one is magnetorheological fluids. Ferromagnetic fluids are colloidal suspensions of very fine magnetic particles (~10 nm), whereas magnetorheological fluids are suspensions of larger magnetic particles, which are usually non-stable. In this review article we mainly focused on ferromagnetic fluids. We review the general classification of ferromagnetic fluids, properties of ferromagnetic fluids and applications of ferromagnetic fluids. A large portion of this review included the results of maximum work which has been done in stability of ferromagnetic fluids till the present.

……………………………………………………………………………………………………....

Introduction:-

Ferromagnetic fluid (also called ferrofluid) is electrically non-conducting colloidal suspensions of solid ferromagnetic particles in a non-electrically conducting carrier fluid like water, kerosene, hydrocarbon or organic solvent etc. These colloidal particles are coated with a stabilizing dispersing agent (surfactants) who prevents particle agglomeration even when a strong magnetic field gradient is applied to the ferromagnetic fluid. These suspensions are stable and maintain their properties at extreme temperatures and over a long period of time. Ferromagnetic fluids behave as a homogeneous continuum and indicate a variety of interesting phenomena. The two main features that distinguish ferromagnetic fluid from ordinary fluid are the body couple and the polarization force. Ferromagnetic fluids are not found in nature, these fluids are artificially synthesized. Ferromagnetic fluid becomes strongly magnetized in the presence of a magnetic field. Stene Papell invented ferromagnetic fluid for NASA in 1963. The difference between ferromagnetic fluids and magnetorheological fluids is the size of the particles. The particles in a ferromagnetic fluid primarily consist of nano-particles (diameter usually 10 nano meters or less) suspended by Brownian motion and generally will not settle under normal conditions. A typical ferromagnetic fluid contains 10^{23} particles per cubic meter. Magnetorheological fluids formed by micron sized particles dispersed in oil, used for dampers, brakes and clutches. For strong magnetic fields, magnetorheological fluids behave like a solid. On the other hand, a ferromagnetic fluids keeps its fluidity even strong magnetic field is applied. Ferromagnetic fluids are optically isotropic, but in the presence of an external magnetic field, they exhibit induced birefringence.

Soon after the method of formation of ferromagnetic fluids, during mid sixties of the twentieth century, the importance of ferrohydrodynamics (FHD) was realized. Ferromagnetic fluids has wide ranges of applications in instrumentation, lubrication, printing, vacuum technology, vibration damping, metals recovery, acoustics and medicine. Ferromagnetic fluids are widely used in sealing of the hard disk drives, the novel zero leakage rotating

Corresponding Author:-Deepti Joshi.
Address**:-**Department of Chemistry, M. B. Govt. P. G. College, Haldwani (Nainital), 263139, India.

shaft seals are used in computer disk drives. Its commercial usage includes vacuum feed through for semiconductor manufacturing, pressure seals for compressors and blowers. One of the major applications of ferromagnetic fluid in electric field is the controlling of heat in loudspeakers which makes its life longer and increase the acoustical power without any changes in the geometrical shape of the speaker system. In order to bring the drugs to a target site in human body, a magnetic field can pilot the path of a drop of ferromagnetic fluid in the human body. Ferromagnetic fluids are also used in the contrast medium in X-ray examinations and for positioning tamponade for retinal detachment repair in eye surgery, therefore it play an important role in the field of bio-medical science also.

A detailed account on the stability of ferromagnetic fluid has been given by Rosenweig (1985) in his monograph. This monograph reviews several applications of heat transfer through ferromagnetic fluid. Ferromagnetic fluids have very large potential applications in electronic devices, mechanical engineering, material science, analytical instrumentation, medicines, optics, arts etc.

Owing the applications of the ferromagnetic fluid, its study is important to researchers. Ferro-fluid technology is well established and capable of solving a wide variety of technical problems. There are many successful applications of this engineering material and there is an immense scope of further research.

In eighteen century, the concept of stability was introduced and in nineteenth century, Clark Maxwell expressed its qualitative concept. Stability theory is a branch of fluid dynamics. To decide the correctness and validity phenomenon, we investigate the stability of the system. Fluid flows are governed by some conservative laws. The governing equations based on these conservation laws are highly non-linear, so their explicit solutions are not possible except in some special cases. Therefore to obtain solutions, we make some simplifying assumptions and approximations. These assumptions make the theoretically obtained flow pattern to be different from the actual flow. To overcome this difficulty, we assume that actual flow is the superposition of theoretical obtained flow and the disturbances due to various factors such as finiteness of the length of channel, irregularities due to roughness of the surface of channel, irregular behaviour of the applied pressure or applied forces etc.

Ferromagnetic fluids are of interest to scientists in such diverse disciplines as surface chemistry, solid-state magnetism, fluid mechanics and non-equilibrium thermodynamics. Ferromagnetic fluids are of particular interest to physicists because of the opportunity they provide to examine coupling between hydrodynamics and magnetism. Rosensweig (1967) was the first to suggest a set of equations of motion for ferromagnetic fluids, which he called "ferrohydrodynamics", which have been expansively developed by Shliomis (1973) and which have remained the basis for most subsequent research on ferromagnetic fluids. Experimental and theoretical physicists and engineers gave significant contributions to Ferrohydrodynamics and its applications. Ferromagnetic fluids behave as a homogenous continuum and exhibit a variety of interesting phenomena. An authoritative introduction to this fascinating subject has been discussed in detail in the celebrated monograph by Rosensweigh (1985). This monograph reviews several applications of heat transfer through ferromagnetic fluids.

Convection in Ferromagnetic Fluids:-

There are various instability problems on ferromagnetic fluids. The convective instability is one of the instability of ferromagnetic fluid. Finlayson (1970) studied the convective instability of a ferromagnetic fluid when placed in a fluid layer which is heated from below in the presence of a vertical magnetic field. He describes the concept of thermo-mechanical interaction in ferromagnetic fluids. In 1971, Lalas and Carmi have investigated the thermoconvective stability of ferromagnetic fluids without considering Buoyancy effects. Berkovskii and Bashtovoi (1971) investigated the problem of gravitational convection in an incompressible non-conducting ferromagnetic fluid resulting from the magnetocaloric effect. The problem of natural convection with a vertical temperature gradient is equivalent to this problem. The linearized relation for magnetized perturbed quantities at the limit of instability has been analyzed by Shilomis in 1973. Berkovsky, et al., (1976) presented numerically and experimentally study of convective heat transfer in a vertical layer of ferromagnetic fluid. A critical relation between heat transfer and characteristic parameters is given. In 1979, Gupta and Gupta have investigated thermal instability in a layer of ferromagnetic fluid subject to Coriolis force and permeated by a vertical magnetic field.

Schwab, et al., (1983) investigated experimentally Finlayson’s problem in case of a strong magnetic field and detected the onset of convection by plotting the Nusselt number versus Rayleigh number. Later, in 1990, Stiles and Kagan examined the experimental problem reported by Schwab, et al., (1983) and generalized Finlayson’s model assuming under a strong magnetic field, the rotational viscosity augments the shear viscosity. To study the effects of buoyancy and surface tension in a layer of ferromagnetic fluid heated from below, Qin and Kaloni (1994) developed a nonlinear stability analysis based on energy method. They assumed the free surface is flat and non-deformable. Venkatasubramanian and Kaloni (1994) investigated the effects of rotation on the thermoconvection instability in a horizontal layer of ferromagnetic fluid in the presence of uniform vertical magnetic field heated from below. Zebib (1996) considered the thermal convection in a ferromagnetic fluid. The stability of a static ferromagnetic fluid is investigated by Polevikov in 1997 under the action of an external pressure drop.

Vaidyanathan, et al., (2001) studied the effect of magnetic field dependent viscosity on ferroconvection in rotating medium. A linear stability analysis is used for his investigation. They found that the field dependent viscosity delays the onset of convection. Lange (2002) studied the thermal convection in a cylindrical layer of ferromagnetic fluid. A detailed account of magnetoviscous effects in ferromagnetic fluids has been given in a monograph by Odenbach (2002). Abraham (2002) investigated analytically the Rayleigh-Bénard convection in a layer of micropolar ferromagnetic fluid in the presence of a vertical uniform magnetic field. They found that the layer of micropolar ferromagnetic fluid heated from below is more stable as compared with the classical Newtonian ferromagnetic fluid. Siddheshwar and Abraham (2003) investigated the effect of time-periodic boundary temperatures/body force on Rayleigh-Bénard convection in a ferromagnetic fluid. They showed that the stability or instability of ferromagnetic fluids can be controlled with the help of imposed time-periodic boundary temperatures and time-periodic body forces. Sunil, et al., (2004) investigated the thermosolutal convection in a layer of ferromagnetic fluid heated and soluted from below in the presence of uniform vertical magnetic field. They considered the case of two free boundaries. Using linear stability analysis theory, an exact solution is obtained. For the case of stationary convection, magnetization has destabilizing effect, whereas stable solute gradient has stabilizing effect on the system. In the absence of stable solute gradient, the principle of exchange of stabilities is found to hold true for the ferromagnetic fluid heated from below in the porous medium. Due to the presence of stable solute gradient, the oscillatory modes are also introduced, which were non-existent in its absence. A sufficient condition for non-existence of the overstability is also obtained. Kaloni, et al., (2005) investigated a weakly non-linear instability of a ferromagnetic fluid rotating about a vertical axis and permeated by a vertical magnetic field. Using multiscale perturbation using, the amplitude equation is developed and they found that as magnetic field increases, the ratio of heat transfer by convection to that by conduction decreases.

In 2006, Ramanathan and Muchikel investigated the effect of temperature dependent viscosity on ferroconvective instability in a porous medium. They found that temperature dependent viscosity has a destabilizing effect on the onset of convection. Sunil, et al., (2007) deal the theoretical investigation of the double diffusive convection in a layer of micropolar ferromagnetic fluid heated and soluted from below subject to a transverse uniform magnetic field. They found that the principle of exchange of stabilities holds good for micropolar ferromagnetic fluid heated from below in the absence of microinertia, solute gradient and micropolar viscous effect. Due to the presence of micropolar viscous effect, microinertia and solute gradient, they also introduce oscillatory modes. Sunil, et al., (2008a) investigated a linear stability analysis for a layer of micropolar ferromagnetic fluid, heated form below subject to a transverse uniform magnetic field in the presence of uniform vertical rotation. In the absence of micropolar viscous effect, microinertia and rotation, the principle of exchange of stabilities is found to hold true for the micropolar ferromagnetic fluid heated from below. Oscillatory modes are also discussed due to the presence of micropolar viscous effect, microinertia and rotation. In 2008b, they developed generalized energy method for convection problem in a magnetized ferromagnetic fluid with magnetic field dependent viscosity heated from below, which gives sufficient condition for stability. To study the nonlinear stability analysis for a magnetized ferromagnetic fluid layer heated from below saturating in a porous medium in the stress-free boundary case, Sunil and Mahajan (2009a) introduced the generalized energy method. They found that the nonlinear critical stability magnetic thermal Rayleigh number does not coincide with that of linear stability analysis and thus indicates that the subcritical instabilities are possible. However, in the case of non-ferromagnetic fluid global nonlinear stability relay number is exactly the same as that for linear instability. It is showed that the subcritical instability reason between the two theories decreases quickly with the increase of magnetic parameter and Darcy number. Sunil and Mahajan (2009b) analysis a non linear energy stability for a rotating layer of magnetized ferromagnetic fluid heated from below in the stress-free boundary case. They found that the subcritical instability region between the two theories decreases quickly with the increase of magnetic parameter. Also with the increase of Taylor number, the subcritical region expands a little for small values and expands significantly for large values. Suresh and Vasanthakumari (2009) applied to Galerkin method to studied ferroconvection induced by magnetic field dependent viscosity in an anisotropic porous medium using Darcy model. For both the stationary and oscillatory modes, they carried linear stability analysis. They found that the increase in magneto viscosity stabilizes the system through stationary mode.

Singh and Bajaj (2009) analysis numerically the effect of frequency of modulation, applied magnetic field and Parandtl number on the onset of a periodic flow in the layer of ferromagnetic fluid using the Floquet theory. Nanjundappa, et al., (2009) investigated theoretically the effect of magnetic field dependent viscosity on the onset of convection in a layer of ferromagnetic fluid heated from below and cooled from above in the presence of vertical magnetic field. The bounding surfaces are considered to be either rigid-ferromagnetic or stress free with constant heat flux conditions. The resulting eigenvalue problem is solved using the Galerkin technique and regular perturbation technique. They found that increase in magnetic field dependent viscosity and decrease in magnetic number is delay the onset of convection while the nonlinearity of fluid magnetization has no influence on the stability of the system.

Belyaev, et al., (2009) studied parametric convective instability of a horizontal layer of homogenous ferromagnetic fluid under the action of an alternating magnetic field. They considered a case with rigid boundaries. Convection thresholds are found. In an alternating magnetic field with a zero mean value, perturbations have synchronous character. They found that Perturbations can belong to different classes because they depend on the temperature difference on the layer boundaries, the layer thickness, the frequency and amplitude of the alternating external field, and physical properties of ferromagnetic fluid.

Belyaev and Smorodin (2010) using the Langevin law of magnetization to study the linear stability of a convective flow in a flat vertical layer of ferromagnetic fluid subject to a transverse temperature gradient and a uniform magnetic field. Ram, et al., (2010) investigated theoretically the effect of porosity on ferromagnetic fluid flow with rotating disk. They calculated the thickness of the boundary layer for different values of porosity and the total volume flowing outward the z-axis. They obtained the solutions of non linear differential equations by power series approximation. Chirikov, et al., (2010) theoretical investigated the viscoelastic properties of ferromagnetic fluids. They have their focus on the study of nonstationary flow and Maxwell-like relaxation of the macroscopical viscous stress after alternation of the shear rate.

Shivakumara, et al., (2011) investigated the effect of Coriolis force on the onset of ferromagnetic convection in a rotating horizontal porous layer of ferromagnetic fluid in the presence of a uniform vertical magnetic field. The boundaries are considered to be either stress free or rigid. The modified Brinkman-Forchheimer-extended Darcy equation with fluid viscosity different from effective viscosity is used to characterize the fluid motion. In the case of free boundaries the Hopf bifurcation is obtain analytically, while for rigid boundaries the eigenvalue problem has been solved numerically using Galerkin method. On the onset of stationary ferromagnetic convection, in the presence of rotation a partial destabilizing effect on the system.

Mokhtar, et al., (2012) studied the effect of feedback control on the onset of Bénard-Marangoni ferroconvection in a horizontal layer of ferromagnetic fluid heated from below. They assume the lower boundary is rigid and the upper free boundary is assumed to be flat and undeformable. The Galerkin method and linear stability analysis method is employed to find the critical stability parameters numerically. They found that the onset of instability can be delayed through the use of feedback control. In 2012 Suresh Chand deals the theoretical investigation of the rotation in a magnetized ferromagnetic fluid with internal angular momentum, heated and soluted from below saturating in a porous medium and subjected to a transverse uniform magnetic field. An exact solution is obtained for a flat layer of ferromagnetic fluid contained between two free boundaries. To study the onset convection, a linear stability analysis theory and normal mode analysis method have been carried out. On the onset of stationary convection, the influence of various parameters such as rotation, medium permeability, solute gradient and internal angular momentum parameters has been analyzed. The critical magnetic thermal Rayleigh number for the onset of instability is also determined numerically for sufficiently large value of Buoyancy magnetization parameter. In the absence of rotation, coupling between vorticity and spin, microinertia and solute gradients, the principle of exchange of stabilities is found to hold true for the ferromagnetic fluid with internal angular momentum saturating in a porous medium heated from below. The oscillatory modes are introduced due to the presence of rotation, coupling between vorticity and spin, microinertia and solute gradients, which were non-existent in their absence. Also find the sufficient conditions for the non-existence of overstability. Govindan, et al., (2012) studied the effect of temperature dependent viscosity on the threshold of ferroconvective instability in an anisotropic porous medium using the Brinkman model is studied with Galerkin method. They found that in the presence of anisotropic porous medium destabilizes the system. Zakinyan, et al., (2012) investigated experimentally the study of the instability of a layer of ferromagnetic fluid on a magnetisable substrate in a perpendicular magnetic field. They measured the critical field strength and the instability wave number.

Chand, et al., (2013a) investigated the Rayleigh-Bénard convection in a horizontal layer of ferromagnetic fluid using Galerkin weighted residuals method. To find expressions for Rayleigh number and critical Rayleigh number they employed linear stability theory based upon normal mode analysis method. They considered the boundaries are to be free-free, rigid-free and rigid-rigid. They observed that system is more stable in the case of rigid-rigid boundaries while in the case of free-free boundaries system is least stable. The principle of exchange of stabilities is valid and the oscillatory modes are not allowed. Further, in 2013b, they investigated the effect of rotation on the Rayleigh-Bénard convection in a horizontal layer of ferromagnetic fluid using Galerkin weighted residuals method. Linear stability theory based upon normal mode analysis and perturbation method is used to find expression for Rayleigh number for free-free boundary layer of ferromagnetic fluid. They observed that the system is more stable in the rotating ferromagnetic fluid then the non-rotating layer of ferromagnetic fluid. The principle of exchange of stabilities is not valid and oscillatory convection is possible only for certain conditions. Suresh Chand (2013) investigated the triple-diffusive convection in a layer of micropolar ferromagnetic fluid heated and soluted from below is considered in the presence of a transverse uniform magnetic field. For a flat layer of micropolar ferromagnetic fluid contained between two free boundaries, an exact solution is obtained. A linear stability analysis and a normal mode analysis method are carried out to study the onset convection. They found the principle of exchange of stabilities is found to be true for micropolar ferromagnetic fluid heated from below in the absence of micropolar viscous effect, the microinertia and the solute gradients. In the absence of micropolar viscous effect, the microinertia and the solute gradients, the oscillatory modes not exist. Sufficient conditions for the existence of overstability are also obtained.

Nanjundappa, et al., (2014) investigated the effect of temperature-dependent viscosity on the onset of Bénard-Marangoni ferroconvection in a ferromagnetic fluid saturated horizontal Brinkman porous layer in the presence of a uniform vertical magnetic field. They considered the viscosity is varying exponentially with temperature. The lower rigid boundary and the upper free boundary at which the surface tension effects are accounted for assumed to be perfectly insulated to temperature perturbations. They solved eigenvalue problem using Galerkin technique and analytically by regular perturbation technique with wave number as a perturbation parameter. Aggarwal and Makhija (2014) have studied the effect of Hall Current on thermal stability of ferromagnetic fluids heated from below in porous medium in the presence of horizontal magnetic field. They considered fluid layer contained between two free boundaries. Using linear stability analysis theory and normal mode analysis method, an exact solution is obtained. For the case of stationary convection, magnetic field and magnetization have stabilizing effect on the system whereas Hall Currents have a destabilizing effect on the system. The principle of exchange of stability is not valid for the above problem whereas in the absence of Hall Current, it is valid under certain conditions. In 2014 Ram, et al., investigated the effect of magnetic field dependent viscosity on the revolving axi-symmjetric steady laminar flow of viscous incompressible electrically non-conducting ferromagnetic fluid with rotating disk by solving the boundary layer equations. The non-linear coupled partial differential equations involved in the problem are solved by asymptotic approximations. They calculated the displacement thickness of the boundary layer, angle of rotation and an expression for total volume flowing outward the z-axis.

Nanjundappa, et al., (2015) investigated the thermal convection in a horizontal layer of ferromagnetic fluid saturating in a porous medium in the presence of a uniform vertical magnetic field and throughflow. The flow in the porous medium is defined by the modified Brinkman equations with fluid viscosity different from effective viscosity. Using Galerkin technique and analytically using regular perturbation technique, the resulting eigenvalue problem is solved numerically. The direction of throughflow has no influence on the stability characteristics of the system, and the effect of throughflow-dependent Peclet number is to delay the onset of ferroconvection.

Pant, et al., (2016) investigated the combined effect of Hall Current and rotation on thermal stability of ferromagnetic fluids saturating in a porous medium under varying gravity field. To find the exact solution for a layer of ferromagnetic fluid contained between two free boundaries, they used a linear stability analysis and normal mode analysis method. They found that Hall Current has stabilizing effect on the system under some conditions and $\lambda > 0$. Further rotation has stabilizing effect on the system for the case $\lambda > 0$ and destabilizing effect for $\lambda < 0$. Also the effect of magnetic field on the system is to stabilize the system under some conditions and $\lambda > 0$ and to destabilize the system for $\lambda < 0$. The principle of exchange of stabilities is not satisfied for this problem while in the absence of rotation and Hall Current, it is found to be satisfied under certain condition. Bhandari, et al., (2016) investigated the ferrofluid flow due to a rotating disk in the presence of a non-uniform magnetic field in the axial direction. Contour and surface plots in the presence of 10 kilo-ampere/meter, 100 kilo-ampere/meter magnetization force are presented here for radial, tangential and axial velocity profiles, and results are also drawn for the magnetic field intensity.

Bhagat, et al., (2016) deals with the study the Hall Effect on Rayleigh-Bénard convection of ferromagnetic fluid saturating in a porous medium in the presence of rotation. They used a linear stability analysis and normal mode analysis methods to find the exact solution for ferromagnetic fluid layer contained between two free boundaries in the presence of rotation. A dispersion relation governing the effect of Hall Current and rotation is derived theoretically. They found that in case of stationary convection, the Hall Current and rotation has stabilizing effect on the system under certain conditions. But, in the absence of rotation, Hall Current has destabilizing effect. Further, the case of oscillatory mode is also considered. It is found that the principle of exchange of stabilities is not valid for the problem, but in the absence of Hall Current and rotation, it is valid under the certain condition.

Pant, et al., (2017) studied the effect of Hall Current on thermal convection of rotating ferromagnetic fluid in the presence of vertical magnetic field saturating in a porous medium. A linear stability analysis and normal mode analysis methods are used to find the exact solution for rotating ferromagnetic fluid layer contained between two free boundaries. A dispersion relation governing the effect of Hall Current, magnetic field, rotation and medium permeability is derived theoretically. From the analysis, they found that in case of stationary convection, the Hall Current, magnetic field and rotation has stabilizing effect on the system under certain conditions. But, in absence of rotation, Hall Current has destabilizing effect. For stationary convection, it is also found that the medium permeability has destabilizing effect on the system under certain condition. Further, the case of oscillatory mode is also considered. It is found that the principle of exchange of stabilities is not valid for the problem, but in the absence of Hall Current and rotation, it is valid under the certain condition. The effects of all studied parameters on ferromagnetic fluid are also verified numerically.

Convection in Ferromagnetic Fluids in the Presence of Dust Particles:-

Many investigators [Siddheswar, 1993, 95, 98, 2003; Aniss, et al., 1993, 2001 and Sunil, et al., 2004] have been considered the Bénard convection in ferromagnetic fluids. In all the above studies, the ferromagnetic fluid has been considered to be clean. In many situations the fluid is not pure but contains suspended dust particles. In 1962, Saffman considered the stability of laminar flow of a dusty gas. The effect of suspended particles on the onset of Bénard convection has been considered by Scanlon and Segel (1973), where as Sharma, et al., (1976) have studied the effect of suspended particles on the onset of Bénard convection in hydromagnetics. He found that the critical Rayleigh number is reduced because of the capacity of the particles. In 1982, Sharma and Sharma have been discussed the rotation and solute gradient on the thermal instability of fluids through a porous medium. He observed that the suspended particles have destabilizing effect on the layer. Palaniswamy and Purushotham (1981) have studied the stability of shear flow of stratified fluids with fine dust. He found that the fine dust increases the region of instability. Many investigators investigated the effect of dust particles on non-magnetic fluids. The main results of all these studies is that the dust particles are destabilizing and the sufficient conditions for the non-existence of over stability is the specific heat of fluid is greater than the specific heat of particles.

Sunil, et al., (2005) theoretically investigated the effect of dust particles on the thermal convection in a ferromagnetic fluid subjected to a transverse uniform magnetic field. They considered a flat layer of ferromagnetic fluid contained between two free boundaries. Using linear stability analysis, the exact solution is obtained. For the case of stationary convection, dust particles and non-buoyancy magnetization always have a destabilizing effect. For the onset of instability, the critical wave number and critical magnetic thermal Rayleigh number are determined numerically for sufficiently large values of the buoyancy magnetization parameter. In the absence of dust particles, the principle of exchange of stabilities is found to hold true for the ferromagnetic fluid heated from below. The oscillatory modes are introduced by the dust particles. A sufficient condition for the non-existence of overstability is also obtained.

Sunil, et al., (2008) investigated the effect of magnetic field dependent viscosity on the thermal convection in a layer of ferromagnetic fluid in the presence of dust particles. They considered a ferromagnetic fluid layer is contained between two free boundaries. Applying linear stability analysis and normal mode analysis method, the exact solution is obtained. Dust particles always have a destabilizing effect on the system for the case of stationary convection, whereas the magnetic field dependent viscosity has a stabilizing effect on the system. In the absence of magnetic field dependent viscosity, the destabilizing effect of magnetization is depicted. For the onset of stationary convection, the critical wave number and the critical magnetic thermal Rayleigh number are also determined numerically for sufficiently large values of buoyancy magnetization parameter. They observe that the critical magnetic thermal Rayleigh number is reduced solely because the heat capacity of clean fluid is supplemented by that of the dust particles. In the absence of dust particles, the principle of exchange of stability is found to holds good for the ferromagnetic fluid heated from below. In the presence of dust particles, the oscillatory modes are also introduced, which where non-existent in the absence of dust particles. A sufficient condition for the non-existence of overstability is also obtained.

Pant, et al., (2016) study the effect of magnetic field and suspended particles on thermal convection in ferromagnetic fluid with varying gravity field saturating in a porous medium. A linear stability analysis and normal mode analysis methods are used to find the exact solution for ferromagnetic fluid layer contained between two free boundaries. A dispersion relation governing the effect of magnetic field, suspended particles and medium permeability is derived theoretically. From the analysis, they found that in case of stationary convection, the magnetic field has stabilizing effect on the system for $\lambda > 0$ and has destabilizing effect for $\lambda < 0$. For stationary convection, it is also found that suspended particles and medium permeability have destabilizing effect on the system under the condition $\lambda > 0$ whereas for $\lambda < 0$, the nature of their effect reverses. Further, the case of oscillatory mode is also considered. It is found that the principle of exchange of stabilities is valid for the problem under certain condition. The effect of all studied parameters on ferromagnetic fluid is also verified numerically.

Bhagat, et al., (2016) investigated the combined effect of rotation and magnetic field on the onset of thermal convection in a horizontal layer of dusty-ferromagnetic fluid with varying gravitational field saturating in a porous medium. A linear stability analysis and normal mode analysis methods are used to find the exact solution for a dusty-ferromagnetic fluid layer contained between two free boundaries. The regular perturbation method is employed to compute the critical value of Rayleigh number. A dispersion relation governing the effect of rotation and magnetic field is derived theoretically. From the analysis, they found that in case of stationary convection, rotation has stabilizing effect on the system for $\lambda > 0$ and destabilizing effect for $\lambda < 0$. In the absence of rotation, magnetic field has stabilizing effect on the system under the condition $\lambda > 0$ whereas for $\lambda < 0$, the nature of their effect reverse. However, in the presence of rotation, magnetic field still has stabilizing effect under certain conditions. Further, the case of oscillatory mode is also considered. The oscillatory mode may or may not be allowed for the present problem. However, in the absence of rotation and magnetic field, it is not allowed and principle of exchange of stability is valid under certain condition.

References:-

1. Abraham, A. (2002): Rayleigh-Bénard convection in a micropolar ferromagnetic fluid. Int. J. Engg. Sci., 40: 449-460.
2. Aggarwal, A.K. and Makhija, S. (2014): Hall Effect on thermal stability of ferromagnetic fluid in porous medium in the presence of horizontal magnetic field. Thermal Science, 18: 503-524.
3. Aniss, S., Souhar, M. and Brancher, J.P. (1993): Thermal convection in a magnetic fluid in an annular hele-shaw cell. JMMM, 122: 319-322.
4. Aniss, S., Belhaq, M. and Souhar, M. (2001): Effects of a magnetic modulation on the stability of a magnetic liquid layer heated from above. J. Heat Transfer, 123: 428-433.
5. Belyaev, A.V. and Smorodin, B.L. (2009): Convection of a ferrofluid in an alternating magnetic field. Journal of Applied Mechanics and Technical Physics, 50: 558-565.
6. Belyaev, A.V. and Smorodin, B.L. (2010): The stability of ferrofluid flow in a vertical layer subject to lateral heating and horizontal magnetic field. Journal of Magnetism and Magnetic Materials, 322: 2596-2606.
7. Berkovskii, B.M. and Bashtovoi, V.G. (1971): Gravitational convection in a ferromagnetic liquid. Magnitnaya Gidrodinamika, 7: 24-28.
8. Berkovsky, B.M., Fertman, V.E., Polevikov, V.E. and Isaev, S.V. (1976): Heat transfer across vertical ferrofluid layers. Int. J. Heat Mass Trans., 19: 981-986.
9. Bhagat, N., Pant, S. and Kumar, A. (2016): Hall Effect on Rayleigh-Bénard convection of ferromagnetic fluid saturating in a porous medium in the presence of rotation. CONIAPS XIX, MS-101.
10. Bhagat, N. and Pant, S., (2016): Effect of rotation and magnetic field on the onset of thermal convection in dusty-ferromagnetic fluid with varying gravitational field in porous medium. Acta Ciencia Indica, XLII (M): 239-249.
11. Bhandari, A. and Kumar, V., (2016): Ferrofluid flow due to a rotating disk in the presence of a non-uniform magnetic field. Int. J. of Applied Mechanics and Engineering, 21: 273-283.
12. Chand, R. and Bala, A. (2013a): On the onset of Rayleigh-Bénard convection in a layer of ferrofluid. IJERA, 3: 1019-1025.
13. Chand, R. and Bala, A. (2013b): Effect of rotation on the onset of Rayleigh-Bénard convection in a layer of ferrofluid. IJMER, 3: 2042-2047.

14. Chand, S. (2012): Effect of rotation on triple-diffusive convection in a magnetized ferrofluid with internal angular momentum saturating a porous medium. Applied Mathematical Sciences, 6: 3245-3258.
15. Chand, S. (2013): Linear stability of triple-diffusive convection in micropolar ferromagnetic fluid saturating porous medium. Appl. Math. Mech.-Engl. 34: 309-326.
16. Finlayson, B.A. (1970): Convective instability of ferromagnetic fluids. J. Fluid. Mech., 40: 753-767.
17. Govindan, S., Vasanthakumari, R. and Sacravarthy, P., (2012): Numerical study on the effect of temperature dependent viscosity on ferroconvection in an anisotropic porous medium. Int. J. of Emerging Tech. and Advanced Engg., 2: 51-55.
18. Gupta, M.D. and Gupta, A.S. (1979): Convective instability of a layer of a ferromagnetic fluid rotating about a vertical axis. Int. J. Eng. Sci., 17: 271-277.
19. Kaloni, P.N. and Lou, J.X. (2005): Weakly nonlinear instability of a ferromagnetic fluid rotating about a vertical axis. JMMM, 284: 54-68.
20. Lange, A. (2002): Thermal convection of magnetic fluids in a cylindrical geometry. JMMM, 252: 194-196.
21. Lalas, D.P. and Carmi, S. (1971): Thermoconvective stability of ferrofluids. Phys. Fluids, 14: 436-438.
22. Mokhtar, N. and Arifin, N. (2012): Bénard-Marangoni ferroconvection with feedback control. Int. J. of Modern Phys., 9: 552-559.
23. Nanjundappa, C.E., Shivakumara, I.S. and Srikumar, K., (2009): Effect of MFD viscosity on the onset of ferromagnetic fluid layer heated from below and cooled from above with constant heat flux. Measurement Science Review, 9: 75-80.
24. Nanjundappa, C.E., Savitha, B., Arpitha Raju, B. and Shivakumara, I.S. (2014): Effect of temperature-dependent viscosity on the onset of Bénard-Marangoni ferroconvection in a ferrofluid saturated porous layer. Acta. Mech., 225: 835-850.
25. Nanjundappa, C.E., Shivakumara, I.S., Arunkumar, R. and Tadmor, R. (2015): Ferroconvection in a porous medium with vertical throughflow. Acta Mech, 226: 1515-1528.
26. Odenbach, S. (2002): Magnetoviscous effects in ferrofluids. Springer-Verlag, Berlin, Heidelberg.
27. Palaniswamy, V.A. and Purushotham, C.M. (1981): Stability of shear flow of stratified fluids with fine dust. Phys. Fluids, 24: 1224-1228.
28. Pant, S., Bhagat, N. and Singh, B. (2016): Combined effect of Hall Current and rotation on thermal stability of ferromagnetic fluids saturating in a porous medium under varying gravity field. IJSEAS, 2: 237-249.
29. Pant, S., Bhagat, N. and Kharayat, H. (2016): Effect of suspended particles and magnetic field on thermal convection in ferromagnetic fluid with varying gravitational field in porous medium. IJAR, 4: 939-946.
30. Pant, S., Bhagat, N. and Kharayat, H. (2017): Effect of Hall Current on the thermal convection of rotating ferromagnetic fluid in the presence of vertical magnetic field saturating in a porous medium. Int. J.Curr. Sci. Tech., 6: 26-39.
31. Polevikov, V.K. (1997): Stability of a magnetic fluid under the action of an external pressure drop. Fluid Dyn., 32: 457.
32. Qin, Y. and Kaloni, P.N. (1994): Non-linear stability problem of a ferromagnetic fluid with surface tension effect. Eur. J. Mech. Fluids, 13: 305-321.
33. Ram, P., Sharma, K. and Bhandari, A. (2010): Effect of porosity on ferrofluid flow with rotating disk. Int, J. of Appl. Math and Mech., 6: 67-76.
34. Ram, P. and Sharma, K. (2014): Effect of rotation and MFD viscosity on ferrofluid flow with rotating disk. Indian Journal of Pure and Applied Physics, 52: 87-92.
35. Ramanathan, A. and Muchikel, N. (2006): Effect of temperature dependent viscosity on ferroconvection in a porous medium. Int. J. Appl. Mech. and Engg., 11: 93-104.
36. Rashmi Venkatesh Murthy, (2010): Effect of temperature modulation on Rayleigh-Bénard convection in a rotating layer of a ferromagnetic fluid. [Dissertation-(Submitted to Christ University)].
37. Rosenwieg, R.E. (1985): Ferrohydrodynamics. Cambridge University Press, Cambridge.
38. Saffman, P.G. (1962): On the stability of a laminar flow of a dusty gas. J. Fluid Mech. 13: 120-128.
39. Scanlon, J.W. and Segel, L.A. (1973): Some effects of suspended particles on the onset of Bénard convection. Phys. Fluids, 16: 573-578.
40. Schwab, L., Hildebrandt, U. and Stierstadt, K. (1983): Magnetic Bénard convection. JMMM, 39: 113-114.
41. Sharma, R.C., Prakash, K. and Dube, S.N. (1976): Effect of suspended particles on the onset of Bénard convection in hydromagnetics. Acta Physica Hungarica, 40: 3-10.
42. Sharma, R.C. and Sharma, K.N. (1982): Thermal instability of fluids through a porous medium in the presence of suspended particles, rotation and solute gradient. J. Math. Phys. Sci., 16: 167.

43. Shivakumara, I.S., Lee, J., Nanjundappa, C.E. and Ravisha, M. (2011): Ferromagnetic convection in a rotating ferrofluid saturated porous layer. Transp. Porous Med., 87: 251-273.
44. Shliomis, M.I. (1973): Convective instability of a ferrofluid. Fluid Dynamics-Sov. Res., 6: 957-962.
45. Siddheswar, P.G. (1993): Rayleigh-Bénard convection in a magnetic fluid with second sound. Jpn Soc. Mag. Fluids, 25: 32-36.
46. Siddheswar, P.G. (1995): Convective instability of ferromagnetic fluids bounded by fluid-permeable, magnetic boundaries. JMMM, 149: 148-150.
47. Siddheswar, P.G. and Abraham, A. (1998): Convection in a ferromagnetic fluid occupying a vertical enclosure. Ind. J. Engg. Matl. Sci., 5: 423-426.
48. Siddheswar, P.G. and Abraham, A. (2003): Effect of time-periodic boundary temperatures/body force on Rayleigh-Bénard convection in a ferromagnetic fluid. Acta Mech., 161: 131-150.
49. Singh, J. and Bajaj, R. (2009): Temperature modulation in ferrofluid convection. Phys. Fluids, 21: 064105.
50. Stiles, P.J. and Kagan, M. (1990): Thermoconvective instability of a horizontal layer of ferrofluid in a strong vertical magnetic field. JMMM, 85: 196-198.
51. Sunil, Bharti, P.K. and Sharma, R.C. (2004): Thermosolutal convection in a ferromagnetic fluid. Arch. Mech., 56: 117-135.
52. Sunil, Sharma, A., Sharma, D. and Sharma, R.C. (2005): Effect of dust particles on thermal convection in ferromagnetic fluid. Zeitschrift fur Natyrforschung, 60a: 494-502.
53. Sunil, Sharma, A. and Shandil, R.C. (2008a): Effect of magnetic field dependent viscosity on ferroconvection in the presence of dust particles. J. Appl. Math. Comput, 27: 7-22.
54. Sunil, Chand, P. and Bharti, P.K. (2007): Double-diffusive convection in a micropolar ferromagnetic fluid. Appl. Math. and Computing, 189: 1648-1661.
55. Sunil, Chand, P., Bharti, P.K. and Mahajan, A. (2008b): Thermal convection in a micropolar ferrofluid in the presence of rotation. JMMM, 320: 316-324.
56. Sunil and Mahajan, A. (2009a): A nonlinear stability analysis for thermoconvective magnetized ferrofluid saturating a porous medium. Trans. in Porous Media, 76: 327-343.
57. Sunil and Mahajan, A. (2009b): A nonlinear stability analysis for rotating ferrofluid heated from below. Appl. Math. and Computation, 204: 299-310.
58. Suresh, G. and Vasanthakumari, B. (2009): Comparison of theoretical and computational ferroconvection induced by magnetic field dependent viscosity in an anisotropic porous medium. Int. Jl. Recent Trends in Engg., 1: 41-45.
59. Vaidayanathan, G. and Swkar, R. (2001): Effect of magnetic field dependent viscosity on ferroconvection in rotating medium. Indian Journal of Pure and Applied Physics, 40: 159-165.
60. Venkatasubramaniam, S. and Kaloni, P.N. (1994): Effects of rotation on the thermoconvective instability of a horizontal layer of ferrofluids. Int. J. Engg. Sci., 32: 237-256.
61. Zakinyan, A.R. and Mkrtchyan, L.S. (2012): Instability of the ferrofluid layer on a magnetizable substrate in a perpendicular magnetic field. Magnetohydrodynamics, 48: 615-621.
62. Zebib, A. (1996): Thermal convection in a magnetic fluid. J. Fluid. Mech., 321: 121-136.