Linear Stability Analysis of Ferrofluids in Porous and Non porous Medium

UGC-MRP: 43-420/2014(SR), Dated: 18/09/2015

Final Progress Report

(01-07-2015 to 30-06-2018)

Professor Jyoti Prakash

Principal Investigator (UGC-MRP)

DEPARTMENT OF MATHEMATICS AND STATISTICS

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(INDIA)

ANNEXURE-IX

UNIVERSITY GRANT COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002

FINAL REPORT OF THE WORK DONE ON THE MAJOR RESEARCH PROJECT

1. Title of the Project : Linear Stability Analysis of Ferrofluids in Porous and Non Porous Medium
2. Name and Address of the Principal Investigator : Dr. JYOTI PRAKASH, Professor, Department of Mathematics and Statistics, Himachal Pradesh University, Shimla-171005 (H.P.)
3. Name and Address of the Institution: Himachal Pradesh University, Summerhill, Shimla-171005
4. UGC Approval Letter No and Date : 43-420/2014(SR) Dated : 18th SEPTEMBER, 2015.
5. Date of Implementation: 01/07/2015.
6. Tenure of the Project: **Three Years.**
7. Total Grant Allocated: **Rs. 10,90,000/-(Rupees Ten Lakhs and Ninety Thousand only)**
8. Total Grant Received: **7,70,379/-**
9. Final Expenditure:**7,13,345/-**
10. Title of the Project : Linear Stability Analysis of Ferrofluids in Porous and Non Porous Medium
11. Objectives of the Project:See Annexure-A
12. Whether Objectives were achieved: Yes. All the objectives of the Project has been achieved.
13. Achievements from the Project:
    (i) Two Project Fellows were appointed subsequently. First Project Fellow , Miss Kultaran Kumari got regular job in between the project, so she resigned. Then new Project Fellow, Mr. Pankaj Kumar was appointed. Both the Project fellows working on the project are already registered for the Ph.D. with the Principle Investigator. The Ph. D. degree will be awarded to the Project fellows on the basis of the work done in the project. Mr. Pankaj Kumar has submitted the Ph. D. thesis and final thesis written work of Miss Kultaran Kumari is in progress.
    (ii) The work done in the project has been published (five papers) in National/International journals of repute. Two papers are communicated and few manuscripts on ferroconvection and double diffusive ferroconvection are under preparation for the publication in the journals of repute.
    (iii) The Project Fellows appointed in the project has been exposed to various scientific techniques related to the requirements of the work being done in the project.
14. Summary of the Findings: See Annexure-B
15. Contribution to the Society: See Annexure-C
16. Whether any Ph.D. enrolled/ Produced out of the Project: Yes.

1.	Shweta Manan	Awarded In 2017	On Some Stability Problems In Triply/Multi Diffusive Convection And Ferromagnetic Convection In Porous And Non-Porous Medium
2.	Pankaj Kumar (Project Fellow-II)	Ph.D. Thesis submitted (Regd. in 2016)	On Some Buoyancy Driven Instability Problems in Multicomponent Convection and Ferromagnetic Convection in Porous/Non-Porous Medium
3.	Kultaran Kumari (Project Fellow-I)	Synopsis approved. Thesis writing work is in progress (Regd. in June-2014)	ON Some Instability Problems In Triply Diffusive, Ferromagnetic And Double Diffusive Binary Viscoelastic Fluids Configurations In Porous And Non Porous Medium

17. **No. of Publications out of the Project**: **05**.

In addition to this there are **07** more papers in which the financial aid of the project has been acknowledged.

(See **Annexure-D** for list of publications)

(PRINCIPAL INVESTIGATOR)
Dr. Jyoti Prakash
(Principal Investigator)

(REGISTRAR/PRINCIPAL)
Registrar
H.P. University
Shimla-171005
(Seal)

ANNEXURE – A

OBJECTIVES

Banerjee et al.(1981)formulated a noble way of combining the governing equations and boundary conditions for double diffusive convection problem so that a semicircle theorem is derivable and which in turn yields the desire bounds. They also used this technique to derive sufficient conditions for the validity of 'the principle of the exchange of stabilities' in different hydrodynamic and hydromagnetic stability problems. Banerjee et al's technique together with its appropriate modifications to suit applications in our problems has been used to handle more complex problems in ferromagnetic convection. Since some result involve Rayleigh number which is an eigenvalue, therefore some numerical calculations has also been performed by using software Scientific Work Place.

This research will provide the up-to-date information to wide range of fluid professional, including mechanical, chemical, nuclear and aeronautical and civil as well as physicists and mathematicians interested in fluid dynamics and transport phenomenon.

References

Banerjee, M. B., Katoch, D. C., Dube, G. S. and Banerjee, K., (1981), Bounds for growth rate of perturbation in thermohaline convection, *Proc. Roy. Soc. London Ser. A*, **378**, 301 – 304.

ANNEXURE-B

SUMMARY OF THE FINDINGS

Ferrofluids (also known as magnetic fluids) are unique colloidal suspensions of magnetic nanoparticles which are coated with a surfactant in an organic or non-organic carrier liquid like water, kerosene, hydrocarbon etc. The surfactant prevents particle agglomeration. The nature of the surfactant, the carrier liquid and magnetic particle size are the determining parameters for the stability of magnetic fluids. Due to high magnetization and liquidity, magnetic fluids have vast applications e.g. liquid cooled loud speakers, energy conversion devices, novel-zero leakage, rotatory shaft seals used in computer disc drives, liquid sealing in chemical and biochemical reactors and medical sciences (drug targeting, endoscopic analysis, magnetic separation of cell and magnetic resonance imaging (MRI))(Rosensweig (1985), Odenbach (2002)).

We have studied some stability problems in ferromagnetic convection relevant to the project which have been published in National/ International Journals of repute. The work done has been listed and explained in essence as follows:

1. **Jyoti Prakash** and Renu Bala, On Arresting the Complex Growth Rates in Ferromagnetic Convection with Magnetic Field Dependent Viscosity in a Rotating Sparsely Distributed Porous Medium, Journal of Applied Mechanics and Technical Physics (Moscow), vol. 57(4), 2016, 623-636. (**Manuscript attached**)

   In this paper it is proved analytically that the complex growth rate $\omega = \omega_r + i\omega_i$ (ω_r and ω_i are respectively the real and imaginary parts of ω) of an arbitrary oscillatory motion of growing amplitude in ferromagnetic convection, with magnetic field dependent viscosity, in a rotating sparsely distributed porous medium for the case of free boundaries , must lies inside a semicircle in the right half of the $\omega_r\omega_i$ - plane whose centre is at the origin and $(radius)^2$ = greater of $\left\{\frac{RM_1}{P_r},\ T_a\right\}$, where R is the Rayleigh number, M_1 is the magnetic number, P_r is the Prandtl number and T_a is the taylor number. Further, bounds for the case of rigid boundaries are also derived separately.

2. **Jyoti Prakash,** Shweta Manan and Pankaj Kumar**,** Ferromagnetic Convection In A Sparsely Distributed Porous Medium With Magnetic Field Dependent Viscosity Revisited, J. Porous Med. 21(8):749–762 (2018) (**Begell House**) USA.(**Manuscript attached**)

In this paper the effect of magnetic field dependent (MFD) viscosity on the thermal convection in a ferromagnetic fluid in the presence of a uniform vertical magnetic field has been studied for a fluid layer saturating a sparsely distributed porous medium by using Darcy Brinkman model. A correction is applied to Vaidyanathan et al. (Ind. J. Pure Appl. Phys., **40(3),** (2002), 166) which is very important in order to predict the correct behavior of MFD viscosity. A linear stability analysis has been carried out for stationary modes. The critical wave number and critical Rayleigh number for the onset of instability, for the case of free boundaries, are determined numerically for sufficiently large values of the magnetic parameter M_1. Numerical results are obtained and are illustrated graphically. It is shown that magnetic field dependent viscosity has stabilizing effect on the system, whereas medium permeability has a destabilizing effect.

3. **Jyoti Prakash**, Renu Bala and Kultaran Kumari, Upper bounds for the complex growth rates in ferromagnetic convection in a rotating porous medium: Darcy-Brinkman Model, Bull. Cal. Math. Soc., **109(2)**, (2017), 153-170. (**Manuscript attached**)

   In this paper ferromagnetic convection in a rotating porous medium has been studied by using Darcy-Brinkman model. It is proved that the complex growth rate $\omega = \omega_r + i\omega_i$ (ω_r and ω_i are respectively the real and imaginary parts of ω) of an arbitrary oscillatory motion of growing amplitude in ferromagnetic convection, in a rotating sparsely distributed porous medium for the case of free boundaries, must lies inside a semicircle in the right half of the $\omega_r\omega_i$ - plane whose centre is at the origin and $(radius)^2$ = greater of $\left\{\frac{RM_1}{P_r}\ ,\ T_a\right\}$, where R is the Rayleigh number, M_1 is the magnetic number, P_r is the Prandtl number and T_a is the Taylor number. Further, bounds for the case of rigid boundaries are also derived separately.

4. Thermal Convection in a Ferromagnetic Fluid Layer with Magnetic Field Dependent Viscosity: A Correction Applied. Studia Geotechnica et Mechanica**(Germany) 39(3)**, (2017),39-46.(**Manuscript attached**)

   In this paper the effect of magnetic field dependent (MFD) viscosity on thermal convection in a horizontal ferromagnetic fluid layer has been investigated numerically. A correction is applied to Sunil et al. (Chem. Eng. Comm., 195(2008), 571) which is very important in order to predict the correct behavior of MFD viscosity. Linear stability analysis has been carried out for stationary convection. δ, the MFD viscosity parameter as well as M_3, the measure of nonlinearity of magnetization both have stabilizing effect on the system. Numerical results are also obtained for large values of magnetic parameter M_1 and predicted graphically.

5. **Jyoti Prakash**, Pankaj Kumar, Kultaran Kumari and Shweta Manan, Ferromagnetic convection in a densly packed porous medium with magnetic field dependent viscosity revisited, Z. fur neturfor. A doi.org/10.1515/zna-2017-0215 (2018), 1-7. **(Manuscript Attached)**

In this paper the effect of magnetic field dependent (MFD) viscosity on the thermal convection in a ferromagnetic fluid in the presence of a uniform vertical magnetic field has been investigated for a fluid layer saturating a densely packed porous medium by using Darcy model. A correction is applied to Sunil et al. (Z. Naturforsch. **59**, 397 (2004)), wherein they have resolved the MFD viscosity into components along the coordinate axes which is not correct since viscosity, being a scalar quantity, cannot be resolved in such a manner. So this correction is very important in order to predict the correct behaviour of MFD viscosity. A linear stability analysis has been carried out for stationary modes. The critical wave number and critical Rayleigh number for the onset of instability, for the case of free boundaries, are determined numerically for sufficiently large values of the magnetic parameter M_1. Numerical results are obtained and are illustrated graphically. It is shown that magnetic field dependent viscosity has stabilizing effect on the system, whereas medium permeability has a destabilizing effect.

Annexure-C

Contribution to the Society

Ferrofluids have several applications in mechanical engineering, analytical instrumentation, heat transfer, electronic devices, pressure seals for compressors and blowers, aerospace etc. and are widely used in rotating X-ray tubes, sealing of computer hard disk drives and high-speed, inexpensive, noiseless printing systems. Ferrofluids are also used as lubricants in bearing and dumpers. In medical sciences these are used in drug target ring, endoscopic analysis, magnetic separation of cells and Magnetic Resonance Imaging (MRI).

Ferrofluids are also used in liquid cooled loudspeakers that employ mere drops of ferrofluids to conduct heat away from the speaker coils. Magnetic field can pilot the path of a drop of ferrofluid in the body, bringing drugs to a target site and ferrofluid serves as a tracer of blood flow in noninvasive circulatory measurements. Ferrofluids are also used in the industries to separate mixtures of industrial scrap metals such as titanium, aluminium and zinc and also used to sort diamonds. Moreover, there exist wide and unlimited areas of application open for exploration. The work done in the projeck will provide an up-to-date information to wide range of fluid professional working in the above mentioned areas.

ANNEXURE-D
LIST OF PUBLICATIONS

(a)

1. **Jyoti Prakash** and Renu Bala, On estimating the complex growth rates in ferromagnetic convection with magnetic field dependent viscosity in a rotating sparsely distributed porous medium, J. Applied Mechanics and Technical Physics, (**Springer**), **57(** 4)(2016) 623–636.
2. **Jyoti Prakash**, Renu Bala and Kultaran Kumari, Upper bounds for the complex growth rates in ferromagnetic convection in a rotating porous medium: Darcy-Brinkman Model, Bull. Cal. Math. Soc., **109(2)**, (2017), 153-170.
3. **Jyoti Prakash,** Rajeev Kumar and Kultaran Kumari, Thermal convection in a ferromagnetic fluid layer with magnetic field dependent viscosity: a correction applied, Studia Geotechnica et Mechanica, **39(3)**, (2017),39-46.
4. **Jyoti Prakash**, Pankaj Kumar, Kultaran Kumari and Shweta Manan, Ferromagnetic convection in a densly packed porous medium with magnetic field dependent viscosity revisited, Z. Naturforsch., vol. **73(3),** (2018), 181-189.

5. **Jyoti Prakash,** Shweta Manan and Pankaj Kumar**,** Ferromagnetic Convection In A Sparsely Distributed Porous Medium With Magnetic Field Dependent Viscosity Revisited, J. Porous Med., **21(8)**, 749–762 (2018) (**Begell House**) USA.

(b) Papers Communicated for Publication

1. J. Prakash, K. Kumari, P. Kumar, R. Kumar and K.R. Sharma, Ferromagnetic Convection in a Rotating Medium with Magnetic Field Dependent Viscosity. A Correction Applied, (Technische mechanik, Germany).

2. Jyoti Prakash, Pankaj Kumar, Shweta Manan, & Khem Raj Sharma, The effect of magnetic field dependent viscosity on ferromagnetic convection in a rotating sparsely distributed porous medium – revisited, (International J. of Applied Mechanics and Engineering, Poland).

(c) In addition to the above publications there are 07 more papers in which the financial aid of the project has been acknowledged. These are as follows:

1. **Jyoti Prakash** and Sanjay Kumar Gupta, On non-existence of oscillatory motions in magnetothermohaline convection in porous medium, J. Porous Media, **19(7)**, (2016), 567–581.
2. **Jyoti Prakash**, Kultaran Kumari and Rajeev Kumar, Triple diffusive convection in a Maxwell fluid saturated porous layer: Darcy Brinkman-Maxwell model, J. Porous Media, **108(5)**, **19(10)**, (2016), 871–883.
3. **Jyoti Prakash** and Shweta Manan, On Rotatoryhydromagnetic multicomponent convection, Int. J. Appl. Sci. Eng. Res., 5(6), (2016), 405-420.
4. **Jyoti Prakash**, Rajeev Kumar and Kusum Lata, The onset of convection in a multicomponent fluid layer in the presence of uniform magnetic field, J. Appl. Mech. Tech. Phys. (Moscow), (**Springer**), **58(1),** (2017), 36-46. **(Impact Factor 0.351).**
5. **Jyoti Prakash**, Renu Bala, Kanu Vaid and Vinod Kumar, On Arresting the Complex Growth Rates in Rotatory Triply Diffusive Convection, Applications and Applied Mathematics- An International Journal (AAM) (USA), **11(2),** (2016), 722-734.
6. **Jyoti Prakash** and Shweta Manan, A Sufficient Condition for the Exchange Principle in Multicomponent Convection Problem in Completely Confined Fluids, J. Raj.Acad. Phys. Sc. 15(4),(2016), 245-253.
7. **Jyoti Prakash** and Rajeev Kumar **,** On Linear Stability Analysis of Magnetorotatory Triply Diffusive Convection with Viscosity Variations, International Journal of Mathematics and Statistics,**18(1)**, (2017), 36-46.