On the Stability of Natural Convection Flows in Laterally Heated Non-Newtonian Fluid Layers

Name of the graduate program (Master 2) : M2 MFE
Laboratory for the internship : LMFA
Supervisor : Séverine MILLET
Université Claude Bernard Lyon 1 - Polytech Lyon
Laboratoire de Mécanique des Fluides et d'Acoustique - UMR CNRS 5509
Email : severine.millet@univ-lyon1.fr
Co-Supervisor : Abdessamed MEDELFEF
Université des Sciences et de la Technologie Houari Boumediène - Alger
Laboratoire de Mécanique des Fluides Théorique et Appliquée
Email : abdessamed.medelfef@usthb.edu.dz

Summary :

This MSc internship offers an opportunity to deepen the understanding of natural convection phenomena in non-Newtonian fluids. It will enable the student to develop advanced skills in numerical modeling and stability analysis while contributing to advancing knowledge in this domain. The results could also pave the way for applications in various sectors, such as geothermal energy, energy recovery, or industrial processes involving non-Newtonian fluid flows.

Project :

Natural convection flows are ubiquitous, both in industry and in nature. Their omnipresence makes them of significant interest from a physical standpoint, positioning these phenomena at the heart of physics research for decades. Pioneering studies, such as those by Rayleigh and Bénard (for bottom heating) and by Hadley and Hart (for lateral heating), have shaped this field of study.
This master's thesis proposes to investigate a Hadley-type flow, i.e., natural convection driven by lateral heating in an extended cavity. This configuration is particularly relevant to material fabrication processes via directional solidification, such as the horizontal Bridgman method, where a fluid is moved horizontally through a furnace with a longitudinal temperature gradient. This temperature gradient generates a convective flow which, beyond a certain forcing threshold, becomes unstable, leading to the emergence of unsteady patterns within the furnace. These instabilities cause manufacturing defects and must therefore be mitigated and controlled.
Although numerous studies have focused on the characterization and control of such instabilities using magnetic fields, acoustic forcing, rotation, vibrations, etc., the behavior of non-Newtonian fluids has received very little attention in the literature. The aim of this project is to undertake an original study on the stability of convection flows for fluids governed by a rheological law, such as the power-law or Carreau model. This work will be carried out in collaboration between the host team (LMFA, UCBL1, France) and an Algerian research team (LMFTA, USTHB, Algeria) specializing in the subject.

Work Plan :

The selected student will carry out the following tasks :
• Literature review : Explore existing studies on flow stability, non-Newtonian fluid behavior, and suitable numerical methods.
• Base flow determination : Identify stationary solutions governing natural convection flow in a non-Newtonian fluid layer.
• Development of a numerical code : Use the spectral collocation method to solve the equations governing natural convection in a non-Newtonian fluid.
• Linear stability analysis : Perform an in-depth stability analysis of the base flow using the developed numerical code to identify unstable modes and characterize their behavior.
• Interpretation of results : Provide an analysis of the observed stability mechanisms and propose relevant physical explanations for the studied configuration.

Bibliography :

Kaddeche, S., Henry, D., and Ben Hadid, H. (2003). Magnetic stabilization of the buoyant convection between infinite horizontal walls with a horizontal temperature gradient. J. Fluid Mech., 480 :185–216.

Lappa, M. (2005). Thermal convection and related instabilities in models of crystal growth from the melt on earth and in microgravity : Past history and current status. Cryst. Res. Technol., 40(6) :531–549.

Lappa, M. (2007). Secondary and oscillatory gravitational instabilities in canonical three-dimensional models of crystal growth from the melt. Part 2 : Lateral heating and Hadley circulation. C. R. Mécanique, 335(5-6) :261–268.

Dridi, W., Henry, D., and Ben Hadid, H. (2008). Influence of acoustic streaming on the stability of melt flows in horizontal bridgman configurations. Journal of Crystal Growth, 310(7) :1546–1551.

Dridi, W., Henry, D., and Ben Hadid, H. (2010). Stability of buoyant convection in a layer submitted to acoustic streaming. Phys. Rev. E, 81 :056309.

Medelfef, A., Henry, D., Bouabdallah, A., Kaddeche, S., and Boussaa, R. (2017). Effect of rotation on the stability of side-heated buoyant convection between infinite horizontal walls. Phys. Rev. Fluids, 2 :093902.

Henry, D., Millet, S., Dagois-Bohy, S., Botton, V. , Ben Hadid, H. (2022), Rayleigh-Bénard flow for a Carreau fluid in a parallelepiped cavity. J. Fluid Mech., 936 :A24.

Medelfef, A., Henry, D., Kaddeche, S., Mokhtari, F., Bouarab, S., Botton, V., and Bouabdallah, A. (2023). Linear stability of natural convection in a differentially heated shallow cavity submitted to high-frequency horizontal vibrations. Phys. Fluids, 35 :084107.