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Transient buoyant convection of a highly thermodependant viscous fluid in a cylindrical drum

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Extended Abstract

The study of the thermal behaviour of highly thermodependant fluids is primordial to study several topics. The most prolific field is the earth mantle study [1-3]. However, rock is not the only material that undergoes large viscosity variations with temperature. Bitumen is also a candidate to such variations. The study of this material is important as it is used in several fields implying transient variations of temperature, such as building. Another minor field is the management of radioactive bituminous waste products (BWP) contained in drums, and more specifically their behaviour while undergoing a thermal stress. This configuration is transient, and the behaviour of the fluid during each time step is important to predict the behaviour of these waste packages to a thermal stress.

Usually, convective systems are studied in permanent state [4-5]. The main known conclusions are that there is a separation between a viscous cold domain and a fluid hot domain, with two distinct convective or diffusive regimes. Heat transfers are imposed by the diffusive part, but the convective one reduces the length scale of the first one. All of this is driven by the viscosity ratio. Regarding transient systems, there are fewer studies available only in 2D [6-8]. Moreover, to the author's knowledge, there is a lack of study for cylindrical shapes. The present study aims at fulfilling this gap.

The configuration of a constant temperature stress on the vertical boundary is then considered. To estimate the key features of the system, a simplified view of the problem is proposed. Since the large thermodependancy (more than 6 decades in viscosity ratio between the hot and cold parts and an activation energy of around 150 kJ/mole) leads to regions of distinct behaviour, an ideal system composed of two phases of constant viscosities is studied. This allows us to draw a first general understanding of the system behaviour, assumed to be representative of the real system. Numerical simulations for various parameters on a 3D Finite Element solver with the Boussinesq approximation are then carried out to confirm the analytical results.

The main parameters influencing the characteristic times and intensities of the heat fluxes are the density difference, the viscosity ratio, the diffusivity and the length scales of the drum. Four phases are enhanced: a diffusive thermal choc, a vertical boundary layer convection, a global convection lead by the collapse of the cold inner core, and finally the heating of the remaining cold area by diffusion. The flow is globally driven by a competition between this collapsing inner cold core and the movement of the surrounding hot fluid. This primarily changes the speed of heating of the upper parts of the drum, while the bottom is mainly heated by diffusion during the end of the process. Consequently, the radius and the diffusivity mostly set the order of magnitude of the time of homogeneity.

Additional simulations with non-newtonian rheological laws (such as Hershel-Bulkley model) were also tested. The addition of a yield stress reduces the convection and thus the intensity of the second and third phases.

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