FRAGMENTATION AND EXCHANGES DURING PLANETARY CORE FORMATION

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Telluric planet formation involved the settling of large amounts of liquid iron coming from impactors into an ambient viscous magma ocean [1]. Planetary initial state was largely determined by diffusive exchanges of heat and elements during this iron rain. Current models often assume that the metal rapidly equilibrated as drops of single capillary size settling at the Stokes velocity. But the dynamics is more complex, and influenced by the large viscosity ratio between the metal and ambient fluid. We study this two-phase flow using a model experiment, where a balloon of heated liquid metal is popped at the top of a tank filled with viscous liquid (see figure 1). We explore the relevant planetary regimes, including the whole range of viscosity ratios. High-speed videos allow determining the statistics of drop sizes, shapes, and velocities. Measures of the temperature decrease during settling allow defining a global turbulent diffusion coefficient, confronted to current analytical models.

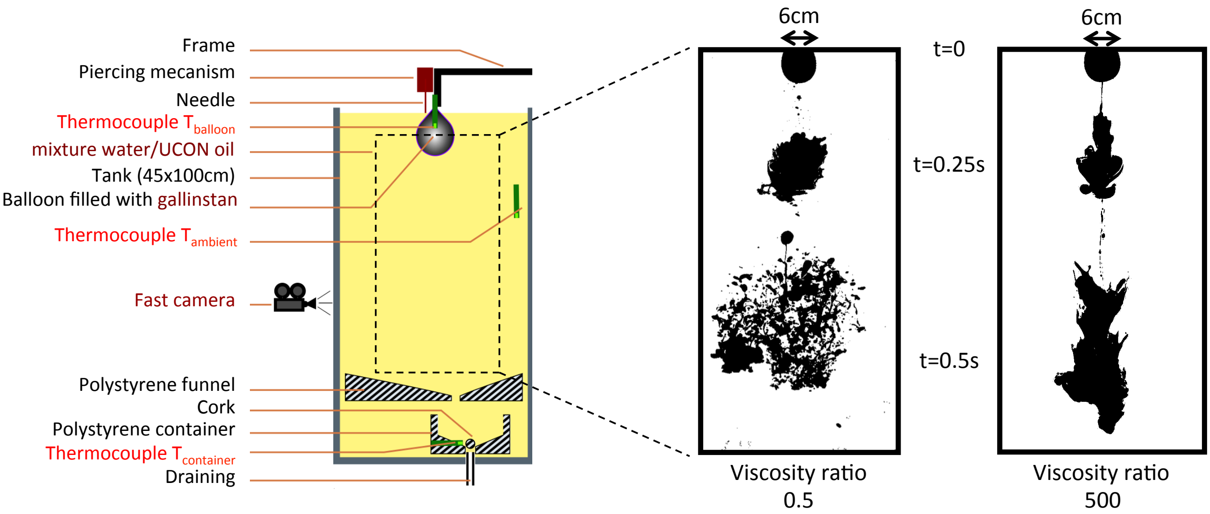

Figure 1. Sketch of the experimental set-up (left) and two examples of the observed sedimentation and fragmentation processes for identical initial metal blobs (right). Only the viscosity of the ambient fluid is changed between the two experiments, with pure water on the left and a mixture of water and Ucon oil on the right, leading to a viscosity ratio of 0.5 and 500 respectively. Each picture shows the liquid metal blob at two times following the balloon piercing at $t = 0$.

Our first conclusion is directly visible in the pictures of figure 1: while the mean settling of a metal blob does not depend on the ambient viscosity (i.e. our study is indeed in the Newtonion regime), the fragmentation dynamics strongly depends on the ratio between the ambient and internal viscosities. A low viscosity ratio leads to the standard formation of an "iron rain", with a Gamma distribution of drop sizes [2]. But a large viscosity ratio leads to the overall stabilisation of large blobs with a significantly distorded surface. It is then expected that these different behaviors lead to different equilibration scalings. The classical approach of equilibration consists in quantifying temperature exchanges by considering diffusion across a turbulent boundary layer scaling as the square root of the Péclet number (e.g. [3]). To assess this model, we systematically measure the temperature decrease of the metal blob during settling in our tank. Using systematic experiments, we propose new scalings laws regarding the evolution of the turbulent diffusion coefficient as a function of the Reynolds number and viscosity ratio. Building upon a better understanding of the sedimentation and fragmentation processes provided by our fluid mechanics approach, more relevant models of planet formation based on a reliable dynamical ground will be developed.

References

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