M2 Internship Proposition

Hydrodynamics and precipitation

Laboratory: Institut ∂'Alembert, UMR 7190 (Sorbonne Université/CNRS), Paris

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Context and general objective

Precipitation is usually introduced in high school chemistry classes by mixing vigorously two liquids and observing the spontaneous formation of disordered, slowly sinking solid flakes. When this phenomenon occurs in industrial or geophysical environments though, precipitation forms large-scale cohesive structures sculpted by the flow: adhesive scaling building up in heat exchangers pipes, several tens of meters-high hydrothermal vents harbouring primitive ecosystems or perfect AI-looking travertin terraces found in Yellowstone are all but random flakes. **How fluid flows influence the precipitation process?** This is the key question that motivates the present internship, whose primary objective is to investigate **experimentally** and **theoretically** the interplay between precipitation and hydrodynamics.

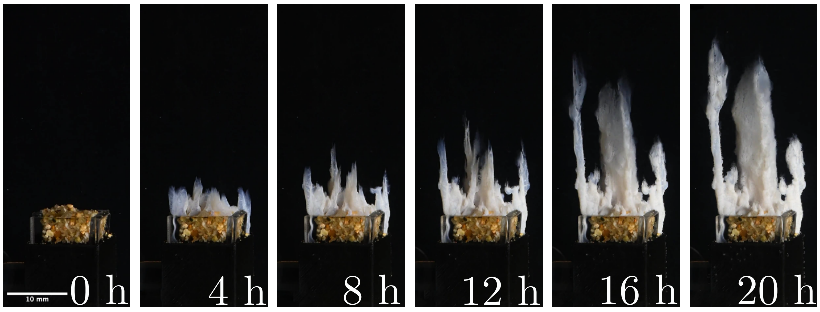

Fig. 1: Sequence monitoring the growth of a tubular precipitate forming upon injection of an alkaline solution into a model ocean containing magnesium salts (PhD thesis of C. Vermelle, ongoing).

Work program

A striking manifestation of flow-driven precipitation is the formation of tubular aggregates templated by buoyant jets (see Fig. 1 and Stone *et al.*, 2005). These hollow, self-assembling mineral tubes emerge when a reactive fluid is injected into another of contrasting composition and density. Examples include chemical gardens, where metal salt solutions react with alkaline solutions to produce self-growing, plant-like tubes (Haudin *et al.*, 2014), and hydrothermal chimneys, where seawater reacts with venting fluids—whether acidic and metal-rich at black smokers or alkaline at Lost City (Kelley *et al.*, 2001). The key idea driving the insternship is to understand **how the interplay between hydrodynamics and chemistry determines** the resulting solid **morphology** and its **temporal evolution**.

In order to build an understanding of the intertwined mechanics of flow and precipitation, several research tracks will be explored:

1. **Reproduce** at the lab-scale, **observe** and **monitor** the growth of jet-templated precipitate, and **experimentally investigate** the role of the key parameters (flow rate, concentration of chemical species, buoyancy...) in the overall shape and growth kinetics of the structure.

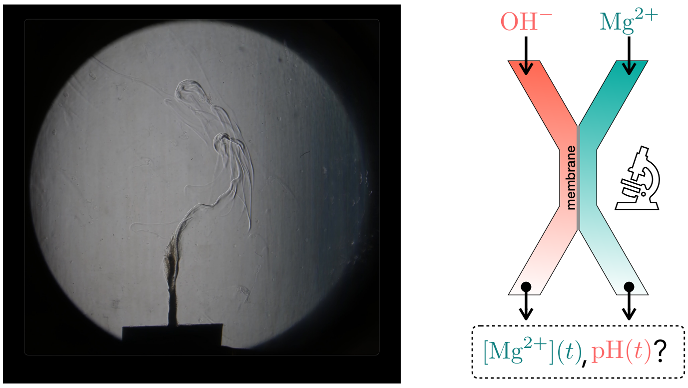

FIG. 2: Left: Schlieren photography of the rising alkaline plume from the precipitate (preliminary experiment). Closer inspection reveals the existence of buoyant chemical boundary layers rising along the tube and possibly interacting with its construction. Right: sketch of a millifluidic setup allowing to monitor the growth of a precipitate membrane along with the ionic fluxes crossing it.

2. **Reveal** the hidden flows carrying the chemical elements (i.e. the building blocks for the solid structure). Schlieren imaging will here help visualize density variations arising from compositional gradients, revealing the chemical boundary layer forming outside the tube as reactive species are consumed at the wall (see Fig. 2 for a preliminary experiment). The resulting local density decrease is expected to drive buoyancy-induced convection, that in turns modulates ionic fluxes at the precipitation wall.
3. Perform an **experimental model** of the build-up process by designing a **millifluidic cell** (see Fig. 2) to monitor the growth of the solid (but porous) membrane and track the ionic fluxes through it.
4. Write an **asymptotic model** for the tube growth. Here we will build up on the analogy between the growth of tubular precipitates and the growth of ice tubes under ice shelfs (so-called *brinicles*), which have been well captured with asymptotic theories such as the Graetz model Martin (1974). We will set out to expand this approach by looking for scale invariant descriptions for the chemical boundary layers developing inside and outside the tube.
5. Identify the possible **hydrodynamical instabilities** in the various flows developing inside and outside the precipitate: rising plume and buoyant boundary layers. Do fluid instabilities alter the growing structure?

▷ **Keywords.** Fluid dynamics, precipitation, experiments, theory/asymptotic analyses.

▷ **Possibility for a PhD thesis.** This internship is part of a larger project aimed at deciphering the mechanisms behind precipitation under flows. A PhD thesis starting at fall 2026 is envisioned.

▷ **Where?** The internship will take place at Institut ∂'Alembert, Sorbonne Université, Paris.

▷ **Salary.** The trainee will receive a monthly allowance of $\mathcal{O}(600$ €$)$.

References

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Kelley, D. S., Karson, J. A., Blackman, D. K., Früh-Green, G. L., Butterfield, D. A., Lilley, M. D., Olson, E. J., Schrenk, M. O., Roe, K. K., Lebon, G. T. & Rivizzigno, P. 2001 An off-axis hydrothermal vent field near the mid-atlantic ridge at 30 ° N. *Nature* **412** (6843), 145–149.

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