PhD thesis 2

2 PhD positions in:

Architecting health-devoted microcapsules via non-Newtonian in-air microfluidics and dynamic chemistry

Context. **In-air microfluidics** (IAMF) is an emerging technique that enables the preparation of functional microdroplets in open air without the need for traditional microfluidic chips [1]. By precisely controlling the impact of fluid jets and their chemical interactions mid-flight, this approach allows for high-throughput droplet formation, mixing, and encapsulation with remarkable speed. In the example presented here, droplets from Jet 1 collide with Jet 2. Given the difference in surface tension between the liquids of Jets 1 and 2 (i.e., $\sigma_1 > \sigma_2$), the encapsulation of the droplet is driven by the Marangoni effect. The **solidification of the droplet** (via **gelation**, for instance) is achieved by incorporating **chemical components** with complementary functions in the fluid of the jets — for example, a functional **polymer** in Jet 1 and a **cross-linker** in Jet 2.

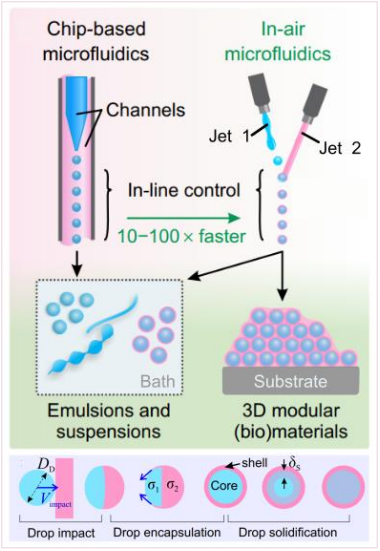

Figure adapted from [1]

IAMF offers significant advantages over traditional microfluidic methods: 1) it generates droplets at a frequency 10–100 times faster; 2) it requires relatively simple equipment that is accessible to a broad range of users; and 3) it does not require a non-solidifying carrier flow (e.g., oil), which simplifies droplet isolation and minimizes waste. These key features make IAMF ideal for applications in **bio-material synthesis**, **drug delivery**, and **3D printing of tissues**.

Key challenges. The pioneering work that introduced IAMF has prompted many intriguing questions from a physics and chemistry point of view [1]. For instance, the fabrication of **health-devoted microparticles** via IAMF involves the stretching and subsequent breakup of **non-Newtonian fluids** at very high strain-rate levels ($\approx 10^4 s^{-1}$-$10^5 s^{-1}$), a problem of fluid mechanics that remains unresolved. **Control over these fluids under such conditions is generally based on trial and error** [2], limiting the ability to rationally design the microcapsules. In terms of chemistry, relatively simple hydrogel formulations have been reported to be used with IAMF thus far. Elaboration of the chemical structure of the hydrogel and controlling its nanostructural assembly, all in the context of the processing conditions of IAMF, are exciting routes to access biomaterials with advanced functions [3].

Objective (PhD thesis 2). This project seeks to highlight the **physicochemical mechanisms driving the generation of non-Newtonian compound droplets in IAMF devices** with the **ultimate goal of controlling (architecting) the shape of the produced microcapsules**. The analyses will be conducted through a **mixed approach combining experiments** (rheometry techniques and in-air microfluidics captured with high-speed cameras), **multiphase numerical simulations**, and **AI strategies devoted to shape optimization** [4, 5]. Close collaboration with chemists will be essential to harness the non-Newtonian flow properties accentuated by the gelation kinetics.

Participants. We are seeking a **highly motivated researcher who has recently completed a master's degree in physics, chemical physics, rheology, mechanical engineering or chemical engineering**. Experience with rheology, experiments, numerical simulations, and AI are highly appreciated. This PhD candidate will be based at the **Centre for Material Forming (Cemef, Mines Paris - PSL), and will start ideally on September/October 2025**.

Collaboration. This candidate will join a collaborative project between the **CFL Research Group at Cemef**, **Mines Paris - PSL** and the **C3M Laboratory at the ESPCI Paris - PSL**. He will collaborate with another PhD student based at the ESPCI Paris - PSL, who will be focused on the implementation of new dynamic covalent and non-covalent motifs [6] into the formulation of the hydrogel generated upon drop solidification, and researchers from the ***Centre des Matériaux*** **(CMAT), Mines Paris – PSL**. The candidate will have the opportunity to work with other academic and industrial partners.

How to Apply. Please send your CV, letter of motivation, and bachelor/master transcripts **before May 29** to:

- Anselmo PEREIRA (anselmo.soeiro_pereira@minesparis.psl.eu), Associate Professor at Cemef, Mines Paris - PSL
- Elie Hachem (elie.hachem@minesparis.psl.eu), Professor at Cemef, Mines Paris - PSL
- Nathan VAN ZEE (nathan.van-zee@espci.psl.eu), CNRS Researcher at the ESPCI Paris - PSL
- Laurent CORTÉ (laurent.corte@minesparis.psl.eu), Professor at Mines Paris - PSL & ESPCI - PSL

Funding. The selected candidate will join an application to PSL University's *Appel à projets : Thèses binômées 2025*, which will be submitted on **May 31**. Please see the website dedicated to this program (Link) for details.

References

[1] Visser, Kamperman, and co-workers. *Sci. Adv.* **2018**, *4*, eaao1175. Link | [2] Veesler and co-workers. *Biomat. Res.* **2021**, *25*, 41. Link | [3] Yang, Pitera, Hedrick, and co-workers. *ACS Nano*, **2012**, *6*, 9191. Link [4] Isukuwem and co-workers. *Journal of Fluid Mechanics* **2024**, *978*, A1. Link | [5] Viquerat and co-workers. *Journal of Computational Physics* **2021**, *428*, 110080. Link | [6] Van Zee and co-workers. *Macromolecules* **2024**, *57*, 9030. Link