PhD Project - Bubble encapsulation into droplets:

a new class of soft matter building blocks for food structure design

Supervision

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Scientific context

Complex fluid structures combining multiple phases at the microscale are central to modern soft matter and food engineering. This project focuses on a novel and largely unexplored object: gas bubbles encapsulated within liquid droplets, here termed "Bubblets". These hybrid inclusions differ fundamentally from classical emulsions, foams, or double emulsions, as they combine deformable liquid interfaces with compressible gas cores.

Understanding and controlling these structures opens new directions in:

- multiscale soft matter physics
- interfacial transport and stability
- design of advanced food textures with tailored rheology and mouthfeel

Objectives

This doctoral project aims at studying the encapsulation of bubbles into droplets (Figure 1) and the stability of the resulting novel food structural building block: the Bubblets. This study will combine experimental observations with numerical simulations to answer these research questions:

i) **Formation mechanisms.** What properties and conditions (e.g. viscosity ratio, interfacial tension, capillary number) favour the encapsulation of bubbles inside droplets to form a "Bubblets"? What governs the dynamics of the process?

ii) **Stability and lifetime.** How can a "Bubblet" be stabilised? What are the key destabilization mechanisms (film drainage, rupture, gas diffusion, interfacial instabilities)? How can they be modulated controlled and slowed down?

iii) **Structure–property relationships.** How are the rheological and tribological properties of a suspension of "Bubblets" linked to its structure? Can their hybrid nature (liquid shell + gas core) generate novel mechanical responses compared to classical emulsions or foams?

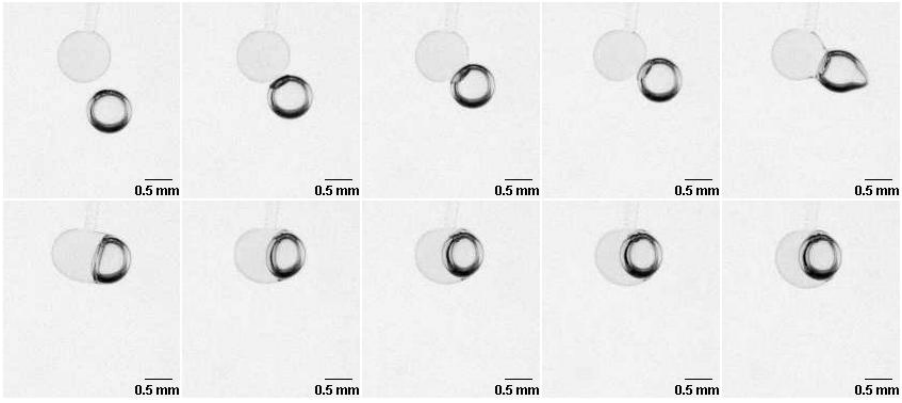

Figure 1: Observation of the encapsulation of a raising air bubble into a static oil droplet.

Research Plan

In a recent preliminary study, an oil droplet was held stationary, while the impact of a stream of air bubbles could be observed (Figure1). Using olive oil droplets, it was observed that the closer the size of the air bubble to that of the oil droplet, the higher the encapsulation rate. Preliminary results were also obtained on the effect of interfacial tensions and of the spreading factor on the duration of the contact between the bubble and the droplet.

The doctoral project combines experiments, modelling, and simulations in a coordinated manner.

02/04/2026

The project is planned around the following activities:

- Review of the relevant scientific literature,
- Development of a millifluidic system to generate Bubblets with controlled size ratios and flow conditions at high throughput.
- Experimental characterization of the stability of two "Bubblets" to investigate: pairwise interactions and coalescence, lifetime and aging mechanisms, role of interfacial properties (tension, elasticity, surfactants)
- Structural, rheological and tribological characterisation of Bubblet suspensions to identify: flow regimes (dilute, concentrated, possibly jammed), viscoelastic and yield stress behavior, lubrication and friction properties relevant to food applications
- Simulations (e.g. interface-resolved CFD or mesoscopic methods) will be performed to provide access to local flow and stress fields, test physical hypotheses and scaling laws, guide experimental design and interpretation

Expected outcomes

The project is expected to deliver:

- A mechanistic understanding of bubble encapsulation in droplets
- Identification of key dimensionless parameters controlling formation and stability
- Structure–property relations enabling rational design of new complex fluids
- Publications in leading journals in soft matter and fluid mechanics

Hosting labs

Upon successful funding by an U.Paris-Saclay ABIES grant in the context of a competitive selection process, this three-year doctoral research project will start in autumn 2026 and will be **hosted partly by the SayFood research unit** (Experimental soft matter, food physics, interfacial phenomena), located on the AgroParisTech/INRAE campus, **Université Paris-Saclay, Palaiseau, France** and **partly by the group Bottega della Materia Soffice** (Rheology, modelling, and numerical simulation of complex fluids)**,** at the Chemical Eng. Dept. (DICMAPI) **of the University Federico II in Naples, Italy**. The PhD candidate will be registered as a PhD student at University Paris-Saclay with joint supervision from Italy. The candidate will benefit from interdisciplinary training, international research environment, strong supervision across two leading groups.

Candidate profile, application and selection process

We are looking for a highly motivated candidate with a Master degree in Physics, Mechanical or Chemical Engineering, with strong interest for soft matter, interfacial phenomena and rheology, and should be fluent in English. **Applications should comprise i) CV, ii) University transcripts, iii) a short motivation letter and iv) academic reference letters (if available) and should be submitted by April 17th, 2026 to marco.ramaioli@inrae.fr.**

The selection process will initially take place online, but the final stage will be held in June 2026 in person at U.Paris-Saclay. Options exist to to cover the cost of travelling to France from within Europe.