

Thesis offer

Context:

Freeze drying, or lyophilization, is a highly effective preservation method that can dramatically reduce losses of fruits, berries, and vegetables by extending their shelf life far beyond that of fresh produce. By removing 98–99% of the water content, freeze-drying inhibits the growth of spoilage microorganisms and enzymatic reactions that lead to decay, allowing products to remain stable and safe for consumption for more than 3 years under proper storage conditions. Similarly, freeze-drying is extensively used in the pharmaceutical industry to improve the shelf life of products such as vaccines and probiotics. By drastically reducing food waste and stabilizing life-saving medicine, freeze-drying is a cornerstone of sustainable development—yet it remains a process in urgent need of real time optimization to overcome its inherent efficiency challenges.

Batch lyophilization is currently the prevalent method of freeze-drying of bio-pharmaceuticals where modelling is used to gain valuable process insights¹. Typically batch lyophilization is modelled both at the product scale (typically fruit or vial with pro-biotics) and at the chamber scale. Pseudo-steady-state heat and mass transfer balances are solved at the product scale². The chamber and the condenser are modelled using computational fluid dynamics (CFD). Process Analytical Technologies (PAT) are often an integral part of freeze-dryers. These include hardware sensors such as temperature probes, capacitance- and conductivity-based pressure sensors (Pirani gauges), wireless temperature sensors, as well as soft sensors such as manometric temperature measurement (MTM) systems that use data analytics and modelling to monitor the process. Soft sensors fall under the ambit of digital shadows. Besides process optimization and design, process control is key to ensuring product quality and consistency. Process simulations and model-guided control systems are known to yield robust process performance.

The concept of Digital twins is closely associated with process control and monitoring. The Digital twin represents a virtual replica of the freeze-drying process that enables real-time monitoring, simulation, and optimization³. By integrating process data with predictive models, digital twins allow for precise control over critical parameters such as temperature, pressure, and drying time. This enhances process efficiency, reduces variability, and improves product quality by anticipating and mitigating potential issues before they occur. The application of digital twins in freeze-drying supports the development of more robust, scalable, and cost-effective manufacturing processes, making them invaluable tools in pharmaceutical, food, and nutraceutical industries. Despite their potential, existing models and digital twin frameworks⁴ for freeze-drying face significant limitations that hinder their adoption at an industrial scale. This research project seeks to overcome these barriers, bridging the gap between theoretical modelling, real-time monitoring and large-scale manufacturing.

Research Objectives

The core of this project is to move beyond the "average product" behaviour by evolving current Smart Lyo technologies (based on MTM⁵) into a high-fidelity MTM 2.0 framework. You will tackle the limitations of spatial variability and geometric constraints to enable industrial-scale digital twin deployment.

A) MTM 2.0 Development: Engineer a next-generation Manometric Temperature Measurement (MTM 2.0) model from first principles. This model must account for the inherent heat transfer variability across the shelf (e.g., the "edge vial effect") rather than relying on a single averaged value which is shown to correspond to the coldest spots in the freeze-dryer.

B) Comparative Performance Benchmarking: Evaluate and validate MTM 2.0 against legacy MTM predictions using both in silico and physical experiments. You will test these across diverse geometries—including glass vials and bulk trays—and varying mass transfer resistances for different products.

C) Real-Time Integration: Implement and validate the MTM 2.0 framework within a physical freeze-dryer environment, focusing on its efficacy for real-time process control and decision-making.

D) Geometric Versatility: Extend the methodology to complex food and nutraceutical geometries, such as spherical or conical products (e.g., strawberries, blueberries⁶), bridging the gap between pharmaceutical and food applications.

Competences required:

- Academic Background: Master's degree or Engineering degree in a related discipline with expertise in mathematical modelling and simulation. A research experience is required.
- Technical Core: Strong foundation in mechanistic modelling (specifically heat and mass transfer), control systems, and instrumentation.
- Programming & Software: Proficiency in scripting languages (Python, R, or MATLAB) and exposure to simulation platforms such as COMSOL. Experience in image analysis or process engineering is highly valued.
- Experimental Mindset: Hands-on experience or strong motivation for lab work, including Design of Experiments (DoE) and the implementation of computational models on physical hardware.
- Languages: Good proficiency in English is required; proficiency in French is a distinct advantage.
- Bonus Skills: Expertise in data-driven modelling or Artificial Intelligence is a plus.

Research environment and conditions of work:

This offer is funded from the start-up purse of a junior professor (Chaire de professeur junior - CPJ). The SPAB and MMIP departments of AgroParisTech are co-sponsors of this project: SPAB for aspects relating to the instrumentation, control and optimisation of food processes; MMIP for aspects relating to modelling, simulation, artificial intelligence and data processing. This position will be based in the ModIC (Modelling and Computer based Engineering) team at SayFood (Paris-Saclay Food and Bioproduct Engineering Joint Research Unit), with strong interactions with MIA Paris Saclay (Paris Saclay Applied Mathematics and Computer Science Joint Research Unit).

Food and Bioproduct Sciences and Processes (SPAB, AgroParisTech) department positions its teaching and research activities in the general perspective of the challenges of the valorisation of agricultural resources through their transformation.

Mathematical, Computer and Physical Modelling (MMIP, AgroParisTech) department is interested in implementing methods for modelling, processing, and analyzing data to support decision-making in food and bio-product processes using approaches from mathematics, computer science, and physics.

SayFood (INRAE, AgroParisTech, Univ. Paris-Saclay) is a joint research unit whose activities focus on the physical, biochemical and microbiological processes that govern food processing. Within this unit, the ModIC team focuses on the developing mechanistic models and applying the developed models for engineering applications.

MIA Paris-Saclay (INRAE, AgroParisTech, Univ. Paris-Saclay) brings together statisticians and computer scientists specializing in statistical and computational modelling and learning for biology, ecology, the environment, agronomy, and the agri-food sector.

Each of the units has been in new premises since 2022, close to each other, on the Paris-Saclay site of AgroParisTech. The doctoral student will work at the AgroParisTech - Palaiseau campus and will have open access to a wide range of leading experimental tools, modelling tools and associated expertise.

The doctoral candidate will be affiliated with the ABIES doctoral school and will be registered at Université Paris-Saclay.

General information:

Duration: 3 years

Registration: Université Paris-Saclay, ABIES Doctoral School

Location: Palaiseau, Ile-de-France

Salary: gross 2300 € per month

Benefits: Reimbursed public transport (75%), flexible working hours, multidisciplinary scientific group

Starting date: October 2026

Secularism: The recruited person will be subject to the charter on [secularism in public services](#) (French law 2021-1109 of 24 August 2021). In particular, no religious symbols may be worn in the workplace.

Application deadline: 20 June 2026. Early applications welcome.

Candidature:

Applications (CV + motivation letter + last 3 years grades) and any requests for information can be sent to:

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References:

- [1] [Kasper, Julia Christina, and Wolfgang Friess. *The freezing step in lyophilization: Physico-chemical fundamentals, freezing methods and consequences on process performance and quality attributes of biopharmaceuticals*. European journal of pharmaceutics and biopharmaceutics 78.2 \(2011\): 248-263.](#)
- [2] [Pikal, Michael J., Michael L. Roy, and Saroj Shah. *Mass and heat transfer in vial freeze-drying of pharmaceuticals: Role of the vial*. Journal of pharmaceutical sciences 73.9 \(1984\): 1224-1237.](#)
- [3] [Zadravec, M., Metsi-Guckel, E., Kamenik, B., Rimmelgas, J., Khinast, J., Roscioli, N., ... & Sarkar, A. *A Digital Twin of primary drying in lyophilization using coupled 3-D equipment CFD and 1-D vial scale simulations*. 208 \(2025\), 114662.](#)
- [4] [Pikal, M.J., Tang, X., Nail, S.L., *Automated process control using manometric temperature measurement*, US Patent: US6971187B1, patent no: US 6,971,187 B1, Dec. 6, 2005](#)
- [5] [Tang, X., Nail, S.L. and Pikal, M.J., *Evaluation of manometric temperature measurement, a process analytical technology tool for freeze-drying: part I, product temperature measurement*. AAPS PharmSciTech, 7\(14\), \(2006\) E95-E103.](#)
- [6] [Trelea, I. C., Passot, S., Marin, M., & Fonseca, F., *Model for heat and mass transfer in freeze-drying of pellets*. 131\(7\), \(2009\), 074501:1-4.](#)