PhD thesis offer:

Investigating the coupled effect of the freezing process and storage conditions on the quality of frozen products. Application to porous media

1. The hosting research unit

Irstea (National Research Institute of Science and Technology for Environment and Agriculture) is an EPST (Public Scientific and Technical Research Establishment) that conducts research addressing the agricultural and environmental issues in the fields of water, natural risks, territorial development and environmental technologies. The research and expertise activities developed are multidisciplinary and oriented in support of public policies. They involve a strong partnership with French and European universities and research organizations, economic actors and public authorities. These activities are spread in France in 9 regional centers structured around three departments (Waters, Territories and Ecotechnologies) organized through 12 research themes. Within the research theme SPEE (Structures, Processes, Flow, Energy) of the Ecotechnology department, is the Research Unit of Refrigeration Process Engineering located on the site of Antony (GPAN), which proposes this thesis.
The GPAN unit is currently composed of 21 permanent staff (including 14 researchers and engineers), 13 doctoral students and 1 postdoctoral fellow. It develops finalized research activities in the field of refrigeration through the study of the thermic and energetics implemented in industries (food, pharmaceuticals, air conditioning, etc.) using cold as well as in supply chains associated. All these activities combine modeling, experimental validation and expertise through research projects either with an industrial partnership or by responding to a national or international call for research project proposals. The unit consists of two teams:
- ENERFRI team: Refrigeration equipment, energy and energy-storage optimization. This team develops activities related to the thermic and energetic of refrigeration systems for the design of equipment with reduced environmental impact. It is particularly interested in two-phase refrigerant fluids, the misting of condensers, energy storage ... The objectives are to develop systems for energy-efficient and environmentally-friendly cold production.
- METFRI team: Controlling flow and transfer in the refrigeration chain and associated processes. The research activities developed by METFRI team deals with the study of heat and mass flows and transfers in food products and refrigeration processes associated, taking into account the impact of technologies on the quality and safety of the products treated. The team is particularly interested in modeling the physical processes involved in the cold chain, in air flow in refrigeration equipment and in crystallization in frozen products.
This thesis is proposed as part of the activities of this last team.

2. Scientific and technological issues

The frozen food industry is constantly evolving in recent decades and must preserve the economic viability of the sector by satisfying the expectations of consumers in terms of sanitary, , organoleptic and nutritional quality. A new challenge is also to respond to the societal challenges of reducing food waste and ensuring for all people an access to foods with a good quality. In order to address these major issues, it is necessary to implement a controlled and constant cold chain from production to consumption through transport and storage stages. Indeed, frozen products are likely to undergo physical changes that can alter their quality throughout the cold chain, especially under temperature fluctuations. These modifications are essentially related to the microstructure of the products, which is defined initially during the freezing process with the formation of ice crystals and which evolves throughout the cold chain, with, in particular, the recrystallization (growth of size of ice crystals) and sublimation (surface dehydration and frost formation) phenomena. While it is now recognized that the microstructure of food products influences to a large extent their physical, textural and organoleptic properties, but also their stability and therefore their shelf life, the mechanisms that took place at the microscopic scale are still poorly controlled. Knowledge and understanding of the formation and evolution of the microstructure of frozen products in the cold chain is an area that still requires much research. The control of the quality of frozen products was identified as a major

industrial problematic. It then becomes necessary to bring a better knowledge of the process-microstructure-properties interactions, in particular using robust tools allowing a fine characterization of the different components of this microstructure.
The Metfri team, in collaboration with the SP2 team of UMR 1145 Food Process Engineering (AgroParisTech / INRA) has developed in recent years knowledge on freezing (pre-freezing of sorbets and ice creams, freezing by immersion, cryogenic freezing) and the storage of frozen products (frost formation, recrystallization of water) from the experimental point of view as well as the modeling. The desire to characterize the internal structure of frozen products at the microscopic scale (ice crystals, alveoli, cells) motivated the use of X-ray microtomography, as an original tool for this type of application. The originality of the methodology developped in the previous works is related to a technique of characterization at storage temperature (negative temperature) by coupling the X-ray microtomograph to a cooling stage. The use of X-ray microtomography as well as optical microscopy allowed a better characterization of the phenomena involved during freezing and during storage of products. The modeling works at the microscopic scale also made it possible to better undertand the changes observed at the macroscopic scale.

However, this work has a number of limitations:

- Freezing and storage have been studied as two independent links in the cold chain. However, the microstructure developed during storage also depends on its initial state which is defined during the crystallization process occurring during the freezing of the product;
- Previous works were done exclusively on real products, making it difficult to generalize the results obtained and to extend to other types of products;
- the method of characterization of the microstructure at negative temperature (X-ray microtomography) has given access to new results that should be compared with other complementary methods such as cryoMEB that allows to have access to lower resolutions even it is only on the surface.
- The potentialities offered by X-ray microtomography have not been fully exploited. In particular, 3D images are able to give access to local parameters that are difficult to measure experimentally and that are necessary for modeling the phenomena involved.

3. Scientific issues and objectives

Following the aforementioned limitations, new scientific questions have arisen:

- How to define a model food that is representative of a set of foods undergoing freezing? What criteria should be defined? What are the steps to characterize in order to progressively extrapolate the results to a real food?
- In which way can the freezing process (temperature, transfer coefficient) influence the development of the microstructure of the frozen product during storage?
- How to relate the evolution of the product at the microscopic scale for various operating conditions to structural changes at a macroscopic scale? How to extract microscopic parameters from RX measurements to characterize the macroscopic state of the frozen food?
- In which way are the results obtained by the negative temperature 3D microtomography imaging technique similar to those visualized by the electron cryomicroscope?

The answer to these questions would remove the lock for a better understanding of the mechanisms involved at the crystal scale as well as the techno-functional properties induced on the product.
This thesis will therefore seek to answer these scientific questions with the main objective of studying the coupled impact of two links in the cold chain, freezing and storage, on the quality of a frozen model product. The study will concern porous food products which are not much studied to date. The impact of the parameters of each of the two links on the final quality of the product will be characterized experimentally from the point of view of its structure on the macroscopic and microscopic scale. The idea would be to start with one or more model products of varied and increasing complexity that can reproduce the characteristics and behavior of real food products. In this work, two methods of characterization of the microstructure of the frozen products will be coupled: X-ray microtomography and CryoMEB. In parallel with the experimental work, a model at the scale of crystals, alveoli and cells will be developed to represent phase change phenomena (nucleation, growth and dissolution of crystals) and water and energy transfer at micro-scale taking into account the structure observed by X-ray microtomography. This model will be used to feed a

multiphasic continuous medium model to represent the transfers at the product scale by considering its real geometry and taking into account the conditions (speed, temperature) in its environment.

4. Thesis Organization

This thesis is proposed in collaboration with the University of Grenoble Alpes and the Center for Snow Studies of Grenoble, which have been conducting researches for more than a decade on X-ray microtomography applied to snow, particularly with skills in analytics, 3D image processing and multi-scale modeling. This collaboration is justified by the complementarity in X-ray microtomography skills and the crystallization / recrystallization modeling aspects that the GPAN team has developed for applications in frozen food products. This collaboration includes two hosting laboratories, stays distributed between the two laboratories and a thesis agreement between the different structures.

Thesis codirection: Hayat BENKHELIFA (ADR - MC AgroParisTech with a hosting agreement at GPAN, Irstea)

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Joining date: October 2018

Remuneration: 1874.41 €/per month (without taxes)

5. Profile sought

The candidate must be graduated of a Research Master or equivalent in Process Engineering, Engineering Science or Thermal Science with good knowledge in heat and mass transfer phenomena. Knowledge in Food Science would be appreciated. The candidate must also have the following skills:

- Knowledge of experimental approaches, knowledge in image analysis would be appreciated
- Good knowledge of modeling and simulation approaches (especially with Matlab software)
- Ability to draft reports, papers and articles.

6. Contact

CV and cover letter to be sent to:

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