EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:
https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report")*,
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round - **5th March**
- 10th September Proposal Round - **13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** In situ visualization of fluid flow during deep-fat frying process using ultrafast synchrotron microtomography.	**Experiment number**: LS-3126
Beamline:	**Date of experiment**: from: 28 October 2022 to: 31 October 2022	**Date of report**: 13 February 2023
Shifts: 9	**Local contact(s)**: Bratislav Lukic, Ludovic Broche	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Ujjwal Verma[1]*

Isabella Maria Riley[2]*

Pieter Verboven[1]*

Bart Nicolaï[1]*

[1]Division BIOSYST-MeBioS, KU Leuven, 3000, Leuven, Belgium
[2]Laboratory of Food Chemistry and Biochemistry (LFCB), KU Leuven, 3000 Leuven, Belgium.

Report:

The goal of the experiment was to use the fast imaging capabilities of the ID19 beamline to visualize the microstructural changes and fluid flows that take place during and after frying. The experiments were performed at 2.2 µm and 5.5- µm at 1 tomograph/second (1000 images) at 6 time points with 10 s and 3 s intervals. During the beamtime, we scanned a total of about 150 samples using different configurations.

A custom experimental setup (**Error! Reference source not found.**) was used to perform the in-situ tomography, the samples were lowered into heated oil(180 °C) remotely to image the first few seconds of frying. Additionally, to observe the oil uptake during cooling the sample was imaged after remotely retracting the sample from the hot oil post-frying. The beam had to pass through about 8 mm of borosilicate glass, 50 mm oil, 2.5 mm teflon and 14 mm aluminium rod during rotation, which resulted in some unavoidable artefacts such as streaking and poor contrast in certain cases. Although we faced several minor issues related sample movements and unexpected beam loss during scanning, we successfully completed all planned samples.

The imaging at 2.2 µm provided an important insight into the pore formation and structure deformation influenced by different sample compositions, the shorter 3 s interval between scanned time points added context to the large deformations previously missed in 10 s intervals (Table 1).

This allowed us to make some new observations on structure deformation, where pores formed during sample formulation expand first in the outer regions as the starch gelatanizes, these pores are subsequently compressed and collapsed by the expansion of pores in the core regions, thus deforming the structure as a whole and creating site for future oil uptake.

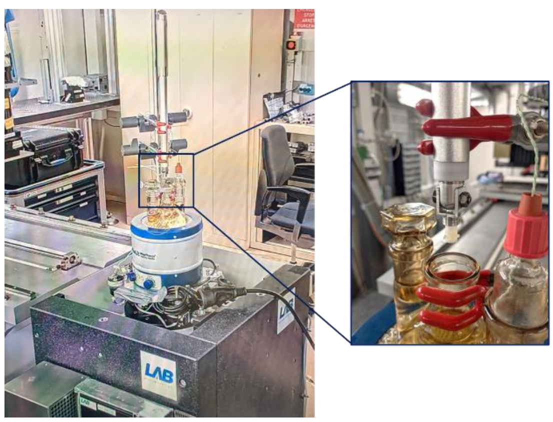


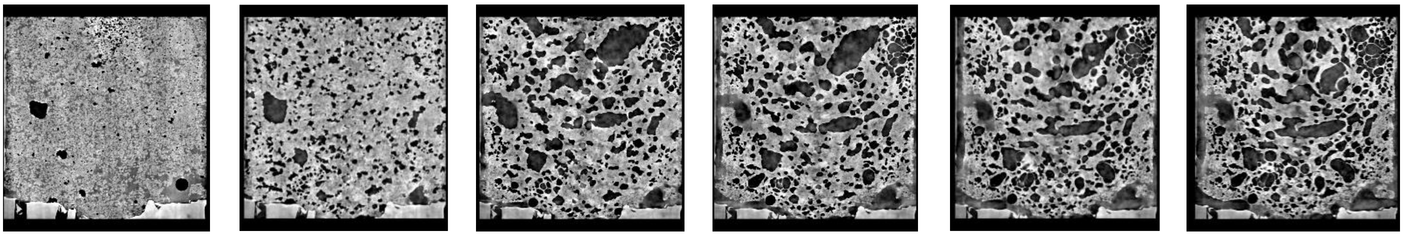
Figure 1: Experimental setup (inset:sample holder)

It was also confirmed that, with the exception of low moisture samples, the oil uptake in the porespace was limited by a combination of initial structure expansion and gases escaping from the surface.

In addition, a smaller subset of samples was tested at two different oil temperatures to study the effect of frying temperature on structure deformation and subsequent oil uptake.

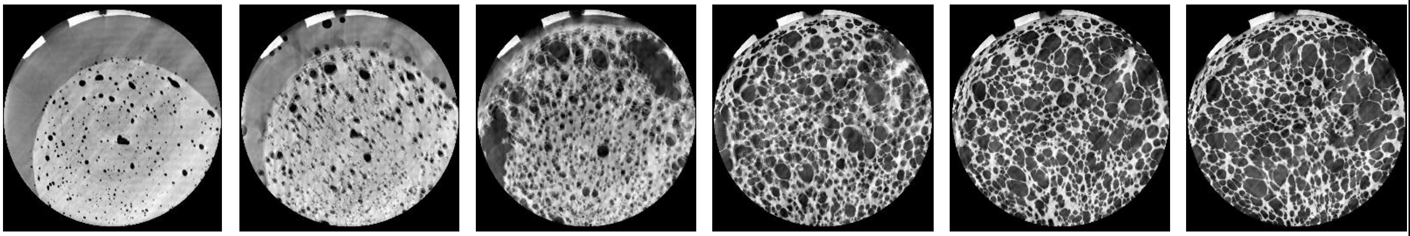
Table 1: Reconstructed images of fried samples at different time intervals

During frying Sample #1: interval 10 s



t = 0 s	t = 11 s	t = 22 s	t = 33 s	t = 44 s	t = 55 s

During frying Sample #2: interval 3s

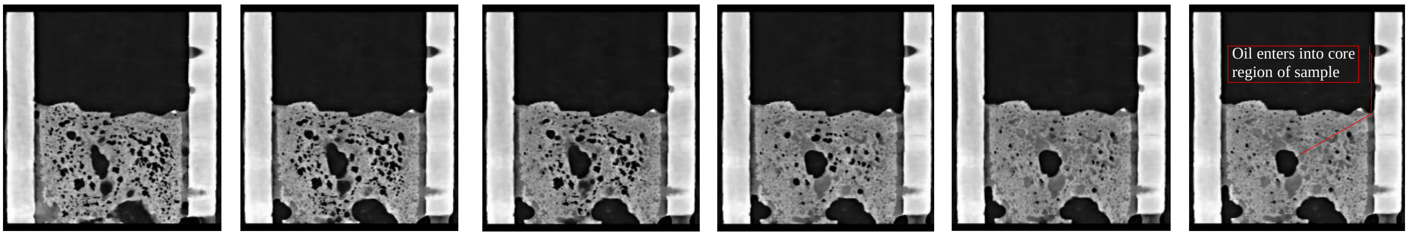


t = 0 s	t = 4 s	t = 8 s	t = 12 s	t = 16 s	t = 20 s

The second set of scans at 5.5µm were primarily performed to observe the oil invasion into the pores during the cooling phase. These scans provided valuable information of 3D distribution oil uptake in the first few seconds after frying. It was observed that most of the oil uptake is during this period and greatly influenced by the structure deformations during frying. Oil invasion could primarily be driven due to a combined capillary action and reduction of vapour pressure during cooling.

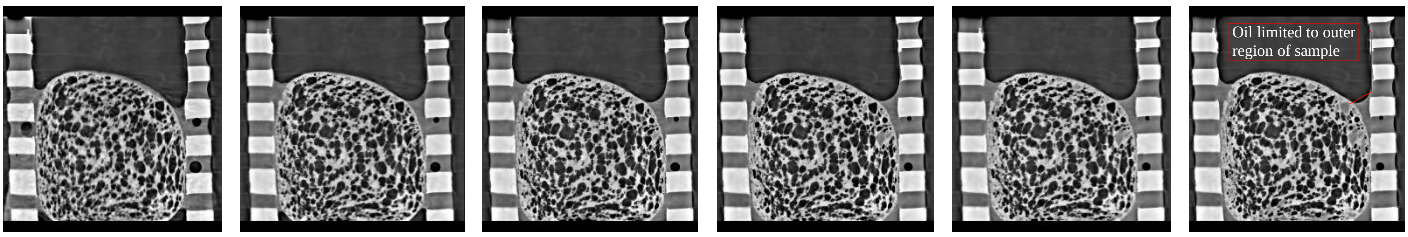
Table 2:Reconstructed images of fried samples during the cooling phase to visualize oil uptake

During cooling Sample #1: interval 10s



t = 0 s	t = 11 s	t = 22 s	t = 33 s	t = 44 s	t = 55 s

During frying Sample #2: interval 10s



t = 0 s	t = 11 s	t = 22 s	t = 33 s	t = 44 s	t = 55 s

In summary this experiment is, to our knowledge, a first-time experiment combining in situ deep frying and post-frying cooling phase with high speed tomography to observe physical changes and oil uptake in real time.