Food product characterization by acoustical techniques

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Summary
Among porous materials, food products represent a large range of micro-structures usually studied in acoustics. These media may indeed include open or closed cell foams, fibrous materials, granular materials, functionally graded materials, porous media with poro-elastic inclusion etc. Therefore, they represent major modeling and experimental challenges. The aim of the present work is to examine the feasibility of alternate characterization procedures, compared to widely used ultrasonic techniques, based on the approaches used for the characterization of acoustical parameters of porous media. In a first stage, impedance tube measurement data were collected for various food products, including bread, pasta, rice, cereals and flour. Several situations where these media contain porous, rigid or elastic, inclusions were also studied. In a second stage, the micro-structure of these media was assessed using standard characterization procedures used for acoustical porous media. At this stage, the links with between the characterized parameters and the food micro-structure are discussed. Thirdly, non-conventional situations where these media exhibit multi-scale effects are discussed based on the implementation of the appropriate models : double porosity, porous composites or more general micro-macro approaches. This study is still ongoing and only a few results are presented below for bread, rice with inclusions and honey corns. These results allow to discuss the perspectives to build strategies for the control of food products.

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1. Introduction

Sound waves emitted or scattered by an object are closely connected to its micro-structure. Therefore, in the context of food processing, this type of data could be used to provide useful information to be related to e.g. the structure homogeneity or transformation during the food process.

On the one hand, acoustic emission could be used to monitor a prescribed transformation : heating, pressing, crushing etc. Among many other works about food, one could refer for instance to a recent paper studying the noise emitted by roasted coffee grains[1]. On the other hand, sound waves are propagating through, dissipated and reflected back to the emitter. Mainly ultrasound techniques have been used whereas audible sound waves have been used to a minor extent, see for instance [2].

In addition, experimental techniques developed for porous materials are now mature in the sense that they provide relevant micro-structure related parameters together with accurate predicting models. The models may also account for possible layered structure and presence of heterogeneities. This degree of complexity is needed since food products cover a large range of porous materials : various fiber arrangements, reticulated and non-reticulated foams, grains packing, multiple scale porous materials, porous substrate embedding various types of inclusions, functionally graded materials . . .

The present work aims at examining the feasibility of using porous material characterisation techniques to assess the micro-structure of various food products. This work, still under progress, includes air saturated, partially saturated and fluid saturated media, raw and cooked products, homogeneous and heterogeneous porous materials, materials with solid, elastic, poro-elastic inclusions, non consolidated media etc. This paper present only a few results acquired so far. Four types of products are reported below : bread, rice with inclusions, breakfast corns and yogurt. For each product, sound absorption measured data are presented together with various strategies of characterisation and modeling. Finally, the link between the collected data and the product micro-structure is discussed.

Figure 1. Sample of bread slices.

2. Bread

The first experiment concerns bread, typically used for English toasts (see Fig. 1). A stack of five slices was used in order to reach a total thickness of approximately 50 mm, as for the other food products tested below. This part of the work specially aims at monitoring the evolution of the bread properties while aging at ambient conditions of temperature, pressure and humidity.

Protocol was as follows. A series of bread slices were dried at ambient conditions of temperature, pressure and humidity during a period of four days. Each day, new samples were extracted according to the tube dimensions and care was taken during the sample mounting to avoid any leakages between the samples and the tube wall.

Each day, a complete characterisation, as described in [3] and [4] was carried out for the stack of five bread slices. The complete set of parameters for the Johnson-Champoux-Allard-Lafarge model was obtained, namely the static air flow resistivity, the open porosity, the high frequency limit of the dynamic tortuosity, the viscous and thermal characteristic lengths and the static thermal permeability. Only results for the static air flow resistivity and the porosity are shown below, respectively in Fig. 2 and Fig. 3.

In addition, the elastic properties of a single slice of bread have been measured. These data are still under post-processing and will be presented during the conference.

These results show that the static air flow resistivity globally decreases as the bread is drying. To the contrary, the porosity is less influenced by the drying process. This result is coherent with the measured

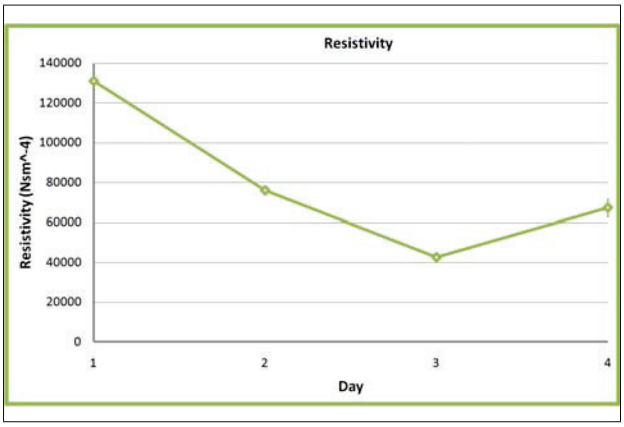

Figure 2. Bread 50 mm thickness under various stages of drying : evolution of the static air flow resistivity.

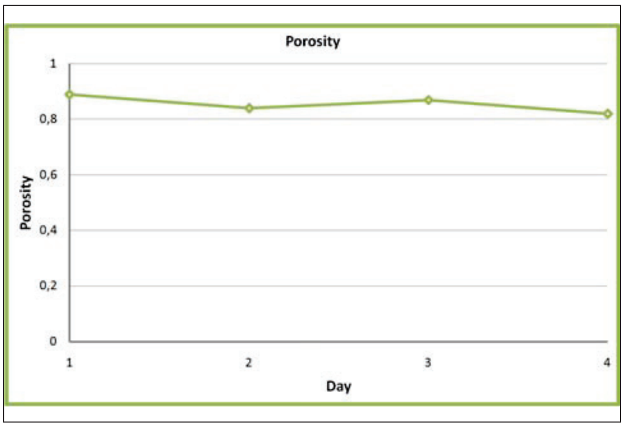

Figure 3. Bread 50 mm thickness under various stages of drying : evolution of the open porosity.

mass density of the sample, which also decreases along the drying process, mainly due to water evaporation.

These results were coherent with the characterized values of thermal characteristic lengths. Results showed that the value of this parameter was clearly decreasing during the drying process, by a factor 1.5 approximately. one should keep in mind that this parameter is related to the radius of pores of cellular structure.

These results are finally confirmed by the evolution of the sound absorption measured in impedance tube. Results of Fig. 4 were obtained on a second sample of bread slices than the ones used for the above characterisation. For this experiment, the bread was dried on a period of five days. These results show that, along the drying process, the maximum level of absorption and the frequency at which it occurs increase. These results are consistent with an increasing static air flow resistivity, still in the range of moderate values around 50 k.N.s.m^{-4}.

In total, these results tend to show that as the bread dries, the characteristic dimensions of the micro-structure are reduced while the global geometry is maintained. This result is expected but this mainly confirms that techniques used for acoustical

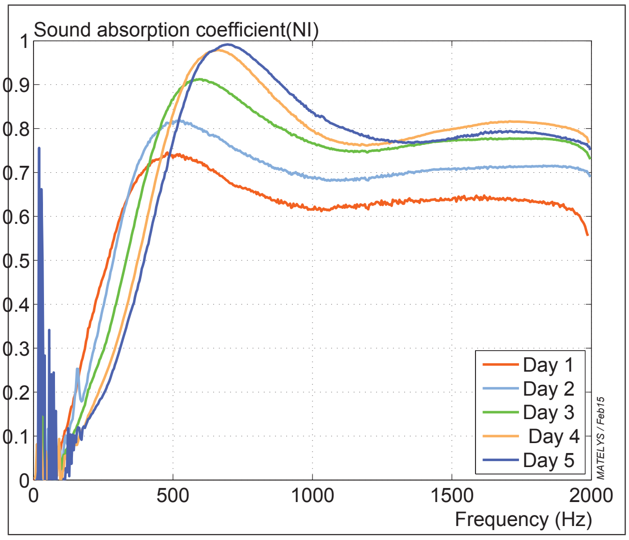

Figure 4. Bread 50 mm thickness under various stages of drying : evolution of the sound absorption coefficient measured using the impedance tube. Bread different from that used for the characterisation (see previous figures).

porous material are suited to assess the bread microstructure[2].

3. Rice with embedded inclusions

Next example of food product concerns a porous substrate hosting some inclusions. As a canonical representation of this situation, the present work examines the sound absorption coefficient of raw rice hosting glass beads or polystyrene balls.

The beads were carefully placed on three successive layers inside the rice (see for instance Fig. 6). Several configurations were tested with an increasing number of glass beads, various rates of inclusion, various sizes and arrangements in the porous medium. Results are shown below for two configurations having almost equal rate of inclusion (13.2 %) for inclusions have different diameters, namely 16 mm for glass beads and 20 mm for polystyrene balls. The measured sound absorption coefficient are shown in Fig. 7.

These results show that in the presence of solid inclusions, the frequency of maximum absorption is shifted towards higher frequencies. The maximum level of absorption is not affected for the studied inclusion size and rate of inclusion. The frequency shift could reach 200 Hz.

Therefore, this result shows that it possible to detect, within a porous substrate, the presence of solid inclusions provided that the size of an individual inclusion is sufficient. Further work is in progress to study the range of inclusion rate which could be addressed. It is further shown in the next example that acoustical methods could be used to detect if the inclusions are porous or not.

Figure 5. Samples of raw rice with embedded glass beads.

Figure 6. Samples of raw rice with embedded polystyrene balls.

4. Breakfast honey corns

Next example of food product consists in honey corn balls. This product presents a fairly regular macroscopic structure in the form of approximate spherical balls, which in addition are porous (see Fig. 8). Therefore, the question rises either or not there exists an interaction between these two scales of porosity : the inner porosity of the balls and the interstitial porosity between the balls.

Measurements of the sound absorption of a stack of 50 mm thickness of honey corn balls are shown in Fig. 9. This figure also compares simulation results using three different assumptions. All models are based on a so-called porous composite model as proposed in [5] which allows to account for porous or solid inclusion in a porous or solid matrix. This models also allows to account for the shape of the inclusion.

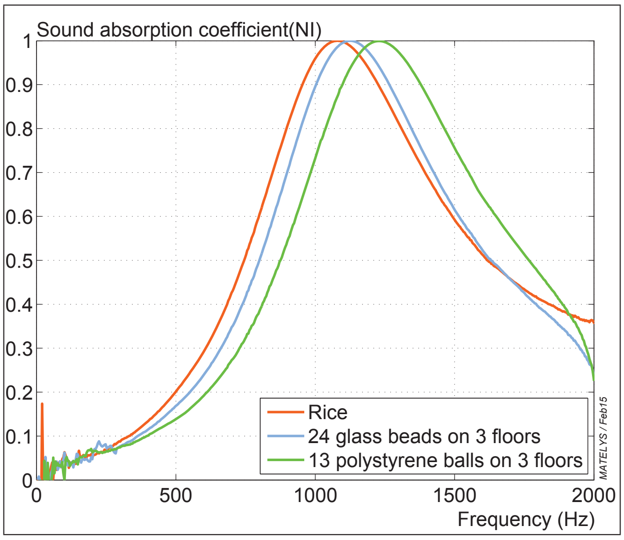

Figure 7. Rice with embedded inclusions 50 mm thickness : sound absorption coefficient measured using the impedance tube.

Figure 8. Samples of honey pops.

The first model accounts for the spherical shape of the corn balls. In this sense, this model, referred to as *Model PC as Arb* is the most complete compared to the other two models. Instead of reproducing the exact shape of the balls, the second model only considers the rate of the inclusion and uses a mixing law (ML) to compute the properties of the porous substrate with inclusions. This model is referred to as *Model PC as ML*. The third model is similar to the *Model PC as Arb* but considers impervious inclusions, thus avoiding the possible interaction between the ball inner porosity and the inter-balls porosity. In the figure below, corresponding simulation results are referred to as *Model PC as Arb imper. incl.*

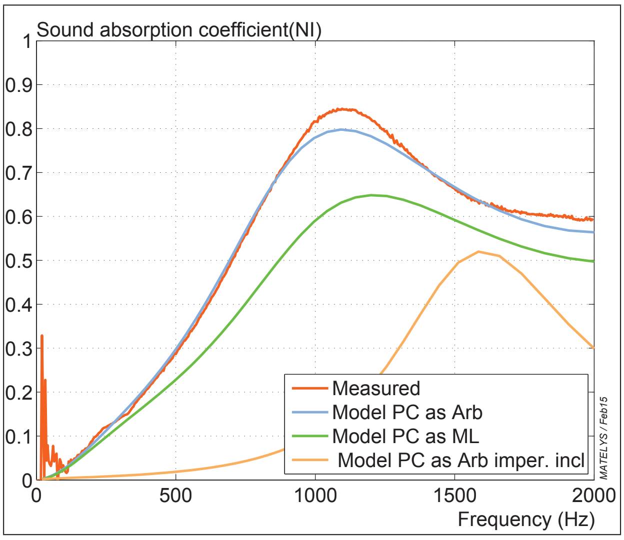

Figure 9. Honey pops 50 mm thickness : sound absorption coefficient measured using the impedance tube.

These results show that there is a significant interaction between the two scales of porosity. Indeed, the model which considers impervious spherical balls fails to predict correctly measured sound absorption coefficient.

In addition, the mixing law is not sufficient to reproduce correctly the sound absorption coefficient as measured in the impedance tube. This shows that the dissipation occurring in the portion of fluid contained between the balls is significant.

Therefore, this type of measurements could be used to test if the balls are suitably grilled and honey covered and to a minor extent to test if the spherical structure is preserved after, e.g. packaging or transport.

5. Yogurt pot

Last example does not aim to characterise directly the food micro-structure but is related to the quality control of food product. The sound absorption coefficient of a yogurt pot was carefully measured in impedance tube for different positions of the closing cap.

The yogurt was selected so that the pot was closely fitting in the 100 mm diameter impedance tube (see Fig. 10). Sound absorption was first measured for the cap totally closed. Then, the cap was successively and gradually open. Fig. 11 shows a scheme of the different positions examined. For each position, the sound absorption coefficient was measured in the impedance tube.

Among other positions, Fig. 12 and Fig. 13 show the resulting sound absorption coefficient as a function of the frequency, respectively for the pot with a closed cap and for the pot with a partially open cap.

The measured sound absorption spectra significantly differ for the two configurations. When the cap

Figure 10. Picture of yogurt pot with partially open cap.

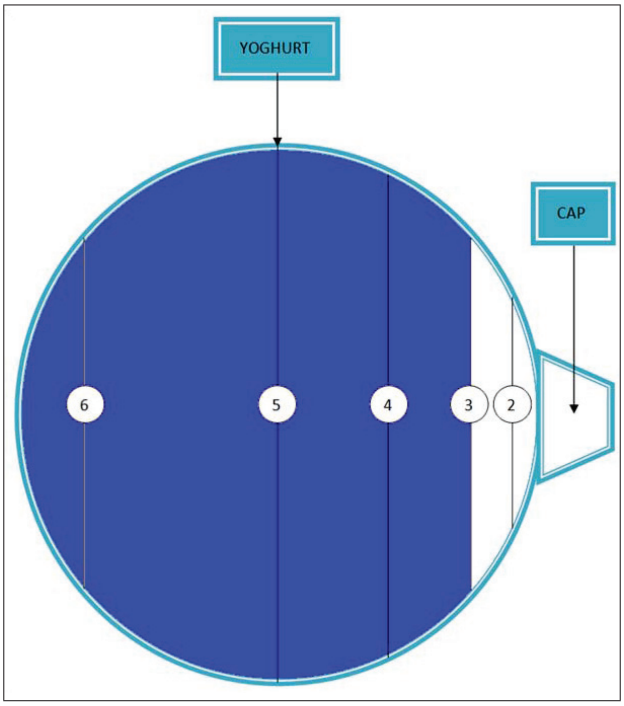

Figure 11. Scheme of opening position of the yogurt cap.

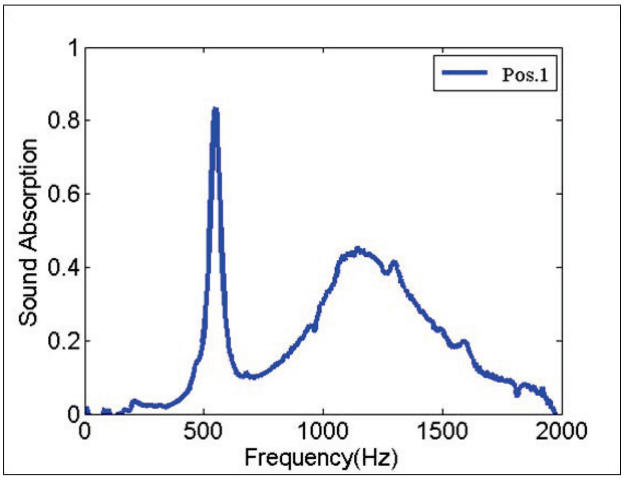

Figure 12. Yogurt pot : sound absorption coefficient measured using the impedance tube. Cap totally closed (position *cap* in Fig. 11).

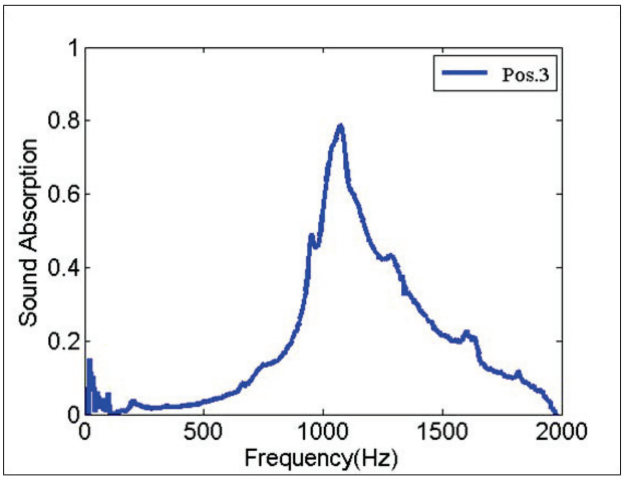

Figure 13. Yogurt pot : sound absorption coefficient measured using the impedance tube. Cap partially opened (position *3* in Fig. 11).

is totally closed, the sound absorption coefficient exhibits a sharp, high peak in the low frequency range, here around 500 Hz. This peak disappears when the cap is partially open : it is also absent for other open positions not shown here. Instead, for these latter positions, the sound absorption spectra exhibit a broad peak at higher frequencies, around 1 250 Hz. It may be noted that the width of this peak, around 500 Hz, does not overlap the low frequency peak visible when the cap is totally closed. Therefore, for this yogurt, simple strategies based on basic signal processing could be thought to detect either or not the cap is correctly sealed.

6. Conclusions

This paper presents a feasibility study of using sound waves in the audible frequency range to monitor food products. Products having various micro-structures were studied experimentally and appropriate models for homogeneous or heterogeneous porous materials were implemented. Various purposes were illustrated :

- the monitoring of the product micro-structure,
- the control of the quality of product inclusions,
- the quality control of food products.

Further work is ongoing to define systematic control strategies and signal processing techniques for other food products including liquid products or other functionally graded materials.

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