Design of Low Frequency Ultrasonic Sensors for Cheese Draining Investigation

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Introduction

Ultrasonic waves have been widely used to measure the physical characteristics of heterogeneous materials. Metal composites, wood [Sandoz, 1996], bones [Campistron, 2002], blood, tissue and food such as cheese [Benedito and al., 2002] are only examples. The interest resides in the fact that ultrasonic waves are non destructive, which is of major interest for many food materials, and are sensitive to small textural variations that allow to trace the evolution of processes. Our aim is to develop a system capable of studying the development of cohesion of cheese curd grains during drainage in a mould. This being a particular heterogeneous medium where the evolution depends on combined physical and biochemical parameters.

System description

The ultrasonic sensors

The measurement system is based on point-shaped, thin, quasi-triangular ultrasonic transducers (see figure1). Previous studies in food science have shown the efficiency of this sensor type due to its good adaptation to the medium without the need of any coupling material [Nassar et al., 2001].

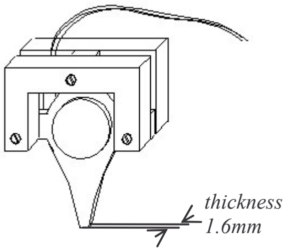

Figure 1: An ultrasonic point-shaped transducer

These sensors present as well the following advantages:

- The triangular form magnifies the amplitude of the emitted wave [Shuyu, 1997],
- The thin blade shape allows the flowing medium to mould around it.
- The small surface of the tip provides high repeatability between measurements.

The sensors act as point sources having an omni-directional wave and several resonance frequencies given theoretically by the maximum velocity of particles, V_{max}.

The velocity of a particle, v, depends on the signal frequency, ω, and on the particle's position in the blade, x, by the following differential equation [Nassar, 1997]:

$$\frac{\partial^2 v}{\partial x^2} + \frac{1}{x_1 + x}\frac{\partial v}{\partial x} + \frac{\omega^2}{c^2} v = 0 \qquad (1)$$

Where c is the ultrasonic longitudinal velocity in the sensor.

The solutions for V_{max} give the resonance frequencies of the sensor which are verified to coincide with the minima of experimental frequency analysis (see figure 2).

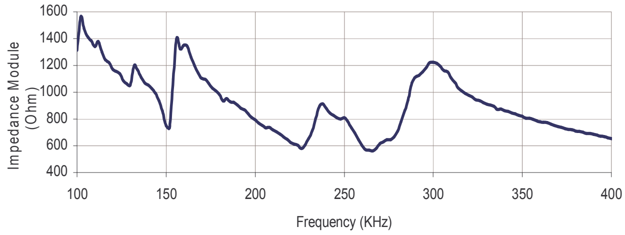

Figure 2: Spectrum analysis of a point-shaped transducer as seen by an analyser, confirming the theoretical results.

The measurement system

The measurement system consists of the drainage mould and three sensors: one emitter and two receivers. The receivers are fixed at the same height and at 120° at each side of the emitter inside the mould which is specifically designed for the experiment. It is a small (diameter 9cm), cylindrical mould made of perforated stainless steel allowing even evacuation of whey without interfering with the sensors' precision.

Sample preparation

The sample, a mixture of curd grains and whey, is prepared from a milk powder solution with a cheesemaking protocol, adjusted to the experimental requirements. The milk is renneted for 30 min. It is then cut into grains. The grains are stirred for another 30 min. This mixture is then poured into the mould and pressed (pressure range: 10-65g/cm²) where its evolution with time is observed.

Measurement method

The emitter is excited with an electrical pulse of amplitude 220V and duration 15µs. Due to the sensor conception several frequencies are emitted and propagate in different directions arriving at the receiver in a large time interval. We are interested in the direct longitudinal wave. The amplitude is therefore measured at the first extremum of the received signal (see figure 3). The measured amplitude A_{meas} is normalized with respect to the value in pure water at 32°C, A_{water} :

$$A_{norm} = \frac{A_{meas}}{A_{water}} \qquad (2)$$

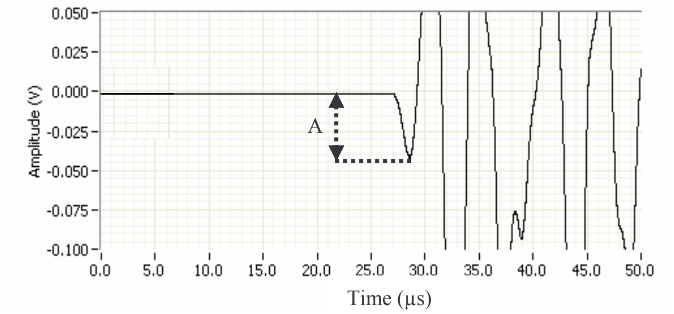

Figure 3: The amplitude is measured at the first extremum of the received signal, amplified 20 times.

Results and discussions

The cohesion time of curd grains depends on their surface properties, on the ambient temperature and on the biochemical reactions taking place both inside and at the surface of the grains. In order to avoid variations due to temperature, all the measurements are made in an ambient temperature of 35°C in a controlled chamber.

The ultrasonic amplitude increases (attenuation decreases) as the medium evolves.

The attenuation is caused by different factors:

- The intrinsic attenuation due to the absorption in the medium, depending on its properties: elasticity, rigidity, viscosity and density.

The density and elasticity of the medium increase with time thus decrease the signal attenuation.

- Reflections and dispersion of the signal at the interfaces between grains. These interfaces being composed of the grain surface itself, of the whey between the two grains and on the surface of the neighbouring grain.

As the curd grain cohesion develops, interfaces disappear and the transmitted energy increases.

These two parameters affect the signal in the same sense, decreasing the attenuation with time.

The first results examine a medium that develops weak elastic properties with two different moulding methods (see figure 4). The first method creates a medium containing air inclusions that penetrate while moulding and the other is moulded avoiding the penetration of air.

In the first case the signal attenuation, in addition to the attenuating factors mentioned above, is due to reflections and dispersion at the air inclusions depending on their relative positions and sizes.

Having acoustical properties very different from those of the grains and the whey, the air creates large signal fluctuations disturbing the observed signal.

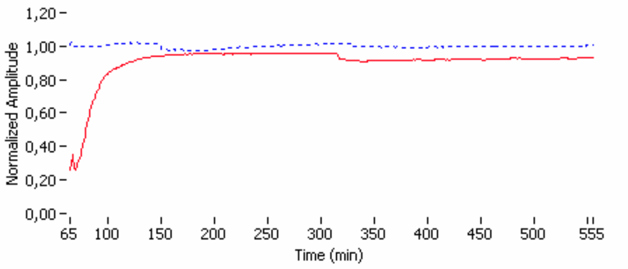

Figure 4: Evolution of the ultrasonic amplitude in the draining grains: grains moulded with air inclusions (average of 4 curves) ____ grains moulded without air inclusions (average of 4 curves) ----- .

Figure 5 shows the evolution of a curd prepared with protein-rich milk and acidified by GDL (Glucono-Delta-Lactone) before rennet addition. The signal observed shows a significant evolution of the curd properties appearing at around 400 minutes after rennetting. This evolution is independent of the drainage of whey which occurs mostly in the first 200 minutes after rennetting.

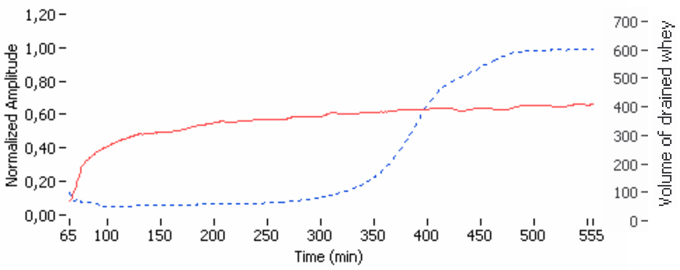

Figure 5: The evolution of cheese curd grains draining under pressure (ultrasonic normalized amplitude) ---- compared with the volume of drained whey ____.

Conclusions and perspectives

We have developed an ultrasonic sensor system to survey the development of the cohesion of curd grains during drainage. We will proceed to explore the effect of the variation of the grain properties on their cohesion.

References

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