ACOUSTICALLY ASSISSTED PORK MEAT BRINING KINETICS

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ABSTRACT

Meat brining process with and without ultrasonic application was studied to determine the ultrasonic influence. Pork loin slices were immersed in a saturated brine of NaCl for 15, 30, 45, 60, 90 and 120 minutes. Two levels of intensity at 290 kHz were tested (0.4 and 1.3 W/cm^2). Moisture content and NaCl gain referred to initial dry matter were determined. A multifactor ANOVA showed that ultrasonic experiments presented a significant greater dewatering than non ultrasonic experiments. The ultrasonic treatment at higher power level showed a higher NaCl gain than ultrasonic treatment at lower power level and non ultrasonic treatment. Diffusion coefficients of water and NaCl were determined using Fick's model.

INTRODUCTION

Power ultrasound produces a series of effects when traveling across a medium. Some of these effects are a microstirring in the solid-liquid interfaces (Floros and Liang, 1994) and compressions and expansions in the material (Gallego-Juárez et al. 1999). If the expansions and compressions take place in a liquid, bubbles can be produced. These bubbles tend to expand and contract at the same frequency that ultrasound (stable cavitation). If phase of expansion is larger than phase of contraction, the size of bubble increases and implodes (transient cavitation) (Boistier-Marquis et al. 1999). When the bubble is near a solid surface, the implosion is asymmetric and produces a microjet of liquid to the surface (Mason and Cordemans, 1996). All this effects can influence the mass transfer processes.

Mass transfer occurs in a number of meat processing operations (dehydration, curing, cooking…). In the brining process, the meat is immersed in a NaCl saturated brine. When a biological material is immersed in a hipertonic solution water migrates from the biological material to the solution and, simultaneously, solute can migrate from the solution to the biological material. If biological material has soluble compounds, these can migrate to the solution too. As a whole, usually, it is found a net decrease of the moisture content and a net solute gain that diminishes the water activity of the material (Palmia, 1982). Several factors such as temperature, solution concentration, nature of biological material, structure, pretreatments like freezing or thawing (Lazarides and Mavroudis, 1995; Mavroudis et al. 1998; Panagiotou et al., 1998) can affect the mass transfer process.

Ultrasound has been applied to improve mass transfer in food processes. Extraction processes can be enhanced such as the extraction of chymosin from the stomach of milk-fed calves for manufacturing of cheese (Kim and Zayas, 1991), bioactive principles from plant materials (Vinarotu et al., 1997) and supercritical fluid extraction (Jun et al., 1997). Da-Mota and Palau (1999) applied acoustic energy at low frequencies (1.6 and 3.2 kHz) to drying onion using a siren system. They found an increase in the drying rate of onion slices in experiments with application of acoustic vibrations, even at low temperatures. Gallego-Juárez et al. (1999) developed a new technology of high intensity air-borne ultrasound in forced-air drying processes. They applied this technology to carrot drying. In liquid-solid systems, ultrasounds have been applied to affect the mass transfer process in the osmotic dehydration of apple (Simal et al. 1998), in cheese brining process (Sánchez et al. 1999) and in meat brining (Cárcel et al. 1999).

The aim of this work was to evaluate the influence of power ultrasound in meat brining and model the mass transfer process.

MATERIALS AND METHODS

Pork meat, "*Longissimus dorsi*", was used in the experiments. The moisture, fat, protein and ash content were determined according to the AOAC official methods (AOAC, 1997; 950.46; 991.36; 726.08 and 923.03 respectively). Carbohydrates were computed by difference. The pH was measured on the raw material with a Crison pH/mV meter 501 equipped with a puncture electrode.

Meat slices (0.5 x 4 x 5 cm) were cut from the muscle (*Longissimus dorsi*) and frozen. Before carrying out the brining experiments, the slices were slowly thawed at constant temperature (2 ^{o}C) during 18 h.

Brining experiments were carried out, in all cases, placing 900 mL of saturated brine into a 1000 mL glass beaker. During the experiments brine temperature was kept constant at 2 $\pm$ 0.5 ^{o}C by recirculating a cooling liquid around the beaker. Six times of treatment (15, 30, 45, 60, 90 and 120 minutes) and three levels of ultrasonic intensity (0, 0.4 and 1.3 W/cm^2) were tested. For every treatment, at least, three replicates were made. After brining, the samples were immersed into distilled water for 1 min to remove adhered brine, superficially dewatered using paper towels and then the moisture and sodium chloride content determined in triplicate.

Ultrasound energy, at 290 kHz of frequency, was applied to the brine using a probe system made in the own laboratory from a piezoelectric ceramic disc. The electric signal came from a function/arb. waveform generator (HP 33120 A) and an amplifier (ENI 1040 L). Ultrasonic brining experiments were performed introducing the probe 1 cm into the brine. The distance between the probe tip and samples was always 2 cm.

A calorimetric method was used to evaluate the intensity of the ultrasonic field. The rate of temperature increase of the system with time in adiabatic conditions was measured with a digital data logger (HP DATA LOGGER 34970 A). The power (P) was calculated from:

$$P = MC_p \frac{dT}{dt} \qquad \text{Eq.1}$$

where M is the mass of solution, Cp is the heat capacity of the brine and $\frac{dT}{dt}$ was estimated from the slope of the temperature-time curve.

The evolution of moisture content of samples during treatments was modeled using a diffusional model based in Fick's law. The behaviour of the sample was assumed similar to an infinity slab of the same thickness (0,5 cm). The mathematical model for moisture content was:

$$\frac{\partial W}{\partial t} = D_{eff}\left(\frac{\partial^2 W}{\partial x^2}\right) \qquad \text{Eq. 2}$$

where W is the local moisture of the samples after treatments, t is the time of treatment, D_{eff} is a effective diffusivity and x is the distance from the symmetry axis.
To solve this differential equation, the followings hypothesis were assumed:

- Initial moisture content uniform.
- Shrinkage is negligible.
- The external resistance to mass transfer is negligible.
- Assuming the symmetry of system: $\frac{\partial W}{\partial x(x=0)} = 0$

Combining the eq. 2 with the previous assumptions, it is possible to calculate the local moisture content. Integrating for the whole volume, a relationship between average moisture and time of treatment was obtained (Eq. 3)

$$\frac{W - W_e}{W_o - W_e} = 2\sum_{\upsilon=0}^{\infty}\frac{1}{\left[(2\upsilon+1)\frac{\pi}{2}\right]^2}\left[\exp\left[(2\upsilon+1)\frac{\pi}{2}\right]^2\frac{D_{eff}}{L^2}t\right] \qquad \text{Eq.3}$$

where W_e is the moisture at equilibrium, W_o is the initial moisture and L is the half thickness of the sample. A similar expression was obtained to model sodium chloride content. D_{eff} of the moisture and the sodium chloride content was estimated using the optimisation tool SOLVER of the spreadsheet EXCEL™ by minimization the sum of squared differences between experimental and calculated moisture.

In order to evaluate the accuracy of the model for simulation purposed, the percentage of explained variance (%var) (Eq. 4) was computed (Sanjuán et al., 2001)

$$\%\text{var} = \left[1 - \frac{S_{yx}^2}{S_y^2}\right]100 \qquad \text{Eq. 4}$$

where $S_y{}^2$ and $S_{yx}{}^2$ are the standard deviation of the sample and the corresponding estimation, respectively.

RESULTS AND DICUSSION

For the brining treatments considered, two phenomena were evaluated: the loss of moisture and the gain of salt. Figure 1 shows the brining process evolution for both variables: moisture content (a) and NaCl content (b) referred to initial dry matter. Each point represents the average of, at least, three replications.

The influence of ultrasound treatments in the variables moisture content and NaCl content was studied using a multifactor ANOVA. The factors considered for both variables were intensity of ultrasound applied (0, 0.4 and 1.3 W/cm^2) and time of treatment (0, 15, 30, 45, 60, 90 and 120 min).

For moisture content the effect of ultrasonics and time was significant (95%). The LSD (Least Significance Difference) intervals (95%) showed that brining without ultrasound application was significantly different from ultrasound experiments. Therefore, the dewatering in samples brined without ultrasound was less intense than in experiments with ultrasound application. Nevertheless no difference was found between both intensities applied (0.4 and 1.3 W/cm^2).

For the variable NaCl content the multifactor ANOVA showed that experiments without ultrasonic application and application at 0.4 W/cm^2 intensity were statistically similar. The ultrasonic treatment at 1.3 W/cm^2 intensity was significantly higher (95%) in NaCl content than the two others. This would mean that NaCl gain was enhanced by ultrasound when a threshold of intensity is reached.

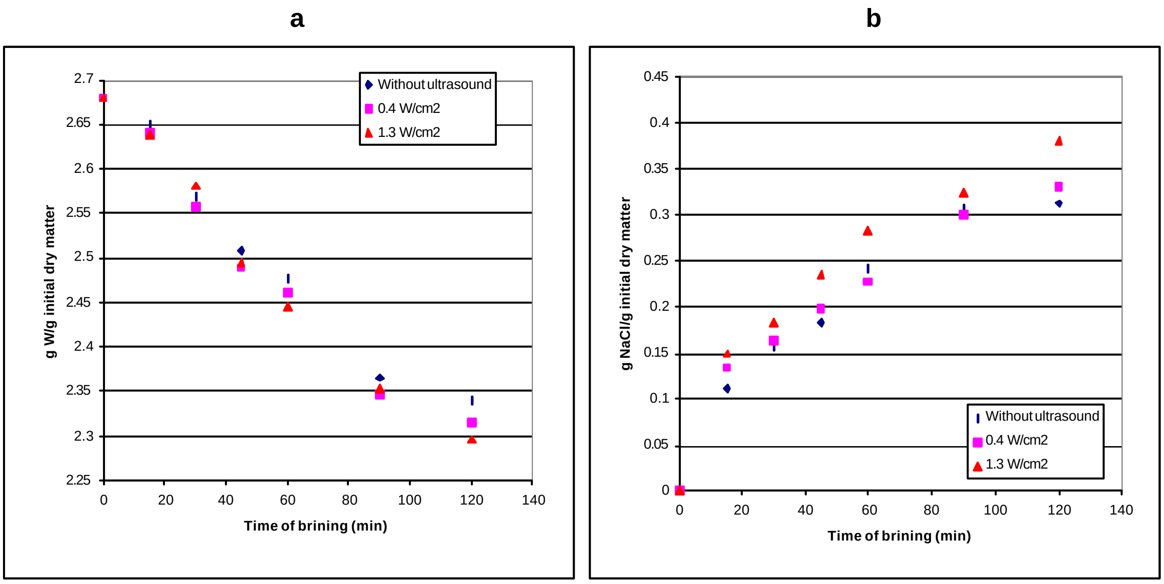

Figure 1. Results of brining experiments for the ultrasonic intensities at 290 kHz tested (0, 0.4, 1.3 W/cm^2).
a.- Final moisture after brining vs initial dry matter
b.- NaCl content after brining vs initial dry matter

By using the model previously described the effective diffusion coefficient was computed for both components considered: moisture and NaCl (Table 1).

Intensity of ultrasound applied during brining	Moisture		NaCl content	
	Diffusivity (m^2/s)	% var	Diffusivity (m^2/s)	% var
Without ultrasound	$1.18 \cdot 10^{-10}$	86.45	$1.94 \cdot 10^{-10}$	98.05
0.4 W/cm^2	$1.60 \cdot 10^{-10}$	85.50	$2.03 \cdot 10^{-10}$	99.12
1.3 W/cm^2	$1.60 \cdot 10^{-10}$	83.45	$2.67 \cdot 10^{-10}$	99.26

Table 1. Diffusivity estimated from experimental data for moisture and NaCl content.

As can be observed in Table 1 diffusivity of moisture for ultrasonic treatments are similar between them and significantly higher than without ultrasound brining experiments. For NaCl content the diffusivity of ultrasonic experiment at 1.3 W/cm^2 is significantly higher than for both ultrasonic brining at 0.4 W/cm^2 and non ultrasonic brining. Therefore the ultrasonic treatment at 290 kHz affects mass transfer process in meat brining increasing mass transfer rates. This influence was observed at lower levels of ultrasonic intensity for moisture (0.4 W/cm^2) than for NaCl content (1.3 W/cm^2).

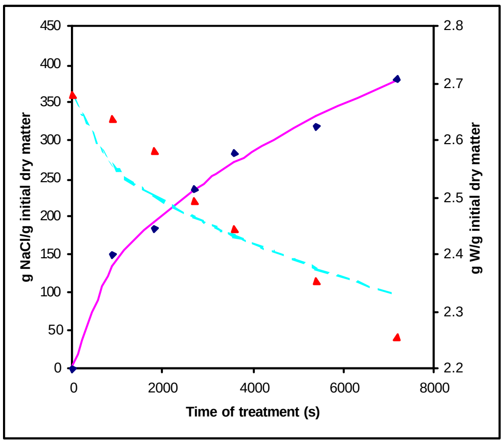

Figure 2. Experimental vs estimated data for NaCl and moisture content referred to the initial dry matter in a brining process with application of ultrasound (1.3 W/cm^2; 290 kHz). Moisture content ▲ ; fit of model - - - - ; NaCl content ◆ ; fit model ———

The diffusive model, used to describe the mass transfer process, fitted well (Figure 2) the NaCl content evolution. In this case the percentage of explained variance, for all treatments, was higher than 98 %. However, for moisture content, the percentage of explained variance was lower, ranging from 83 % to 87 %. Additionally, as can be seen in Figure 2, the behaviour (shape) of experimental and predicted data was clearly different. Therefore, the Fick's model used, based in the difference of concentration between sample and equilibrium, do not describe the dewatering process at the considered condition. Further work is needed to adequately describe water transfer.

CONCLUSIONS

Ultrasound affects mass transfer of processes in meat brining. The losses of moisture during brining were higher in experiments with ultrasonic application than for non ultrasonic experiments at the frequency of 290 kHz and the intensities considered. The increase of NaCl content of meat was higher in ultrasonic treatment at the intensity of 1.3 W/cm^2 than for the other treatments. No difference were found between non ultrasonic and ultrasonic treatment at the intensity of 0.4 W/cm^2 in NaCl gain.
The diffusive model proposed predict well the evolution on NaCl gain of samples but do not the moisture content.

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