Effect of Power Ultrasound on Mass Transfer in Food Processing

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Abstract

The use of power ultrasound in food industry has increased during the last few years. A progressive number of studies have been carried out in that direction. Ultrasonic energy represents a promising tool to produce or to enhance a series of food processes without affecting the quality of the foodstuff.

Mass transfer processes are some of the most effective for the application of ultrasonic energy. This work deals with two different kind of mass transfer processes assisted by power ultrasound: water transfer in vegetable dehydration and supercritical CO_2 transfer in almond-oil extraction. Ultrasonic energy was applied in direct contact with the substance to be transferred. Although clear differences were observed among the two treatments the effect of the ultrasonic energy was evident in all cases. The parametric study of the water transfer process here presented illuminates about the mechanisms involved.

1. Introduction

One emergent application of power ultrasound in food industry is the enhancement of mass transfer in processes where diffusion takes place. In fact, the kinetics of these processes can be accelerated by making use of the physical effects produced by high intensity ultrasound (radiation pressure, streaming, high amplitude compressions and depressions…). Following this objective, we have utilized high-intensity ultrasound to remove the moisture content from the interior of porous materials [1,2,3] and to accelerate supercritical fluid extraction processes [4,5]. In fact, water transfer in vegetable dehydration and supercritical CO_2 transfer in extraction represent two clear examples of mass transfer enhancement by ultrasonic energy. This paper is devoted to analyze both processes and to fit the experimental results with preliminary diffusion models

2. Effect of power ultrasound on water transfer in vegetable dehydration

An experimental set-up for the dehydration of materials by direct contact ultrasonic vibration has been designed, developed and tested. It consists in a piezoelectric transducer working at 20kHz with a power capacity of 100W driven by a power generator system. The generator is composed of an impedance matching unit, a power amplifier and a resonant control system. This system was specifically developed to keep constant the power applied at the resonance frequency of the transducer during the process.

The experimental procedure in all trials basically consisted of measuring the moisture content of food samples (apple and potato disks) after different times of application of high-amplitude ultrasonic vibrations in combination with forced-air (T=31C, flow rate=1m/s). To examine the effect of the ultrasonic energy all experiments were carried out with (+US) and without (+US) ultrasound. In all trials, the frequency was kept constant at about 20kHz, while different vibration amplitudes (0, 30 and 42 microns), static forces (70 and 220 g) and suctions (10 and 20 mbar) were applied. The dehydration curves were fitted to a diffusion model in order to identify the parameters of interest.

A model, which allows to describe diffusion of moisture by the Fick's second law [6] gives for a plane sheet sample of thickness *2l* the following expression of the dimensionless average moisture content :

$$\psi = \frac{W(t) - We}{Wo - We} = \sum_{n=1}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left(\frac{-D(2n+1)^2 \pi^2 t}{4l^2} \right) \quad (1)$$

where the parameter of the model is the effective diffusivity D (m^2/s). W is the moisture content in dry basis (kg water/ kg dry solid), the subscripts indicate equilibrium (*e*) and initial conditions (*o*) and *t* the time.

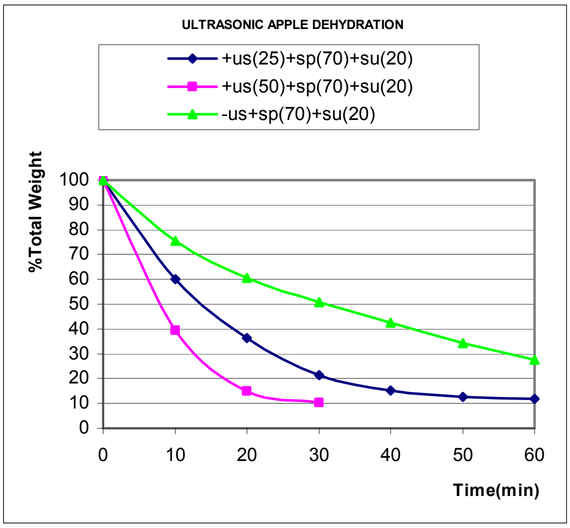

Figure 1. Apple dehydration curves with (+US) and without (-US) ultrasound.

Figure 1 shows the results obtained with ultrasound in combination with forced-air. It seems clear that the ultrasound increases the drying rate and consequently the water transfer.

By applying the proposed diffusion model the following values of D were obtained from the trials presented in Figure 1: 4.23×10^{-8} (-US, 0μm); 1.08×10^{-7} (+US, 30μm); 1.95×10^{-7} (+US, 42μm).

3. Effect of power ultrasound in oil extraction using supercritical CO_2

The experimental work was carried out in a pilot plant of supercritical fluid extraction where a 20kHz ultrasonic transducer was integrated inside of the extractor unit. CO_2 was used as a solvent to extract oil from grounded almonds. The operational conditions were P=280bar and T=55C with a flow rate of 20kg/h and the average time for each trial of about 8h30m. All experiments were done with and without ultrasound application. In all cases a power of 50W was applied to the transducer and 1500g of grounded almonds were used.

The extraction curves were fitted to a theoretical model developed by Sosová [7] in order to identify the parameters of interest. The yield of extracted oil, Y, from particulate almonds could be described by the equation of the model:

$$Y = x_o - \frac{y_t}{W} \ln\left\{1 + \left[\exp\left(\frac{W x_o}{y_t}\right) - 1\right] \exp\left[W\left(q_m - q\right)\right] \frac{x_k}{x_o}\right\}$$
$$q \geq q_n \qquad (2)$$

where W the dimensionless mass transfer parameter in the solid phase, q is the specific amount of solvent passed through the extractor, y_t represents the apparent solubility of the solute in the solvent; x_o and x_k represents total initial solute content and the initial concentration of the difficult accessible solute in the solid; z_w the dimensionless axial coordinate between fast and slow extraction; q_m the q value when extraction begins inside the particles; and q_n the q value when the easily accessible part of solute is all extracted.

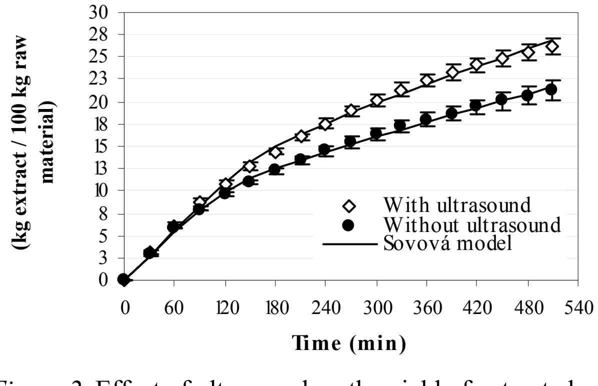

Figure 2. Effect of ultrasound on the yield of extracted oil from particulate almonds. Predicted results (lines).

Figure 2 shows that ultrasound has not effect on the linear part of the extraction curve which is the stage of the controlled by the solubility of the solute in the solvent. On the contrary, ultrasound clearly improves the part of the curve governed by diffusion. These results may indicate that ultrasound increases mass transfer by favouring the penetration and diffusion of the solvent in the solute.

4. Conclusions

It is clear from this research that high-intensity ultrasound improves mass transfer processes inside and outside of the solid. Such effect seems to be well modelled by using diffusion equations.

5. Acknowledgements

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6. References

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