# APPLICATION OF HIGH-POWER ULTRASOUND FOR DRYING VEGETABLES

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E. Riera-Franco de Sarabia, J.A. Gallego-Juárez, G. Rodríguez-Corral, V.M. Acosta-Aparicio, E. Andrés-Gallegos
Instituto de Acústica, CSIC
Serrano 144
28006 Madrid, Spain
0034915618806
0034914117651
jgallego@ia.cetef.csic.es

**ABSTRACT**

High power ultrasound represents a means for food dehydration without affecting the main characteristics and quality of the product. The application of ultrasonic energy can be made alone or in combination with other kind of energies such as hot-air. In this latter case ultrasound helps in reducing temperature or treatment time.

This paper deals with an experimental work in which the results obtained with different kind of vegetables (apple, carrots, mushroom, etc.) under the application of ultrasonic vibration at 20 kHz are presented. Several experimental techniques such us direct contact of the ultrasonic vibration with the product, standing wave and near-field conditions were tested, together with hot-air at several temperatures.

**INTRODUCTION**

The application of high power ultrasound for dehydration of porous materials may be very effective in processes in which heat-sensitive materials such as foodstuff have to be treated [1-4]. In fact, high-intensity ultrasonic vibrations are capable of affecting mass transfer processes with the result of increasing the drying rate of materials. In this way the ultrasonically assisted hot-air drying process may permit the use of lower temperatures or shorter treatment times. As a consequence, this process may be useful for vegetal dehydration without affecting their main characteristics and quality.

This paper deals with an experimental work in which the results obtained with different kind of vegetables (apple, carrots, mushroom, etc.) under the application of ultrasonic vibration at 20 kHz are presented. Several experimental procedures such as direct contact of the ultrasonic vibration with the product, standing wave and near-field conditions were tested, together with hot-air at several temperatures.

For the generation in air of ultrasonic energy a stepped-plate directional transducer working at 21 kHz with a power capacity of 500W, a beamwidth (at 3 dB) of 1.5º and an efficiency of about 80% was used [5].

**EXPERIMENTAL SET-UP FOR FORCED-AIR DEHYDRATION ASSISTED BY ULTRASOUND**

The experimental set-up for vegetable drying by direct coupled ultrasonic vibration and air-borne ultrasonic radiation is shown schematically in Figure 1. It mainly consists of the following components: (i) the stepped-plate power ultrasonic transducer with the corresponding electronic generator; (ii) a flat plate parallel to the ultrasonic radiator acting as a sample holder and as a reflector for standing wave conditions, where the suction pump is applied to remove the moisture extracted from the vegetable; (iii) a static pressure system by means of three pneumatic pistons to get good mechanical coupling between the samples and the vibrating plate of the transducer; (iv) a hot-air generator. In addition, complementary sets of equipment for measuring temperature, air flow velocity and weight were also used. To control the parameters of the driving signal (voltage, current, phase, power applied), a digital power meter was used. An impedance matching box was also used to transfer the maximum electrical energy from the electronic generator to the high-power ultrasonic transducer.

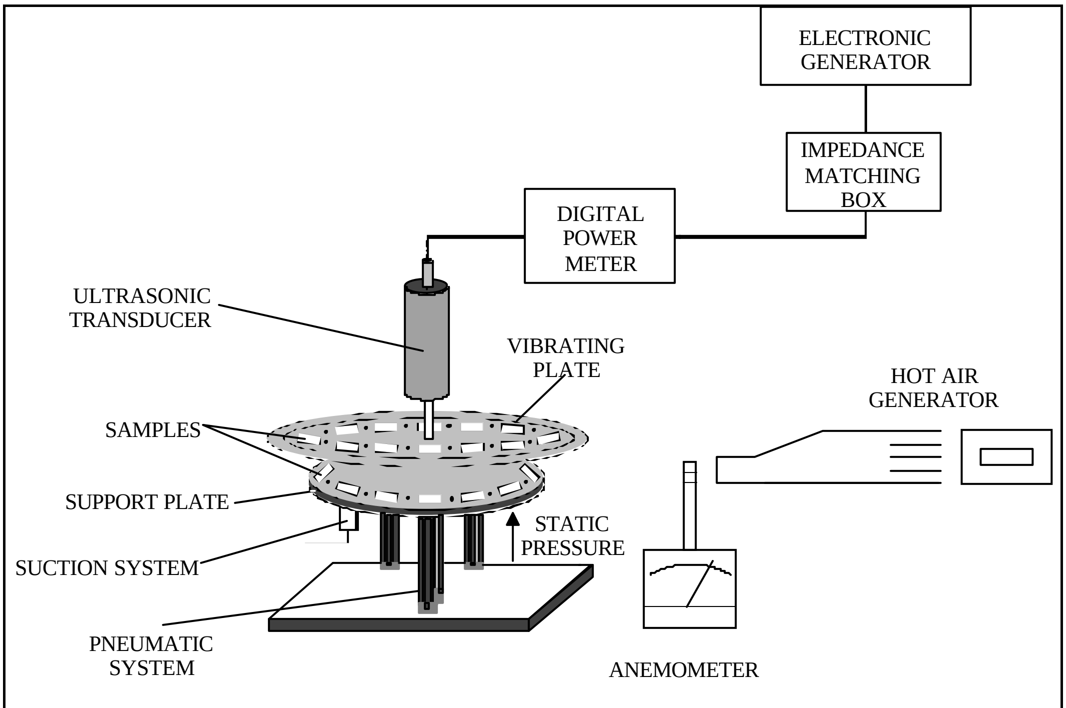

Figure 1. Experimental set-up for vegetable dehydration by high-power ultrasound

The effect of high-power ultrasound on the vegetable drying is the extraction of the moisture from the interior to the surface of the material, where the forced-air and the suction pump help in the last stage of the drying process.

The experimental procedure in all tests basically consisted in measuring the moisture content of vegetable samples at different times of application of high-intensity ultrasonic fields in combination with forced-air at room temperature (20ºC) and at 55ºC and flow velocities of 1.7 and 2 m/s. Both ultrasonic frequency and applied power level were kept constant at about 21 kHz and 100W, respectively. The moisture content of the samples was measured by weighting them. The vegetable samples to be dried were carrot slices of circular shape (14 mm in diameter and 4 mm in thickness), apple slices of rectangular shape (50x20mm and 4 mm in thickness) and mushroom slices (≈ 50x20 mm and 4 mm in thickness).

**DEHYDRATION BY HIGH INTENSITY ULTRASONIC VIBRATION**

Four different procedures by using forced-air and ultrasonic vibration at 20 kHz and 100W were studied:

1. Simple direct contact of the ultrasonic vibration with the vegetable samples.

2. Direct contact under static pressure of the ultrasonic vibration with the vegetable samples.
3. Air-borne ultrasonic radiation by standing wave and near-field conditions

To prepare vegetable samples of apple, carrot and mushroom for drying we follow some general recommendations: choose tender vegetables; wash them; remove any damage area and cut them into even pieces. In addition, apple and carrot samples were blanched during 3 minutes in boiling water before be drained.

1. Simple Direct Contact of the Ultrasonic Vibration with the Samples.

Direct contact increases the ultrasonic effect on vegetable dehydration by reducing the mismatch between the acoustic impedance of the transducer and the samples with regards to the forced-air dehydration assisted by air-borne ultrasound [3]. In fact, the penetration of the ultrasonic energy in the vegetable material strongly depends on this impedance mismatch. To that purpose, the samples were placed on the back surface of the transducer radiating plate as it is shown in Figure 2, between two consecutive nodal circles of the plate. An air flow at 1.7 -2 m/s and 20ºC and 55ºC were also applied to facilitate the removal of the moisture. The drying effect was measured following the experimental procedure previously presented. Experimental tests were carried out with apple, mushroom and carrot samples.

Figure 2. Carrot and mushroom dehydration by applying simple direct contact ultrasonic vibration and forced-air.

Mushroom Dehydration

Figure 3 shows the comparison among the different results obtained by applying ir-flow at two different temperatures (20ºC and 55ºC) with (+US) and without (-US) the ultrasonic vibration. It can be observed that the drying effect is remarkably improved by the ultrasonic energy. The best results are obtained always in presence of ultrasound, although the temperature also plays an important role. The maximum value of temperature used in the experiments (55ºC) doesn't produce deteriorative changes in the vegetable material.

Dry material which corresponds to a sample weight of the order of 10% of the initial total weight of the sample was obtained after 90 minutes of treatment time with forced air at 55ºC and ultrasound. By using only forced-air at the same temperature more than 240 minutes were needed to obtain the same result. Comparison between results obtained at 55ºC with (+US) and without (-US) shows the benefit of using ultrasound by reducing the treatment time up to three times.

Apple Dehydration

A similar behavior was observed with apple samples, as it can be seen in Figure 4. The main difference between the results presented in Figures 3 and 4 is the treatment time needed to reach the dried material. In fact, with apple samples this time was reduced dramatically up to only 30 minutes. It is important to mention that the samples used in the experiments have all of them (apple, mushroom and carrot) 4 mm in thickness. Nevertheless, the initial moisture content in the apple, mushroom and carrot samples was different. Dried apple represents ~ 6% of the initial weight of the samples, instead of the 10% measured in mushrooms and carrots.

Other important factor that influences dehydration rate process is that the apple samples were blanched in boiling water, but not the mushroom. In fact, blanching involves opening pores in the material making easier and quicker the removal of the moisture.

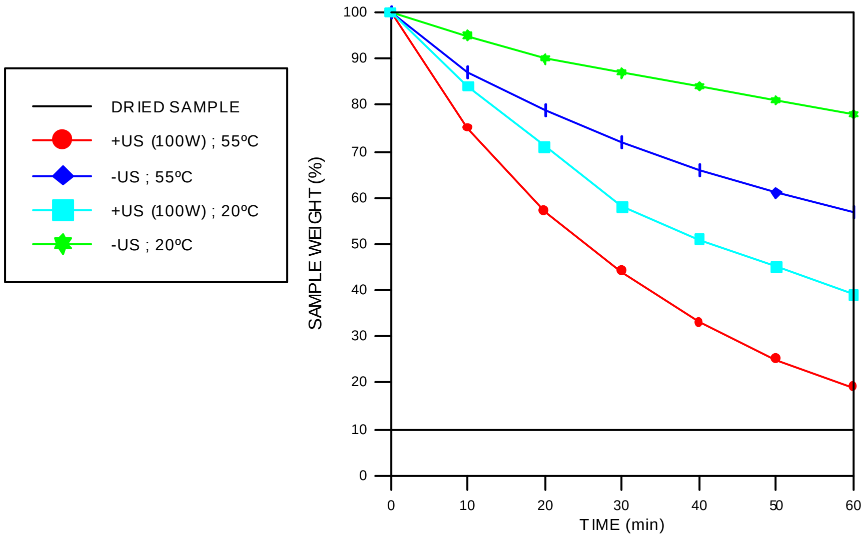


Figure 3. Mushroom dehydration curves obtained by applying simple direct contact ultrasonic vibration and forced-air.

Comparison between the final sample weight obtained at 55ºC with (+US) and without ultrasound (-US) shows (see Figure 4) that by the action of ultrasound the weight of the samples decreases dramatically up to 6% (+US) after 30 minutes treatment time, while without ultrasound the final weight in the same period is 40%. In other words, the ultrasound accelerates forced-air drying process demonstrating to be very effective for food dehydration

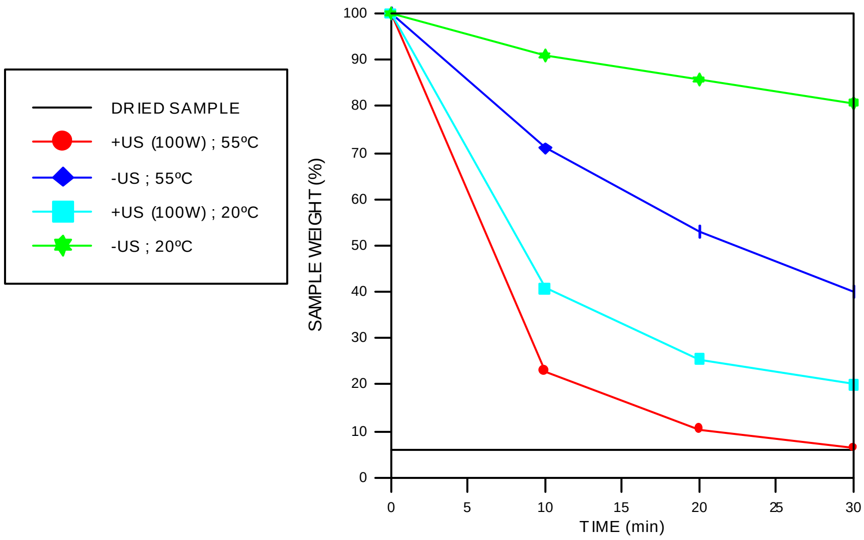


Figure 4. Apple dehydration curves obtained by applying simple direct contact ultrasonic vibration and forced-air.

<u>Carrot Dehydration</u>

To obtain dried carrot (sample weight ~ 10%) at 55ºC, the ultrasound (100W) was applied to the samples during 50 minutes. On the contrary, more than 2 hours were needed to get the same result in absence of ultrasound. At lower temperature of the air (about 20ºC) dried carrot requires

100 minutes of treatment approximately. Longer times, higher than 3 hours were needed to reach values of the order of 25% of the initial total weight of the sample. Therefore the effect of ultrasound is to reduce notably treatment times without using high temperatures.

2. Direct Contact Under Static Pressure of the Ultrasonic Vibration with the Vegetable Samples.

By means of this procedure developed and patented by the High-Power Ultrasonics Group of the Instituto de Acústica the ultrasonic vibration was applied in direct contact with the vegetable samples and together with a static pressure (see Figure 5) [3]. The samples were placed on the surface of the flat plate holder and the transducer radiating plate was kept there during the treatment time by applying a static pressure of about 0.05kg/cm$^2$. Although an air-flow at 1.7-2m/s and 20ºC and 55ºC was also applied to facilitate the removal of moisture, the benefits of using forced-air were less evident than previously. This was probably because the narrow gap between the vibrating plate and the flat plate acting as a sample holder where the suction pump is applied. The dimension of the gap was diminishing with treatment time in proportion with the amount of moisture removed from the samples. The thickness of the samples at the end of the ultrasonic drying process was less than 1 mm. So, in this case static pressure and suction pump have a more relevant role than the force-air flow in the vegetable drying process.

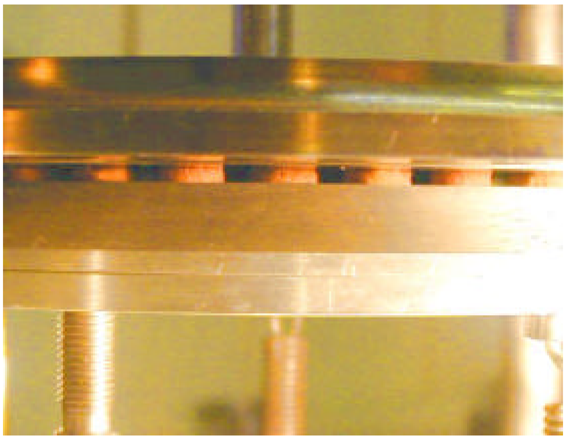

Figure 5.- Carrot dehydration by using directly coupled ultrasonic vibration

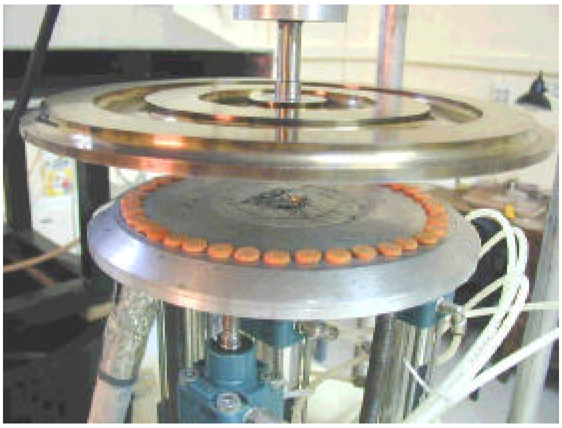

Figure 7. Carrot dehydration by using air-borne ultrasonic standing wave field and suction.

Figure 6 shows the results obtained with carrot slices. It can be appreciated that the drying effect was improved by ultrasonic vibration at both temperatures (20ºC and 55ºC). In fact, the drying process is not only quicker but it is more powerful: the final moisture content could be less than 1%. In addition, due to the processing time and low temperature of the air flow, the product qualities are well preserved.

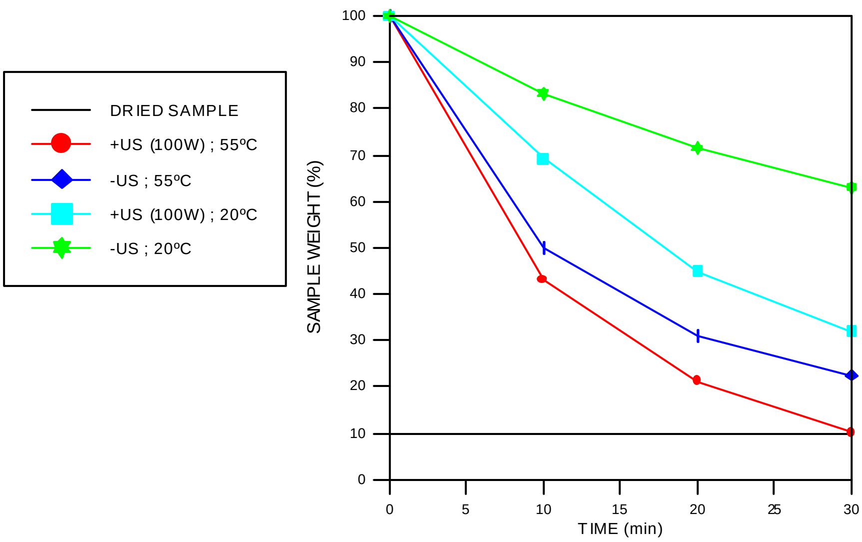

Figure 6. Carrot dehydration curves by directly coupled ultrasonic vibration under static pressure

Apple samples at 55ºC and 20ºC only need 20 and 60 minutes of ultrasonic treatment, respectively, to be dried. In contrast, for the same conditions, but in absence of ultrasound, 60 and more than 200 minutes were required, respectively, to get the same result. To dry mushroom at both temperatures, 40 and 120 minutes were needed with ultrasound (+US), and much longer process times (> 2 hours at 50ºC and > 4 hours at 20ºC) without ultrasound (-US) were required.

3. Air-borne ultrasonic radiation by standing wave and near-field conditions

The effect of air-borne ultrasonic drying under a standing wave field was also analyzed. To that purpose the stepped-plate power ultrasonic transducer was separated from the flat plate parallel to the radiator which acts as a reflector and tuned for the formation of a standing wave field. In this procedure, samples were placed on a metal grid located between the vibrating plate and the reflector. In these experiments, only carrot was tested. The results show that the effect of ultrasound is a little higher at low than at high air-flow temperature. Better results were obtained by working in the near-field. In this other procedure, carrot samples were placed directly on the flat plate holder. The distance between the vibrating plate and the flat plate was of about 1 mm higher than the thickness of the samples (~ 4 mm). To get a 4% of initial moisture content in the samples, a 30 minutes treatment was adequate.

## ACKNOWLEDGEMENTS

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## CONCLUSIONS

From the investigation presented in this work on the application of high-power ultrasound for drying different kind of vegetable materials (apple, carrot and mushroom) the following conclusions can be stated:

The application of a high-power ultrasonic vibration in direct contact with samples in both, without and with static pressure, has confirmed to be a very effective procedure for vegetable dehydration. Direct coupled vibrations accelerates forced-air drying process notably. Both procedures may be useful for vegetable dehydration as a method for preserving foods without affecting their main characteristics and quality.

The improvement obtained by applying high-intensity air-borne ultrasound for vegetable dehydration is less than with direct contact. This fact can be due to the low penetration ultrasonic energy in the vegetable material produced by the mismatch between the acoustic impedance of both media, the air and the vegetables. Nevertheless, an experiment carried out in the near-field gave results closer to the contact technique. This point should be studied with more detail

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