

# An Introductory Review of Applications of Ultrasound in Food Drying Processes

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## Abstract

In this study, applications of ultrasound in food drying processes have been reviewed. High frequency ultrasonic treatment can be used in food drying processes as a pretreatment or for the improvement of the main process and the traditional driers. Ultrasonic waves at low frequency can also be used as a diagnostic method for measuring properties of the final dried products and controlling the drying process. Ultrasonic pretreatment has direct and indirect applications. Ultrasonic direct pretreatment improves drying processes by intensifying heat and mass transfer. Indirect implementations of this technology involve the ultrasonic waves as parts of drying systems such as nozzles of spray-driers or freezing sections in freeze-drying systems.

**Keywords:** Ultrasound; Drying; Ultrasonic pretreatment

## Introduction

Dehydration can be regarded as one of the oldest methods of food preservation. For thousands of years humans have dried or smoked meat, fish, fruits and vegetables to sustain them during out of season periods. Today, the dehydration section of the food industry is large and extends to all countries in the world [1]. The reduction of water content of products contributes to the preservation of the raw matter by preventing the degradation during the storage and transportation [2]. Drying facilities range from simple sun- or hot-air driers to high capacity, sophisticated spray- or freeze-drying units [1].

The use of ultrasound within the food industry has been subject of many studies [3]. Ultrasonic waves are sound waves with frequencies far beyond that to be detected by the human ear [4]. Electrical energy can be converted into ultrasonic sound waves (20 kHz–10 MHz), which are produced via an ultrasound vibration probe or an ultrasonic bath equipped with piezoelectric crystals. The type of application can determine the intensity and the frequency of the sound used in a processing unit [5]. Low-power, high-frequency ultrasound (<1 W/cm<sup>2</sup>; >100 kHz) is normally used to monitor products or processes and high-power, low-frequency ultrasound (10–1000 W/cm<sup>2</sup>; 20–100 kHz) is normally used to alter the properties of a material or to facilitate the progress of a process [4]. One major impact ultrasound has on the material is cavitation, which leads to the production of gas bubbles and occurrence of micro streaming through the materials by applying low frequency ultrasound waves [6]. Ultrasonic properties of materials where ultrasonic waves strike to the material and reflect which can be measured and used for non-destructive diagnostic tests [7], for measuring flow rates, temperature, density, porosity, pressure, viscosity and other transport properties such as level, position, phase, thickness, composition, texture, grain size, stress and strain, elastic properties, bubble, particle and leak detection, acoustic emission and imaging and holography [8].

Ultrasound has become an efficient tool for large scale commercial applications such as emulsification, homogenization [9], extraction [10], crystallization, dewatering, low temperature pasteurization, degassing, defoaming, activation and inactivation of enzymes [5], particle size reduction, viscosity alteration [9], germination of seeds [11], evaporation, oxidation for pharmaceuticals [12], food and other industries [8]. Ultrasound causes of intensifying mass and heat transfer can be used in many operations such as drying and dehydration [13,14]. In the current study, application of ultrasound in food drying processes

for the diagnostic tests after process has been reviewed.

## Ultrasonic Pretreatment before Drying Process

Ultrasound technology has been directly or indirectly used as a pretreatment in many drying and/or dehydration applications [15]. Direct pretreatment improves the drying process by intensifying mass and heat transfer and the microstreaming phenomena in the structure of the material [16]. Indirect pretreatment effects work in operations relevant to drying or dehydration operations [17]. Ultrasonic pretreatment can be used before air-drying and osmotic dehydration of vegetables and fruits [18]. Studies show that the effective water diffusivity increases after application of ultrasound causing a reduction of about 16% in the drying time [19]. The increase in the effective water diffusivity has been estimated at 28.8% after 20 min of ultrasound and this phenomenon may happen due to the process of formation of microchannels during the application of ultrasound in the structure of the material [16]. The power to increase the effective diffusivity of water in air-drying and osmotic dehydration makes the use of ultrasound as an interesting pretreatment operation complementary to the classical drying procedures [20,21]. Ultrasonic pretreatment can reduce sugar content of vegetables and fruits so such a pretreatment stage can be a practical process to produce dried fruits with lower sugar contents [22]. Cause of this effect is more intense in the release of water-soluble solids during the ultrasonic treatment in the ultrasonic bath [12,15–17]. This pretreatment can also increase water absorption of the dried product after drying process [23].

Indirect effects of ultrasonic pretreatment can be applied in operations related to drying such as freezing, atomization and blanching that are used in freeze-drying, spray-drying and other drying procedures [5]. In freezing operations, the created cavitations promote ice nucleation and as a result heat and mass transfers are accelerated.

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Ice crystals will fracture when subjected to alternating acoustic stress, consequently leading to the production of smaller size crystals. This reduction in size can help reduce the destructive effect of large crystals on the texture of food materials [6]. Vibration probes can be used to produce ultrasonic waves for such pretreatment [23].

Ultrasonic nozzle systems are used as an atomization appliance in spray-driers. When liquids are pumped through the orifice at high pressure and velocity, piezoelectric crystals can increase the intensity of liquid atomization [24]. So, this effect can improve the efficiencies of spray-driers in spray-drying processes. An ultrasonic atomization system is shown in Figure 1 published by Riemer [23,25].

### Ultrasonic Treatment during the Drying Process

High power-low frequency ultrasound represents a means for food dehydration without affecting the main characteristics and quality of the product [26]. The application of ultrasonic energy can be made alone or in combination with other kinds of drying methods such as hot-air and osmotic dehydration [27]. Studies have shown that ultrasonic treatment can also be used to develop the drying process of such vegetables as apple, carrot and mushroom [28]. Application of ultrasonic vibration at 20 kHz for such treatment has been reported [27]. By increasing heat and mass transfer during the drying process, ultrasonic treatment used with hot-air drying can reduce the input power to approximately 20% in comparison with non-treated ultrasonic drying systems [29]. It can also lead to a decrease of 6% in the final moisture level [30] and decrease of 16% in the duration of drying process [2].

Ultrasound has been used as a means to enhance the efficiency of mass transfer during the osmotic dehydration of fruits and vegetables. The responsible phenomenon is called the sponge effect [14]. Ultrasonic waves can cause alternating compressions and expansions resulting in microscopic channels in the porous materials [13]. Cavitation can also collapse explosively and generate localized pressure accelerating the degassing process resulting in higher diffusion rates in such processes as osmotic dehydration [2]. An ultrasound-assisted hot-air drying system (in non-contact condition) is shown in Figure 2, which consists of a hot air generator, an ultrasonic transducer with the corresponding electronic generator and a flat plate parallel to the ultrasonic radiator acting as a reflector for the formation of a standing wave and also as sample holder. Complementary sets of equipment for measuring temperature, air flow velocity, and weight were used. Equipment for hot-air drying system assisted by ultrasonic waves is shown in Figure 3 [31].

### Ultrasonic Drier

With the use of ultrasonic vibration under the vacuum condition, ultrasonic waves can intensify the mobility of water molecules and facilitate the evaporation process. Therefore, it can be used in place of heating for the removal of water molecules [32]. Ultrasound-assisted driers can dehydrate the porous materials by using an ultrasonic vibrating plate (in contact mode) and applied vacuum condition [27,33]. A dehydration unit applied for drying of carrots by using directly coupled ultrasonic vibration (ultrasonic drier) was reported by Riera [27]. The above-mentioned drying technology takes advantage of low frequency ultrasonic waves (20 KHz) with high-power [28]. Enhanced energy efficiency, better quality products, reduced environmental impact and safety of system are considered as advantages reported for this new technology [34].

### Applications of Ultrasound in Diagnostic Methods

High frequency ultrasonic waves can reflect after striking to the

surface of a material. The reflected wave is then recorded by appropriate detector(s). This is the basis of applying ultrasonic waves for diagnostic purposes [35]. Using this technology, physico-mechanical properties of materials such as porosity of porous and aerated materials can be measured during or after the process and the process can be controlled online. Other physico-mechanical characteristics of food products during or after drying process such as weight-loss and thickness can also be assessed by using velocity and absorption coefficients of ultrasound in food product sample.

### Conclusions

In the present study, different applications of ultrasound in food drying process were divided into ultrasonic pretreatment, ultrasonic treatment during the drying process, ultrasonic drier and diagnostic ultrasonic methods. Ultrasonic pretreatment makes direct effects in drying process or can be used as part of a drying system such as nozzle in spray-driers or in freezing sections of freeze-drying systems. Ultrasonic waves with intensifying heat and mass transfer during the drying process can also be developed. Ultrasonic diagnostic methods are also used to investigate the final characteristics of dried products and also for the online control of a drying process.

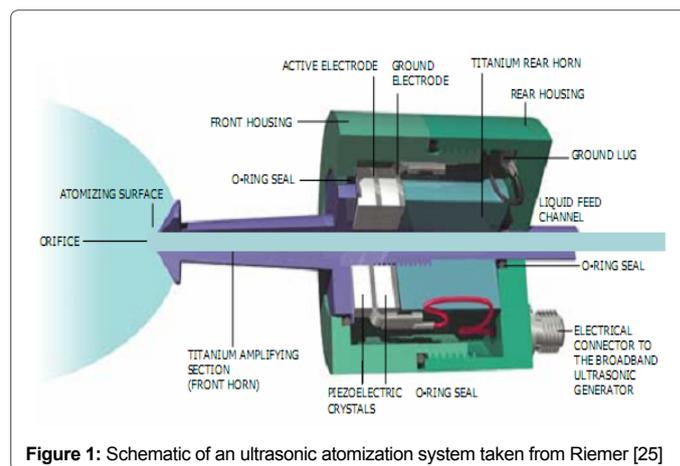


Figure 1: Schematic of an ultrasonic atomization system taken from Riemer [25]

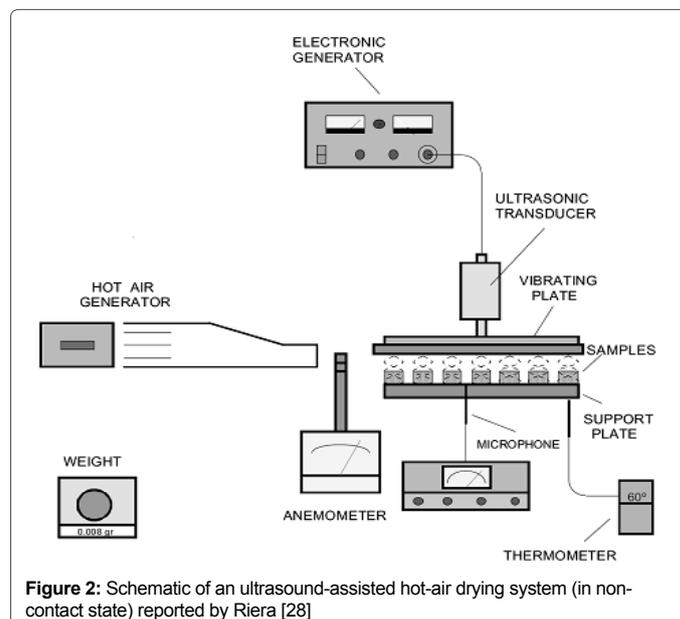


Figure 2: Schematic of an ultrasound-assisted hot-air drying system (in non-contact state) reported by Riera [28]

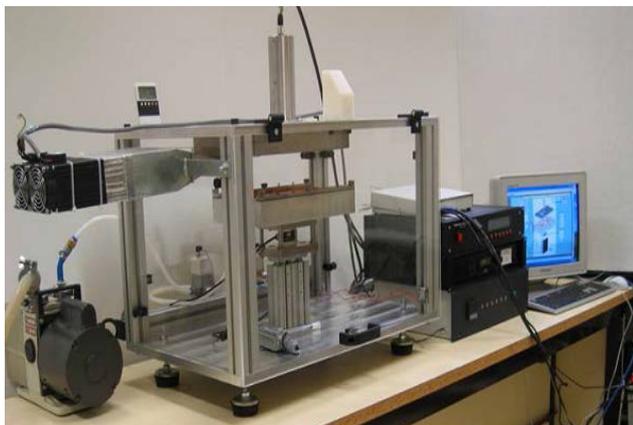


Figure 3: Equipment used by Riera [31] for air-drying system assisted by ultrasonic waves

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