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How to make a microwave vacuum dryer with turntable

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ABSTRACT

A domestic microwave oven was modified in order to operate as a microwave vacuum dryer with turntable. The dryer performance was assessed with banana, grape tomato and carrot slices, dried under vacuum. Three different levels of microwave power (400, 700 and 1000 W) were tested to evaluate the influence of microwave power on the drying. The experimental results showed that it is possible to produce dried fruits and vegetables with characteristics similar (crisp and crunch) to those produced from a freeze-drying process, in much shorter process times, e.g. 20 min against the 14–16 h, typical of freeze-drying processes. The system presented in this work is a low cost, flexible and ease-to-assemble device, which can be made from domestic microwaves. It works properly with turntable, under vacuum that allows controlling the temperature and leads to uniform food heating, which improves the quality of the dried fruits and vegetables. In this way, this low-cost microwave vacuum drying is very useful to investigate the drying of fruits and vegetables at lab scale, and can be the base for making larger equipment.

1. Introduction

Food dehydration processes are used to reduce the moisture content and water activity, in order to inhibit microbial growth, decrease enzymatic activity and chemical reactions rates. Drying extends the shelf life of foods and reduces the costs of transportation and storage, because the products have lower weights and volumes and can be stored at room temperature (Van Arsdel, 1963; Fellows, 2000; Ratti, 2001; Aguilera et al., 2003; Singh and Heldman, 2009). In addition, this food preservation method helps to smooth out (seasonal) variations in consumption oscillations and to develop new food products.

Classically, freeze-drying has been considered an excellent dehydration procedure for thermosensitive fruits and vegetables, because it maintains the structural rigidity during dehydration, avoiding the structure collapse and leads to a preserved porous structure (Ibarz and Barbosa-Canovas, 2003; Ratti, 2008). However, freeze-drying is a time-consuming and relatively costly process, which limits its use to products with high added value (Louka and Allaf, 2002).

Vega-Mercado et al. (2001) considered dehydration processes which involve high-vacuum, microwaves, radio frequency and refractance window as the fourth generation drying technology. These processes can produce dried fruit and vegetables with higher quality. Drying processes based on the application of instant controlled pressure drop (Louka and Allaf, 2002; Mounir and Allaf, 2008) and successive cycles of heating-vacuum pulses (Zotarelli et al., 2012) are reported in the literature as capable of producing dehydrated-and-crunch products.

Microwave drying has the advantages of shortening drying times and improving product quality, resulting in high nutritional and sensory quality products (Datta and Anantheswaran, 2000; Zhang et al., 2006). The energy absorption by the wet material depends on its moisture distribution, which causes selective heating of its interior parts, protecting low moisture parts, e.g. material surface, from overheating (Chandrasekaran et al., 2013). Moreover, microwave heating causes volumetric heating, so vapor is generated inside the product, developing internal pressure gradients that cause water flow from the interior to the surface of the material (drainage). In this way, food shrinkage is reduced (Zhang et al., 2006).

Literature reports many studies on the use of mathematical models in microwave heating (Geedipalli et al., 2007; Salvi et al., 2011; Pitchai et al., 2012), microwave drying (Constant et al., 1996; Boldor et al., 2005; Chatterjee et al., 2007) and microwave assisted drying (Perre and Turner, 1997; Gowen et al., 2008; Kowalski et al., 2010; Rakesh et al., 2010; Malafronte et al., 2012). Furthermore, mathematical models have been used to assess the influence of the main process variables on the final

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product quality, in order to an effective production control (Malafronte et al., 2012).

Vacuum drying is particularly suitable for products that are sensitive to heat, such as fruits with high sugar content and certain vegetables with high added value (Zhang et al., 2006). Microwave heating under vacuum improves the efficiency of drying and prevents or reduces oxidation, preserving product color, texture and flavor, leading to products with quality compared to freeze-dried products (Gunasekaran, 1999; Lin et al., 1998).

On the other hand, one disadvantage of microwave heating is the inherent lack of uniformity of the electromagnetic field inside the microwave dryer, which can lead to non-uniform heating. However, this problem can be partially offset by using wave-guides and a rotating tray (Cohen and Yang, 1995). Literature reports many studies on microwave vacuum drying of fruits and vegetables, as banana (Drouzas and Schubert, 1996; Mousa and Farid, 2002), carrots (Lin et al., 1998), garlic (Figiel, 2009), mint leaves (Therdthai and Zhou, 2009), mushrooms (Giri and Prasad, 2007), potatoes (Song et al., 2009), among others. However, these studies did not report the use of turntables to improve the homogeneity of microwave distribution into the food.

There are several studies that report rotating system for a better distribution of microwaves in fruits and vegetables during drying (Cui et al., 2003; Clary et al., 2005, 2009; Sutar and Prasad, 2007; Puschner, 2012-2015; Calín-Sánchez et al., 2014; Ghazi et al., 2014). Microwave drying of cellulose derivative (hydroxypropyl methyl cellulose, HPMC) was done in a chamber with two integrated mode stirrers for a better distribution of the electromagnetic waves in the drying chamber and samples (Barba et al., 2013). Rinaldi et al. (2015) reported microwave reactors able to operate with rotating vessel under vacuum.

In this context, the present study explains how to adapt a microwave oven with turntable for operating as a microwave vacuum dryer, capable of promoting uniform food heating that leads to high quality dried fruits and vegetables. The developed device was tested for drying bananas, grape tomatoes and carrots. Freeze-dried samples were prepared in order to compare processes and products.

2. Materials and methods

2.1. Samples preparation

Bananas (*Musa sapientum* L., Prata variety), grape tomatoes and carrots (*Daucus carota*) were purchased in a local market (Florianopolis, SC, Brazil). The fruits and vegetables were selected based on their state of ripeness, evaluated from the visual appearance, soluble solid content (using a digital refractometer, Model AR200, Reichert, USA), and resistance to penetration (using a penetrometer, Model FT 327-$\varnothing = 8$ mm, Effegi, Italy). Banana samples presented diameter of 27.6 ± 3.5 mm, with soluble solid content of 22.5 ± 1.6 °Brix and penetration resistance of 5.9 ± 1 N. The grape tomatoes were considered as cylindrical, with length of 29.1 ± 3.6 mm and diameter of 20.2 ± 3.2 mm, presenting soluble solid content of 7.3 ± 0.7 °Brix. The carrots presented diameter of 38.4 ± 4.0 mm. The selected bananas and carrots were washed, peeled and cut into slices of 5 mm of thickness, avoiding fruit and vegetables ends, where diameters are smaller. The grape tomatoes were washed and cut in half, in the axial direction.

2.2. Experimental device

A sketch of the microwave vacuum dryer, which operates under vacuum and with turntable, is given in Fig. 1a. A domestic microwave oven (Electrolux, Model MEX55, Joinville, Brazil) with internal space of 45 L, maximum magnetron output power of 1000 W and frequency of 2450 MHz was chosen for making the dryer. A container of polypropylene was used as the vacuum chamber in the interior of the oven Polypropylene was selected because it is a nontoxic material with appropriate dielectric properties (dielectric constant, $\varepsilon' = 2.2$, and loss tangent, $\tan\delta = 0.0003$–0.0004)) and good mechanical resistance. The container was connected to a vacuum service line capable of establishing a vacuum pressure of 4 kPa, registered by a pressure transducer (Warme, Model WTP – 4010, Itú-SP, Brazil) connected to a computer. A column of silica gel was used for adsorbing the water vapor at low pressure from the dryer, helping the pump system to maintain the vacuum level. Fig. 1b shows details of the rotary system with mechanical seal, which allows the vacuum chamber to rotate with the turntable.

Roughly, the rotary system consists of a T valve connected to a rotary joint formed by a fixed shaft (connected to the vacuum service line) and a free shaft (connected to the vacuum chamber). As mentioned before, this rotating system helps homogenizing the absorption of microwaves by the fruit samples during drying.

In more detail (see Fig. 1b), the rotary system comprises: (1) T valve; (2) rotary joint (mechanical seal); (3) free axis of the rotary joint; (4) TC (Tri-clamp) silicone gasket; (5) stainless steel bushing with a TC nipple at the top end and a flange at the bottom end; (6) external metal cover of the microwave oven; (7) metal ceiling of the microwave oven; (8) teflon shaft connected to the polypropylene lid by a male thread, and to the rotary joint free axis by a female thread; (9) lid of polypropylene; (10) nylon bushing with TC nipple at the bottom; (11) brass hex nipple screwed laterally to the rotary joint free axis and fixed vertically to the nipple of a Teflon tube; (12) Teflon tube; (13) hex nuts; (14) Teflon nipple. The stainless steel bushing and the nylon bushing with a TC silicone gasket in the middle were coupled by a stainless clamp. The blue dashed line represents the free path that connects the rotating system to the vacuum chamber.

Microwave energy is attenuated as it passes through a circular waveguide having a diameter less than that which allows the power to propagate freely. This circular waveguide is commonly called a "cut-off tube" and is used extensively in the design of window screens, ventilation ports and other such openings for microwave cavities (GAE, 2005-2009). The rate of power attenuation is a function of its wavelength and cut-off tube radius, based on the following equation for the attenuation constant α (dB/m), Eq. (1),

$$\alpha = 8.686\sqrt{\left\{\left(\frac{2\pi}{\lambda_c}\right)^2 - \left(\frac{2\pi}{\lambda_0}\right)^2\right\}} \tag{1}$$

in which λ_c (cut-off wavelength) = 3.413 × tube radius (for propagation mode transverse electric dominant for cylindrical wave guide TE_{11}, $f = 2.45$ GHz), λ_0 (wavelength in unbounded medium) = 0.1224 m (for dielectric air) (Meredith, 1998; GAE, 2005-2009).

GAE (2005-2009) application bulletin plots curves of Tube ID vs attenuation from Eq. (1), for ISM frequencies at 915 MHz, 2450 MHz and 5.8 GHz, which are used to find the minimum cut-off tube length given the tube diameter and the entering and exiting power densities, applying only to empty (air filled) cut-off tubes.

The tube radius in this study (part 5, Fig. 1) measures 0.02185 m, which yields attenuation of 580 dB/m from Eq. (1).

The maximum output from industrial equipment and consumer appliances should be limited to 1 mW/cm^2, when measured at 5 cm from the source (FDA, 2012). A conservative estimate of the maximum incident power density in a lightly loaded cavity is given by (GAE, 2005-2009).