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Study of the effect of microwave power coupled with hot air drying on orange peel by dielectric spectroscopy

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ABSTRACT

Monitoring moisture and water activity during drying is crucial for process optimization, avoiding inadequate uses of energy. The main objective of this work was to study the dielectric properties of orange peel during hot air drying at 55 °C (HAD) and microwave power coupled with hot air drying at different power intensities (2 W/g, 4 W/g and 6 W/g). At 5, 15, 40, 60 and 120 min mass, a_w, moisture, and permittivity were measured in fresh and dried samples. Results allowed developing a dielectric isotherm technique by adapting the GAB model to predict a_w in dried orange peel by using ε' (20 GHz). The physical meaning of the dielectric isotherm parameters (ε'_0 and C_d) was studied. The value of ε'_0 at 20 GHz (γ-dispersion) represents the induction effect of the minimum quantity of adsorbed water or the monomolecular moisture layer. The parameter C_d is related with isosteric heat, as well as the C parameter of the GAB model. The application of MW power produced an increase of isosteric heat or adsorption energy of the monomolecular layer, improving surface tension of samples and thus the hygroscopicity, explaining the reduction of the ε'_0 independently of the quantity of the water molecules adsorbed.

1. Introduction

Drying costs are a major issue in most valorisation processes, especially when the water content of the material is as high as citrus by-products (85%), being critical for their economic feasibility. Therefore, moisture monitoring plays a key role in food processing operations such as drying. However, water interaction with air and food depends more on water activity than on moisture, because the reactivity and the mobility of water are directly related with the water activity. The most common and faster tool to obtain the water activity from the moisture is the sorption isotherm. Sorption isotherms relate water activity to water content of a food product at a certain temperature and pressure. The sorption isotherms have an important role in the quantitative approach to the prediction of shelf-life of dried foods, due to their sensitivity to moisture and water activity changes.

On the other hand, the research of electrical properties of food systems has received tremendous attention in the recent years due to the increased development and application in the range of Hz to THz (radiofrequency, microwaves and infrared) for heating, drying or process monitoring in the food industry. The physical properties that define the heating capability of any material are permittivity for the photon electric interactions and permeability for the photon magnetic interactions (Pozar, 2012). They are affected by many different factors, depending on the range of frequency of the photon flux emitted (Castro-Giraldez, Balaguer, Hinarejos, & Fito, 2014), such as amount of water, temperature, structure (i.e. charge conformation of proteins) and chemical composition (i.e. electrolytes), especially on the presence of mobile ions (Castro-Giraldez, 2010). In the case of electric properties, the permittivity must be explained as a vector number, polar or complex. Permittivity explained as a complex number has two parameters, the dielectric constant ε' and the loss factor ε'', being the real and imaginary terms of permittivity (ε), respectively. The dielectric constant is related to the material ability to absorb and store electric energy, and the loss factor is related to the dissipation of the electric energy in other energies such as thermal energy.

In the range of microwaves, the interaction of the photon flux with biological tissue produces two main dispersions, γ-dispersion and ionic conductivity. The γ-dispersion is due to the dipolar molecules orientation and induction, producing electric storage

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and dissipation of the electric energy in other energies such as mechanical and thermal energies. The main dipolar molecule of plant tissue is water (Castro-Giraldez, Fito, Chenoll, & Fito, 2010; Castro-Giraldez, Fito, Dalla Rosa, & Fito, 2011; Castro-Giraldez, Fito, & Fito, 2011). The other important effect in microwave range is ionic conductivity. It affects only to the loss factor, because it only produces a repulsion of charged molecules, transforming electric energy into others.

Dielectric spectroscopy has been used for many applications as non-destructive technique for monitoring different processes: pork meat salting (Castro-Giraldez, Fito, & Fito, 2010; Kent, Peymann, Gabriel, & Knight, 2002; Lyng, Zhang, & Brunton, 2005), brewing (Velázquez-Varela, Castro-Giraldez, & Fito, 2013), dehydration (Feng, Tang, & Cavalieri, 2002) and osmotic dehydration of apple (Castro-Giraldez, Fito, & Fito, 2011) and kiwi (Castro-Giraldez, Fito, Dalla Rosa, et al., 2011) and also for determination of apple maturity (Castro-Giraldez, Fito, Chenoll, et al., 2010). Traffano-Schiffo, Castro-Giraldez, Colom, and Fito (2015) analyze the viability of monitoring drying meat processes by using dielectric properties measurements at microwaves frequencies. The authors showed that there was a direct relationship between the dielectric loss factor with respect to sample surface and the number of water molecules at 20 GHz, obtaining also the desorption isotherm. This relationship can also be used for determining food product composition by applying dielectric spectroscopy. Iaccheri et al. (2015) studied water features in green and roasted coffee beans by dielectric spectroscopy.

Talens, Castro-Giraldez, and Fito (2015) analyzed the dielectric loss factor at 2.45 GHz (most commonly used MW frequency in Europe) of orange peel dried by hot air-microwave drying in order to quantify the amount of microwave energy that was absorbed and transformed into heating energy. This calorific energy was absorbed by the water molecules because at 2.45 GHz the relaxations phenomena were caused by the induction of polar molecules like water. Fava et al. (2013) also applied microwave drying to citrus by-products in order to dehydrate the final product for further conversion into dietary fiber with optimal microbial, sensory and technological properties.

In microwave assisted drying processes, the knowledge of dielectric properties and parameters that affect their values allows to predict moisture content, water activity and drying kinetics (Barba & d'Amore, 2012). The aim of this work was to develop and to determine dielectric tools to predict the moisture and water activity by using dielectric spectroscopy and sorption isotherms of orange peel dried by microwave power coupled with hot air drying.

2. Materials and methods

Oranges (*Citrus sinensis* (L.) Osbeck var Washington Navel) were bought from a local supermarket in Valencia (Spain). Orange peels were used for the experiments. 60 orange peel cylinders (20 mm diameter and 3 mm thickness) were cut with a core borer. A diagram of the experimental procedure is shown in Fig. 1.

Samples were subjected to hot air drying (HAD) and microwave assisted air drying (HAD + MW) (Fig. 2), using a specially designed MW-air drying oven (Martín, Martínez-Navarrete, Chiralt, & Fito, 2003) with maximum output 2000 W at 2450 MHz, connected to a computer where temperature of ambient air and hot air, relative humidity of ambient air and incident and reflected microwave energy could be registered. In order to measure incident and reflected energy a directional coupler with power meter was also connected to the computer. The modified microwave oven presents two parallel connected lines (diameter = 105 mm), one for the application of hot air and another for the generation and application of the microwaves. Drying chamber has a Teflon chamber (edge = 100 mm) and a mode stirrer to ensure a homogeneous microwave distribution. Different variables were measured in drying chamber for process control: hot air temperature by a Pt100

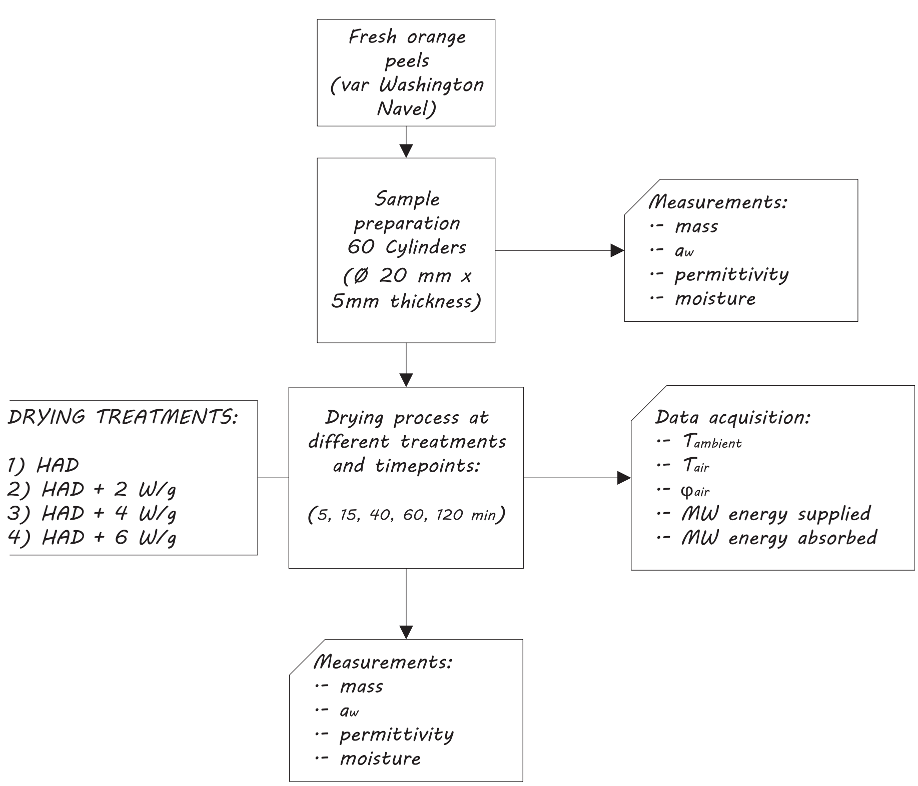

Fig. 1. Schematic diagram of the experimental procedure.