Journal of Food Engineering 190 (2016) 167–175

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Effect of relative humidity on microwave drying of carrot

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ARTICLE INFO

Article history:
Received 7 October 2015
Received in revised form
26 June 2016
Accepted 29 June 2016
Available online 1 July 2016

Keywords:
Microwave drying
Humidity control
Carrot
Drying rate
Quality

ABSTRACT

The aim of this study is to investigate the influence of the relative humidity on the product quality during microwave drying process. A new microwave drying system with humidity control was developed. Twelve schemes were planned in the experiments, for the purpose of changing the relative humidity of the convection air. The relationship between the humidity and the drying rate as well as the product quality were discussed. Nonparametric ANOVA and multiple comparisons were conducted. Results showed that the complementary water method could provide the best product quality, followed by the accelerated and low rate air flow schemes. High flow rate and decelerated air schemes should be avoid if the product quality is of utmost consideration. The accelerated air schemes should be a compromise proposal if the drying rate is also concerned.

1. Introduction

Microwave drying is an efficient method for postharvest processing of agricultural products. Its time efficiency, low energy consumption and high product quality are three major factors which can be taken advantage of by drying industry. With the development of new technologies, more parameters can be monitored and controlled today during the drying process, such as temperature, weight, power, odor etc. (Bouraoui et al., 1994; Kowalski and Mielniczuk, 2007; Li et al., 2010a; 2010b; Li et al., 2011; Li et al., 2010c; 2010d; Raghavan et al., 2010; Seyfarth et al., 2003).

Our previous researches show that, the increased relative humidity of the convection air could be a prominent factor which might slow down the drying speed but protect the surface or even inside quality of the products. During microwave drying, the convection air serves as a carrier of the volatile compounds which continuously emitted from the being dried matter. The diffusion model for the volatile compounds is similar to the moisture transport equation, whose driving force depends on the concentration difference. We hypothesize that the full or half saturated humidity of the convection air surrounding the samples can prevent the over fast run out of useful volatile compounds from the product, and also disperse the microwave energy to avoid damage of the product.

Existing researches reported on drying kinetics related to the humidity mostly aimed to improve the drying rate by lowering the relative humidity of the convection air (Iguaz et al., 2003; Krokida et al., 2003; Léonard et al., 2005; Ondier et al., 2010; Toğrul and Pehlivan, 2002; Villeneuve and Gélinas, 2007). Only a few literature could be found on the employment of high humidity in drying process (Estrada and Litchfield, 1993; Westerman et al., 1973). Moreover, the drying method in these works involved natural, solar and convective drying only, but not the microwave drying. An investigation shows its necessity on the effect of high humidity on the drying rate as well as the product quality in microwave drying, which could be a useful technology for industries such as drying vegetables and fruits in closed packages.

To address the problem, the humidity of the convection air is attempted to be monitored and controlled in this study. A new microwave drying system was developed for this purpose. The system was combined with three subsystems, a thermostatic microwave heating system with online mass weighting, a one-way air flow control system used to evacuate the gaseous moisture, and a humidity measuring system. Carrot was used as the drying samples as it is easy to obtain and has intense volatile compounds. Different schemes were planned for the purpose of adjusting the relative

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http://dx.doi.org/10.1016/j.jfoodeng.2016.06.027
0260-8774/

Table 1
Sensory evaluation scale for dry carrot sample.

Evaluation	Grading standard
Odor	strong odor of carrot (8–10); relatively light carrot odor (5–7); charring odor (0–4)
Shape	smooth surface (8–10); blistered surface (5–7);curly surface (0–4)
Taste	crunchy and sweet (8–10); soft, with lighter flavors (5–7); charring taste (0–4)
Consistency	good (8–10); neutral (5–7); poor (0–4)

humidity surrounding the samples. The relationship between the relative humidity and the drying rate, as well as the relationship between the relative humidity and the product quality were analysed and discussed. The results will be used to validate the hypothesis that high humidity is a benefit to the product quality.

2. Material and methods

2.1. Microwave drying system

A 2450 MHz microwave oven (Midea, MM720KG1-PW) was modified for the experiments as the microwave dryer (see Fig. 1). The dryer employed a 700 W magnetron which had separate power supplies for the cathode and the anode plate. If keeping the cathode's power supply constant, power output can be controlled with a computer program. The program gave out a signal between 0-5v to change the voltage of the anode plate from 0 to 4000 V. This modification made the microwave dryer have the capability of changing its power linearly from 0 to 700 W. The microwave oven had a rotatable microwave stirrer installed on the top of the cavity to evenly distribute the microwave power.

Samples were placed in a closed Teflon container. The container was a cylinder with 110 mm in height and 120 mm in diameter. There was also a shelf with holes fixed at 20 mm over the bottom of the container. Four penetration fittings were mounted on the sidewall for inlet flow, outlet flow and two fiber sensors. The container was supported by an I-shaped supporter through the bottom plate of the oven. The distance between the container and the oven bottom was 40 mm. The other end of the supporter was placed on an electronic balance (Lightever, LBA5200) so as to measure the weight of the samples. Ambient air (temperature between 23 and 25 °C, relative humidity between 10% and 20%, dried with desiccant) was introduced by an air compressor (OutStanding, 750-30L), and flowed along the Teflon tube to the sample container. A mass flow controller (SevenStar, MFC D07-19C) was installed between the air compressor and the container to measure and control the flow rate. Thermal insulated tube and cavity was installed after the sample container, so as to avoid condensation

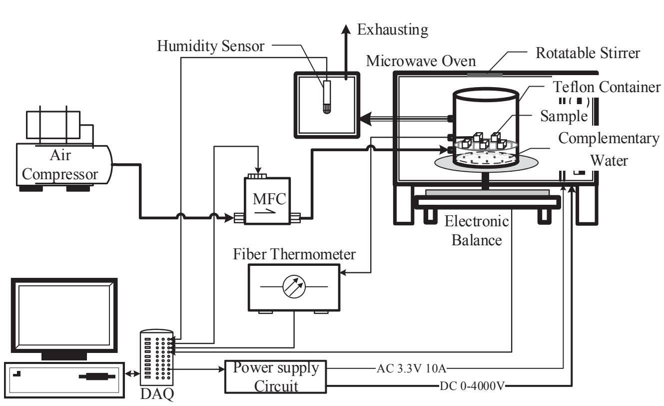

Fig. 1. Schematic diagram of the microwave drying system.

before the humidity was measured. When the compressed air pushed moisture out, the relative humidity (RH) was measured with a high precision electronic hygrometer (Vaisala, HMT130).

A fiber optic sensor (Optsensor, ThermAigle-RD HQ-28) was inserted in one of the samples for temperature measurement. The measured data of temperature, weight, humidity and flow rate were transferred to the PC for controlling and recording purposes. Weight reading, humidity reading, power control, temperature control and flow rate control were integrated in a DAQ board (USB 6259, National Instruments, TX, USA) with a self-developed LabVIEW program. All the data were recorded in a time interval of 1 s.

2.2. Samples preparation

Carrots procured from the local market were used in the experiments. They were washed, peeled, and cut into uniform cubes of 10 × 10 × 10 mm using a kitchen slicer. Only the outside layer was chosen as its uniform structure and color. The initial moisture content was measured as 90.96% (w.b., wet basis) in a preliminary experiment. Before drying, the samples were blanched in hot water (80 °C) for 1 min. Samples of 20 ± 1 g were used in each experiment and were dried to around 10% moisture content (w.b., or 0.4 in d.b., dry basis). All experiments were performed in triplicates.

2.3. Experimental procedure

In all the experiments, the temperature of samples were controlled constantly at 70 ± 0.5 °C, which was benefited from a PID feedback algorithm optimized for temperature control. Two methods were employed in this study to control the relative humidity of the convection air surrounding the samples: one is to control the rate of the air flow; the other is to add some complementary water in the container. The effect of the relative humidity on the drying rate as well as the product quality was investigated under different experimental conditions.

For the flow control method, the ambient air (relative humidity around 20%) was blown into the sample container and pushed the gaseous moisture out. Nine schemes with different air flow rates were then proposed:

Scheme 1–5. Supplying the air flow with fixed rate levels (2, 3, 4, 5, 6 L/min).

Scheme 6–7. Changing the air flow rate stepwise from fast to slow (2, 4, 6 L/min), and vice versa. The change points were chosen at 20% and 50% of the moisture ratios (MR). Specifically, 2 → 4 L/min @ 50% and 4 → 6 L/min @ 20% in stepwise up schemes, 6 → 4 L/min @ 50% and 4 → 2 L/min @ 20% in stepwise down schemes.

Scheme 8–9. Changing the air flow rate linearly from 1 L/min to 6 L/min, and vice versa. The speed of the changing was adjusted linearly according to the moisture ratio (±0.0625 L/min/1%). The moisture ratio was calculated and used as the signal to control the flow rate in the program.

For the complementary water method, the air flow rate was fixed at 4 L/min. Three groups of experiments were conducted, with