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Characterization of a combination oven prototype: Effects of microwave exposure and enhanced convection to local temperature rise in a moist substrate☆

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ABSTRACT

The combination of microwaves exposure with the classical convection heating is seen as a practical solution to improve the uniformity and control of pure microwave heating of moist porous substrates. In the present paper, the complex coupling of electromagnetic exposure and enhanced fluid flow and heat transfer is explored, with an emphasis on the competition of such different mechanisms. To this end, some simple experimental techniques have been adopted to determine the thermal response of a common biological substrate in a microwave/jet-impingement oven prototype (1 kW of nominal power), allowing for the local characterization of its electromagnetic and fluid dynamic behavior. A rational approach is proposed by presenting a number of descriptors to help identify the interrelationships for all phenomena at stake, including the total process time (up to 1 min), the jet temperature (in the 60–100 °C range) and Reynolds number (in the 8000–15 000 range). Therefore the effects of microwave exposure and relaxation times, working air velocity and temperature on the substrate's local temperature rise, are reported and discussed. Even in the explored range of microwave and jet thermization potentials investigated herein, different substrate portions experienced different temperature rises. The proposed configuration and analysis can be used to exercise due control of material conditioning and treatment in a combined microwave/forced convection framework.

1. Introduction

Although the use of microwave (MW) ovens has been proven beneficial in material conditioning due to its speed and convenience, the potential of MW heating is currently not fully realized due to its generally non-uniform effects on the substrate finishing. This is particularly important for moist substrates (such as food). In these cases, during MW exposure heating occurs differently than with the conventional bulk convection, in that the thermal perturbation is solely applied on the sample's external surface by forced air, whereas the driving mechanism within the substrate is the sole heat conduction. MW heating acts directly within the substrate proper instead, as it is due to the interaction between an electromagnetic field and dipolar molecular species, such as water, or ionic, such as salts. The friction produced by the dipoles rotation and by the migration of ionic species to regions of opposite charge generates heat, specially where the water content is in relative excess [1–3].

A major problem found in MW treatments is then the local moisture excess due to the rapid volumetric heating, which cannot be removed by a bulk convective flow, thus resulting in an undesirable general non-uniformity moisture, particularly at the substrate's surface [4,5]. Generally speaking, the amount of MW energy that must be absorbed by the substrate sample to accomplish the drying can be estimated by its temperature rise, but this energy cannot be absorbed uniformly throughout the sample itself [1]. Nonetheless, MW processes have been adopted by a number of researchers, as in Ref. [6], or in assistance of traditional processes [7]. In the field of food treatment, different systems have been tried, and have been found nowadays in the consumer market to alleviate problems, such as the use of barriers, succeptors, intermittent rotation and alternative internal tray [8,9]. But due to their limited response in process performance, MW treatments are being more often proposed in combination with other heat transfer mechanisms, as with sole bulk convection: some authors focused on changes in quality parameters and in mechanical properties of different food substrates undergoing combined convective and MW drying [10–13], some others proposed to combine convection as a method to control MW power and heating [14,15] while some more [3,16,17] focused on theoretical and modeling approaches. Sole localized convection was then explored [8,9,18], while sole infrared [19,20], infrared and bulk convection [21], and a combination of radiant and localized forced convection [22,23] were implemented as well. It is then seen that bulk convection can help increase surface temperature (then reducing surface moisture), but not as effectively as infrared heat, due to its inefficient surface heat

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