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Industrial-scale radio frequency treatments for insect control in walnuts I: Heating uniformity and energy efficiency

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Abstract

Conducting industrial-scale confirmatory treatments is the final step in developing commercially and environmentally sound insect control technologies for in-shell walnuts using radio frequency (RF) energy as an alternative to chemical fumigation. Improving heating uniformity of in-shell walnuts in the industrial process is essential to ensure insect control without quality degradation. An industrial-scale 27 MHz, 25 kW RF system was used to determine the heating uniformity of in-shell walnuts. Non-uniform vertical temperature distributions were measured in the RF unit, indicating that mixing and circulated hot air were needed to obtain the required treatment uniformity. Using a uniformity index derived experimentally for the RF unit, we showed that a single mixing of the walnuts was required to optimize heating uniformity. The predicted standard deviation of walnut surface temperatures was verified experimentally. The average energy efficiency of two RF units in series was estimated to be 79.5% when heating walnuts at 1561.7 kg/h. This study provided the basis for subsequent evaluations of treatment efficacy and product quality needed in developing an industrial-scale RF process to control insect pests in walnuts.

Keywords: Heat treatment; Insect control; Phytosanitary; Quarantine; Walnut

1. Introduction

The use of methyl bromide (MeBr) has been declining since 1999 and its production for most applications was banned in January 2005 by the U.S. Environmental Protection Agency in compliance with the Montreal Protocol (USEPA, 1998; Tang et al., 2000). Currently, use of MeBr is restricted to quarantine applications, requiring industries to apply for yearly critical use exemptions for phytosanitary postharvest treatments. Such restrictions on the use of MeBr fumigation have forced the multi-billion dollar nut industries in the USA and other developed countries to seek alternatives for control of postharvest insect pests. Because the future of alternative chemical fumigants such as phosphine and sulfuryl fluoride is uncertain (USEPA, 1998; Fields and White, 2002) and public concern over pesticide residues in consumer products is high (Govindasamy et al., 1997), non-chemical control methods are of particular interest. Several laboratory-scale studies have described radio frequency (RF) as a new means to rapidly heat walnuts (*Juglans regia* L.) to control postharvest insects without significant quality degradation (Wang et al., 2001a, 2002; Mitcham et al., 2004). However, it is important to transfer laboratory research results to industrial-scale applications.

RF energy has long been used in studies to kill insect pests by heating them beyond their thermal limits (Headlee and Burdette, 1929; Frings, 1952; Nelson, 1996). The RF frequencies 13.56, 27.12 and 40.68 MHz are allocated by the U.S. Federal Communications Commission (FCC) for industrial, scientific and medical applications, and can be used for industrial postharvest insect control. Most early research on RF insect control has focused on stored grain pests in small laboratory RF units (Nelson and Whitney, 1960). Although many of these studies showed that RF could provide efficacious insect control, the method was not cost effective when compared to inexpensive chemical fumigations in use at that time (Nelson, 1996). Recently, Wang et al. (2001a, 2002) developed a successful laboratory-scale RF treatment to disinfest in-shell walnuts using a systematic approach based on the thermal death kinetics of the

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targeted insects (Johnson et al., 2004), dielectric properties of walnuts (Wang et al., 2003b), differential heating of insects in walnuts (Wang et al., 2003a) and the thermal responses of walnuts (Buranasompob et al., 2003). RF treatments provide a major advantage over hot air heating for in-shell walnuts, because of significant thermal resistance in the porous walnut shell and the in-shell void that hinder the transfer of thermal energy from external hot air to the walnut kernel. Our earlier results have shown that it would take more than 40 min to raise in-shell kernel temperature to within 5 °C of the final set temperature when heated from 20 to 53 °C by air, whereas only 4 min are required with RF energy for the same temperature rise (Wang et al., 2001a). However, those pervious studies were conducted with laboratory systems in a batch mode, and commercial treatments based on RF energy need to be studied as continuous processes to handle large quantities of walnuts during the relatively short harvest seasons.

Heating uniformity is one of the most important considerations in scaling-up the established treatment protocol for walnuts. Temperature variations after RF heating may result from variations in thermal properties and moisture contents of walnuts and a non-uniform electromagnetic field. The effect of walnut size, orientation and location on RF heating uniformity may be reduced by a thorough mixing of the nuts between RF exposures (Wang et al., 2005). The number of mixings needed can be calculated from the required insect mortality level, and from the minimum and average final product temperatures selected for the proposed treatment (Wang et al., 2005). In the development of an optimal commercial treatment protocol, the heating uniformity for an industrial-scale RF unit must be determined to calculate the appropriate number of mixings needed between RF exposures to minimize the effect of walnut orientation and position.

The objectives of this study were: (1) to determine the heating uniformity in the industrial-scale RF system; (2) to determine the number of mixings needed for industrial-scale RF treatments to meet the required insect control for in-shell walnuts; (3) to determine the treatment parameters in developing commercial postharvest insect treatments; (4) to estimate the heating efficiency and throughput of the continuous RF process.

2. Materials and methods

2.1. Description of industrial-scale RF systems

A 25 kW, 27 MHz industrial-scale RF system (Model S025/T, Strayfield International Limited, Wokingham, UK) (Fig. 1) was used in this study. The RF unit had two pairs of identical electrodes (1.3 m L × 0.6 m W × 0.4 m H). Different heating rates were obtained by adjusting the gap between the electrodes from 260 to 400 mm. Adjustable conveyor belt speeds from 4.8 to 57 m/h provided different product residence times and corresponding throughputs. The total treatment and heating times were calculated from the belt speed and the lengths of the RF cavity and the two electrodes.

The RF system was equipped with an auxiliary hot air system that helped to maintain walnut surface temperature. Ambient air was forced through a 9 kW heater and, along with air used to cool the RF triode tube, was sent through a distribution pipe at the back side of the unit and up through the conveyor belt (Fig. 1). Hot air was collected above the right electrode and exhausted through the top of the unit. The temperature of the hot air from the 9 kW heater was nearly constant, but hot air obtained from cooling of the RF triode tube gradually increased in air temperature with the warm-up time and treatment periods.

The control screen of the RF system displayed the electrical current being used, but not RF power. A correlation between the output RF power and electrical current of the RF unit was derived experimentally with a water load and provided by the manufacturer (Fig. 2). The initial current when the RF cavity was empty varied from 0.34 to 0.44 A, depending upon the gap between the electrodes. The maximum current could reach 3.5 A

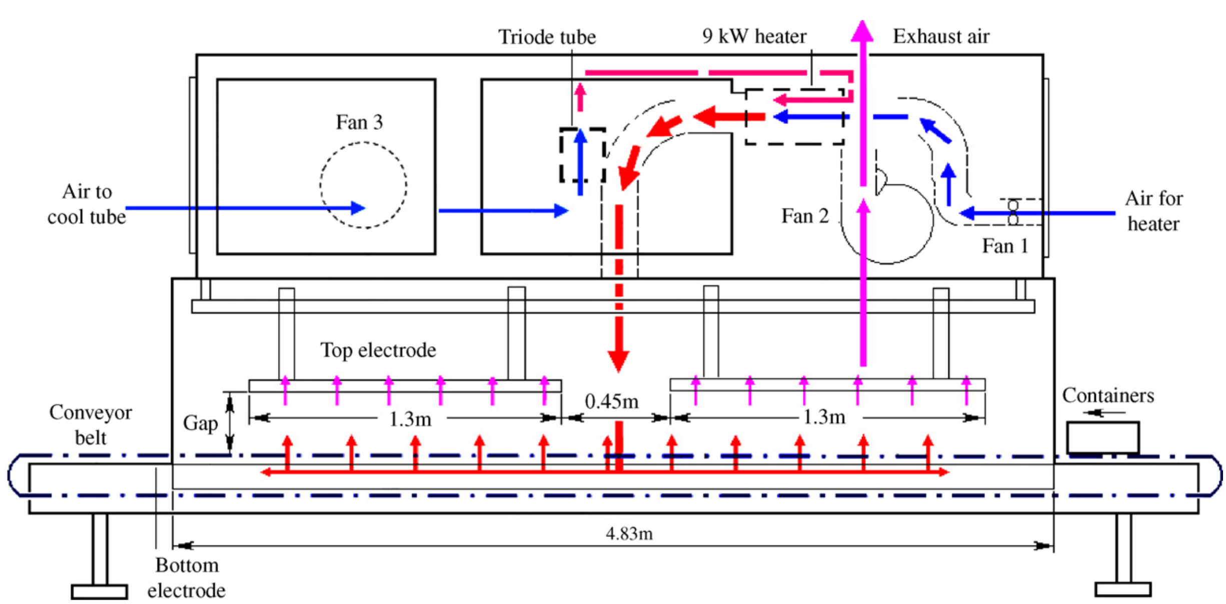

Fig. 1. Schematic view of the industrial-scale 25 kW, 27.12 MHz radio frequency (RF) unit showing the two pairs of plate electrodes and the hot air system.