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Computational evaluation of food carrier designs to improve heating uniformity in microwave assisted thermal pasteurization

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ABSTRACT

Microwave assisted thermal pasteurization system (MAPS) is a novel food safety technology that employs carriers made from stainless steel to move pre-packaged foods inside 915 MHz single mode microwave cavities to eliminate bacterial and viral pathogens. This paper studied the performance of metal carriers for 16 oz and 10 oz food packages in the MAPS. A simulation model built with Quick-wave software was developed to analyze the electromagnetic field distribution inside a MAP system as affected by the presence of the metal food carriers. Computer simulations were validated using a mashed potato model food processed in a pilot scale MAP system; heating patterns of the samples were detected by a chemical-marker based computer vision method. Results showed that different designs of the food carriers could be used to modify electric field distribution to obtain relatively uniform heating patterns within the microwave cavities. Simulation results also illustrated that magnetron frequency variations between 900 MHz and 920 MHz do not affect the heating patterns of food packages processed using carriers containing metal parts. The results demonstrated that the MAPS with moving metal carriers has stable and predictable heating patterns.

Industrial relevance: Microwave transparent materials such as plastics have been used to make transport carriers for food packages in microwave assisted thermal sterilization (MATS) (Tang, 2015). However, polymers may have a short life in the high-temperature processing conditions and thus may not be desirable in an industrial setting. The simulations and experiments conducted in this work showed that the novel concept of metal tray carrier is an effective mechanism for transporting pre-packaged foods in microwave heating systems. The validated computer simulation model presented in this work will be a time efficient, economical and convenient tool to evaluate tray carrier designs for efficient and uniform microwave heating in MAPS.

1. Introduction

Pasteurization is a food preservation technique that involves applications of temperatures in the range of 70–95 °C for a certain length of time to inactivate viral pathogens and vegetative bacterial cells (Peng et al., 2017; Bhunia et al., 2016). Microwave assisted thermal pasteurization system (MAPS) is a novel technology developed at Washington State University for pasteurization of pre-packaged food products. The MAPS technology is based on simultaneous heating of food by microwaves and hot water (Resurreccion et al., 2013). Fig. 1 provides a schematic of a pilot scale MAPS. It has four sections, i.e. preheating, microwave heating, holding and cooling sections, each section is filled with circulating water at a set temperature. MAPS microwave cavities are designed to operate in single mode at 915 MHz which ensure predictable and stable heating patterns as explained in detail by Tang (2015). The combination of hot water and microwave heating results in shorter processing time than conventional surface heating methods, and hence better quality of food products (Tang, 2015). Non-uniform microwave heating may be a major challenge in large scale industrial systems where high microwave power is used for the processing. It is possible that the food at the hot spot locations may be overcooked to acheived the required thermal lethality at the cold spots. Therefore, for the commercialization of the technology, small temperature differences between hot and cold spots are highly desirable to improve food quality.

Single mode cavity design in combination of circulating water in the MAPS system provided flexibility for placing and moving different types of materials, including metals, inside the microwave cavities (Tang & Liu, 2017). Specially designed tray carriers made up of rectangular thin metal sheets, and cylindrical shape Polyetherimide (*Ultem*

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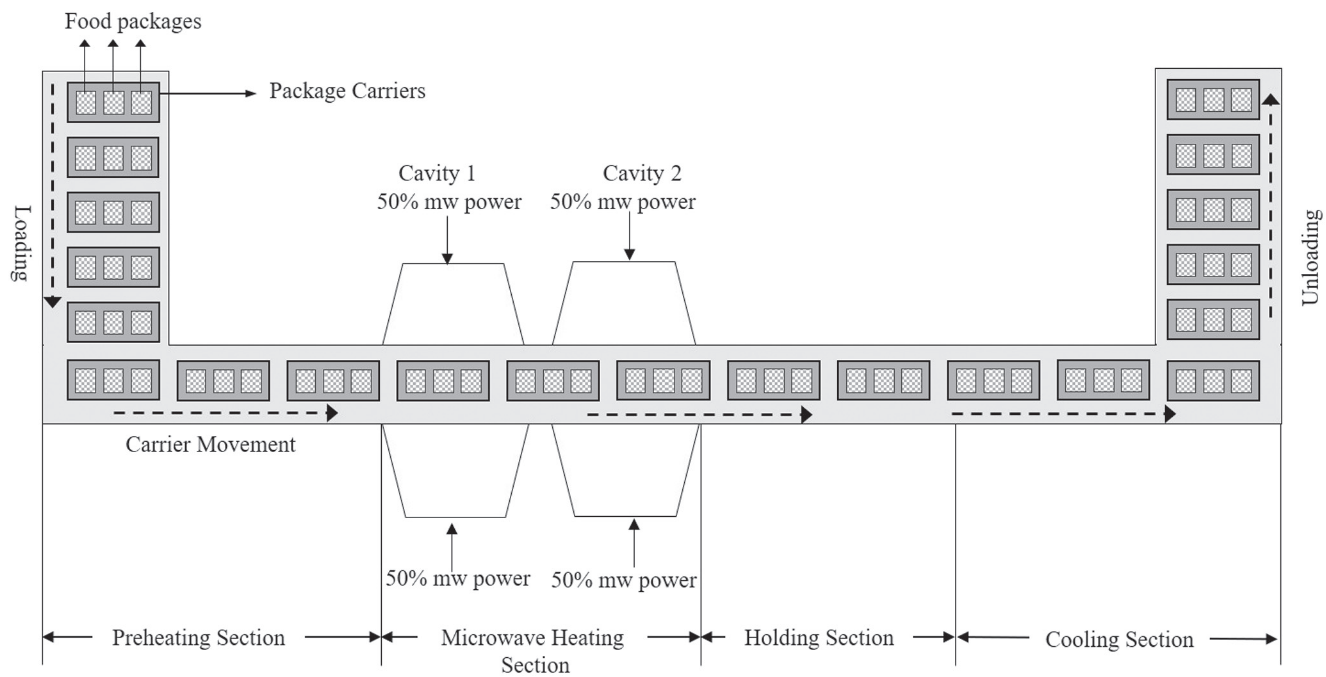

Fig. 1. Schematic diagram for pilot scale microwave assisted thermal pasteurization system consisting of preheating, microwave heating, holding and cooling sections.

TM) parts were used to distribute the electric field more evenly and provide better heating uniformity for 16 oz and 10 oz food packages (Tang & Liu, 2018). The designs of these carriers can be easily configured for different sizes and shapes of the food packages to obtain higher heating uniformity. Use of stainless steel in designing the carriers for food packages also resists corrosion in water immersion system and adds durability. Direct measurement of reflected microwave powers from the cavities indicated that the metal carriers do not adversely affect coupling of microwave energy from the generator. The heating rate at the cold spots in food packages remains similar to that in the packages transported with plastic carriers (Tang & Liu, 2018).

The electromagnetic field distributions inside the microwave cavity is impacted by the presence of food packages and transport carriers leading to variations in heating patterns and temperature profiles. Till now, there are no effective sensors for the accurate measurement of electric field in high permittivity materials such as food. Therefore, a 3-D computer simulation model (CSM) was developed and validated to explore the electric field patterns in pilot scale microwave assisted thermal sterilization system (MATS-CSM) (Resurreccion et al., 2013). The MATS-CSM was used to analyze the electromagnetic field distributions, heating patterns and temperature profiles for foods moving on a polymeric conveyor mesh belt (Resurreccion et al., 2013; Luan et al., 2015; Luan, Tang, Pedrow, Liu, & Tang, 2013; Luan, Wang, Tang, & Jain, 2017). The conveyor belt was microwave transparent; therefore, it was not considered while simulating the MATS system. Design of the MAPS is different from MATS pilot scale system in the manner that food packages are transported throught the microwave cavities. In MAPS, the conveyor mesh belt is replaced by stainless steel carriers. The carriers are loaded with the pre-packaged food and are moved through the cavities on a set of wheels. Different components of the tray carriers interact with the microwave field and aids in directing the microwave energy to the food packages. Movement of objects that can distort the microwave field distributions within the cavities also affect the temperature profiles of the food items. Thus, it is imperative to include the metal transport carriers in the simulation model of the MAPS process. This work was focused to develop and validate a simulation model for MAPS system with newly designed metal carriers. A validated model will be an important tool to design tray carriers for various sizes, shapes and orientations of the food packages to generate more efficient and uniform heating patterns.

In this work, four different types of food carrier designs suitable for 16 oz and 10 oz food packages were studied using computer simulations. Electric field distributions and heating patterns of the food packages were analyzed computationally. For the experimental validation, fructose based chemical marker in the mashed potatoes was used as described in Jain, Wang, Liu, Tang, and Bohnet (2017). The chemical marker technique is based on the browning reaction of reducing sugars in a model food and has been used effectively to study heating patterns in microwave assisted thermal processing (Pandit, Tang, Liu, & Mikhaylenko, 2007; Luan et al., 2013, 2015; Zhang et al., 2015; Resurreccion et al., 2013, 2015).

2. Materials and methods

2.1. Computer simulation procedure

2.1.1. Microwave assisted thermal pasteurization (MAPS): physical system

As illustrated in Fig. 1, the pilot scale MAPS consists of four sections, i.e., preheating, microwave heating, holding and cooling. Each section contains circulating water at different temperature, e.g., preheating at 61 °C, microwave heating, and holding at 75–95 °C and cooling at 25 °C. Microwave heating section consists of two connected rectangular cavities which are connected to a generator by a standard waveguide WR975, through which only TE10 mode is supported. Vacuum sealed food packages are secured onto the tray carriers with the help of metal clips. The carriers packed with food items are placed into the MAPS in the loading area, and are moved into the pre-hating section. After preheating for a certain time, tray carriers are transported to the microwave heating section followed by the holding section. The carriers are then moved to the cooling section, and taken out from the unloading zone. The residence time of the food inside each section is controlled by speed of the moving food carrier.

2.1.2. Simulation software

In this study, the computer simulation model was built in Quickwave 3D (QW-3D, QWED, Poland) version 7.5, that uses finite