CONTINUOUS MICROWAVE PROCESSING OF PEANUT BEVERAGES

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Accepted for Publication February 29, 2008

ABSTRACT

The feasibility of peanut beverage sterilization by continuous microwave heating as an alternative to conventional ultrahigh temperature (UHT) system processing was studied. Dielectric properties of two products, Peanut Punch (Nestle Trinidad and Tobago Ltd., Port of Spain, Trinidad and Tobago) and Jamaican Irish Moss Peanut Drink (distributed by Eve Sales Co., Bronx, NY) were measured. The products had similar dielectric properties. Values for the dielectric constant (average of 60) and dielectric loss (average of 23) indicated that the two products were good candidates for rapid microwave heating. The products were processed in a 5 kW focused microwave unit, at two different flow rates, 1 and 2 L/min. The short time required to reach 130C and the uniformity of the temperature distribution indicated that microwave heating could be used as a sterilization step in a UHT process for peanut-based beverages. Further studies need to be conducted on microbiological and

The research reported in this publication was a cooperative effort of the USDA, ARS and the North Carolina ARS, Raleigh, NC 27695-7643. Use of trade names in this publication does not imply endorsement by the USDA or the North Carolina ARS of the products named nor criticism of similar ones not mentioned.

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chemical changes of the product before continuous microwave heating can be implemented as an alternative sterilization step to conventional UHT processes of peanut beverages.

PRACTICAL APPLICATIONS

The short time required to reach 130C and the uniformity of the temperature distribution suggest that microwave heating could be used as a sterilization step in an ultrahigh temperature process for peanut-based beverages.

INTRODUCTION

Heat sterilization is the unit operation in which foods are heated at a sufficiently high temperature and time to completely inhibit microbial and enzymatic activity (Fellows 2000). The most widely used systems for sterilization are overpressure retorts and ultrahigh temperature (UHT) systems. A major problem with in-container sterilization is the low rate of heat penetration from the walls to the thermal center, thus requiring long processing times. In addition, the severe heat treatment of the product close to the walls often produces substantial detrimental changes in the nutritional and sensory quality of the food.

The bases of UHT processing or aseptic processing are rapid heat transfer and sterilization of the product prior to its packaging in a sterile atmosphere. Microwave heating can be used in the UHT process as an alternative to “outside-in” conventional heating. In a continuous microwave heating system, heat is delivered to the food volumetrically, which decreases the processing time significantly and reduces product thermal damage.

Microwave sterilization occurs in the temperature range of 110–130C under pressure conditions (Giese 1992). Heat inactivation of microorganisms and thermal degradation of heat-labile food components during microwave heating are governed by the same kinetics specific to conventional heating. Microwave heating prevents overheating of surface layers and underheating of center layers in heat-sensitive food products normally occurring in conduction heating methods (Mudgett 1982), resulting in a higher product quality.

Microwave pasteurization and sterilization have been studied for many types of liquid foods, including milk and milk products, soy milk and fruit juices. Villamiel *et al.* (1998) examined the effect of continuous-flow microwave heat treatment on orange juice and found that continuous microwave process proved to be an effective system for pectinmethylesterase inactivation. Sierra *et al.* (1999) demonstrated that microwave heating did not modify the vitamin B_1 content of milk, whereas an analogous treatment with a plate heat exchanger led to a loss of this vitamin. Unlike UHT milk, microwave-processed milk generally did not have cooked or scorched flavor and was more acceptable to consumers (Vasavada 1990). Changes during the storage of microwaved milk were similar to those of milk heated in a conventional system under the same treatment as shown by Valero *et al.* (2000). It is clear that because of the rapid temperature rise with microwave heating, less destruction of nutrients takes place during the heating process compared to conventional processes (Datta and Hu 1992).

Temperature increase of a product during microwave heating is caused by internal heat generation caused by absorption of electrical energy from the microwave field. The heat generated is subsequently distributed throughout the product by conduction and convection. Absorption of energy from the microwave field is influenced by a number of factors associated with the product and the equipment. Product-dependent factors include product dielectric and thermal properties. Besides dielectric properties, equipment factors such as frequency, power and geometry influence the heating pattern of foods. Permittivity is the dielectric property of greatest interest in microwave heating. It is composed from the dielectric constant (ε') and the dielectric loss (ε''). The dielectric constant of dielectric materials is a measure of the capacity of the material to store electromagnetic energy. Dissipation of electromagnetic energy as heat is described by the dielectric loss. Dielectric properties of food products may vary considerably with the processing frequency and with the temperature, chemical composition and physical state of the product.

The goal of this research was to determine the feasibility of microwave sterilization of peanut-based liquids as an alternative to conventional UHT heating processes. The objectives of the study were to characterize product microwave interaction based on the dielectric properties of two peanut-based liquid products, and to examine the temperature profiles of the products heated to 130C in a 5 kW continuous microwave system at two different flow rates, 1 and 2 lpm.

MATERIALS AND METHODS

Two peanut-based drinks (Peanut Punch and Jamaican Irish Moss Peanut Drink) were obtained from Eve Sales, Inc. (Bronx, NY). The dielectric properties of the two products were measured as a function of temperature at 915 MHz using an HP 8753C Network Analyzer and an HP 85070B dielectric probe kit (Hewlett-Packard, Palo Alto, CA). The dielectric properties were measured for the two samples in duplicate, and the results were averaged.

The products were heated in a 5 kW continuous microwave (Industrial Microwave Systems, Morrisville, NC) at two different flow rates, 1 and 2 lpm.

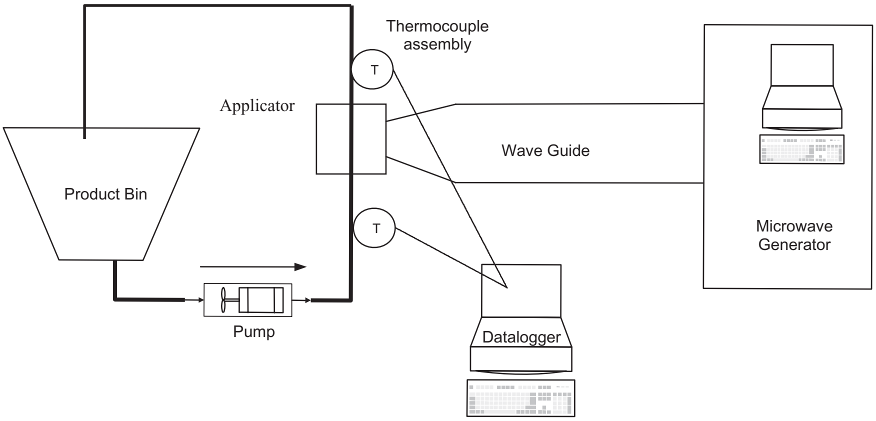

FIG. 1. SCHEMATIC DIAGRAM OF THE SYSTEM
The system includes: product bin, pump, applicator, datalogger, thermocouple assembly, waveguide and microwave generator.

A total amount of 4.250 L product was used in each run. The product was pumped through the microwave applicator (1.5′ in diameter) with a positive displacement pump with a variable speed motor (Seepex RD11H, Seeberger GmbH + Co., Bottrop, Germany) and then recirculated until the outlet temperature reached 130C (Fig. 1).

The inlet and outlet product temperatures were recorded as a function of time using T-type thermocouples connected to a datalogger (model DAS16, Keithley Metrabyte, Taunton, MA). The inlet temperature was measured at one location, as the temperature of the incoming product was uniform. The outlet temperature was recorded at nine different locations within the cross section of the applicator tube using a thermocouple array as shown in Fig. 2 (Coronel *et al.* 2003).

RESULTS AND DISCUSSION

Dielectric Properties

The dielectric properties of Peanut Punch and Jamaican Irish Moss Peanut Drink at 915 MHz were similar. Dielectric constant decreased with temperature, and dielectric loss increased with temperature. The loss tangent, defined as the ratio of the two, increased with temperature (Figs. 3 and 4). The dielectric constant varied between 68 at 18C and 52 at 90C. The dielectric loss values measured 18 at 18C, and 28 at 90C for both products. The second-order

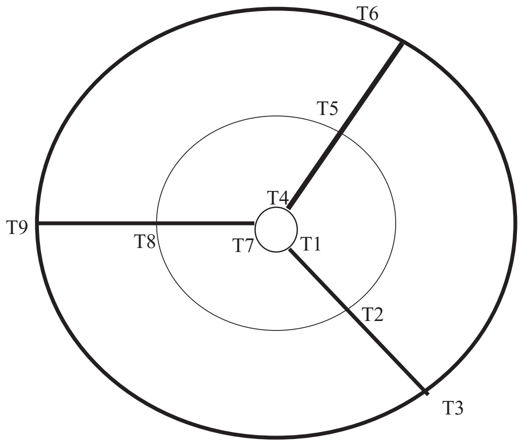

FIG. 2. THERMOCOUPLE ARRAY DESIGNED TO MEASURE THE OUTLET TEMPERATURE OF THE PROCESSED PRODUCTS AT NINE DIFFERENT LOCATIONS, IDENTIFIED BY T1–T9

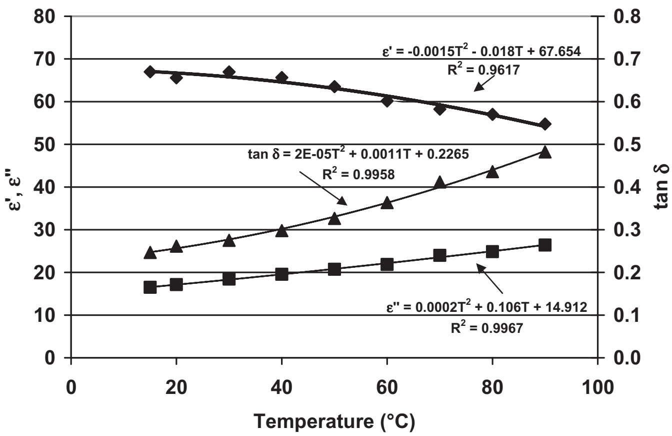

FIG. 3. DIELECTRIC PROPERTIES OF PEANUT PUNCH AS A FUNCTION OF TEMPERATURE

See primary *y*-axis for dielectric constant (ε′) and dielectric loss (ε″), and secondary *y*-axis for loss tangent (tan δ), defined as the ratio of the two (ε″/ε′).

polynomials which describe the temperature dependence of dielectric properties are summarized in Table 1. Similar dielectric properties of Peanut Punch and Jamaican Irish Moss Peanut Drink were the result of similar compositions of the two products. In general (on an equal serving size of 354 mL, which was

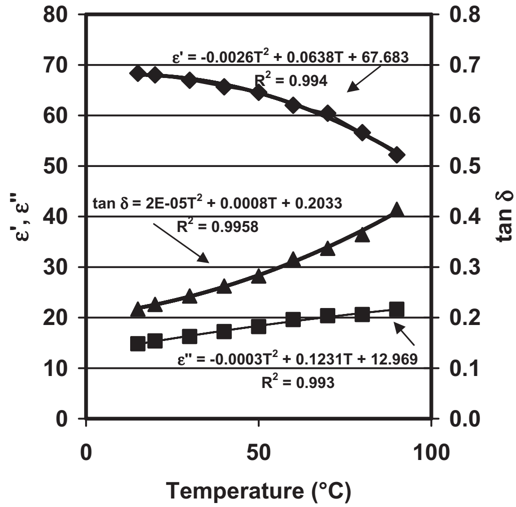

FIG. 4. DIELECTRIC PROPERTIES OF JAMAICAN IRISH MOSS AS A FUNCTION OF TEMPERATURE

See primary *y*-axis for dielectric constant (ε′) and dielectric loss (ε″), and secondary *y*-axis for loss tangent (tan δ), defined as the ratio of the two (ε″/ε′).

TABLE 1.
DIELECTRIC PROPERTIES OF PEANUT PUNCH AND IRISH MOSS

Product	ε′	ε″	tan δ
Peanut Punch	$-0.0015T^2 - 0.018T +$ 67.654 (average = 62.1)	$0.0002T^2 + 0.106T +$ 14.912 (average = 21.1)	$2E - 5T^2 + 0.0011T +$ 0.2265 (average = 0.35)
Irish Moss	$-0.026T^2 + 0.0638T +$ 67.683 (average = 62.8)	$-0.0003T^2 + 0.1231T +$ 12.969 (average = 18.2)	$2E - 5T^2 + 0.0008T +$ 0.2033 (average = 0.30)

Temperature (T) in degrees Celsius.

the serving size of the Irish Moss), the Irish Moss contained 13 g total fat, 45 g carbohydrates (about 1 g fiber and 36 g sugar) and 4 g of protein, while the Peanut Punch had 14.2 g total fat, 42.6 g carbohydrates (2.8 g fiber, 38 g sugars) and 17 g protein.

Temperature Profiles

Because the dielectric properties are identical for Peanut Punch and Irish Moss, the temperature profiles should be similar when heated under similar conditions (frequency, power, geometry). Experimental data proved that the

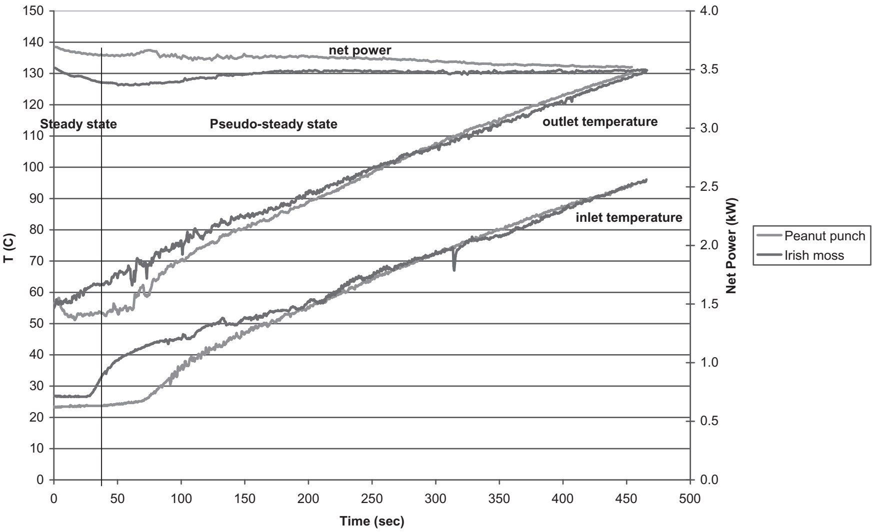

FIG. 5. TEMPERATURE PROFILES AND ABSORBED POWER FOR PEANUT PUNCH AND JAMAICAN IRISH MOSS PEANUT DRINK PROCESSED IN A CONTINUOUS FOCUSED MICROWAVE UNIT AT 2 lpm
Inlet and outlet temperatures have a steady-state region and a pseudo-steady-state region. The absorbed power is represented on the secondary axis.

inlet and the outlet temperatures (primary *y*-axis), and the absorbed power (secondary *y*-axis) for Peanut Punch and Irish Moss processed at 2 lpm were indeed similar throughout the heating process (Fig. 5). The temperature increase in one pass through the microwave applicator was the same for both products (ca. 30C). Additionally, the time required to reach sterilization temperatures was the same (460 s), and the power absorbed by the products was very similar (ca. 3.5 kW). The difference between the heating patterns for Peanut Punch and Irish Moss was apparent only at the beginning of the process, and this difference may be attributed to slightly different volumes of the product being recirculated through the system.

Because of the similar dielectric properties and thermal behavior of the two products during sterilization, a detailed discussion of the heating profile of Peanut Punch at two different flow rates will follow, keeping in mind that the analysis holds true for both products (and for products with similar composition and properties).

The inlet temperature, outlet temperatures (average, minimum and maximum) and absorbed power were plotted as a function of time for Peanut Punch processed at 1 and 2 lpm, (Figs. 6 and 7), respectively. A transient state region, a steady-state region and a pseudo-steady-state region are identified in

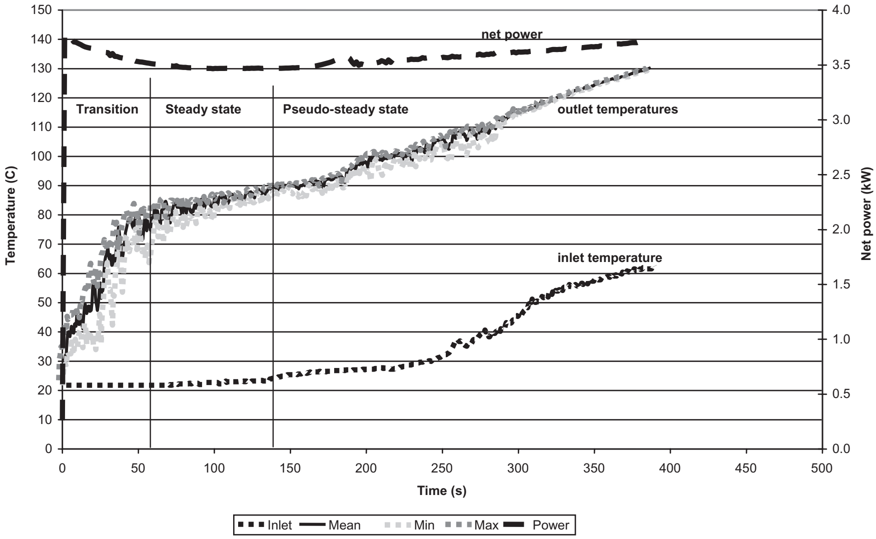

FIG. 6. TEMPERATURE PROFILES AND ABSORBED POWER FOR PEANUT PUNCH PROCESSED IN A CONTINUOUS FOCUSED MICROWAVE UNIT AT 1 lpm
Inlet and outlet temperatures (average in black, minimum and maximum in gray) have three distinct regions: transition, steady state and a pseudo-steady state. The absorbed power is represented on the secondary axis.

Figs. 6 and 7. The transient state was characterized by a constant inlet temperature and an increasing outlet temperature, which lasted for 32 s at a flow rate of 2 lpm, and 64 s at a flow rate of 1 lpm. This time corresponded to the time it took for the product to be pumped through the applicator tube from the inlet thermocouple to the outlet thermocouple. The steady-state region was characterized by constant inlet and outlet temperatures. The steady-state region lasted until the product traveled through the system and returned the second time to the applicator tube. The pseudo-steady-state region was characterized by a linear increase in the inlet and the outlet temperatures as a function of time.

The temperature distribution in the heated product was measured by the thermocouple array at nine different locations. Results showed that the outlet temperature distribution in the product was uniform throughout the heating process, more so at higher temperatures occurring later in the process. Some temperature variations were evident in the beginning of the process, and they may be attributed to nonuniform absorption of microwave energy by product regions of different dielectric properties because of different temperatures of these regions.

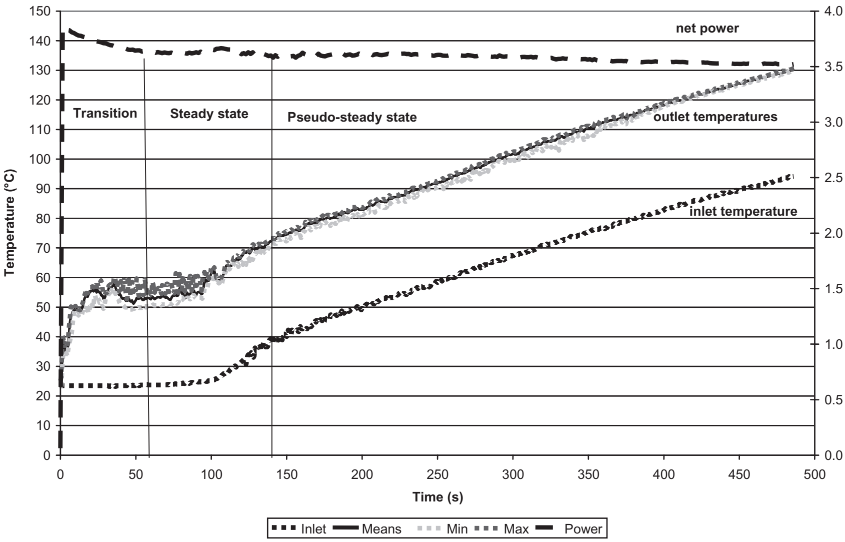

FIG. 7. TEMPERATURE PROFILES AND ABSORBED POWER FOR PEANUT PUNCH PROCESSED IN A CONTINUOUS FOCUSED MICROWAVE UNIT AT 2 lpm
Inlet and outlet temperatures (average in black, minimum and maximum in gray) have three distinct regions: transition, steady state and a pseudo-steady state. The absorbed power is represented on the secondary axis.

During steady state and pseudo-steady state, the temperature increased ca. 60C (standard deviation of 3.8C) in one pass through the applicator tube (heating region) of the microwave at 1 lpm. At 2 lpm, the temperature increased by approximately 30C per pass (standard deviation of 1.95C). An increase in flow rate resulted in a smaller temperature difference between the output and the input, as expected. In contrast, an increase in the microwave power would lead to a greater increase in the temperature of the product per pass. It is possible to design a system which would increase the temperature of the product from room temperature to sterilization temperatures in one pass. As an alternative to the single-step increase to sterilization temperatures mentioned before, a continuous microwave sterilization process can be designed using several applicator tubes functioning at a lower power that would increase the temperature stepwise to the desired final temperature.

The net power absorbed by the products during the heating was the same at the two different flow rates studied, and equals to 3.5–3.75 kW at each particular time. However, the total energy consumption to reach the desired sterilization temperature of 130C was different at the two different flow rates, because of the residence time of the product in the system. The total time required for the products to reach the sterilization temperature was different for the two flow rates (400 versus 490 s for 1 and 2 lpm, respectively), with the result that less energy was required to reach sterilization temperatures at lower flow rates. However, low flow rates indicate a low throughput process. Therefore, a comprehensive analysis of all these factors, including flow rates, required throughput and energy efficiency, should be considered when designing a continuous microwave heating process.

CONCLUSION

This study showed that the dielectric properties of Peanut Punch and Jamaican Irish Moss were similar and that the two products were good candidates for continuous thermal processing using microwave heating. The temperature profiles during microwave heating indicated that the thermal behavior of the two products during microwave heating was similar. Moreover, the spatial outlet temperature distribution in the product was uniform, showing the high potential of this particular microwave technology for rapid uniform heating. As a result of the radial temperature uniformity, the overprocessing commonly encountered in conventional processing can be eliminated, with a significant retention of nutrient quality.

While this project successfully evaluated the potential of microwave technology for continuous thermal processing of peanut-based beverages, more research is needed to evaluate the microbiological and chemical changes of the product during microwave processing.

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