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Temperature dependent electrical conductivities of fruit purees during ohmic heating

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Abstract

Ohmic heating takes its name from Ohm's law; the food material switched between electrodes has a role of resistance in the circuit. In this study, the apricot and peach purees were heated on a laboratory scale static ohmic heater by applying voltage gradients in the range of 20–70 V/cm. The voltage gradient was statistically significant on the ohmic heating rates for both purees ($P < 0.05$). The linear temperature dependent electrical conductivity relations were obtained. Bubbling was observed above 60 °C especially at high voltage gradients. The ohmic heating system performance coefficients were in the range of 0.49–1.00. The unsteady-state heat conduction equation for negligible internal resistance was solved with an ohmic heating generation term by the finite difference technique. The predictions of the mathematical model using obtained electrical conductivity equations were found to be very accurate.

Keywords: Fruit purees; Ohmic heating; Electrical conductivity; Modelling

1. Introduction

Ohmic heating is based on the passage of electrical current through a food product that serves as an electrical resistance (Reznick, 1996; Sastry, 1989). Heat is generated instantly inside the food. The amount of heat generated is directly related to the current induced by the voltage gradient in the field, and the electrical conductivity (Sastry & Li, 1996). The applicability of ohmic heating depends on the product electrical conductivity.

In recent years, the world's food industry has focused increasing attention on ohmic heating of pumpable foods. It is a highly attractive technique for continuous food processing. It can be used as a continuous in-line heater for cooking and sterilization of viscous and liquid food products. Palaniappan and Sastry (1991) studied the effects of insoluble solids and applied voltage on electrical conductivity of the pre-pasteurized carrot and tomato juices during ohmic heating. Qihua, Jindal, and van Winden (1993) made performance evaluation of an ohmic heating unit for liquid foods. They reported that the temperature affected the electrical conductivity values of fresh orange juice, but the relationships were not given. Castro, Teixeira, Salengke, Sastry, and Vicente (2003) discussed the effect of temperature and sugar content on the electrical conductivity values of strawberry based products whereas Castro, Teixeira, Salengke, Sastry, and Vicente (2004) studied the effect of electrical field strength. Ohmic heating is currently being used for the processing of whole fruits in Japan and the United Kingdom (Sastry & Barach, 2000), for production of syruped fruit-salad and fruit juices (Anonymous, 2002).

Fruit purees are to be potentially used in baby food productions. The thermal processes applied to the baby foods are critically important to guarantee their microbiological safety. The data on the electrical conductivity changes of fruit purees during ohmic heating is very

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Nomenclature

A_e	area of cross-section of the electrodes (m^2)	T	temperature (°C)
$B1$	empirical temperature constant (S/mK), Eq. (7)	V	voltage applied (V)
$B2$	empirical temperature constant (S/mK), Eq. (8)	Xw	weight fraction of the water in the sample
$C1$	empirical constant (S/m), Eq. (7)	σ	specific electrical conductivity (S/m)
$C2$	empirical constant (S/m), Eq. (8)		
Cp	specific heat capacity (J/kg K)	*Subscripts*	
$D1$	empirical voltage gradient constant (S/m(cm/V)$^{-N1}$), Eq. (8)	adb	adiabatic
E	amount of energy (J)	exp	experimental
I	current (Ampere)	f	final
Kc	cell constant (1/m)	g	given
L	the distance between the electrodes (m)	i	initial
m	mass of the sample (kg)	loss	lost
Q	the amount of heat (J)	t	taken
R	resistance of the sample (m)	T	temperature dependent
t	time (s)	TV	temperature and voltage gradient dependent
		Superscripts	
		$N1$	constant in Eq. (8)

important in designing ohmic heating systems to be used in baby food lines. Castro et al. (2004) mentioned that it was important to evaluate the electrical properties of a food intended to be processed by ohmic heating by clearly demonstrating the significant differences of electrical conductivity between the several products tested.

The aim of this study was to obtain electrical conductivity data for apricot and peach puree to be heated ohmically in food industry. Effects of temperature and voltage gradients on ohmic heating rates of fruit purees were studied. Ohmic heating of purees as a single phase were also mathematically modelled by taking the system performance coefficients into account.

2. Materials and methods

The ohmic heating system explained in Icier and Ilicali (2005a) was used in ohmic heating of fruit purees. The peach and apricot purees were supplied by a commercial fruit juice producer. The samples were taken from the line before pasteurization. Total solid content, total soluble solid content, pH and acidity values of the fruit purees are given in Table 1. The samples were poured through the thermocouple port; the electronic temperature sensors were inserted and fitted. The distance between two stainless steel electrodes were arranged to apply different appropriate voltage gradients to the purees. The diameter of the electrodes was 0.025 m. After the system was sealed, the sample was ohmically heated up to a temperature of 70 °C at 50 Hz frequency using different voltages. Voltage, current, temperature data were logged at 1 s time intervals during heating. The temperature of each sample was nearly uniform in the cell, since the maximum difference among the measured temperatures at different locations was approximately within 1 °C. So uniform heating was assumed in the model calculations. The experiments were replicated three times. The average temperature of the replicated heating experiments was taken as the measured temperature value. The time constants of Teflon coated temperature sensors were determined by calibrating them in melting point standards (52, 79 and 107 °C, Omega, UK). 12 and 13 different voltage gradients were applied for apricot and peach purees, respectively. Electrical conductivities of samples were calculated from voltage and current data using the following equation (Sastry & Salengke, 1998; Wang & Sastry, 1993):

$$\sigma = \frac{L}{A_e R}. \quad (1)$$

The time–temperature data were plotted to obtain the ohmic heating curves for fruit purees. Electrical conductivity was plotted against the corresponding temperature to obtain the electrical conductivity curves.

The unsteady-state heat conduction equation for negligible internal resistance was solved with an ohmic heating generation term by the finite difference technique. The details of mathematical model have been explained in Icier and Ilicali (2004).

The energy given to the system and the heat required to heat the sample to a prescribed temperature were calculated by using the current, voltage and temperature values recorded during the heating experiments:

$$E_g = \sum \Delta VIt, \quad (2)$$