Error Analysis in Estimating Temperature-Dependent Thermal Diffusivity and Kinetic Parameters using Heat Penetration Data

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Abstract

Methods have been in use for many years to find error in temperature measurements of can centers during food processing due to heat conduction down mounted thermocouples in cans. These methods are generally time consuming and operationally intensive. They also present the potential to add additional error to the analysis, such as the position of the thermocouple hot junction. This study presents a finite element computer method that isolates and quantifies error due to thermocouple presence in temperature, thermal diffusivity, and kinetic degradation parameters of anthocyanin during processing. The presence of the thermocouple cause a RMSE of 0.32 ºC for the center temperatures, a maximum error of 9% in thermal diffusivity, and errors of 6% and 4% were found for

parameters rate c … gy (E_a,) respectively.

Background

Growing consumer demand for nutraceuticals has stimulated interest by food companies to increase levels of these health-promoting compounds. Thermal processing of canned foods in a retort produces a unique problem: some of the nutraceuticals are highly sensitive to temperature, and require accurate parameter estimates to predict their fate during processing. Error in temperature measurement due to heat conduction through the can-mounted thermocouple assembly could potentially have significant effects on kinetic parameter estimation, especially in this study, where the rate constant (k) increases exponentially with temperatures above 100°C. The error due to heat conduction has been quantified and correction factors for time-temperature curves have been published for over fifty years. However, many of these studies used over-simplified geometries to describe the thermocouple in a computer model, or used experiments that could introduce errors other than heat conduction though the thermocouple assembly. In these studies, thermal diffusivity (α) was calculated, it was assumed constant over the temperature range; even though it is known that α in food varies ~10% over a 100°C range. Experiments used to find the error in temperature measurements introduce other errors to the data, such as position of the thermocouple hot junction and moisture convection inside the can. In addition, the resolution of the thermocouple itself may not be sensitive enough to identify this conduction error. Evaluating heat conduction down the thermocouple assembly with a computer simulation model provides a faster, easier way to isolate the error.

Objective

The purpose of this study was, for heat penetration studies in canned foods, to determine the effect of thermocouple presence on error in a) temperature measurement, b) estimation of temperature-dependent thermal diffusivity of the canned food, and c) estimation of nutraceutical kinetic degradation parameters.

Materials and Methods

COMSOL with MATLAB was used to design two separate models for comparison (fig.1). Finite element heat transfer analysis was preformed on both models to calculate can center temperatures throughout the simulated retort process. The real life geometry of a thermocouple inserted inside an arbitrary canned food product was approximated and resulting temperatures used as experimental data points. Another model without the thermocouple was made and subjected to the same boundary conditions. Both models were estimated as axi-symmetric cylinders. The nonlinear regression method for finding thermal diffusivity and kinetic parameters using MATLAB was adopted from Mishra and others, 2008. The resulting can center temperatures, thermal diffusivity parameters, and kinetic degradation parameters for anthocyanin (a nutraceutical) from both of these models demonstrated how much error can be expected in experimental data due specifically to heat conduction through the thermocouple assembly.

In order to check the legitimacy of the approach, the can center temperatures from the finite element model without the thermocouple were compared to center temperatures using an analytical solution. A low root mean square error was expected. In addition, both finite element models were compared using a constant thermal diffusivity. If the resulting temperatures were in agreement with previous studies—the expectation is the presence of the thermocouple will measurably increase the rate of heat transfer to the center of the can—the method could be applied to temperature dependent diffusivity. The

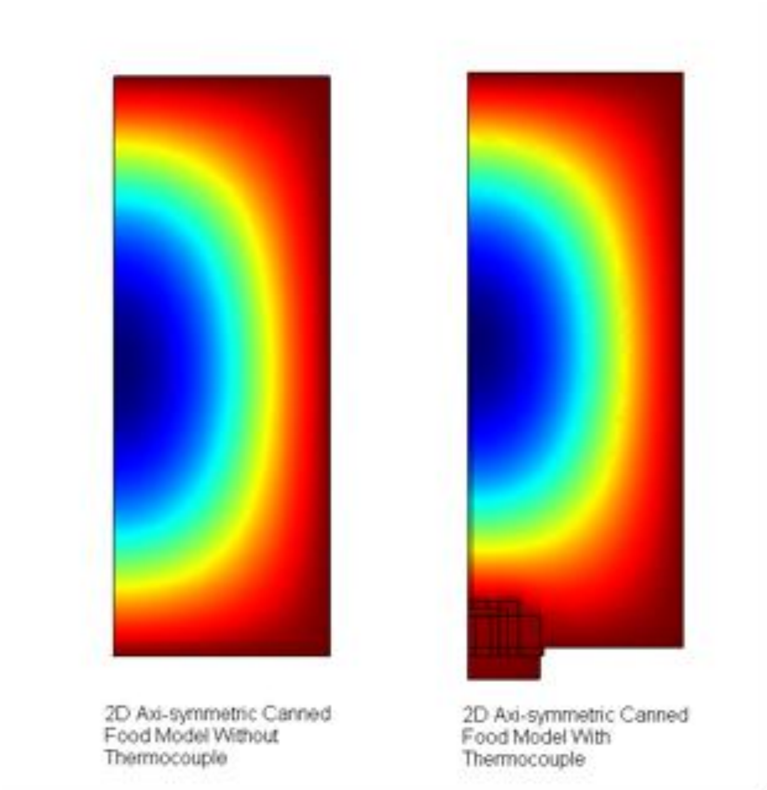

Figure 1

RMSE for the analytical comparison was 0.102 ºC. Therefore, the finite element solution introduces a very small amount of error.
Excluding non-linear regression in MATLAB, a predetermined thermal diffusivity was defined in COMSOL, and the resulting center temperatures, under identical boundary conditions were compared for each model. The model with the thermocouple produced a can center temperature curve with values slightly higher than the model without. The difference at the end of the retort simulation was about 2 ºC. These results suggest the finite element method is sensitive enough to quantify error in temperature measurements due to thermocouple presence in a variable diffusivity food product.

References

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G. Kanellopoulos and M. J. W. Povey, A Finite Element Model for Conduction Errors in Thermocouples During Thermal Sterilization of Conduction Heating foods, *International Journal of Food Science and Technology*, **26**, 409-421 (1991)

Results

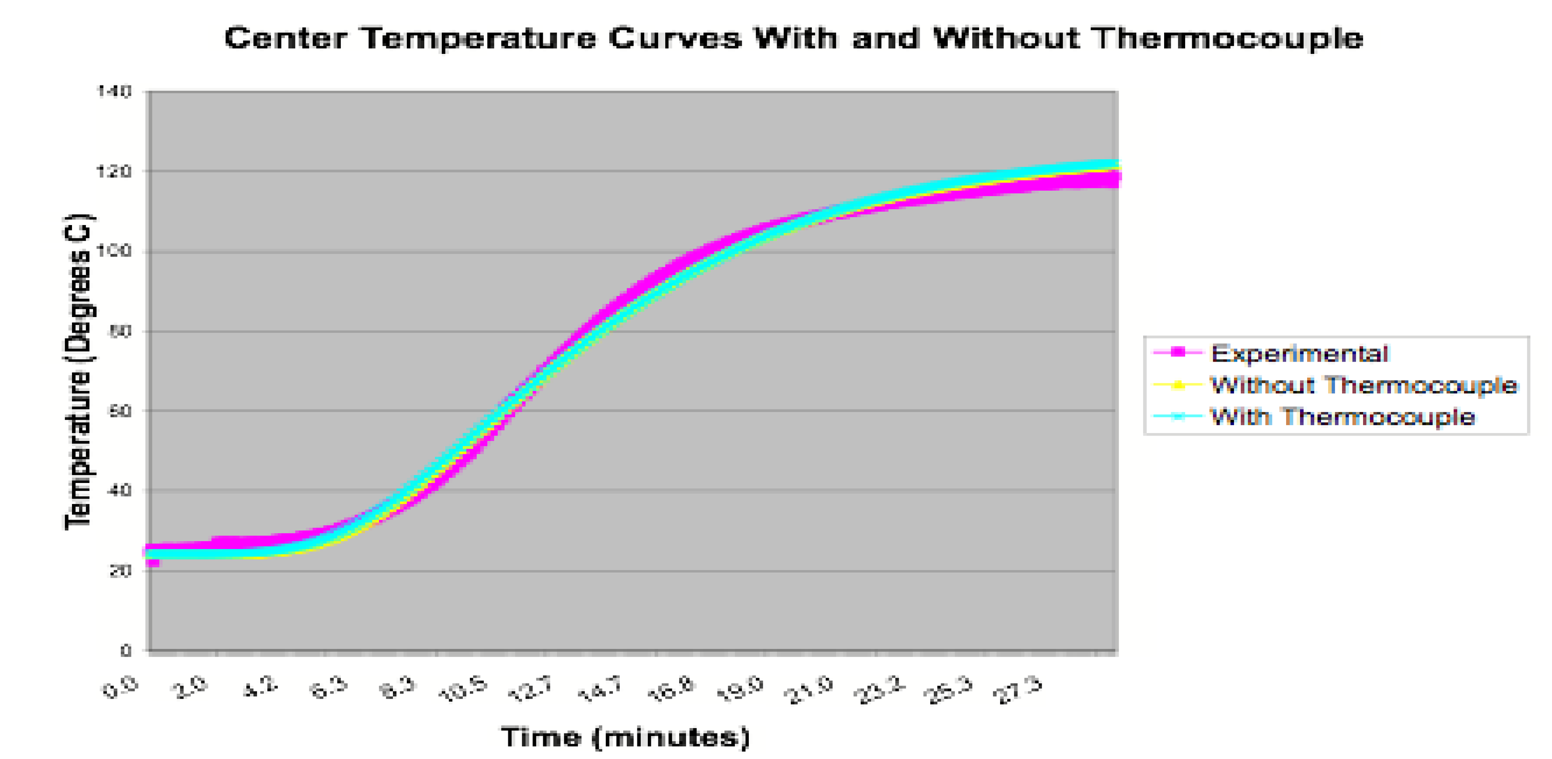

Figure 2

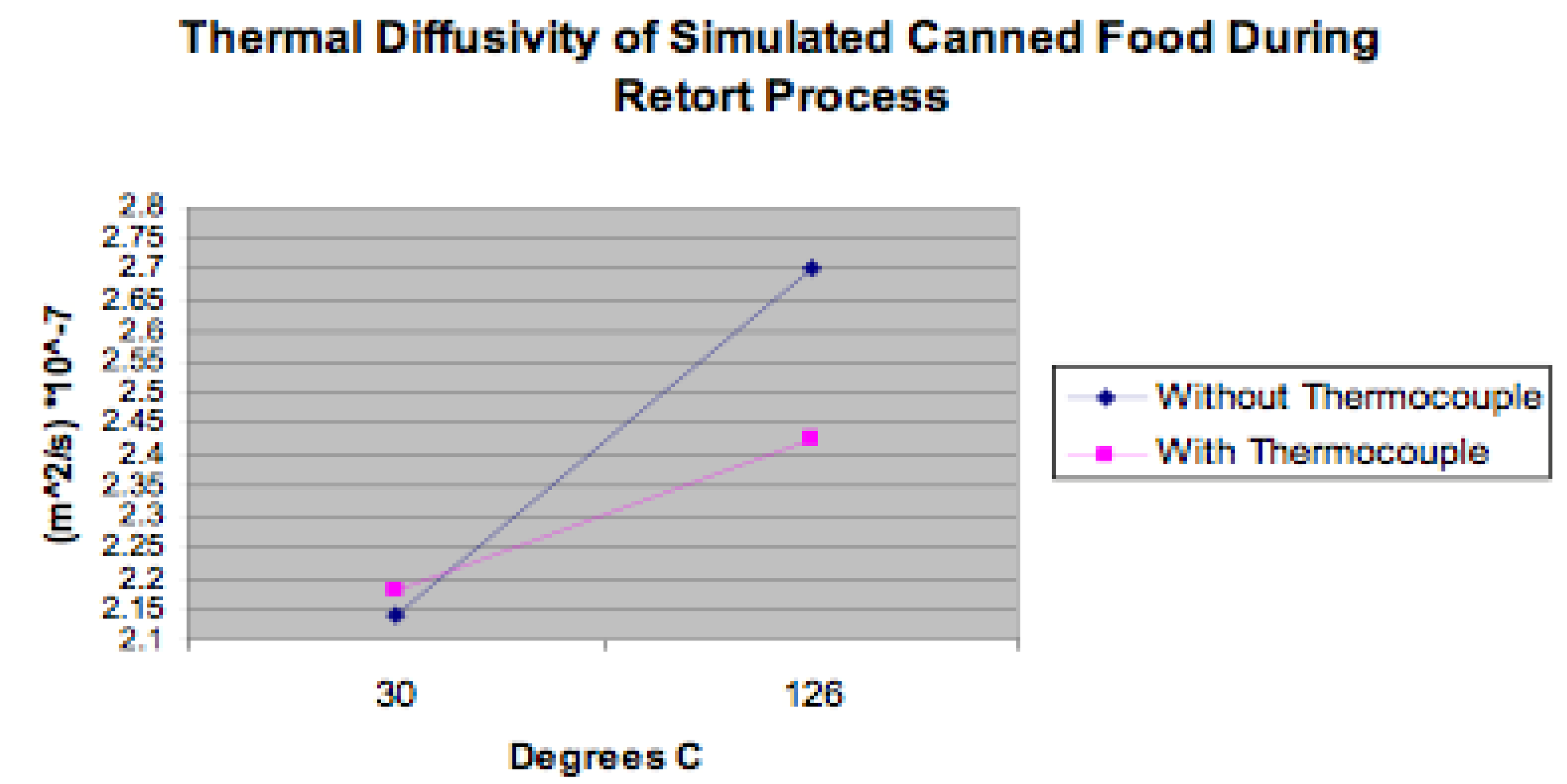

Figure 3

The model was run for steel cans (radius 0.027 m and height 0.073 m), using Ecklund-Harrison model CNS thermocouples and C-5 receptacles. A RMSE of 0.32°C was found for the can center temperatures from the two models, the maximum error was about 1 ºC (fig 2). Greater error in temperature was expected with the addition of temperature depended thermal diffusivity, however, the error is in agreement with previous studies concerning constant thermal diffusivity [2,6,7]The maximum error in temperature dependent diffusivity was 9% and occurred at 126 °C, (fig. 3).

Conclusions

For the can size and heating conditions in this work, the conduction error introduced by the thermocouple was small for temperature measurement (< 1°C), small for thermal diffusivity (<10%), and small for kinetic parameter estimation. Although these results were unexpected, they are favorable in that data from heat penetration experiments similar to these conditions will have small error. The contribution of this study is that we have shown how to quantify these errors using a rapid method with COMSOL and MATLAB.