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

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Introduction

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 ( ) was calculated, it was assumed constant over the temperature range; even though it is known that in food varies ~10% over a 100°C range. Therefore, 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.

Use of COMSOL Multiphysics

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. 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. 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.

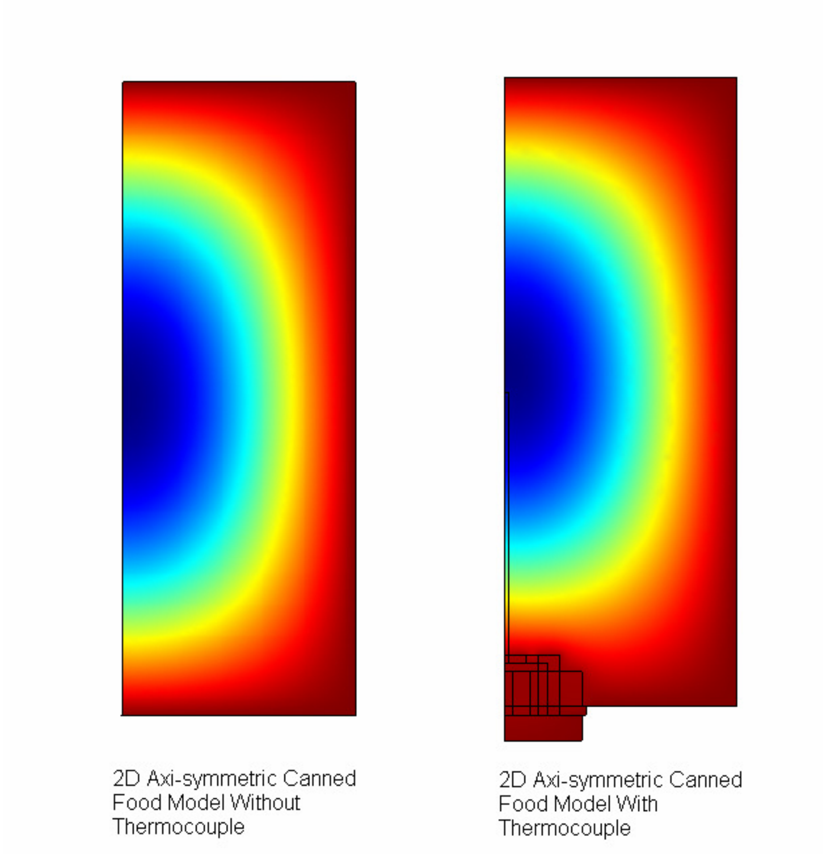

Figure 1

Expected Results

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 error of 0.32°C was found for the can center temperatures from the two models. The maximum error in temperature dependent diffusivity was 9% and occurred at 126 °C, (fig. 2).

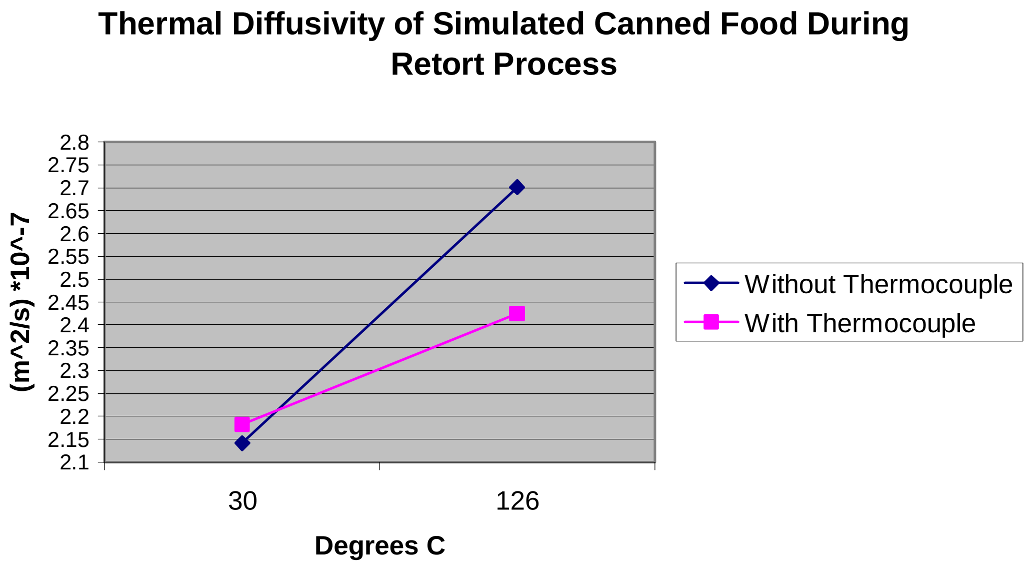

Figure 2

For the kinetic parameters k and E_a, errors were 6% and 4% respectively. This error can easily be evaluated for different can sizes and tabulated using this model.

Conclusion

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.

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