Heat penetration in rendered products:
Thermal conductivity modeling for predicting heat penetration in non-stirred raw rendered products

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Acknowledgments: This project was funded by a grant from the Fats and Proteins Research Foundation, R.R. #2 Box 298, Bloomington, IL 61704. The authors thank Dr. Scott Whiteside for technical assistance.

Technical Contribution No.   of the South Carolina Agricultural Experiment Station, Clemson University, Clemson, South Carolina

Introduction

The rendering industry is committed to processing animal and poultry by-products to produce microbiologically safe finished products. Heat processing of food materials has been well studied using heat penetration data to establish thermal death time values for heat resistant microorganisms. This information has been used extensively in the canned food industry to ensure food safety through adequate heating of foods. In the rendering industry, raw rendered products are cooked to destroy microorganisms. In the following study, canning industry methodology was used to determine the thermal conductivity of raw rendered products. The data collected was used to develop models to predict thermal conductivity in unstirred raw rendered products.

The thermal properties of food and food by-products vary primarily due to the moisture content, temperature and to a lesser degree, other compositional components (Murphy et al., 1998; Murphy and Marks, 1999). Specific heat (Cp) is defined as the energy required to raise one gram of a material one degree celsius. Specific heat is related to thermal conductivity (k):

$$k + Cp\ (\rho)\ (a)$$

where ρ is the density and a is the thermal diffusivity.

Specific heat can be estimated for food materials based on their composition using the formula:

$$Cp = 1.424m_c = 1.549m_p + 1.675m_f + 0.837m_a + 4.187m_m$$

where m_c is the mass of carbohydrate, m_p is the mass of protein, m_f is the mass of fat, m_a is the mass of ash, and m_m is the mass of moisture.

As noted in this formula, moisture has the greatest effect on specific heat and, consequently, the thermal conductivity of a food by-product material. Therefore, the composition of by-products to be thermally processed will alter the processing parameters. The heat delivered during the thermal process will be transferred throughout the material by conduction through the material. Thus, the thermal conductivity of the material will reflect the differences in these heat conduction properties and, also, the thermal process required to make the product safe.

The thermal process relies on a mathematical model to ensure the safety of the final product. The basis of the mathematical model is the time-temperature profile of the material and the kinetics of microbial destruction (Holdsworth, 1985). The rendering industry is committed to processing animal and poultry by-products to produce microbiologically safe finished products. Heat processing of food materials has been well studied using heat penetration data to establish thermal death time values for heat resistant microorganisms. This information has been used extensively in the canned food industry to ensure food safety through adequate heating of foods. In the rendering industry, raw rendered products are cooked to destroy microorganisms. In the following study, canning industry methodology was used to determine the thermal conductivity of raw rendered products. The data collected was used to develop models to predict thermal conductivity in unstirred raw rendered products.

Experimental Procedures

Materials

Samples of raw beef, pork and poultry rendered products were provided by Griffin Industries, Inc., Columbus, IN, American Protein, Inc., Cummings, GA and Darling International, St. Louis, MO. Samples were identified as follows:

1. Primarily Beef Bones
2. Primarily Shop Fat & bones - beef and pork bones, beef offal
3. Tallow - primarily beef tallow with mixed species fat
4. Cattle Offal
5. 100% Feathers
6. Poultry Offal
7. Whole Ground Chicken (WGC)
8. 50% WGC and 50% Feathers (v/v)
9. Pork

Each product was analyzed for percent moisture, fat, total solids and bone.

The nine mixtures of raw rendering materials were examined in heat penetration studies in a Loveless still retort using a TechniCAL CALPlex 32 Datalogger, Ecklund needle thermocouples, 300x406 two piece steel cans and TechniCAL CALSoft data collection software.

Thermal Conductivity Study

In order to provide the rendering industry with an indication of the rate of heating for different raw products, we conducted a study on the thermal conductivity of the provided samples. In this study, samples of each raw rendering product were packed into 300 x 406 steel cans installed with thermocouples. The cans were processed in a Loveless still retort. Throughout the heating process, a datalogger collected heat data at 10 second intervals and recorded the data on CALSoft software (TechniCal, Inc., New Orleans, LA). All samples were processed to at least a 12D process.

Heating Curve Models

The data points collected by the thermocouple datalogger/software system were used to determine a model that would best describe the relationship between temperature and time for the heating curves observed. For each treatment, model terms could then be used to compare treatments. With the exception of Treatment 3, the treatments conformed to a sigmoidal type heating curve characteristic of conductive heating. Treatment 3, which was Primarily Beef Tallow, became liquefied soon after heating commenced and, therefore, demonstrated a steep, straight convective type heating curve. In conductive heating, heat is slowly transferred from one molecule to the next in a solid packed product. In convective heating, the liquified product develops convection currents in which the heated material flows to the center of the can and, thus, heats the entire product much more quickly than in a solid packed material. Treatment 3 was not used in the modeling. The modeling concentrated on conductive heating curves. Two models were proposed for the conductive heating curves. The first was a quadratic of the form:

$$\text{Temperature (F)} = \beta_0 + \beta_1(\text{Time (min)}) + \beta_2(\text{Time (min)})^2 + \text{error}$$

where β_0 is the intercept, β_1 is the linear term, and β_2 is the quadratic term. The second model was a logistic of the form:

$$\text{Temperature} = \frac{G}{1 + e^{(B(A\text{-Time}))}}$$

where A is the inflection point, G is the upper asymptote, and B is the rate term.

Both models were fit to all treatments (except 3) and the model terms (β_0, β_1, and β_2 for quadratic; A, G and B for logistic) were compared across treatments using ANOVA and LSD ($\alpha = 0.05$). The instantaneous slopes for each model ($\beta_1 + 2\beta_2(\text{time})$ for quadratic; $GB\ e^{B(A\text{-time})}/(1+e^{B(A\text{-time})})^2$ for logistic) were also compared across treatments at different times using ANOVA and LSD ($\alpha = 0.05$). Finally, total F and estimated B times were calculated using the General Method Evaluation feature included with the CALSoft software (z = 18) (TechniCAL, Inc., New Orleans, LA). These values were compared across treatments using ANOVA and LSD ($\alpha = 0.05$).

All model fitting and ANOVA calculations were performed using Statistical Analysis Software (SAS) (Cary, NC).

Table 1. Comparison of Quadratic terms: Slope (β_0) and Quadratic term (β_1) for Rendering Products

Treatment	β_0	β_1
1. Pri. Beef Bones	5.08 c	-0.0348 a
2. Pri. Shop Fat & bones	5.30 c	-0.0362 a
4. Cattle Offal	5.60 c	-0.0378 a
5. 100% Feathers	13.20 a	-0.1956 c
6. Poultry Offal	5.64 c	-0.0385 a
7. Whole Ground Chicken (WGC)	6.85 b	-0.0542 b
8. WGC and Feathers	7.02 b	-0.0578 b
9. Pork	5.70 c	-0.0370 a

Quadratic terms followed by the same letter are not significantly different at $\alpha = 0.05$

Table 2. Comparison of Logistic Terms: A, B, and G

Treatment	**A**	**B**	**G**
1. Pri. Beef Bones	12.67 cb	0.078 c	252.66 b
2. Pri. Shop Fat & bones	13.68 ab	0.082 cb	251.12 b
4. Cattle Offal	15.25 ab	0.087 cb	252.15 b
5. 100% Feathers	6.64 c	0.361 a	252.97 b
6. Poultry Offal	15.25 ab	0.092 cb	250.77 b
7. Whole Ground Chicken (WGC)	15.40 ab	0.109 cb	252.16 b
8. WGC and Feathers	13.95 ab	0.124 b	256.14 a
9. Pork	19.01 a	0.088 cb	250.37 b

Logistic terms followed by the same letter are not significantly different at $\alpha = 0.05$

Table 3. Comparison of instantaneous rates of the quadratic model at specified times (°C/min).

	Time (min)						
Treatment	**0**	**10**	**20**	**30**	**40**	**50**	**60**
1. Pri. Beef Bones	5.08 c	4.38 c	3.69 c	2.99 c	2.29 a	1.60 abc	0.90 ab
2. Pri. Shop Fat & bones	5.30 c	4.57 c	3.84 c	3.12 bc	2.40 a	1.67 abc	0.95 ab
4. Cattle Offal	5.56 c	4.81 c	4.05 c	3.30 abc	2.53 a	1.76 ab	1.02 a
5. 100% Feathers	13.20 a	9.28 a	5.37 a	1.45 a	-2.46 b	-6.37 d	-10.3 d
6. Poultry Offal	5.64 c	4.87 c	4.10 c	3.33 abc	2.55 a	1.80 ab	1.01 a
7. Whole Ground Chicken (WGC)	6.85 b	5.77 b	4.70 b	3.60 a	2.52 a	1.43 bc	0.35 bc
8. WGC and Feathers	7.02 b	5.87 b	4.70 b	3.55 ab	2.40 a	1.23 c	0.08 c
9. Pork	5.70 c	4.96 a	4.21 bc	3.50 ab	2.73 a	2.00 a	1.25 a

Instantaneous rate terms followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 4. Comparison of instantaneous rates from the logistic model at specified times (°C/min).

	Time (min)					
Treatment	**10**	**20**	**30**	**40**	**50**	**60**
1. Pri. Beef Bones	4.80 c	4.43 b	3.17 a	1.88 a	0.99 ab	0.493 ab
2. Pri. Shop Fat & bones	4.86 c	4.75 ab	3.42 a	1.96 a	0.98 ab	0.462 ab
4. Cattle Offal	5.18 bc	5.15 ab	3.60 a	2.04 a	1.03 ab	0.494 ab
5. 100% Feathers	15.7 a	0.83 c	0.03 b	0.001 b	0.0001 c	0.000 c
6. Poultry Offal	5.37 bc	5.20 ab	3.57 a	1.95 a	0.95 ab	0.433 ab
7. Whole Ground Chicken (WGC)	6.40 bc	5.83 a	3.46 a	1.70 a	0.77 ab	0.335 abc
8. WGC and Feathers	7.11 b	5.51 ab	3.21 a	1.51 a	0.63 bc	0.246 bc
9. Pork	4.85 c	5.14 ab	4.00 a	2.48 a	1.36 a	0.687 a

Instantaneous rate terms followed by the same letter are not significantly different at $\alpha = 0.05$.

Figure 1. Comparison of predicted linear curves using the quadratic model.

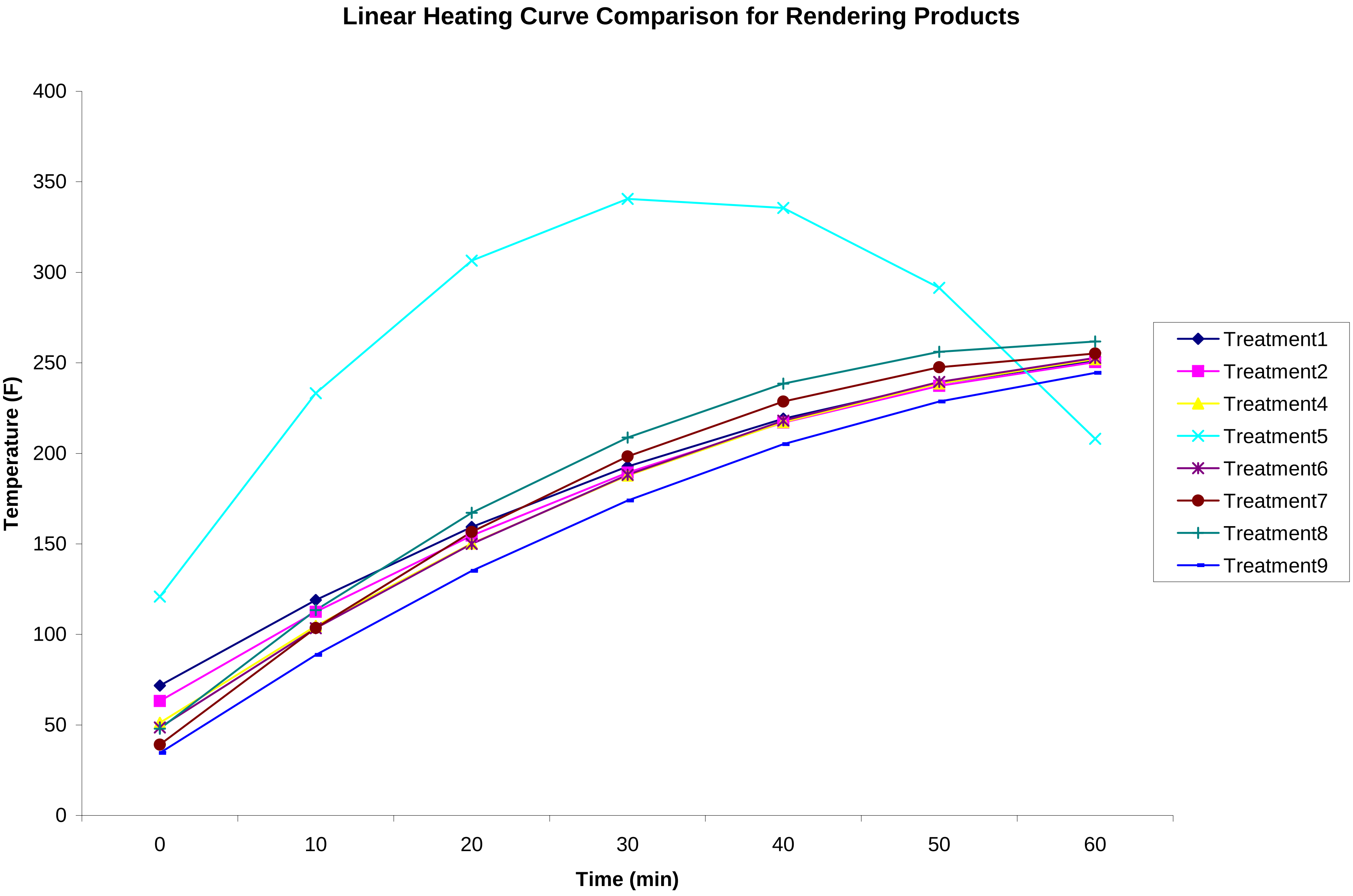
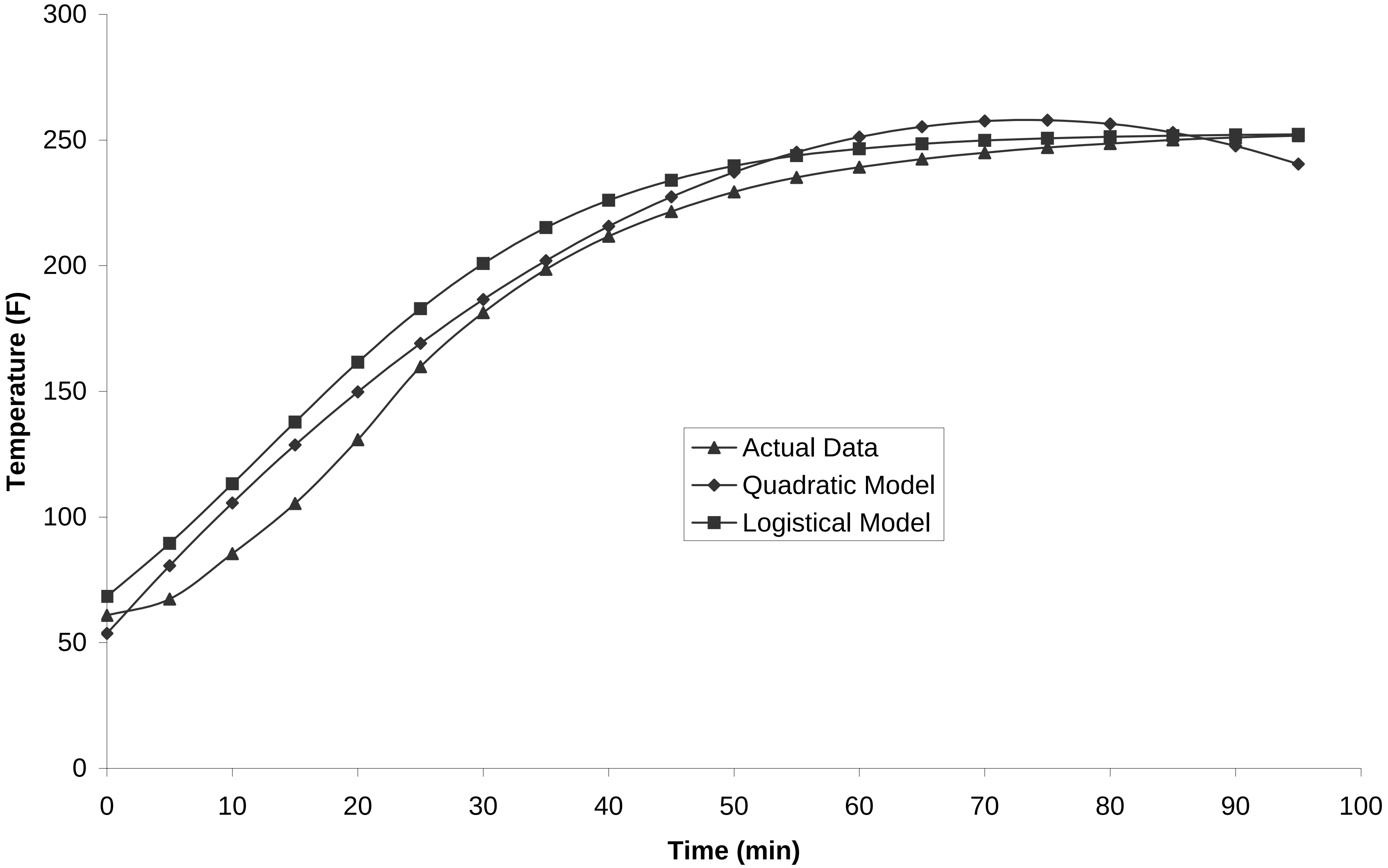


Figure 2. Comparison of an actual heating curve for rendered product vs. quadratic model vs. logistic model.



Results and Discussion

The "best fit" non-linear regression model was a logistical function. A logistic function was fit for each replicate of the treatments and compared to the quadratic linear models for each replicate. In all cases, the logistic model produced a much smaller residual or Sum of Squares for Error (SSE) indicating an overall better fit than the quadratic linear model. The logistic model would be recommended for future analysis.

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