THERMOPHYSICAL PROPERTIES OF PROCESSED MEAT AND POULTRY PRODUCTS.

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ABSTRACT

Data on thermophysical properties are essential for modeling and evaluation of food processing operations involving heat transfer when safety, quality and energy cost are considered. Thermophysical properties of various meat and poultry emulsions were evaluated at 4 temperatures (20, 40, 60 and 80^{o}C). Thermal conductivities (0.26 W/mK to 0.48 W/mK) increased linearly with the temperature from 20 until 60^{o}C. From 60-80^{o}C, it remained stable for most product except the bologna. Curves of thermal conductivities as a function temperatures could roughly be grouped in two categories; products containing meat particles and emulsions. Densities decreased slightly as a function of temperature from 20 to 40^{o}C. A transition phase was observed from 40 to 60^{o}C. It was followed by a decrease from 60 to 80^{o}C. There was a decrease of about 50 kg/m^3 between the density of a raw product at room temperature (at maximum 1070 kg/m^3) and the product heated to 80°C (at minimum 970 kg/m^3) due to the gelation or setting of the structure. After a transition period from 10-30^{o}C, the heat capacity increased linearly from 30 until 80^{o}C. Values ranged from 2850-3380 J/kg^{o}C. Densities and heat capacities were strongly influenced by the carbohydrate content (i.e. as the carbohydrate content increased the density decreased). The fat proportion negatively affected the thermal conductivity and diffusivity. As the water content increased the thermal conductivity and diffusivity increased. The density, heat capacity, thermal conductivity, and diffusivity were not affected by the salt proportion due to the limited amount incorporated in products.

INTRODUCTION:

Thermo-physical properties of food are needed to describe various thermal processes as well as to optimize the design and the operation of heating, cooking, freezing and cooling systems (Karunakar et al., 1998). Thermal properties are also essential for the modeling and evaluation of food processing operations involving heat transfer, especially when energy costs, food quality and safety are considered. Many examples of safety considerations are given in available publications (Unklesbay et al., 1999). For example, the temperature at the centre of a typical sausage must be above a certain level (72°C) by the end of heating and below certain temperature (15^{o}C) at the end of cooling in order to achieve microbiological stability (Akterian, 1997).

There are many methods to measure thermophysical properties (Baik et al., 2001). Thermal conductivity is highly temperature dependent especially in temperature region where a phase change occurs. According to Karunakar et al. (1998), in the low temperature range (0 to 40°C), the thermal conductivity did not show very significant difference for different temperatures. At high temperatures (>50°C), it increases gradually as the temperature increases (Pan and Singh, 2001). Both thermal conductivity and specific heat are known to increase with moisture content increase (Shmalko et al., 1996). Water content will specific heat more than other components, the lower specific heat values generally occurred with the lower moisture content values (Unklesbay et al., 1999). Thermal conductivity and density of foods vary with temperature during thermal processing due to the changes in texture and/or composition (Karunakar et al., 1998). A decrease in density values will become important for its effect on other thermal properties (Mohsenin, 1980). Most changes in meat products occur during heating, shrinkage, tissue hardening, moisture loss, fat loss and discoloration, and are caused by the changes in muscle protein denaturation (Pan and Singh, 2001). All these changes in the meat will affect the thermophysical properties. The objective of the study was to measure thermophysical properties of various meat and poultry emulsions as a function of temperature.

MATERIALS AND METHODS

Products

Five types of meat products were used: fine emulsion of bologna and wieners, coarse emulsion of pepperoni, turkey emulsion and flaky ham. Turkey emulsions and the flaky ham contained muscle particles. Raw products were taken at a typical industrial plant and measurements were made the day after. Products were kept at 4°C in a cold room until they were analyzed. All experiments were performed three times as well as with three different batches. Thermo-physical properties of meat and poultry emulsions were gathered at different temperatures from raw product to cooked product temperature. The composition of meat and poultry emulsions is listed in Table 1.

Table 1. Composition of various meat and poultry emulsions

	Moisture (%)	Fat (%)	Salt (%)	Protein (%)	Carbohydrate (%)
Bologna	61.59	20.31	2.39	11.49	2.39
Pepperoni	57.26	21.72	2.53	12.32	5.22
Wieners	60.51	20.90	2.43	12.40	2.00
Turkey	74.88	1.67	1.54	15.46	1.30
Ham	72.70	6.35	2.78	11.62	2.25

Thermal conductivity

Thermal conductivity measurements of various meat samples were performed using the probe method based on the line-heat source method developed by Sweat (1974). In the probe, there was a heater wire insulated over its length and a thermocouple in the center of this length. The probe was 38 mm long with an outside diameter of 0.66 mm, it consisted of a constantan heater wire and a chromel-constantan thermocouple (type E) (Sweat, 1995). The probe was connected to a power supply (Hewlett-Packard, 6236B) and to a multimeter (TES 2610 multimeter) in order to read the current more precisely; the multimeter was set to the scale mA DC. The thermocouple wires were connected to a data acquisition system (Data Shuttle by Strawberry Tree) that was connected to a computer (Baik et al., 1999). The software "Workbench for Windows version 3" was used to convert the analog signal of the thermocouple in a digital signal, to set the acquisition rate at 1 reading every 2 seconds. The probe had a theoretical internal resistance of 226.67 Ω/m. It was calibrated with glycerol. Values were within 10% of the literature value of 0.284 W/m.K at 20°C.

Four constant temperature water baths were used for the analyses with an increment of 20^{o}C: room temperature bath at 20^{o}C, a 40°C water bath, a 60°C water bath and an 80°C oil bath to prevent evaporation. A copper cylinder (12.7 cm height and 2.54 cm inside diameter with a maximum wall thickness of 0.159 cm) with a high thermal conductivity was used. Samples were inserted using a syringe for the emulsions and by hand for the turkey and the flaky ham because of the muscle parts. A rubber cover was placed at both ends of the cylinder to insulate them in order to keep the heat flow coming only from the side of the cylinder or radial direction. An infinite cylinder was assumed for thermal conductivity calculations. Three cylinders were placed in each of the four temperature controlled water baths. As the core temperature of samples reached the equilibrium with the water bath, the top rubber cover was replaced by a thinner one and the probe was inserted in a small hole made at the center. The probe was placed at the core of the sample. The data acquisition started for 8 seconds to record the initial temperature. Then the power was turned out for a current of 200 mA for 2 min of data acquisition before being stopped. The thermal conductivity was calculated by plotting the temperature versus the natural logarithm of the time and taking the slope of the linear part of this graph. Having the slope, it was possible to calculate the thermal conductivity using the 2 following equations:

$$Q = R_{th} I^2 \tag{1}$$

$$k = \frac{Q}{4\pi m} \tag{2}$$

Where: Q = heat flux (W/m)
R_{th} = probe resistance (Ω/m)
k = thermal conductivity (W/m*K)
I = current (mA)
m = slope of the linear part of the temperature vs. ln (time) graph

Density

Densities were determined from the mass of the samples inserted in the copper cylinder and the volume of the cylinders. Volumes were pre-determined for 6 cylinders and averaged at 55 ml. The mass of the sample was measured at the end of the treatment to verify if there was any weight change during the treatment. The density was calculated with the final mass of the sample and the volume of the sample.

Heat capacity

A modulated differential scanning calorimeter (MDCS 2910, TA Instruments Inc., New Castle, DE) was used with a nitrogen cooling system. The advantage of MDSC over conventional DSC is the two independent heating rates of the MDSC; one heating rate can be zero (isothermal) while the modulated one oscillates over and under the isothermal temperature. It was possible to determine the heat capacity at various temperatures. First, the instrument cell constant was evaluated by running an experiment with Sapphire (Al_2O_3). The ratio of the experimental heat capacity over the theoretical heat capacity of Sapphire was obtained for a cell constant of 1,935. At first, a minimum of 200g of product was homogenized using a "Polytron" (Polytron, PT 10-35 by Kinematica) in order to get a representative sample, especially for coarse emulsion like turkey and ham, and to fill up properly the small capacity of the analytical container. A sample of 10-13 mg was placed into the aluminum pan which was then hermetically sealed with the encapsulating press from TA Instruments Inc. An empty pan, that had been previously weight-matched with the sample pan, was also sealed for reference. The method consisted of equilibrating the sample at 5°C, starting the modulation for a 60-second period with an amplitude of ±1°C, keeping it isothermally for 5 minutes, and heating the sample at a rate of 2.0°C/min from 5°C to 90°C. Helium was used as a purging gas with a flow of 25 ml/min. The instrument gave automatically heat capacity curves from 5 to 90°C.

Thermal diffusivity

The thermal diffusivity values were calculated from the experimental values of density, thermal conductivity and specific heat with the following equation:

$$\alpha = \frac{k}{\rho C_p} \tag{3}$$

RESULTS AND DISCUSSION

Thermal conductivity

As shown in Figure 1, thermal conductivity values increased as a function of temperature for all products. For a fine bologna emulsion, the thermal conductivity increased from 0.304±0.028 W/m.K at 22°C to 0.459±0.100 W/m.K at 80°C and for a fine wieners emulsion, values varied from 0.290±0.022 to 0.419±0.066 W/m.K. For a coarse pepperoni emulsion, the thermal conductivity varied between 0.272±0.019 to 0.402±0.044 W/m.K from 22 to 79°C. For products containing muscle parts, the thermal conductivity of turkey product varied between 0.324±0.040 to 0.482±0.086 W/m.K and for ham product, from 0.340±0.037 to 0.427±0.058 W/m.K. There was a good agreement between results of the three batches. As well, two sets of measurements were performed on the same batch of products to measure the method repeatability. Differences between values were in the same order of magnitude as for the two individual batches indicating that our methodology was highly repeatable.

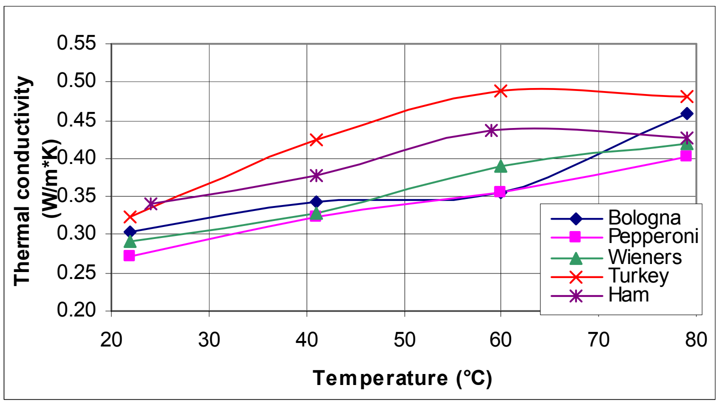

Figure 1: Thermal conductivity of various meat and poultry emulsions at various temperatures.

Density

Observed density changes during cooking were very small. There was no significant mass loss for these particular products. The gelation, or setting of the solid structure of the product caused a small increase in the volume of the sample during the heating stage of the emulsions. The density decreased slightly with temperature (Figure 2). For every product, there was a decrease of about 50 kg/m³ between the raw product at room temperature and the product heated to 80°C. For the raw products, the density was 1034 and 1072 kg/m³ and for cooked products, 967 and 1016 kg/m³ for pepperoni and ham, respectively.

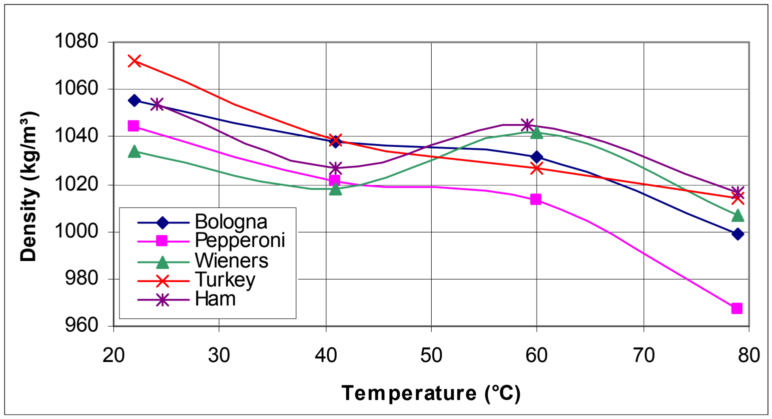

Figure 2: Density changes with temperature of various meat and poultry emulsions

Heat capacity

It is well known that heat capacities vary with temperature. This was confirmed by our results shown in Figure 3. Heat capacity values of meat emulsions increased at constant pressure.

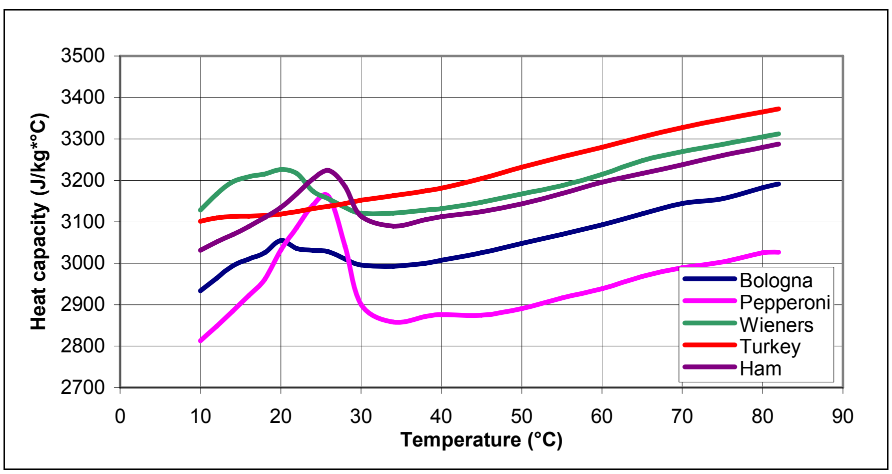

Figure 3: Heat capacity of meat and poultry emulsions at different temperatures

Each heat capacity curve became linear from 35°C to 82°C with a slope of 4.34. For the bologna emulsion, the minimal heat capacity was around 10°C for a value of 2933 J/kg.K and a maximum of 3191 J/kg.K at 82°C. On the heat capacity curve of bologna, a peak at 20°C was noticed, about 100 J/kg.K higher than the 35°C value. A higher peak was also noticeable for pepperoni, the peak was about 300 J/kg.K at 26°C, higher than the one at 35°C. This peak was also the maximum heat capacity value (3160 J/kg.K) observed for pepperoni. The minimum was 2812 J/kg.K at 10°C. The heat capacity curve for Wieners had a similar shape compared to bologna at about 150 J/kg.K higher for all the curve length. For example, the maximum value for the wieners was 3312 J/kg.K at 82°C and the minimum at 30°C is 3121 J/kg.K. For the turkey product, the curve was almost linear from 10 to 82°C with a slope of 3.9 and an ordinate of 3050 J/kg.K. The ham product had a maximum heat capacity of 3287 J/kg.K at 82°C and a minimum of 3031 J/kg.K at 10°C, this curve also included a peak at 20°C (3224 J/kg.K). The average standard deviation for all curves was 115.5 J/kg.K.

Thermal diffusivity

Thermal diffusivity was found to change with product temperature (Figure 4). It represents the relationship between the three abovementioned properties. Thermal diffusivity curves were very similar to thermal conductivity curves because other properties have less influence on this parameter. The thermal diffusivity at room temperature is about 9.0×10^{-8} m²/s compared to 1.35×10^{-7} m²/s at 80°C.

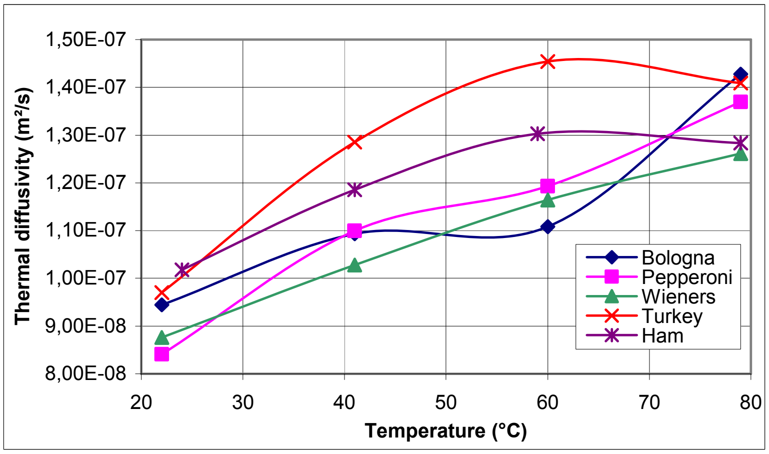

Figure 4: Thermal diffusivity of meat emulsions at various temperatures

Values of thermophysical properties were measured for a variety of meat and poultry emulsions. Significant differences were found that may be attributed to the meat and poultry formulations. Average values of thermophysical properties were correlated to the chemical composition of meat and poultry emulsions. Table 2 shows the correlation matrix. A strong proportional relationship would be indicated by a value close to 1 or to -1 for an inverse proportional relationship. A value close to 0 indicates a weak correlation between the values.

Table 2. Correlation matrix for thermophysical properties vs. emulsion compositions

	k	ρ	C_p	α	Moisture (%)	Fat (%)	Salt (%)	Protein (%)	Carbohydrate (%)
k	1.000								
ρ	0.383	1.000							
C_p	0.744	0.734	1.000						
α	0.959	0.155	0.525	1.000					
Moisture (%)	0.960	0.530	0.743	0.899	1.000				
Fat (%)	-0.978	-0.387	-0.668	-0.957	-0.986	1.000			
Salt (%)	-0.652	-0.099	-0.488	-0.638	-0.450	0.503	1.000		
Protein (%)	0.776	-0.055	0.491	0.799	0.569	-0.654	-0.927	1.000	
Carbohydrate (%)	-0.655	-0.828	-0.972	-0.419	-0.678	0.580	0.471	-0.393	1.000

From a compositional point of view, the proportion of moisture was inversely correlated to the amount of fat. As well, the proportion of salt was inversely related to the percentage of protein in these products. The density and the heat capacity were strongly influenced by the carbohydrate content (i.e. as the carbohydrate content was increased, the density was decreased). As the moisture content increased, the thermal conductivity and diffusivity increased. As the %fat content increased, the value of k and α decreased. The proportion of salt did not have any significant effect on the density, heat capacity and thermal conductivity and diffusivity contrary to expectations. This was probably due to the limited amount (approximately 2%) that can be added to the meat and poultry emulsions. The maximum amount is related to the organoleptic acceptance of final products. The proportion of proteins did not influence significantly these properties as correlation coefficients were smaller than 0.9.

CONCLUSIONS:

Thermophysical properties are important because of their influence on the thermal exchanges between smokehouses or cookers and meat and poultry emulsions since the long cooking-cooling process relies heavily on conduction heating for these particular bulky products. It is also important to identify the movement of heat through the product since proper cooking-cooling cycles are generally established using core temperature measurement that must reach a pre-determined legal requirement at the end of the process. Results of the paper have shown that there are significant differences between thermophysical properties of various emulsions. The correlation matrix revealed that these differences may be attributed the composition of the emulsions. Therefore it is foreseeable that meat and poultry emulsions be formulated with optimal thermophysical properties in order to achieve the best efficient of cooking-cooling cycles. Moreover these properties could be used as input in modeling of heat transfer during the cooking-cooling process of these products.

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