ELECTRICAL PROPERTIES OF FOODS

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Summary

Foods, especially liquid foods, conduct electricity. Unlike in metals, the charge carriers in foods are ions, instead of electrons. Under normal applications, ions carry the charges as the mass of ions moves along the electrical field. The concentration and mobility of ions determine the electrical conductivity. Temperature and other ingredients in the foods affect the ion mobility. Under extreme electric field, electron-hopping takes place between the ions or molecules. This is the precursor of dielectric breakdown of foods, in which case an arc is the observed result. Electrical properties are important in processing foods with Pulsed Electric Fields, Ohmic Heating, Induction Heating, Radio Frequency, and Microwave Heating. These properties are also useful in detection processing conditions or in determining the quality of foods.

1. Electrical Conductivity

The electrical conductivity of foods is of relatively recent interest to researchers. Little literature exists on this topic, since electrical conductivity was not critical in food applications prior to the late 1980s. Recent attention on electrical resistance heating (see *Advanced Thermal Processing*) of foods and pulsed electrical field in pasteurizing foods (see *Nonthermal Processing*) has necessitated the need for information on the electrical conductivity of foods. Electrical conductivity is a critical parameter for both the Ohmic heating and pulsed electrical field processes. Knowledge of a food's electrical conductivity while under Ohmic heating or pulsed electrical field conditions is essential for process design.

Electrical conductivity is the reciprocal of resistance through a unit cross-sectional area A over a unit distance L, or the reciprocal of resistivity.

$$\sigma = L/(AR) \quad (1)$$

or

$$\sigma = (I/V)(L/A) \quad (2)$$

where, A is the area of cross section of the sample (m^2), I is the current through the sample (A), L is the electrode gap or length of sample (m), R is the resistance of the sample (Ω), V is the voltage across the sample (V), and σ is the specific electrical conductivity (S/m).

The definition above has been used to design experiments for measuring the electrical conductivity of foods. Standard methods and commercial conductivity meters are available for electrical conductivity measurements. Some researchers have used a commercial electrical conductivity meter (YSI model 30, YSI Incorporated, Yellow Springs, OH) to determine the conductivity of various food groups, as shown in Table 1. The electrical conductivity of foods has been found to increase with temperature. Others have reported similar results.

	4°C	**22°C**	**30°C**	**40°C**	**50°C**	**60°C**
Beer						
Beer	0.080	0.143	0.160	0.188	0.227	0.257
Light Beer	0.083	0.122	0.143	0.167	0.193	0.218
Coffee						
Black Coffee	0.138	0.182	0.207	0.237	0.275	0.312
Coffee with milk	0.265	0.357	0.402	0.470	0.550	0.633
Coffee with sugar	0.133	0.185	0.210	0.250	0.287	0.323
Fruit Juice						
Apple Juice	0.196	0.239	0.279	0.333	0.383	0.439
Cranberry Juice	0.063	0.090	0.105	0.123	0.148	0.171
Grape Juice	0.056	0.083	0.092	0.104	0.122	0.144
Lemonade	0.084	0.123	0.143	0.172	0.199	0.227
Limeade	0.090	0.117	0.137	0.163	0.188	0.217
Orange Juice	0.314	0.360	0.429	0.500	0.600	0.690
Milk						
Chocolate 3% fat Milk	0.332	0.433	0.483	0.567	0.700	0.800
Chocolate 2% fat Milk	0.420	0.508	0.617	0.700	0.833	1.000
Chocolate Skim Milk	0.532	0.558	0.663	0.746	0.948	1.089
Lactose Free Milk	0.380	0.497	0.583	0.717	0.817	0.883
Skim Milk	0.328	0.511	0.599	0.713	0.832	0.973
Whole milk	0.357	0.527	0.617	0.683	0.800	0.883
Vegetable Juice						
Carrot Juice	0.788	1.147	1.282	1.484	1.741	1.980
Tomato Juice	1.190	1.697	1.974	2.371	2.754	3.140
Veg. Juice Cocktail	1.087	1.556	1.812	2.141	2.520	2.828

Table 1. The electrical conductivity (s/m) of liquid products measured at increasing temperatures.

In addition to temperature, the electrical conductivity of foods is strongly affected by ionic content, moisture mobility, and physical structure, as well as the heating process. Some researchers have studied the changes in electrical conductivity of foods during Ohmic and conventional heating (see *Advanced Thermal Processing*, *Conventional*

Thermal Processing). They concluded that the behaviour of electrical conductivity during both treatments was different. As a result, a device was developed to determine the electrical conductivity of foods under Ohmic or conventional heating conditions (Figure 1). The device consists of a cylindrical sample chamber made of steel tube that contains a Teflon® sleeve inside with a thermocouple opening at the center and rhodium plated stainless steel electrodes at both ends. The tube is fitted with a metallic jacket with a thermocouple opening and an inlet and outlet for circulating heat exchange fluids. A T-type copper-constantan, Teflon® coated thermocouple, with a compression fitting, is used to measure the temperature at the geometric center of the sample. Voltage and current transducers are used to measure the voltage across and the current through the samples.

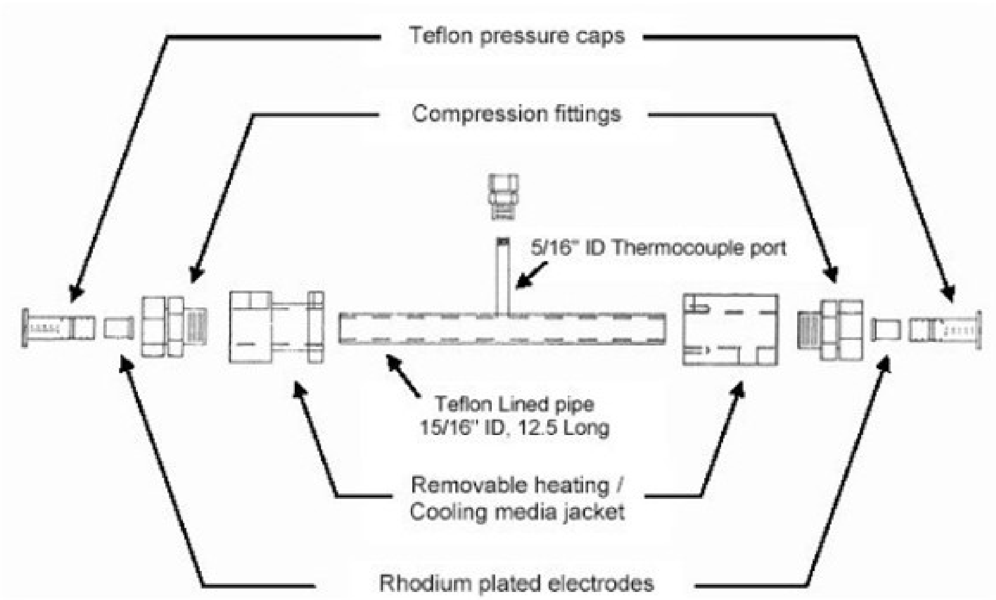

Figure 1. Experimental device for electrical conductivity measurement.
[From: Palaniappan S. and Sastry S.K. (1991a). Electrical conductivities of selected solid foods during ohmic heating. *Journal of Food Process Engineering* **14**, 221-236].

Experimental data on electrical conductivity measured for several food groups have been expressed in mathematical relationships. These models are useful in estimating the electrical conductivity of food materials. Some are presented in the following.

Researchers have reported that electrical conductivity is a linear function for temperature and presented the following model to predict the conductivity of solid foods:

$$\sigma_T = \sigma_{p25} \, [1+K\,(T-25)] \qquad (3)$$

where σ_T = electrical conductivity (S/m) at any temperature T (°C), σ_{p25} = electrical conductivity of particulate at 25°C, and K = temperature compensation constant.

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Biographical Sketch

Dr. Howard Q. Zhang, Research Leader for Food Safety Intervention Technologies Research Unit at the Eastern Regional Research Center, Agricultural Research Service of USDA; and adjunct professor at Ohio State University, received his BS in Agricultural Engineering/Electrical Engineering from Hunan Agricultural College/Central South University of Technology, China, in 1982; MS in Agricultural Engineering from University of Guelph, Canada, in 1987; and Ph.D. in Food Engineering from Washington State University, USA, in 1992. Dr. Zhang is member of IFT, IEEE, and ASAE. Dr. Zhang established a nationally-recognized program in pulsed electric field (PEF) processing and successfully transferred this technology to commercial operation. His pioneering work is evidenced by over 50 journal publications, and more than 150 meeting papers related to PEF. He owns six US patents in the area of PEF. His papers received the 1995 Best Paper Award of ASAE and 1997 Prize Paper Award of IEEE. Nalley's Fine Foods recognized him as the 1995 Outstanding Researcher of the Year. He received the OARDC Outstanding Researcher Award in 1996, 1998 and 2000. He received the IFT Samuel C. Prescott Award for Research in 2001. Other interests include food process instrumentation and automation. Dr. Zhang leads a research team of 14 senior research scientists and 16 support scientists at USDA Eastern Regional Research Center in developing, validating and recommending processing technologies to ensure the safety of fresh produce, juices and beverages and ready-to-eat food products.