Modeling Dielectric Heating: A First Principles Approach

R. W. Pryor, Ph.D.
Pryor Knowledge Systems, Inc., Bloomfield Hills, MI, USA

Introduction: Dielectric heating is a widely used electromagnetic heating technology. Vibrational energy (heat) is induced in the material by the application of an RF field. This model explores the physical effects when different frequencies within the internationally allocated bands[1] are utilized to pasteurize whey gel (≈gelled milk) in order to determine the most efficient parameters.

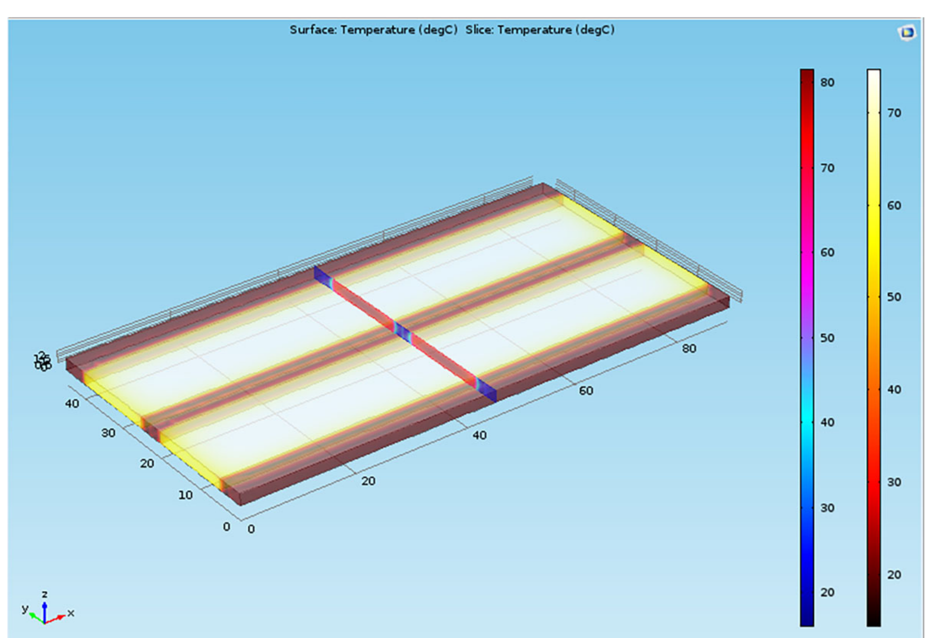

Figure 1. Whey gel pasteurization channels

Computational Methods: A material's electronic heating behavior is represented by its relative permittivity (dielectric constant), i.e. the difference between the material's permittivity relative to that of free space, a fundamental constant whose value is:

$$\varepsilon_0 = \frac{1}{c_0 \mu_0} = 8.85419e{-12}[F/m]$$

The permittivity of a material is:

$$\varepsilon = \varepsilon_r \varepsilon_0$$

For complex materials that have intrinsic phase delays and energy losses, the relative permittivity is represented by a complex number, such as:

$$\varepsilon_r = \varepsilon'(\omega) + i\varepsilon''(\omega)$$

As whey gel is essentially water, the basic physical properties of water from the COMSOL Multiphysics Materials Library were modified by adding the measured complex permittivity values for whey gel [2]. Figures 2 and 3 show the power series polynomial curves generated by the author from the measured permittivity at four individual frequencies.

The model uses the Electric Currents (ec) and the Heat Transfer in Solids (ht) Modules to determine the voltage needed to heat the whey gel to the pasteurization range (71.7 C for 15 sec.). Solving this model required a two-step process: 1) Electric currents using the Frequency domain solver and 2) Heat transfer using the Stationary Solver. Table 1 and Figure 4 show the resulting voltage values and fit curve.

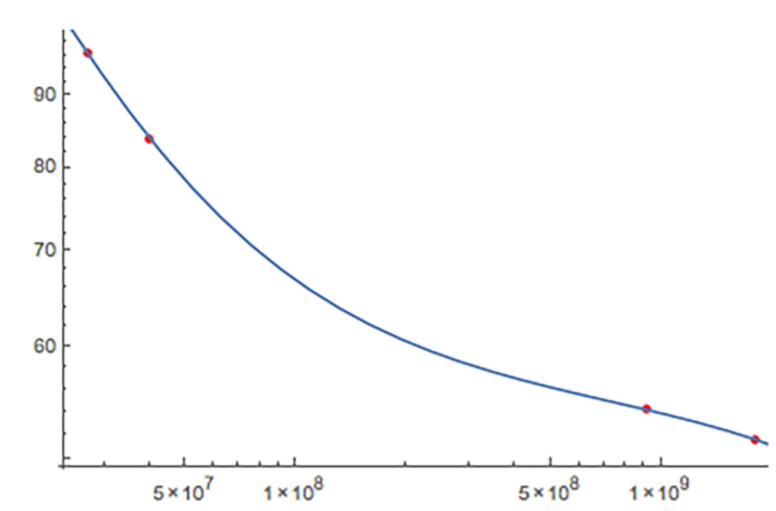

Figure 2. Permittivity Real Data and Fit Curve

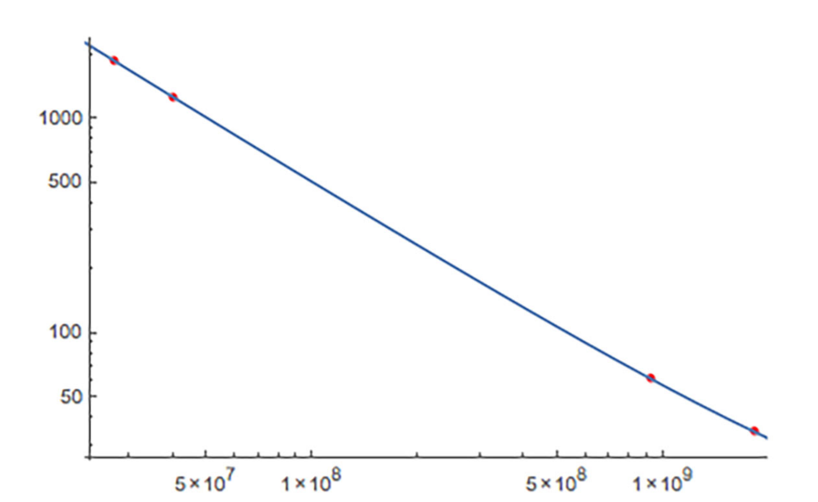

Figure 3. Permittivity Imaginary Data and Fit Curve

Frequency	Voltage
2.45 GHz	4.188 V
915 MHz	4.633 V
40 MHz	4.887 V
27 MHz	4.891 V

Table 1. Input Voltage to Reach Pasteurization T

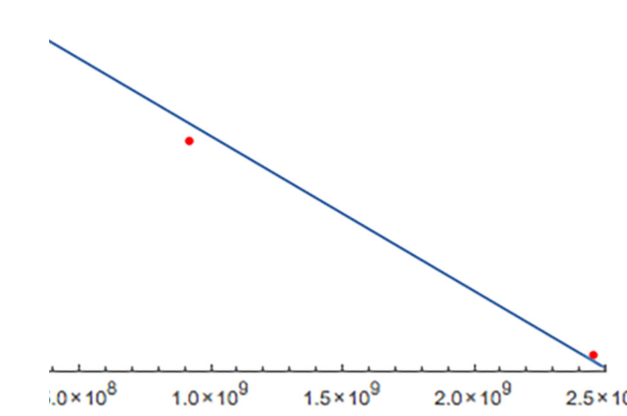

Figure 4. Input Voltage vs. Frequency at a constant T

Conclusions: The results confirm that in materials with a large volumetric fraction of water, the required input voltage decreases as a function of frequency. The modeling process also demonstrated that the results are sensitive to the specific behavior of the material being modeled.

References:

1. Radio Regulations, ITU-R (2012).
2. Yifen Wang, et al., J. Food Eng., 57, 257-268 (2003).

Excerpt from the Proceedings of the 2015 COMSOL Conference in Boston