Development of Calibration Protocol for Measuring Temperature Dependent Dielectric Properties

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Microwaveable foods - convenient

- Growing – Billion dollar industry
Domestic ovens – non-uniform heating

• Temperature dependent properties
• Standing wave pattern
Food quality and safety issues

- Vision, Taste, Smell, Nutrition
- Outbreaks

Marie Callender recall: Linked to salmonella outbreak

On June 6, 2007, a cluster of four human Salmonella serotype I 4,5,12:i:- infections sharing a pulsed-field gel electrophoresis (PFGE) pattern was identified by the Pennsylvania Department of Health and reported to PulseNet.† Initial investigations conducted during June–September 2007 by state and local health departments in collaboration with...
Microwave model can be used for

- Food product design…
  - “Designing food products that respond well to microwave cooking is a mixture of art and science, with heavy emphasis on the science.”

Microwave heating modeling

Electromagnetic & Temperature Fields

Multiphysics Equations

Material Properties
Dielectric properties

• Dielectric properties
  – $\varepsilon^* = \varepsilon' - j \cdot \varepsilon''$
  – Dielectric constant ($\varepsilon'$): capacitance of material and its ability to store electric energy
  – Dielectric loss factor ($\varepsilon''$): ability of material to dissipate electric energy as heat
Electromagnetic power dissipation density

- Electromagnetic power dissipation density
  \[ Q = 2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon'' \cdot E^2 \]
  - \( f \): microwave frequency
  - \( \varepsilon_0 \): vacuum permittivity
  - \( \varepsilon'' \): dielectric loss factor
  - \( E \): Electric filed density
Problems in commonly used dielectric measurement method

• Common calibration method
  ✔ Room temperature
  ✔ Air, short, and deionized water.
• Measurement accuracy may be compromised when dielectric properties are measured at temperatures other than room temperature (calibration temperature).
• Sample temperature control using oil circulation was problematic especially in frozen temperatures.
Objective

• Systematically perform calibration at multiple temperatures and quantify measurement errors
• Develop a method for multi-temperature calibration in order to measure dielectric properties of materials over a wide temperature range.
• Temperature-dependent dielectric properties measurement of lasagna components (ricotta cheese, meat sauce, and pasta).
Dielectric properties measurement system

- Accurately measures properties at frozen state
- High-temp cable provides stability
Dielectric measurement

- Frequency range:
  - 300 – 3000 MHz, interval 5 MHz
- Calibration:
  - Air, Short, deionized water
  - 1, 25, 40, 55, and 85 °C
Sample preparation

- 80% ricotta cheese
- 20% water

Ricotta cheese  Meat sauce  Pasta
Evaluation of room temperature calibration at 2450 MHz

- Room temperature calibration is valid for dielectric constant measurement

Deionized water


Evaluation of room temperature calibration at 2450 MHz

- Room temperature calibration is valid for dielectric constant measurement

![Graph showing dielectric constant and relative error vs. temperature for deionized water]

Deionized water


Evaluation of room temperature calibration at 2450 MHz

- Room temperature calibration is not valid for dielectric loss factor measurement at high temperature.


Evaluation of room temperature calibration at 2450 MHz

- Room temperature calibration is not valid for dielectric loss factor measurement at high temperature.

![Graph showing dielectric loss factor vs temperature for Deionized water](image)


Multi-temperature calibration at 2450 MHz

- Multi-temperature calibration is not needed for dielectric constant measurement.

Dielectric constant of deionized water
Multi-temperature calibration at 2450 MHz

- Multi-temperature calibration is helpful for reducing dielectric loss factor measurement error.
Method for multi-temperature calibration at 2450 MHz

- Calibrations at two temperatures of 25°C and 85°C are sufficient.


Method for multi-temperature calibration at 2450 MHz

- Calibrations at two temperatures of 25°C and 85°C are sufficient.


Frequency dependent dielectric constant of lasagna

Ricotta cheese

Meat sauce

Pasta
Frequency dependent dielectric loss factor of lasagna

Ricotta cheese

Meat sauce
Temperature dependent dielectric constant of lasagna
Temperature dependent dielectric loss factor of lasagna
Conclusion

• Room temperature calibration is valid for dielectric constant measurement, but *not valid* for dielectric loss factor measurement at high temperature.

• Multi-temperature calibration is helpful for *reducing thermal drift errors* and *improving the accuracy* of the temperature-dependent dielectric properties measurement, especially for low-loss materials.

• Calibrations at two temperatures (25 °C and 85 °C) within the range studied were found to be suitable for the temperature-dependent dielectric properties measurement.
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Thank you

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Temperature dependent dielectric constant at 2450 MHz

Dielectric Constant

Temperature, °C

Calibration at 25 °C

Calibration at 85 °C

Ricotta cheese
Temperature dependent dielectric constant at 2450 MHz

Dielectric Constant

Temperature, °C

Calibration at 25 °C

Calibration at 85 °C

Meat sauce
Temperature dependent dielectric constant at 2450 MHz
Temperature dependent dielectric loss factor of at 2450 MHz

Calibration at 25 °C

Calibration at 85 °C

Ricotta cheese
Temperature dependent dielectric loss factor at 2450 MHz
Temperature dependent dielectric loss factor at 2450 MHz
A double beam interferometer technique is applied to precisely determine the amplitude and phase of the electromagnetic wave transmitted through the liquid-filled cell. A waveguide or coaxial line immersed in the liquid is precisely shifted along the direction of wave propagation to probe the electromagnetic field in the cell. The probe signal is compared to that of the reference branch of the interferometer to enable the accurate determination of the wavelength \( \lambda = \beta / 2\pi \) and attenuation coefficient \( \alpha \) and thus the calculation of the complex permittivity of the sample liquid.