Electrical Properties Characterization of liquid food by Impedance Spectroscopy

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Objectives

- Validate impedance spectroscopy as a technique to measure electric properties of liquid food.
- Find a relationship between impedance and electric pulse applied for liquid food.
Introduction

- Impedance Spectroscopy
Impedance Spectroscopy Analysis

Ohm’s law for alternating current defines impedance $Z$ in terms of time-dependent alternating potential $V_t$, and current $I_t$ as:

$$Z = \frac{V_t}{I_t} \quad (1)$$

$V_t = V_0 \text{sen}(wt)$ and for a linear system, the response signal $I_t$, has a phase shift, $\theta$, with amplitude of $I_0$ which can be expressed by $I_t = I_0 \text{sen}(wt - \theta)$. Therefore the impedance, $Z$:

$$Z(w) = \frac{V_t}{I_t} = \frac{V_0 e^{jwt}}{I_0 e^{j(wt-\theta)}} = Z_0 e^{j\theta} = Z_0 (\cos \theta + j\text{sen} \theta) \quad (2)$$
Table 1: Impedance calculation using the shift angle between voltage and current.

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Equivalent circuit

Based on Zia & Mukhopadhyay (2016), the following circuit was developed to register impedance measurements of the samples.

Figure 1: Equivalent electrical system circuit
The expression for the absolute impedance as a function of frequency by the system shown in figure 1 is given as:

\[ Z(\omega) = R_s + \frac{R_{ct}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} - \frac{j\omega R_{ct}^2 C_{dl}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \]  

(3)

Where the real and imaginary part \((Z')\) are given by equations 4 and 5, respectively:

\[ Z'(\omega) = R_s + \frac{R_{ct}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \]  

(4)

\[ Z''(\omega) = -\frac{j\omega R_{ct}^2 C_{dl}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \]  

(5)
Experimental procedure

AC signal generator

Figure 2: Sinusoidal generator
Observation of Signal Voltages

Figure 3: Oscilloscope
Impedance results

Figure 4: Impedance vs frequency
Figure 5: Impedance vs frequency (Randle’s model) Reference: (Zia & Mukhopadhyay 2016)
Figure 6: Phase shift vs frequency
Figure 7: Phase vs frequency (Randle’s model) Reference: (Zia & Mukhopadhyay 2016)
Curve to get $R_s$ form the equation

**Figure 8: Zreal vs frequency**
Figure 9: Reactance vs frequency
Nyquist plot to get $R_s$

Figure 10: Equivalent $|Z_{imag}|$ vs $Z_{real}$
Figure 11: Equivalent Reactance vs Resistance (Randle’s model)
Reference: (Zia & Mukhopadhyay 2016)
Perform this impedance analysis method for different electric pulse applied to observe the electric properties variation of liquid food.