Electrical Properties Characterization of liquid food by Impedance Spectroscopy

Energy Dept., Universidad de Ingeniería y Tecnología
*SoET, PPI, Purdue University, West Lafayette, IN 47907

Jorge Estrada
Lei Zhang
Raji Sundararajan*

June 5, 2018

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:

$$\mathrm{Z} = \frac{\mathrm{V_t}}{\mathrm{I_t}} \tag{1}$$

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

$$\mathrm{Z(w)} = \frac{\mathrm{V_t}}{\mathrm{I_t}} = \frac{\mathrm{V_0 e^{jwt}}}{\mathrm{I_0 e^{j(wt-\theta)}}} = \mathrm{Z_0 e^{j\theta}} = \mathrm{Z_0(cos\theta + jsen\theta)} \tag{2}$$

Table 1: Impedance calculation using the shift angle between voltage and current.

Z	$\lvert Z \rvert$= V/I=$\sqrt{R^2 + X^2}$
R	$R = \lvert \lvert Z \rvert \cos\theta \rvert$
X	$X = \lvert \lvert Z \rvert \text{sen}\theta \rvert$

Equivalent circuit

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

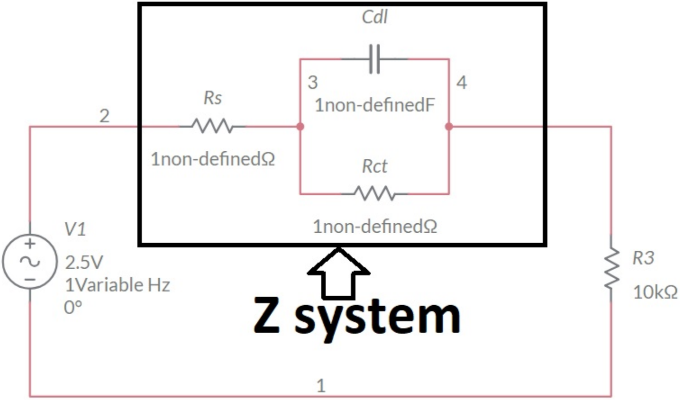

Figure 1: Equivalent electrical system circuit

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

$$Z(\omega) = R_s + \frac{R_{ct}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} - \frac{j\omega R_{ct}^2 C_{dl}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \tag{3}$$

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

$$Z'(\omega) = R_s + \frac{R_{ct}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \tag{4}$$

$$Z''(\omega) = -\frac{j\omega R_{ct}^2 C_{dl}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} \tag{5}$$

Experimental procedure

AC signal generator

Figure 2: Sinusoidal generator

Observation of Signal Voltages

Figure 3: Oscilloscope

Impedance results

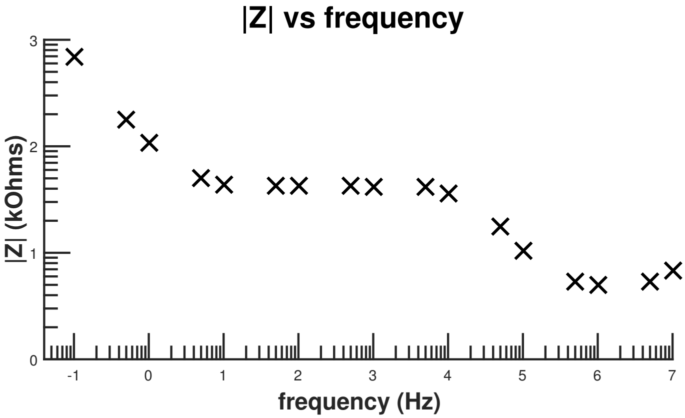

Figure 4: Impedance vs frequency

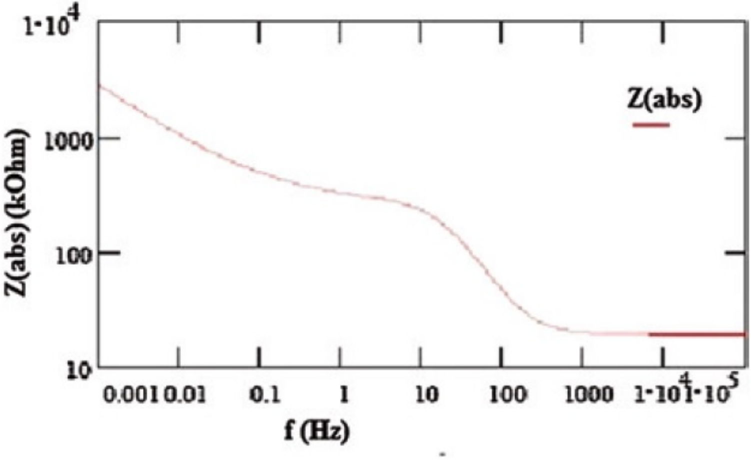

Figure 5: Impedance vs frequency (Randle's model) Reference: (Zia & Mukhopadhyay 2016)

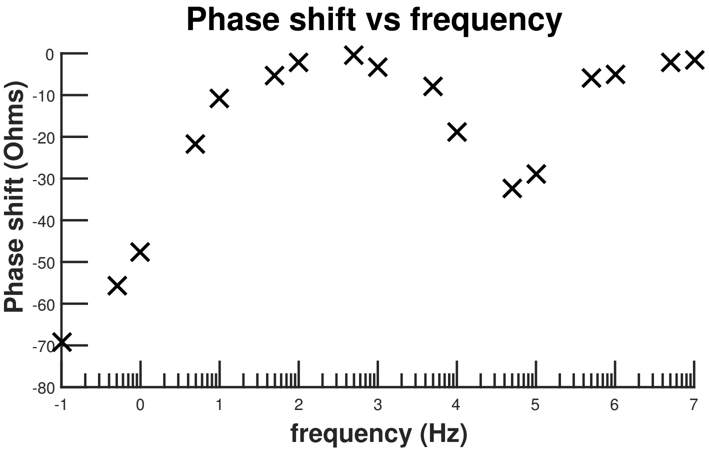

Figure 6: Phase shift vs frequency

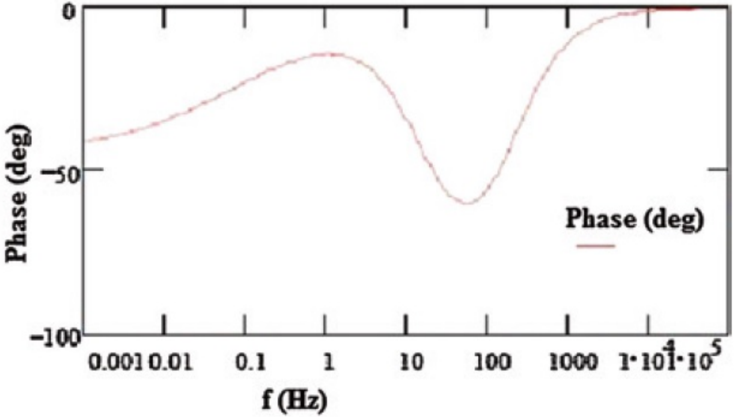

Figure 7: Phase vs frequency (Randle's model) Reference: (Zia & Mukhopadhyay 2016)

Curve to get R_s form the equation

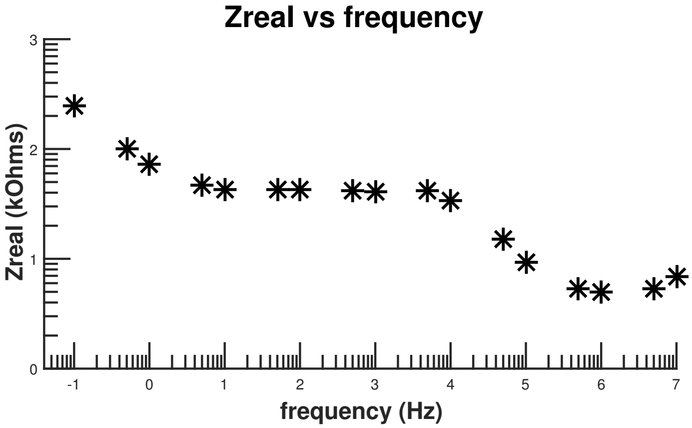

Figure 8: Zreal vs frequency

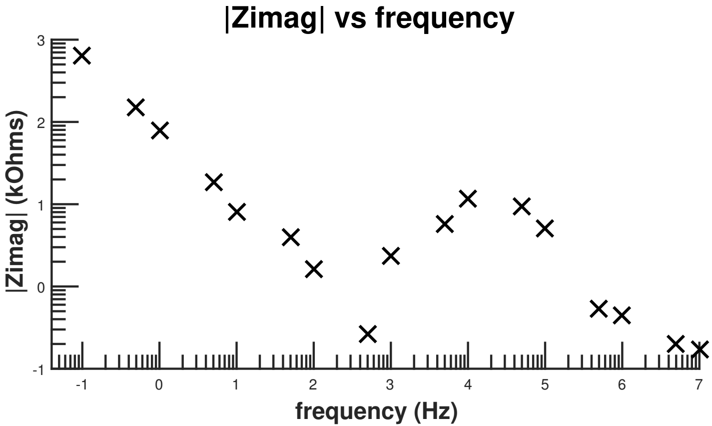

Figure 9: Reactance vs frequency

Nyquist plot to get R_s

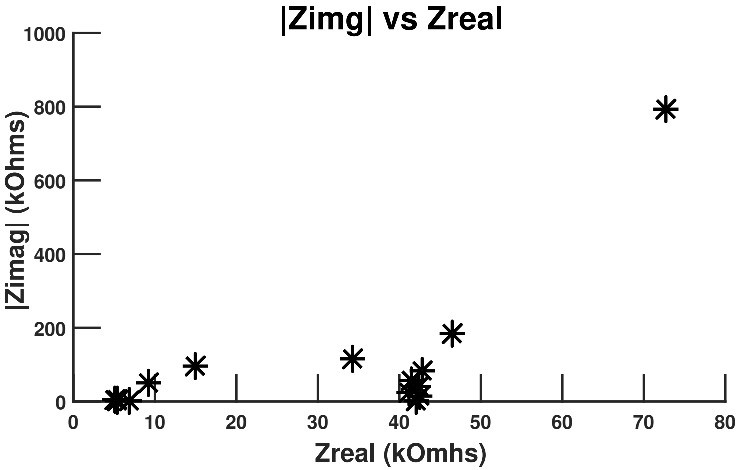

Figure 10: Equivalent Zimag vs Zreal

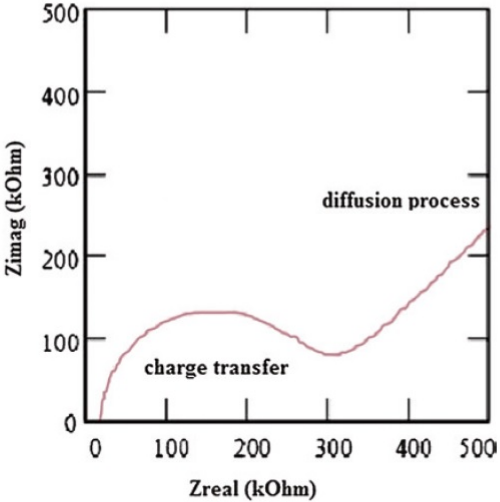

Figure 11: Equivalent Reactance vs Resistance (Randle's model)
Reference: (Zia & Mukhopadhyay 2016)

- Perform this impedance analysis method for different electric pulse applied to observe the electric properties variation of liquid food.

References I

Zia, A. I. & Mukhopadhyay, S. C. (2016), Impedance spectroscopy and experimental setup, *in* 'Electrochemical Sensing: Carcinogens in Beverages', Springer, pp. 21–37.