Journal of Food Engineering 223 (2018) 79–90

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

An automatic system for measuring dielectric properties of foods: Albumen, yolk, and shell of fresh eggs

Soon Kiat Lau [a], Jeyamkondan Subbiah [a, b, *]

[a] Department of Food Science and Technology, University of Nebraska-Lincoln, Lincoln, NE 68588, USA
[b] Department of Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE 68583-0726, USA

ARTICLE INFO

Article history:
Available online 29 November 2017

Keywords:
Dielectric properties
Instrumentation
Automatic
Egg
Radiofrequency heating
Microwave heating

ABSTRACT

An automatic measurement system for measuring temperature-dependent dielectric properties was developed to increase the efficiency of the measurement process. The system was able to measure dielectric properties of samples over a range of temperatures for several hours without human supervision. The system was used to measure the temperature-dependent dielectric properties of the albumen, yolk, and shell of fresh eggs collected within a day of laying. In general, the dielectric constants of all three egg components decreased with frequency, although the temperature dependence of the albumen and yolk was more complicated. The loss factor of all three components generally decreased with frequency and increased with temperature.

1. Introduction

Among all agricultural products, the chicken egg is perhaps one of the most iconic one due to its availability, nutritional content, and wide-ranging functionality as an ingredient. The year 2016 alone saw a total of 8565 million dozen eggs, valued at $7.34 billion, produced in the United States (United States Department of Agriculture, 2017). Due to its sizeable economic influence, there is much research ongoing on the quality and safety of chicken eggs.

The electrical characteristics of dielectric materials are described concisely by a pair of numbers known as dielectric properties. The dielectric properties are the real and imaginary parts of the relative complex permittivity, ε_r which is defined as:

$$\varepsilon_r = \varepsilon_r^{'} - j\varepsilon_r^{''}$$

where $\varepsilon_r^{'}$ is the dielectric constant while $\varepsilon_r^{''}$ is the loss factor. The 'r' subscript is commonly dropped for brevity purposes (and will be done so in this paper) such that one would normally see dielectric constant and loss factor written as $\varepsilon^{'}$ and $\varepsilon^{''}$, respectively. The former is an indicator of the ability of the material to store electric energy, while the latter influences the conversion of electrical energy to heat (Awuah et al., 2015). This set of properties are influenced by the composition of the material, therefore there has been interest in correlating it to various quality indices of eggs such as albumen height, Haugh unit, and yolk index (Guo et al., 2007; Ragni et al., 2008, 2007, 2006). The most direct application of dielectric properties would be in dielectric heating methods such as radiofrequency heating and microwave heating for pasteurization purposes. To this end, some amount of data have been reported for eggs in various forms (natural or reconstituted), temperatures, and frequencies (Dev et al., 2008; Lau et al., 2016; Wang et al., 2009; Zhang et al., 2013). However, no comprehensive dielectric properties data is available for fresh eggs collected within a day of laying. Preferably, egg pasteurization with dielectric heating methods should be performed early in the production chain to reduce proliferation of pathogenic bacteria such as *Salmonella*. Dielectric properties of these fresh eggs would aid in the development of a suitable dielectric heating method for pasteurizing fresh shell eggs.

Traditionally, a typical setup for measuring temperature-dependent dielectric properties of food products involves placing the sample in a temperature-controlled chamber or bath. A user must manually check the temperature of the sample periodically and trigger measurements. The repetitive and time-consuming nature of this process creates an incentive for an automatic measurement system to improve efficiency and reduce human error. Automated measurements will free up lab time for other experiments, and can be performed overnight without supervision.

Because the dielectric properties of eggs have been shown to be

* Corresponding author. Kenneth E. Morrison Distinguished Professor of Food Engineering, 210, L.W. Chase Hall, University of Nebraska-Lincoln, Lincoln, NE 68583, USA.
E-mail address: jeyam.subbiah@unl.edu (J. Subbiah).

https://doi.org/10.1016/j.jfoodeng.2017.11.039
0260-8774/

affected by storage time (Guo et al., 2007; Ragni et al., 2007), there is a need to collect a comprehensive set of dielectric properties data of fresh eggs (within 1 day of laying) for proper characterization of dielectric heating of fresh eggs. Additionally, an automatic system for measuring dielectric properties across a range of temperatures would be a boon to anyone involved in this work. Therefore, the objectives of this study were to: (1) develop an automatic measurement system for temperature-dependent dielectric properties and (2) measure the dielectric properties of yolk, albumen, and shell of fresh eggs from 20 to 70 °C and fit the data to equations.

2. Materials and methods

2.1. Automatic dielectric properties measurement system

The overall goal of the automatic dielectric properties measurement system is to automatically adjust the temperature of the chamber and trigger dielectric properties measurements when the sample has reached a target temperature, based on the initial user input. Additional features, such as measuring at multiple frequencies, could be performed if the dielectric properties measuring equipment has such capabilities. The system used in this study consists of the following:

- Impedance analyzer with an open-ended coaxial probe (E4991A with option 85070E, Agilent Technologies, Inc., Santa Clara, CA). Converts reflected signals (S11) from the sample into dielectric properties. Connects to the computer via GPIB.
- Temperature controlled chamber (MCBH-1.2-.33-.33-H/AC, Cincinnati Sub-Zero Products, Inc., Cincinnati, OH)
- Custom-built stainless steel test cell for the sample (Dixon Valve & Coupling Company, Chestertown, MD)
- T-type thermocouple (TQSS-116U-2, OMEGA Engineering, Inc., Norwalk, CT)
- Data acquisition device with 20-bit resolution for the thermocouple (USB-2001-TC, Measurement Computing Corporation, Norton, MA). Connects to the computer via USB
- Computer with connections compatible with the impedance analyzer, chamber, and temperature acquisition device

Fig. 1 shows an overview of the system. The computer (master) obtains information and sends instructions to all the equipment (slave) through communication cables such as USB or RS-232. The impedance analyzer used in this study requires a code library from the manufacturer with a proprietary algorithm for converting raw/uncorrected measurement data to corrected dielectric property data. If an impedance or network analyzer with no such requirement is used, a smaller microcontroller such as Raspberry Pi or Arduino Uno with sufficient data logging and storing capabilities could be used to simplify the system. Similarly, the slave components can be replaced with comparable counterparts provided that they have capabilities to communicate with a microcontroller or computer.

A computer program implementing the flowchart depicted in Fig. 2 was written in LabVIEW to control the system. LabVIEW programs are available from the manufacturers for interfacing with the temperature-controlled chamber and the temperature data acquisition device. Communication with the impedance analyzer was performed via calls to an external binary library provided by the manufacturer. The program begins with the user entering the program parameters used at every target sample temperature and a location to store recorded data (Fig. 3). These parameters, along with other measured variables, are defined as follows:

- i : Index tracking the number of dielectric properties measurements performed
- n : Total number of dielectric properties measurements to be performed
- $\widehat{T}_s^i$: The target sample temperature for the i^{th} dielectric properties measurement [°C]
- $\widehat{T}_c^i$: The temperature setpoint of the temperature-controlled chamber for the i^{th} dielectric properties measurement [°C]
- T_s : Measured temperature of the sample [°C]
- T_c : Measured temperature of the air in the temperature-controlled chamber [°C]
- α^i : Size of the stabilization region when chamber operation is halted to stop vibrations for the i^{th} dielectric properties measurement [°C]
- β^i : Temperature error tolerance for triggering a dielectric properties measurement for the i^{th} dielectric properties measurement [°C]. α^i should be more than or equal to β^i.

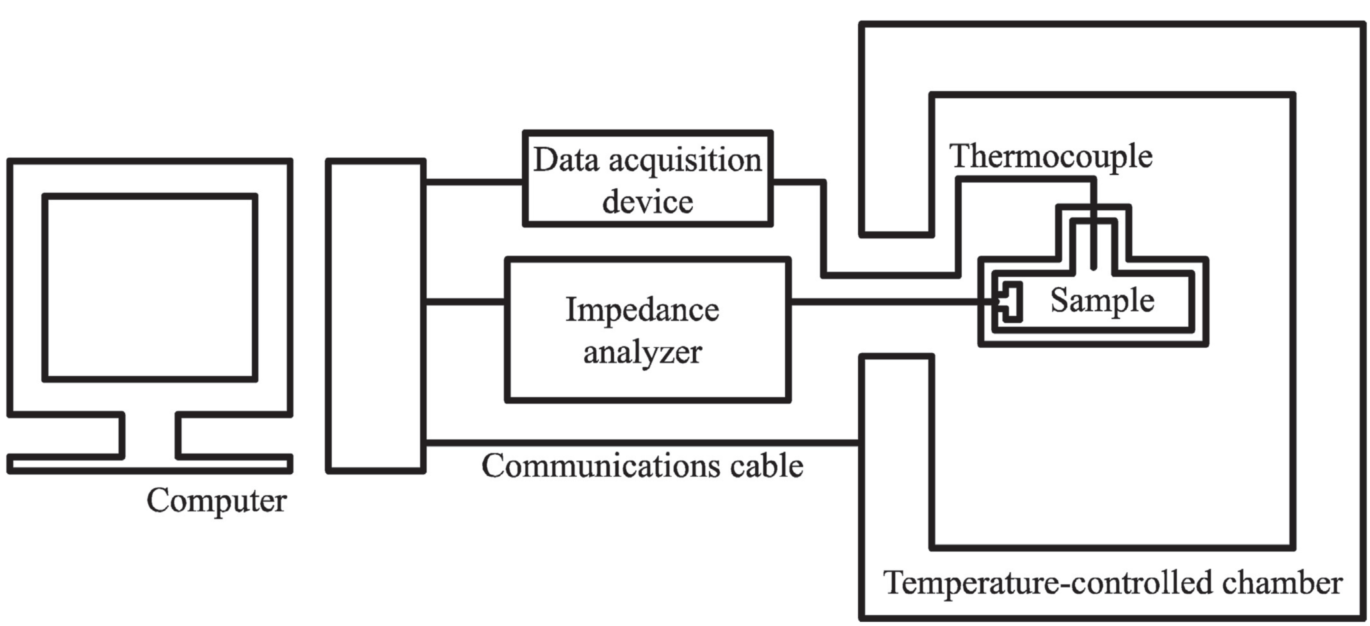

Fig. 1. Instrument setup for the automatic dielectric properties measurement system.