

Ohmic Heating for Tofu Making—A Pilot Study

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Abstract

The aim of this study is to explore the relationship between temperature and electrical conductivity of soya milk under ohmic heating in tofu making. The soya milk of 10 Brix was heated to a steady temperature of 90°C. The applied voltage was increased and the temperature rising rate was investigated for adequate heating profiles in tofu making. Experimental results showed that the electrical conductivity of soya milk is proportional to the heating time. The temperature rising rate was increased from 1.46°C to 3.82°C/min as a result of increased voltage. Hence ohmic heating could be an efficient, convenient heating measure in tofu making.

Keywords

Soya Milk; Ohmic Heating; Electrical Conductivity; Temperature Rising Rate

1. Introduction

Tofu is a salt- or acid-coagulated water-based gel, with soya lipids and proteins as well as other constituents trapped in gel networks [1]. It is made by coagulating soya milk—followed by either pressure or heat treatment after the addition of a coagulant. The taste of tofu is significantly affected by its final texture [2], *i.e.*, by the firmness of the tofu gel's structure. The textural property is determined by the concentration of soya milk, the type and concentration of coagulant, the gelating pressure and temperature, and the gelation time [3].

The quality of a tofu can be examined using destructive testing. A textural analyzer is suitable for characterizing the mechanical property; while microscope analysis explores the chemical composition and the microstructure [4,5]. The above two methods are of a destructive nature and require laboratory practice. They are not suitable for on-line application as a quality indicator. Ultrasound which can give a big amount of information in a short time has been shown to be effective in detecting the gelation process and the final product in an efficient way [3,5]. While ultrasound is a means feasible for on-line quality detection, its setup is expensive.

The formation of a tofu gel requires soya milk mixed with a coagulant to be heated to a reaction temperature. In gelation, protein clusters are formed as a mechanism of ion exchanging between soya milk and the added coagulant. The concentration of the exchanging ions, anions or cations, is a result of the ongoing gelation process. The ion concentration can be easily characterized as electrical conductivity, an easy, economic, and efficient

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measurement [6].

The objective of this study is to investigate the feasibility of using ohmic heating in tofu making with electrical conductivity as a quality indicator. Adequate temperature rising rates of soya milk is examined by applying different voltages onto the soya milk. The temperature profile can be used in tofu making with heat treatment and the electrical conductivity response can be for feedback control of gelation.

2. Ohmic Heating for Tofu Making

2.1. Mechanism of Tofu Formation

Addition of a coagulant into heated soya milk triggers the formation of tofu gels. The formation is a two-step mechanism [1]: soya proteins are denatured and then aggregated by the coagulant. Soya beans contain 35% - 40% of storage and whey proteins by weight. The 7S protein, conglycinin, and 11S protein, glycinin, are the two major proteins that affect the property of a tofu produce [7]. **Figure 1** depicts the mechanism of soya milk transforming to tofu gels. When soya milk is heated to 65°C and beyond, the oil body is released. This is the first step of transformation. The 7S and 11S proteins will escape from the subunits at 75°C and 80°C, respectively. Subunits are surrounded by protein particles with a size of 100nm [8-10]. The transformation completes.

2.2. Principle of Ohmic Heating

The performance of ohmic heating in food processing depends on the electrical conductivity of the foodstuff. DC (direct current) ohmic heating has power conduction by the moving ions in the foodstuff fluid. The viscosity of the fluid decreases in response to a hotter fluid. This speeds up the ionic motion and hence the electrical conductivity. The food fluid consists of conductive and resistive components which in turn, convert the electric current into heat. **Figure 2** shows a model of soya milk under ohmic heating. The traditional heating method conveys heat from the heat generator to the heart of the medium through heat convection or conduction. A temperature gradient forms in traditional heating and leading therefore to a non-uniform temperature distribution, *i.e.* some medium may be overheated. Ohmic heating distributes electrical energy uniformly in the medium by means of the free ions and hence the medium is uniformly heated. The electrical conductivity of the processed medium follows [6]:

$$\sigma = \frac{IL}{VA} \quad (1)$$

with σ in Sm^{-1} the electrical conductivity of the medium, I in A the applied current, V in V the applied voltage, L in m the distance between two electrodes, and A in m^2 the contacting area between the medium and the electrodes.

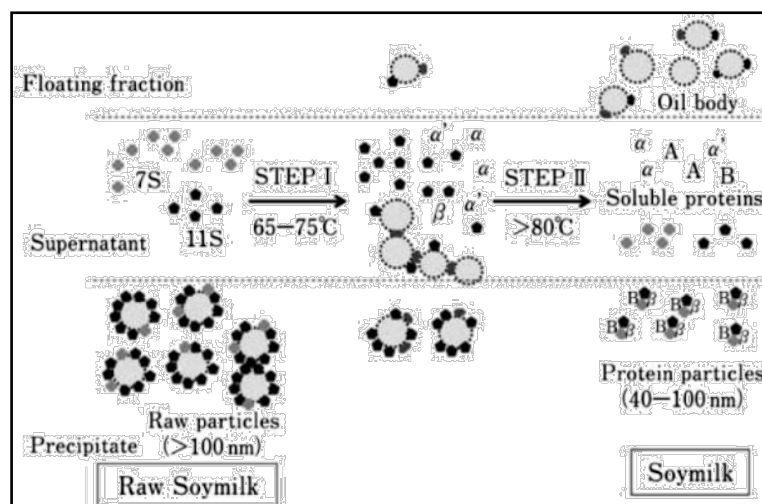


Figure 1. Process of protein separation in heated soya milk [9].

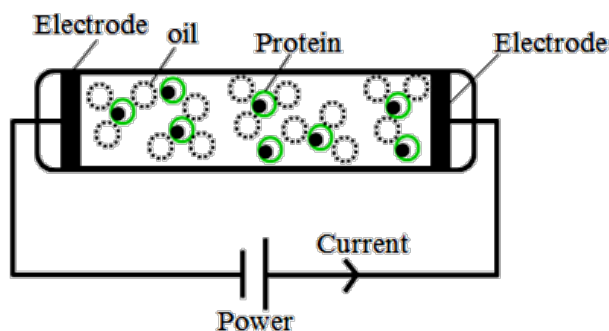


Figure 2. Soya milk under ohmic heating [11].

2.3. Circuit model of Ohmic Heating

Ohmic heating for fluid can be represented with an equivalent circuit model as shown in **Figure 3**. The resistor stands for the intrinsic electrical conductivity of the soya milk. It converts electrical energy from the voltage source (V) to heat. The capacitor describes the capacitive effect built by the two electrode plates with the soya milk as the electrolyte in between. The circuit has the following first-order dynamics:

$$I = \frac{V}{R} + C \frac{dv}{dt} \quad (2)$$

2.4. Factors Effecting Ohmic Heating

An ohmic heating system heats a medium by applying an electrical field into the medium. A voltage (V) applied on the two electrode plates forms the electric field (E) with the correlation $E = V/l$ and the energy density stored in the medium between the two electrodes is $u = 1/2\epsilon E^2$ with ϵ the permittivity constant of the soya milk. The electrical power dissipated by the medium is:

$$P = I^2 \cdot R \quad (3)$$

The steady state of Equation (2) indicates that a larger voltage application will result in a larger current. A larger current heats the medium in an efficient and powerful way. While the temperature of the soya milk increases, the electrical conductivity of the soya milk increases in a positive trend [6]:

$$\sigma_T = \sigma_{ref} \cdot \left[1 + m \cdot (T - T_{ref}) \right] \quad (4)$$

where σ_T is the electrical conductivity at current temperature T and σ_{ref} is the electrical conductivity at the reference temperature T_{ref} . Ions in an electrolyte are easily to escape from the substance molecules. Different substances will have different properties and hence the σ_T is substance-specific [12-14].

3. Materials and Methods

3.1. Materials

Washed soya beans (800 g) were soaked for 8 - 12 hrs at a constant temperature (30°C) in reverse osmosis (RO) water. One time by weight of RO water was added to the equivalent dry weight of the soya beans. The mixtures were ground and centrifugally filtered for 2 min to remove the residue. The soya milk produce was adjusted to a concentration of 10°Brix. The procedure of preparing soya milk is summarized as **Figure 4**.

3.2. Equipment

Figure 5 illustrates the setup for ohmic heating experiments. Soya milk is placed in a steel container (L * W: 11 * 7 cm²) with ceramic coating. The two titanium electrodes are powered with a DC power supply (PSW-720, Instek, Taiwan) which is remotely controlled by a computer using the LabVIEW software (V8.3, National Instrument, USA). The soya milk is continuously stirred for uniform heat distribution. The temperature of the soya

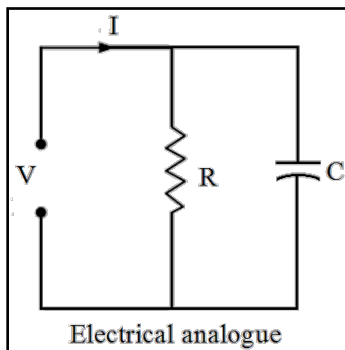


Figure 3. The equivalent circuit model of ohmic heating.

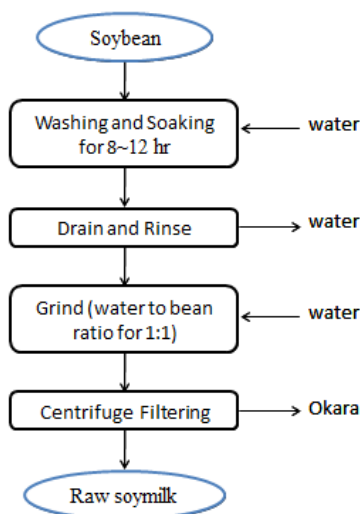


Figure 4. Procedure of soya milk preparation.

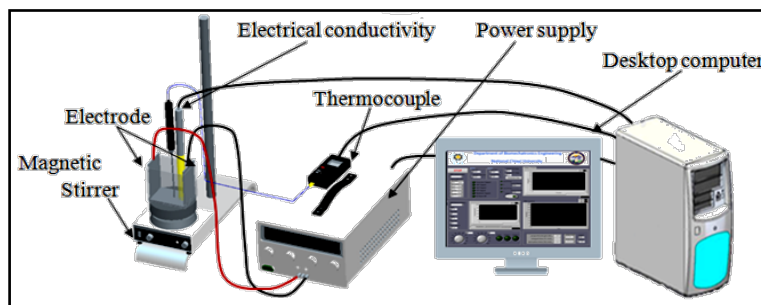


Figure 5. The ohmic heating setup.

milk is detected using a TM-925 temperature transducer (Prosperous, Taiwan) and the electrical conductivity is picked on line using by an electrical conductivity meter (Con 10, Eutch, Singapore).

4. Results and Discussion

4.1. Effect of Voltage Application on Temperature Rising Rate

The soya milk was heated to 90°C by ohmic heating with different voltage but the same current applications within 2 min. **Figure 6** shows temperature responses to different applied voltages. A larger voltage results in a faster temperature rise.

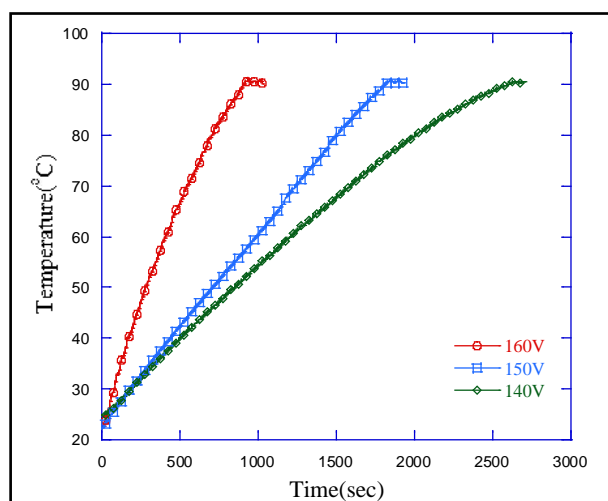


Figure 6. Temperature profiles of soya milks heated by different DC voltages.

Table 1 summarizes the temperature rising rates of different heating voltages. Clearly, increasing the voltage increases the temperature rising rate.

4.2. Current Response of Ohmic Heating

The temperature of the soya milk rises as a result of heating time in controlled current application. **Figure 7** shows the current response at a temperature rising rate of $3.82^{\circ}\text{C}/\text{min}$. The current was large at the beginning as dominated by the first-order dynamics of Equation (2).

4.3. Electrical Conductivity in Ohmic Heating

Figure 8 shows measured and calculated electrical conductivities. There is a big discrepancy in between. This may be caused by the error of current measurement. By referring to **Figure 7**, there is large fluctuation in the current measurement.

4.4. Electrical Conductivity of Different Applied Voltages

Figure 9 shows calculated electrical conductivities of three voltage levels. The estimate is positively proportional to the applied voltage level. When the temperature is between 22 and 60°C , the electrical conductivity of the soya milk has a positive temperature effect. Afterwards, it saturates.

This first-order dynamics effect is caused by the electro-osmotic effect [6]. Only in the beginning, a large amount of ions and salt in the soya solid dissolves in the milk.

5. Conclusion

In this paper, we have presented the potential application of combing ohmic heating and electrical conductivity measurement in tofu making by heat treatment. In theory, the soya milk can be uniformly cooked by ohmic

Table 1. Temperature rising rates of different applied voltages.

ΔT ($^{\circ}\text{C}/\text{min}$)	Applied voltage(V)		
	140	150	160
Samples	3	3	3
Mean	1.46 ^c	2.16 ^b	3.82 ^a
Std	0.24	0.7	0.61

¹Mean \pm Std. with different superscripts in the same row are significantly different ($P < 0.05$), using the Scheffe test.

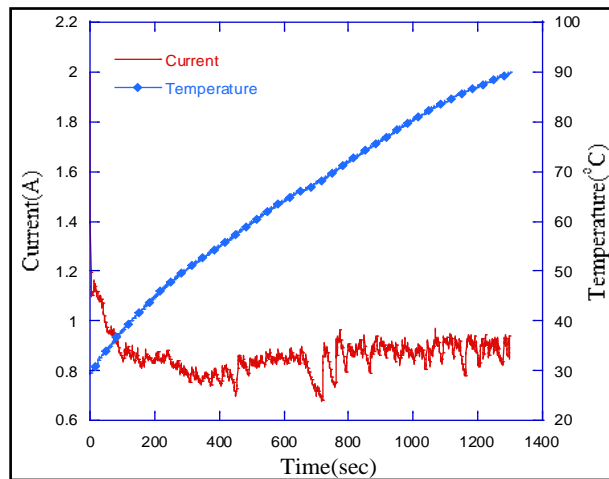


Figure 7. Heating current for a temperature rising rate of $3.82^{\circ}\text{C}/\text{min}$.

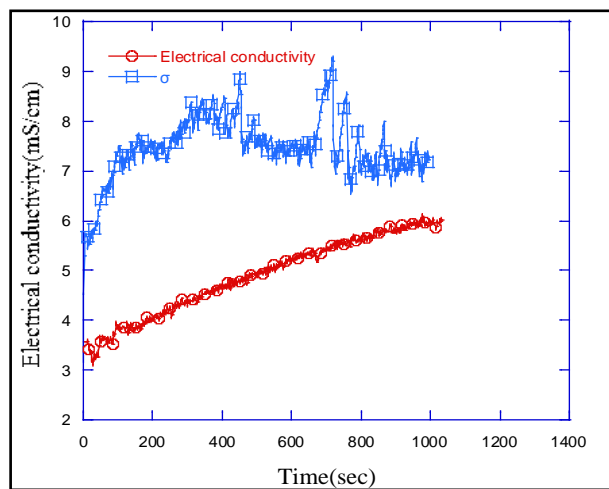


Figure 8. Measured and calculated electrical conductivities.

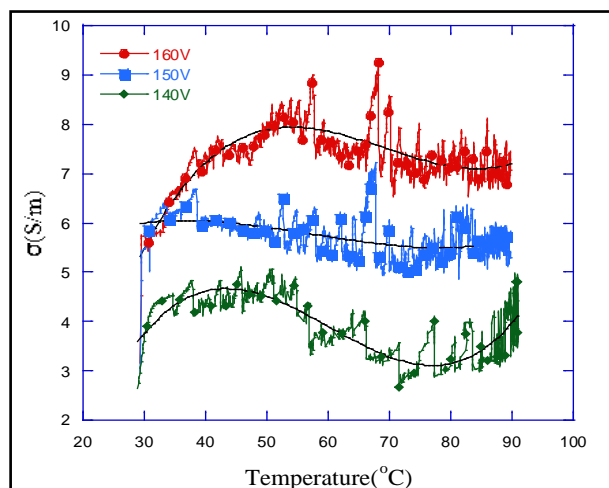


Figure 9. Calculated electrical conductivities at different voltage levels.

heating. The electrical conductivity responses to different voltage levels show clear cuts around 60°C, at this temperature the oil body of the soya milk is released. At temperatures around 75°C and 80°C, the electrical conductivity response reaches a minimum saddle and starts to increase. These two temperatures correspond to the release of the 7S and 11S proteins, major proteins in tofu produce. Hence the electrical conductivity measurement could be a fast, convenient, and non-destructive testing method for on-line indication of tofu quality.

Acknowledgements

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