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A Numerical Modelling for the Prediction of Phase Transition Time(Ice-Water) in Frozen Gelatin Matrix by Ohmic Thawing Process

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Abstract

Ohmic heating occurs when an electric current is passes through food, resulting in a temperature rise in the product due to the conversion of the electric energy into heat. The time spent in the thawing is critical for product sterility and quality. The objective of this study is to conduct numerical modelling between the effect of ohmic thawing intensity on PTT(phase transition time) at constant concentration and the effect of matrix concentrations on PTT at constant voltage condition. the stronger ohmic thawing intensity resulted in decreasing the PTT. High ohmic intensity causes short PTT. And the higher gelatin concentration, the faster increment of PTT. A numerical modeling was executed to predict the PTT influenced by the power intensity using exponential regression and the PTT influenced by gelatin concentration using logarithmic regression. Therefore, from this numerical model of gelatin matrix, it is possible to estimate exact values extensively.

Introduction

Ohmic heating occurs when an electric current is passes through food, resulting in a temperature rise in the product due to the conversion of the electric energy into heat (Joule effect). Ohmic heating also has advantages over conventional heating such as high heating rate, high conventional efficiency, volumetric heating, etc(Rareifad et al.: 1996; Robert et al. 1998). This method can also be used in thawing frozen foods by placing them between two electrodes and applying an alternating current. The application of ohmic thawing technique for the frozen foods are still not well known because the over heating due to the electric power over flowing can destroy the food quality and result the quality loss of frozen food during thawing process. Therefore, thawing rate should be known in order to ensure the proper voltage for the thawing process precisely. In this study, the gelatin matrix was used to show functional relation on ohmic thawing intensity and also to calculate numerically predictable trend value by measured data.

Materials and Methods

Sample preparation

Gelatin(Shinyo Pure Chemicals Co., LTD Osaka, Japan) from 0% to 30% at 10% increments was mixed with distilled water and heated at 80℃. The gelatin solution was put in a rectangle ohmic thawing container(120x56x60 mm) which was made of acrylic plastic. Two Cu electrode plates(120x60 mm) were inserted in the rectangle acrylic container to flow the electric current. After cooling at room temperature each sample was located in the refrigerator in order to form a gel matrix for 24 h. And then, 3 thermocouples(P1, P2, and P3) were positioned in the matrix where P1 was in the geometrical middle of the matrix and P2 was direct at side of Cu electrode. The P3 was in the middle between P1 and P2. The samples were frozen at -40℃ for 12 h in a freezer.

Experimental design

In this study the experimental ohmic thawing system was set up as following; voltage and AC current were supplied and controlled by a digital voltage transducer. The voltage transducer(2 kW) can supply three ohmic units concurrently. The distance between electrodes was 60 mm and two copper electrodes were connected to the power unit. A constant voltage was applied and monitored(TES 2730 Multimeter). Time and temperature transition were recorded from - 40 ℃ to 5 ℃ by 60 second intervals. All data were gathered by automatic mobile corder(The MV 100 Mobile Corder, YOKOGAWA). Firstly, the frozen gelatin matrix of 3% was heated immediately in 0 V, 10 V, 20 V, 30 V, 40 V and 50 V, respectively and secondly, 50V voltage was conducted with 3, 10, 20 and 30 % gelatin concentration to perform trends in electrical conductivity values directly related to their ash content.

Calculation of phase transition time(PTT)

The phase transition time from ice to water was calculated from the time difference between initial temperature T1 to begin melting the ice and the initial temperature T2 to melt out the last ice in the gelatin matrix which was described on the thawing curve(Min: 1994).

Statistical analysis

The experimental results from triplicate replications were statistically evaluated using *Nalimov Data Analysis Program(simplified t-test)* to eliminate the maximum different value from the mean and then *Duncan's Multiple Range Test* was conducted to compare the significance differences among the means of respective experimental conditions using *SAS statistics software(version 8.2).*

Results and Discussion

Thawing curves by ohmic thawing intensity

The thawing curves showed typical s-type curve which was obtained generally as the frozen food was thawed. The electric power intensity had no influence on the shape of thawing curve but on the reduction of thawing time. If electrical conductivity is not changed during ohmic heating, the temperature increases linearly(Shariaty-Niassar et al.: 2000). So, the driving force of food on the ohmic heating was the power intensity. The deviation among the thermocouples' could not be found at the beginning of ohmic thawing. At the end of ohmic thawing process, there was also no big difference of temperature among 3 thermocouples. The rates of increasing temperature were almost the same during ohmic thawing but the ending point of ice phase transition to water shows slight different increasing rates on different position of ohmic thawing system. The position that was closer to the electrodes was reached first at 5℃. However, this was due to the small temperature difference the electrodes surface and the gelatin model food. The thawing profile was quite uniform at any gelatin matrix. As a result shown, it can be considered that the higher voltage, the faster driving force. One of advantages during ohmic heating is that driving force is not decreased. The velocity of heat generation(W/m^3) is known as following method by the law of Ohm(eq.1).

$$Q = kE^2 = k(grad\ \mathrm{V})^2 \qquad (eq.\ 1)$$

(V = voltage, k = electrical conductivity(S/m))

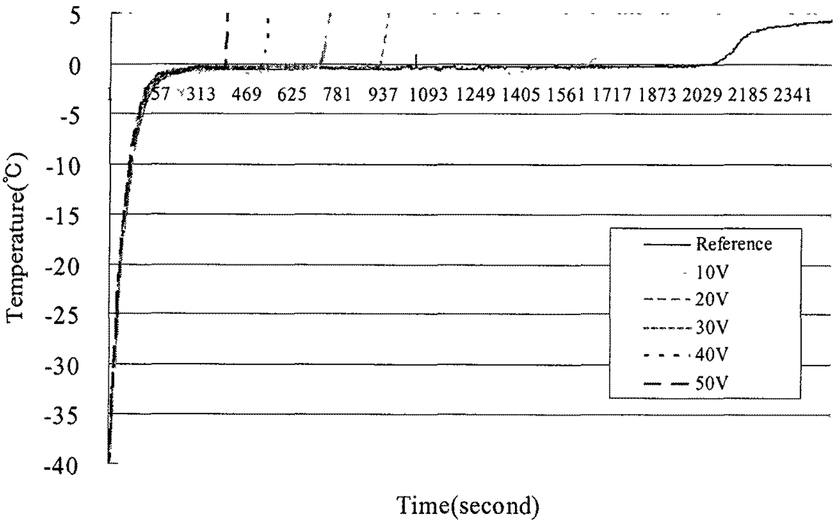

Fig. 1. Thawing curves of gelatin matrix (3%) by ohmic thawing intensity.

Calculation of the phase transition time(PTT) by ohmic thawing intensity

From the thawing curves of 3% gelatin matrix the PTT could be calculated and the data was presented in Fig. 2. The shortest PTT was obtained at 50 V intensity supply. It means that the stronger ohmic thawing intensity resulted in decreasing the PTT. High ohmic intensity causes short PTT. This phenomenon may be attributable to a higher resistance in high ohmic intensity. And then, the numerical modeling was executed to predict the PTT influenced by the power intensity using exponential regression(eq. 2), and it was fairly fit for the functional relation between *Y*, phase transition time(min) and *P*, ohmic intensity(volt) with comparatively high coefficient, R^2 of determination.

$$LnY = 7.7936 - 0.05793 \cdot P \qquad (R^2 = 0.9883) \qquad (eq.\ 2.)$$

P : Ohmic intensity(volt), Y : Phase transition time (min)

Calculation of the phase transition time(PTT) of gelatin matrix with different concentration

The thawing curves of gelatin matrix with different concentrations were similar with the results of thawing curve by ohmic intensity. It was observed that thawing time decreased with increasing the gelatin concentration and the shape of thawing curves was not affected by the gelatin concentrations. Fig. 3 shows that the higher gelatin concentration, the faster increment of PTT. From this character of gelatin, 30 % gelatin matrix had the shortest PTT as Marcotte et al.(1998) studied about ohmic heating behaviour of hydrocholloid solutions. The numerical modeling was executed to predict the PTT influenced by gelatin concentration using logarithmic regression in (eq. 3.) and it was fairly fit for the functional relation between *Y*, phase transition time(min) and *C*, concentration (%) with comparatively high coefficient, R^2 of determination.

$$Y = 152.3858 - 26.387 \cdot ln(C) \qquad (R^2 = 0.9686) \qquad (eq.\ 3)$$

C : Gelatin concentration (%), Y : PTT (min)

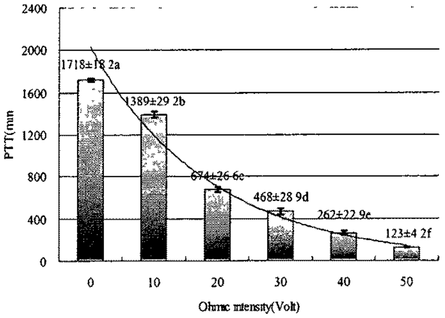

Fig. 2. The effect of ohmic thawing intensity on PTT at 50V.

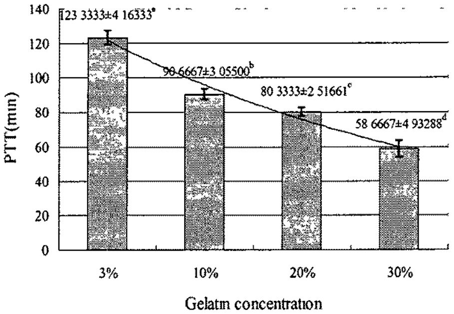

Fig. 3. The effect of gelatin concentration on the reduction of PTT.

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