Technical paper

Studies on the Ohmic Thawing of Frozen Surimi

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A new ohmic thawing system was tested with a frozen saline surimi cube. The thawing rate and surimi gel strength in the ohmic thawing process were investigated, in comparison with conventional thawing technique. The electric mechanism for the ohmic thawing process was also discussed. Under the condition of the applied voltage of 20 V and frequency of 60 Hz, a homogeneous temperature distribution in the frozen surimi was obtained when the concentration of electrode solution was below 4.0%. The thawing rate increased linearly with the increasing concentration of electrode solution. The changes in thawing rate and temperature distribution with the concentration of electrode solution could be explained by an equivalent electric circuit. The ohmic thawing had a higher thawing rate and resulted in stronger gels than the conventional thawing. The present study indicates that the ohmic thawing system can be applied well in the thawing of frozen surimi.

Keywords: ohmic heating, thawing, frozen food, surimi, gel strength

Introduction

Physical, chemical and biological changes such as water evaporation, dripping of cell liquid, oxidization, and microorganism multiplication might occur in the thawing process of frozen foods and food ingredients (Shirai and Yoshikawa, 1990). These changes should be controlled to preserve the taste, texture, nutrition and safety of products. Thawing rate, end temperature, temperature distribution, as well as equipment investment and running cost, are important factors that must be considered in the design of a thawing process. To date, a number of methods such as those using air, water, radio frequency and microwave have been developed for thawing of frozen food ingredients (Tanaka, 1985; Anonymous, 1993). None of these, however, has been able to completely solve the problems presented in the thawing process. These problems include time inefficiency, microbial contamination, inhomogeneous temperature distribution due to low heat conductivity, and prohibitive cost involved. To address these concerns, and to meet various requirements in the food industry, new thawing technologies are required.

Ohmic heating is a heat treatment process in which heat is internally generated within food by passing an alternating current at an appropriate voltage through the food. Ohmic heating rate is principally dependent on the electric conductivity of food materials (Halden *et al.*, 1990) and the frequency of electric current (Imai *et al.*, 1995; Park *et al.*, 1995). Provided that the electric conduct-

ivities of all components in food are similar, ohmic heating has the advantages of high heating rate, homogeneous temperature distribution and energy economization. Ohmic heating is attracting considerable industry interest for continuous sterilization of solid-liquid mixtures with high solids concentration and high viscosity fluid (Khalaf and Sastry, 1995; Sastry and Palaniappan, 1992). An electric field with high strength has both electric field and heat effects on sterilization (Uemura, 2003). Miao *et al.* (2003) have developed an ohmic thawing system, in which frozen food material is electrically connected to two electrodes by electrode solution, and an alternating current is passed for thawing. This system has been used in the thawing of frozen minced-meat and Japanese white radish. It was found that thawing time and temperature distribution varied with applied voltage as well as the concentration of electrode solution.

Frozen surimi (fish-meat paste) is widely used in seafood industries. Thawing of frozen surimi must be carried out carefully by skilled operators to obtain strong surimi gels that enhance the textural strength and resilience of final products. The objectives of the present study were (1) to investigate the effect of the concentration of electrode solution on thawing rate and temperature distribution, (2) to clarify the electrical mechanism, and (3) to investigate the resulted surimi gel strength of ohmic thawing rate, in comparison with conventional thawing

Materials and Methods

Frozen surimi Frozen pollock (*Theragra chalcogram-*

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ma) saline surimi (A/Storm grade A, Tokai Denpun Co., Ltd., Japan) was used as the test material. The frozen surimi was packed to blocks of 60 cm in length, 30 cm in width, and 6 cm in thickness. It contained 2.5% sodium chloride, 17.5% protein and 75.1% water, etc. Samples of 50 mm³ cube were cut from the frozen surimi blocks in a 10°C room and stored in a -24°C freezer before test.

Thawing process The experimental apparatus for ohmic thawing is shown in Fig. 1. A pair of Titanium plate electrodes (1 mm in thickness, 50 mm in width, and 55 mm in height) were fixed on the wall of the sample container. The sample container (56 mm in length, 50 mm in width, and 55 mm in height) was made of polypropylene, and the thermal insulator was made of foam polystyrene. After a cubic frozen surimi sample was put in the sample container, electrode solution was infused into its surrounding space, so that the frozen surimi sample was electrically connected with the two electrodes. Salt solution with a concentration in the range of 0.1% to 8.0% was used as the electrode solution. The electrode solution was kept in a 5°C refrigerator before test. The applied voltage was set at 20 V and the frequency at 60 Hz. Each thawing operation was continued until the temperature at the center of frozen surimi sample reached -2°C.

During the thawing process, temperatures at the center (point P_c) and a point 20 mm apart from the center (point P_s) of frozen surimi samples were measured with commercial K type thermocouples. The thermocouple probes were 0.2 mm in diameter and resin coated. Applied voltage and electric power were measured with a power meter (type 3332, Hioki E. E. Co., Ltd., Japan). The data was recorded using a data acquisition unit (DA 100, Yokogawa Electric Co., Ltd., Japan) and a personal computer (ThinkPad I Series 1400, IBM).

For comparison, conventional thawing of the frozen surimi was also conducted. In the conventional thawing, the same set of sample container, cubic surimi sample and

electrode solution as that used for ohmic heating was placed in a 0°C chamber, so that the energy for thawing was only supplied by heat transfer from the chamber. A 0.2% salt solution was used as the electrode solution. The airflow around the frozen surimi sample was very slow.

Measurement of gel strength The quality of the thawed surimi was evaluated by its gel strength. The thawed surimi was cut into small pieces and mashed with an earthenware mortar. Then the surimi paste was filled into a polycarbonate cylindrical mold of 32 mm in diameter and 25 mm in height, followed by incubation at 10°C for 2 hours in an incubation chamber (M-230F, Taitec Co. Ltd., Japan), heating at 105°C for 30 min in an autoclave (S-90-N, Tomy Seiko Co. Ltd., Japan), and cooling to the room temperature in flowing tap water in 10 min. After this, the strength of the gel specimens was measured within 1 hour.

A rheometer (NRM-1002A, Rheotech Co., Ltd., Japan) equipped with a spherical plunger of 5 mm in diameter was used for the measurement of gel strength. The maximum resisting force, i.e., the gel strength, was determined by inserting the spherical plunger into the surimi gel specimens at a velocity of 2 cm/min. The measurement was replicated 3 times for each surimi sample.

Results and Discussion

Thawing rate The changes of surimi temperature during the conventional and ohmic thawing are shown in Fig. 2. In the conventional thawing, the surimi had a homogeneous temperature distribution, but the thawing time was as long as 580 min. The thawing time was considerably reduced to 59 min by the ohmic thawing with a 2.0% electrode solution. The increase of surimi temperature in the range of -5 to -2°C was relatively slow for both conventional and ohmic thawing, since latent heat was required for fusing of ice crystals.

Since the residence time in the maximum ice-crystal-

Fig. 1. Schematic diagram of the experimental apparatus for ohmic thawing.

Fig. 2. Changes of surimi temperature during the ohmic and conventional thawing.

fusion zone affects the quality of thawed surimi (Khalaf and Sastry 1995), and the surimi temperature increased almost linearly with thawing time in the range of -5 to -2°C , the average increasing rate of central temperature in the range of -5 to -2°C was defined as the thawing rate in this study. For the concentration of electric solution in the range of 0.1% to 0.8% , the ohmic thawing rate increased linearly with the increasing concentration of electrode solution as shown in Fig. 3.

$$r_t = 0.062 + 0.018C \quad (R^2 = 0.944) \quad (1)$$

where r_t is thawing rate (unit: $^{\circ}\text{C}/\text{min}$), and C is the concentration of electrode solution (unit: %). At a concentration of 2.0% , the ohmic thawing had a thawing rate of $0.098^{\circ}\text{C}/\text{min}$. It was approximately 12 times higher than $0.008^{\circ}\text{C}/\text{min}$ in the conventional thawing.

When the central temperature reached -2°C , the temperature difference between the two points, P_s and P_c , was used to evaluate temperature homogeneity within the surimi. The effect of the concentration of electrode solution on temperature difference in the ohmic thawing was shown in Fig. 4. The temperature difference was smaller than 0.5°C when the concentration of the electrode solution was lower than 4.0% , and it increased rapidly with increasing concentration in the range of 4.0% to 8.0% , due to the increase of temperature on the surface. It is indicated that the concentration of electrode solution should be controlled below 4.0% in order to obtain a homogenous temperature distribution in the frozen surimi.

Electrical mechanism Heating rate and temperature distribution in the ohmic thawing are affected by heat generation within the frozen surimi and its surrounding electrode solution, as well as by heat transfer among the frozen surimi, electrode solution and sample container. Theoretical analysis can be done only when all the variables are known.

Figure 5 shows an equivalent electric circuit for discussing heat generation, or electric power consumed in the ohmic thawing. R_s , R_{e1} , R_{e2} are electric resistance

Fig. 3. Effect of the concentration of electrode solution on thawing rate in the ohmic thawing.

Fig. 4. Effect of the concentration of electrode solution on temperature difference in the ohmic thawing.

(unit: Ω) of frozen surimi, a portion of the electrode solution in series with the frozen surimi and another portion in parallel with the frozen surimi, respectively. When a voltage, V (unit: V), is applied to the circuit, total electric power, E (unit: W), is given by the following equations.

$$E = E_s + E_{e1} + E_{e2} \quad (2)$$

and,

$$E_s = \left(\frac{V}{R_s + R_{e1}} \right)^2 R_s \quad (3)$$

$$E_{e1} = \left(\frac{V}{R_s + R_{e1}} \right)^2 R_{e1} \quad (4)$$

$$E_{e2} = \frac{V^2}{R_{e2}} \quad (5)$$

where E_s , E_{e1} , E_{e2} are electric power (unit: W) consumed in R_s , R_{e1} and R_{e2} , respectively. It is clear that the concentration of electrode solution corresponds to R_{e1} and R_{e2} , and has critical effects on the electric power consumption, as well as thawing rate and temperature distribution.

- R_s : electric resistance of frozen surimi (Ω)
 R_{e1} : electric resistance of electrode solution in series with frozen surimi (Ω)
 R_{e2} : electric resistance of electrode solution in parallel with frozen surimi (Ω)
 V applied voltage (V)

Fig. 5. Equivalent electric circuit of the frozen surimi and its surrounding electrode solution.

The changes of total electric power with average temperature at different concentrations of electrode solution are shown in Fig. 6. The average temperature was calculated from the temperatures at the points, P_c and P_s , in the frozen surimi. For each concentration of electrode solution, the total electric power increased rapidly with the increasing average temperature in the range of -5 to -2°C due to a sharp reduction in R_s , R_{e1} and R_{e2} . The reduction of electric resistance with increasing temperature is a typical behavior of semiconductor materials including ice (Maeno 1995). Furthermore, a higher concentration of electrode solution had a larger total electric power, which resulted in a faster thawing (Fig. 3). However, a temperature difference of 7.2°C within the frozen surimi was observed at the concentration of 6.0% (Fig. 4).

Gel strength Figure 7 shows the changes of gel strength of ohmically thawed surimi with thawing rate in the range of $0.066^\circ\text{C}/\text{min}$ to $0.128^\circ\text{C}/\text{min}$. The thawing rate range corresponds to the concentration of electrode solution in the range of 0.1% to 4.0% as shown in Fig. 3, so that the surimi had a homogenous temperature distribution during thawing. The gel strength, G_s (unit: N), could be expressed as a linear function of the thawing rate, r_t (unit: $^\circ\text{C}/\text{min}$).

$$G_s = 10.55r_t + 3.01 \quad (R^2 = 0.688) \quad (6)$$

The ohmically thawed surimi had an average gel strength of 3.7 N and 4.4 N at the thawing rate of $0.066^\circ\text{C}/\text{min}$ and $0.128^\circ\text{C}/\text{min}$, respectively. On the other hand, the conventionally thawed surimi had an average gel strength of 3.3 N. It was obvious that a relatively strong gel could be obtained by the ohmic thawing.

In general, the formation of thermo-irreversible gels from surimi consists of two steps. The first step is the setting of a salt-surimi sol, in which protein was de-

Fig. 6. Changes of total electric power with average surimi temperature.

Fig. 7. Changes of the gel strength of ohmically thawed surimi with thawing rate.

natured by the action of the salt. A sol-gel transition occurs gradually so that an orderly initial protein mash is formed. The second step is the high-temperature heating to form a final 3-dimensional protein network, which leads to aggregation (Kong *et al.*, 2001; Luo *et al.*, 2001). The final structure of protein network is the outcome of denaturation-aggregation during the setting of salt-surimi sol. Luo *et al.* (2001) reported that the setting temperature and time affected both breaking force and breaking distance of the surimi gels from Alaskan pollock and three freshwater fish species. Furthermore, thermal inactivation of heat-stable endogenous protease should be quickly achieved in order to minimize proteolysis. Yongsawatdigul *et al.* (1995) demonstrated that degradation of myosin and actin was minimized, so that gel functionality was maximized by ohmic heating for Pacific whiting surimi.

In the case of frozen saline surimi, thawing could be

considered as another step in addition to the above two steps in the formation of thermo-irreversible surimi gels. In the thawing step, the interaction of denatured protein might be weakened by increasing of ice crystal size. Ice crystal size increases due to recrystallization during long-time storage (Hagiwara *et al.*, 2003) and slow-rate thawing (Anonymous, 1993). Therefore, it is reasonable to believe that the ohmic thawing, as a fast thawing process, can minimize the degradation of proteins and limit the increase of ice crystal size. Furthermore, the presence of an alternating electric field leads to an enhanced diffusion of cell liquids in surimi (Halden *et al.*, 1990). These result in strong surimi gels.

It should be noted that, non-minced fish is different from surimi in chemical composition and micro-structure, so that ohmic thawing of frozen fish must be further studied.

Conclusions

1) Under the condition of the applied voltage of 20 V and frequency of 60 Hz, a homogeneous temperature distribution in the frozen surimi was obtained when the concentration of electrode solution was below 4.0%.

2) In the ohmic thawing process, thawing rate increased linearly with the increasing concentration of electrode solution. The ohmic thawing rate at the concentration rate of 0.2% was 12 times higher than the conventional thawing rate. The changes in thawing rate and temperature distribution with the concentration of electrode solution could be explained by an equivalent electric circuit.

3) The ohmic thawing resulted in stronger surimi gels with the comparison to that of the conventional thawing. It was believed that increase in ice crystal size was minimized and liquid diffusion was enhanced in the ohmic heating.

References

Anonymous, (1993). Japanese Society for Food Science and Technology. *Subject-book for food industry (Shokuhin Kougyou*

Sougoujiten) Tokyo: Korin Publishing Co., Ltd, p.215 (in Japanese).

- Hagiwara, T., Hayashi, R., Suzuki, T., and Takai, R. (2003). Fractal analysis of ice crystals in frozen fish meat. *Japan Journal of Food Engineering*, **4**, 11–17.
- Halden, K., De, Alwis, A.A.P. and Fryer, P.J. (1990). Changes in the electrical conductivity of foods during ohmic thawing. *International Journal of Food Science and Technology*, **25**, 9–25.
- Imai, T., Uemura, K., Ishida, N., Yoshizaki, S. and Noguchi, A. (1995). Ohmic heating of Japanese white radish *Rhaphanus sativus* L. *International Journal of Food Science and Technology*, **30**, 461–472.
- Khalaf, W.G. and Sastry, S.K. (1995). Effect of fluid viscosity on the ohmic heating rate of solid-liquid mixtures. *J. Food Eng.*, **27**, 145–158.
- Kong, C.S., Tashiro, Y. and Ogawa, H. (2001). Elastic modulus of surimi protein and starch in fish-meat gel with added starch pregelatinized at 2 temperatures. *J. Food Sci.*, **66**, 1138–1142.
- Luo, Y.K., Kuwahara, R., Kaneniwa, M. and Yokoyama, M. (2001). Comparison of gel properties of surimi from Alaskan pollock and three freshwater fish species: effects of thermal processing and protein concentration. *J. Food Sci.*, **66**, 548–554.
- Maeno, N. (1995). Science of Ice. *Hokkaido: Hokkaido University Press*, p.96–107 (in Japanese).
- Miao, Y., Kawai, M., Horibe, K. and Noguchi, A. (2003). Ohmic thawing of frozen food. *Proceedings of the 4th Annual Meeting of Japan Society for Food Engineering*. Otsu-city, Japan, p.30. (in Japanese).
- Park, S., Kim, J.D., Uemura, K. and Noguchi, A. (1995). Influence of frequency on ohmic heating of fish protein gel. *Nippon Shokuhin Kagaku Kogaku Kaishi*, **4**, 567–574 (in Japanese).
- Sastry, S.K. and Palaniappan, S. (1992). Ohmic heating of liquid-particle mixtures. *Food Technol., Dec.*, 64–67.
- Shirai, T. and Yoshikawa, T. (1999). Changes in components during freezing and thawing for food storage. *Nippon Shokuhin Kagaku Kogaku Kaishi*, **46**, 447–453 (in Japanese).
- Tanaka, T. (1985). A review of current industrial thawing and future prospects. *Refrigeration*, **60**, 239–245 (in Japanese).
- Uemura, K. (2003). Theory and application of ohmic heating. *Nippon Shokuhin Kagaku Kogaku Kaishi*, **50**, 151–156 (in Japanese).
- Yongsawatdigul, J., Park, J.W., Kolbe, K., Dagga, Y.A. and Morrissey, M.T. (1995). Ohmic heating maximizes gel functionality of Pacific whiting surimi. *J. Food Sci.*, **60**, 10–14.