

**EFFECTS OF THE THERMAL EQUALIZED TREATMENTS
BY FREEZING SYSTEM IN THE PORK**

Jin-Woong Jeong¹, Kee-Jai Park¹, Jeong-Ho Lim¹

¹Korea Food Research Institute, 516 Baekhyeondong, Seongnamsi, Kyunggi-do, Seoul, Korea

e-mail: jwjeong@kfri.re.kr, jake@kfri.re.kr, jhl@kfri.re.kr

Abstract

Freezing of food represents widely used preservation technology. In the frozen food, texture is highly important factor. Freezing system may cause severe damage to tissues, and can cause excessive softening and destruction. The effects of the thermal equalized treatments in frozen conditions on pork quality were analyzed. The pork samples were processed to compare the effect of two freezing methods, and internal pressure, drip loss, Scanning Electron Microscope (SEM) were investigated. Both of the temperature and internal pressure of pork was measured and recorded continuously by a temperature sensor and a pressure sensor during the freezing. In the non-thermal equalized freezing, internal pressure of pork reached approximately 7~8psig, but thermal equalized freezing was shown about 4 psig during freezing. And, the freezing time of pork by thermal equalized treatment was decreased to 10~20% than the other method. Also, the microstructure of frozen pork tissue assisted by thermal equalized treatment was observed much less intercellular disruption. This was attributed to the domination of intracellular small ice crystals. This result suggested that the thermal equalized treatment in freezing system were more effective reduced damage to tissues.

Key words: Pork, Freezing, Thermal equalized treatment, Ice crystal, Internal pressure

1. INTRODUCTION

Freezing food is a phase transition where moisture contained within food is a liquid that turns into a solid by taking heat. This freezing crystallizes ice from free water within the structure by lowering the temperature of food, inhibiting the growth of microorganisms and enzyme activity (Grujic et al. 1993).

Freezing is one of the effective methods for long-term preservation that minimizes the quality degradation of food, whereas, in the case of meat, it reduces quality because drip, protein denaturation and fat oxidation within meat occurs during refrigeration (Ogawa 1987).

One of the factors that significantly affect the physical denaturation of meat is the occurrence of internal pressure due to a rapid temperature drop and the resulting tissue destruction. Also, the expansion pressures generated by the large ice crystals which are formed during food-freezing and freezing-storage processed may damage the food structure and lead to a deterioration in the structure of the frozen food (Inoue et al. 1994; Rasanen et al. 1995).

To minimize such effects, it is suggested that the internal temperature of the object to be cooled is kept uniform by varying the temperature conditions temporarily during freezing, resulting in a distribution of the internal pressure (Miles & Morley 1997).

Many current studies focus on physicochemical changes of freezing (Kim, Yang & Lee 1988), quality and histological changes depending on the freezing rate (Garrol, Cavanaugh & Rorer 1981), and the size of ice crystals (Bevilacqua & Zarizky 1980). New techniques have been developed in food freezing,

such as high-pressure food freezing (Fuchigami et al. 1998), application of ice nucleation active bacteria (Li & Sun 2002; Widehem & Cochet 2003), biological freezing protein technique (Zasytkin & Lee 1999), and ultrasound-assisted food freezing (Zheng & Sun 2006). However, there is little research on actual quality characteristics of meat in accordance with freezing temperatures and variations of refrigeration temperatures

In this study, therefore, changes in the internal pressure according to the conditions of various freezing temperature variations were investigated, serving as a fundamental research to minimize quality deterioration caused by tissue destruction due to internal pressure during the freezing process,

2. MATERIALS AND METHODS

2.1. Materials

For this experiment, pork loin 24 hours after slaughter was purchased from a market and stored at 5 °C for 1 day after being wrapped in polypropylene. After this period, it was cut to a certain size and used in the freezing experiment with the epidermal lipid removed. The thermal equalizing process during freezing was carried out for 6 hours at each of $-1 \pm 0.5^{\circ}\text{C}$, $-10 \pm 0.5^{\circ}\text{C}$ and $-20 \pm 0.5^{\circ}\text{C}$.

2.2. Freezing experiment

The main device for measuring the internal pressure and material temperature according to the processing conditions of the specimen consists of a freezer, a pressure and temperature measurement unit and data output. For the air blast and still air freezing of the specimen, a cryogenic freezer of a two-stage cascade refrigeration system (SW-UF400, Samwon ENG Co., Seoul, Korea) was utilized. The specimen was placed on a tray installed in the center of the freezer (effective area: $L1,850 \times W850 \times H980$ mm) in which the temperature was controlled within a range of $-20 \sim -70^{\circ}\text{C}$ using a thermostat and air flow rate. For immersion freezing using propylene glycol, a 2Hp compressor unit (low-temperature sides: R-503, high-temperature sides: R-502) for cooling brine and a 2.2 kW heater for heating brine were installed

2.3. Measurement of internal pressure and temperature

To measure pressure, a copper pipe having a length of 10 cm and a diameter of 2 mm was connected to the compression unit of a pressure transducer in the range of $-14.8 \sim 100$ psi, and fastened with a screw and sealed. To simultaneously measure temperature, a 0.3 mm K-type copper-constantan thermocouple was fixed together and thermally insulated. The internal pressure and elapsed time during freezing were continuously measured using Hydra data acquisition until the temperature at the geometric center of the specimen reached -18°C . The internal pressure and elapsed time during thawing were also measured following the same method until the material temperature reached 1°C .

2.4. Observation of ice crystals and tissue

Histological investigation was performed using both method of frozen tissue sections and general method of paraffin tissue. First, for the frozen tissue sections, the specimen was immersed in a 10% formal calcium solution made with 100 mL of 40% formal aldehyde, 900 mL of distilled water, and 10% CaCl_2 and then secured for 18 hours at 4°C . Then, after rinsed under running tap water, the tissue was placed in a gum sucrose solution (aqueous solution mixed with 2 g of gum acacia, 60 g of sucrose and 200 mL of distilled water) for 18 hours at 4°C . After this period, using a cryostat microtome, the tissue with the moisture removed was fabricated into a frozen tissue section of $4 \mu\text{m}$ under -15°C chamber temperature. The dried specimens were mounted on aluminum stubs, coated for 90s with gold

using a Hitachi C1010 (Japan) fine coater, and then observed under a scanning electron microscope (Hitachi S-2380, Tokyo, Japan).

In the fabrication of the paraffin tissue sections, frozen tissue from each treatment was placed in a carnoy solution (made with 60 mL of pure alcohol, 30 mL of chloroform, and 10 mL of acetic acid) and fixed for 18 hours at 0 °C. After washing with absolute alcohol and left to soak in pure alcohol for 24 hours at 3~5 °C, the tissue was enclosed in paraffin and fabricated into a tissue section of 5 µm using a rotary microtome (Reichert-Jung 2040, Germany). The fabricated tissue section was dyed in a hematoxylineosin staining solution and its tissue was observed using an optical microscope (Zeiss, Axioskop, Germany).

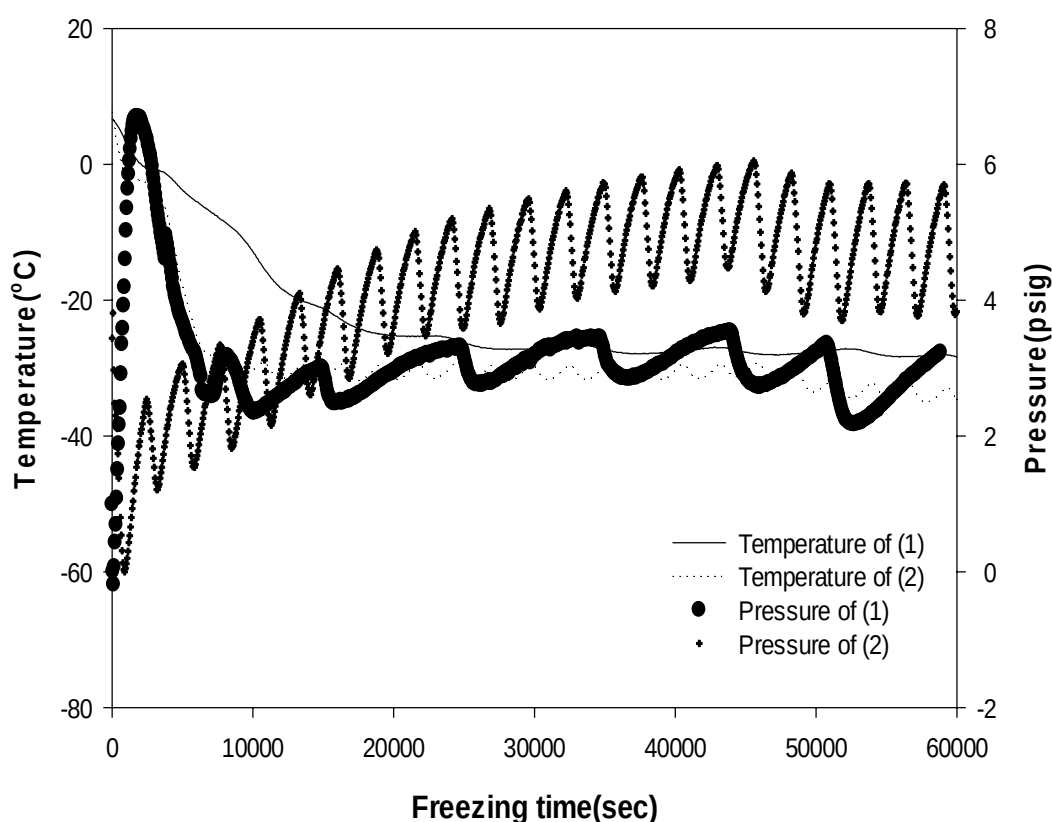


Fig. 1. Changes of internal pressure and temperature on pork loin by immersing freezing type (1) and air-blast freezing type (2) without thermal equalized treatment.

3. RESULTS AND DISCUSSION

3.1. Internal pressure and temperature during without thermal equalized treatment

When pure water turns into ice at 0 °C, it increases in volume by about 8.75% compared to the volume in its unfrozen state. The same applies to food. When fresh food, whose main component is water is frozen, its increased volume expands as well. Also, freezing generally starts to occur from the surface of food before it tightly covers its surrounding and internal moisture is gradually frozen at which the

volume expansion is blocked by the frozen portion of the surface, resulting in a pressure increase inside the food (Grujic et al. 1993).

From the comparison results of the changes in the internal pressure according to the freezing type-during the slow freezing, it is shown that as in Fig. 1, internal pressure in the immersion type for rapidly increased to about 8 psig just prior to freezing and decreased sharply during passing through the maximum ice crystal formation zone. Internal pressure in air-blast type for slowly had increased to about 7 psig during freezing. It also showed a tendency of increased pressure change with repeated increases and decreases by a level of about 2 psig as the internal pressure dropped to the freezing temperature. Overall, the magnitude of the internal pressure during freezing appeared to be about 7-8 psig and this tendency of the change in the internal pressure showed about 1 psig greater in the air-blast type as compared to the immersion type.

Table 1. shows the measurements of the internal pressure according to the processing conditions of freezing where the internal pressure difference due to volume expansion and contraction appears to be most significant at -70°C . Furthermore, the internal pressure is relatively low at -40°C freezing compared to -70°C , indicating the lower the freezing temperature, the larger the magnitude of internal pressure.

Table 1. Internal pressure and temperature of pork loin during freezing

Freezing		Initial temp. ($^{\circ}\text{C}$)	Dimensions		Max.		Min.		D ²⁾ (psig)	FT ³⁾ (min)
Temp. ($^{\circ}\text{C}$)	Methods		Weight (g)	Size (cm)	I. P. ¹⁾ (psig)	Temp. ($^{\circ}\text{C}$)	I. P. ¹⁾ (psig)	Temp. ($^{\circ}\text{C}$)		
-70	Still-air	11.5	527.6	11.5×10.0×7.5	0.33	11.5	-8.38	-57.0	8.71	189.5
-70	Still-air	12.0	268.6	10.0×7.0×4.5	0.85	11.1	-6.19	-53.1	7.04	136.7
-40	Immersion	10.1	242.4	10.0×8.5×4.5	0.51	-25.2	-1.48	-1.2	1.99	87.4
-40	Immersion	7.9	162.8	12.0×8.0×2.5	-0.11	7.3	-6.04	-26.8	5.93	227.3
-50	Air-blast	6.7	536.8	14.5×7.8×7.0	-0.11	6.7	-5.20	-32.8	5.09	104.7
-50	Air-blast	6.5	254.1	12.5×7.5×3.0	0.22	6.5	-3.85	-32.2	4.07	143.7

¹⁾Internal pressure

²⁾Time taken for center to reach -18°C

³⁾Represents the difference between the minimum internal pressure and maximum internal pressure

Table 2. Comparison of freezing time of pork loin by different freezing method without and with thermal equalized treatment

Initial temp. (°C)	Freezing		Width (m)	Thickness (m)	Average thickness ¹⁾ (m)	Freezing time(min)		Difference (%)
	Temp. (°C)	Methods				Thermal equalizing	Non-thermal equalizing ²⁾	
13.1	-70	Still-air	0.11	0.04	0.05867	147.6	155.10	-4.84
10.1	-40	Immersion	0.085	0.04	0.05440	87.4	113.19	-22.78
7.9	-40	Immersion	0.11	0.05	0.05310	109.0	146.35	-25.52
6.5	-50	Air-blast	0.075	0.03	0.04286	83.8	94.12	-10.96

¹⁾By equation ($=2w \times d / (w + d)$), w =width, d =thickness)

²⁾Computed value by Hung & Thompson (1983)

As the internal pressure occurred during freezing decreases, the magnitude that occurred during thawing appears to be relatively small and the internal pressure that occurred during thawing is found to be much larger than the value during freezing.

After observing the magnitude of internal pressure corresponding to the freezing rate, it is found generally in pork that internal pressure due to volume expansion occurred at -70 °C for the still air freezing type and at -40 °C for the immersion freezing type (Table 1.), and with the resulting internal pressure being relatively large, it is quite likely to induce destruction of tissues. It is assumed that the expansion pressure generated inside frozen food increases with the progress of freezing and causes cracks or bumps on the surface of the frozen food (Ogawa 1987; Miles & Morley 1977). Therefore, by using a method that allows dissipation of internal pressure that occurs during freezing, the deformation and destruction of food due to freezing is expected to be reduced.

3.2. Internal pressure and temperature during with thermal equalized treatment

The internal pressure that occurs during freezing of food depends on the type and size of food and the freezing method. When food having a large moisture content and thickness is rapidly frozen, the pressure within food largely occurs and cracks occur significantly. The thermal equalized treatment, in which the material temperature is lowered stepwise during freezing while maintaining the temperature for a certain period of time, can be used to reduce pressure that occurs during freezing. Also, the freezing time of pork by thermal equalized treatment was decreased to 10~20% than the other treatment (Table 2.). From the comparison results of the internal pressure within the pork with and without the thermal equalized treatment during freezing, it is shown that as in Fig. 1, for freezing without the treatment, the internal pressure in the immersion freezing type rapidly increased just prior to freezing and decreased sharply

when passing through the maximum ice crystal formation zone. After this period, the internal pressure tended to rise while repeating increases and decreases by levels of about 2 psig as the internal pressure decreased again.

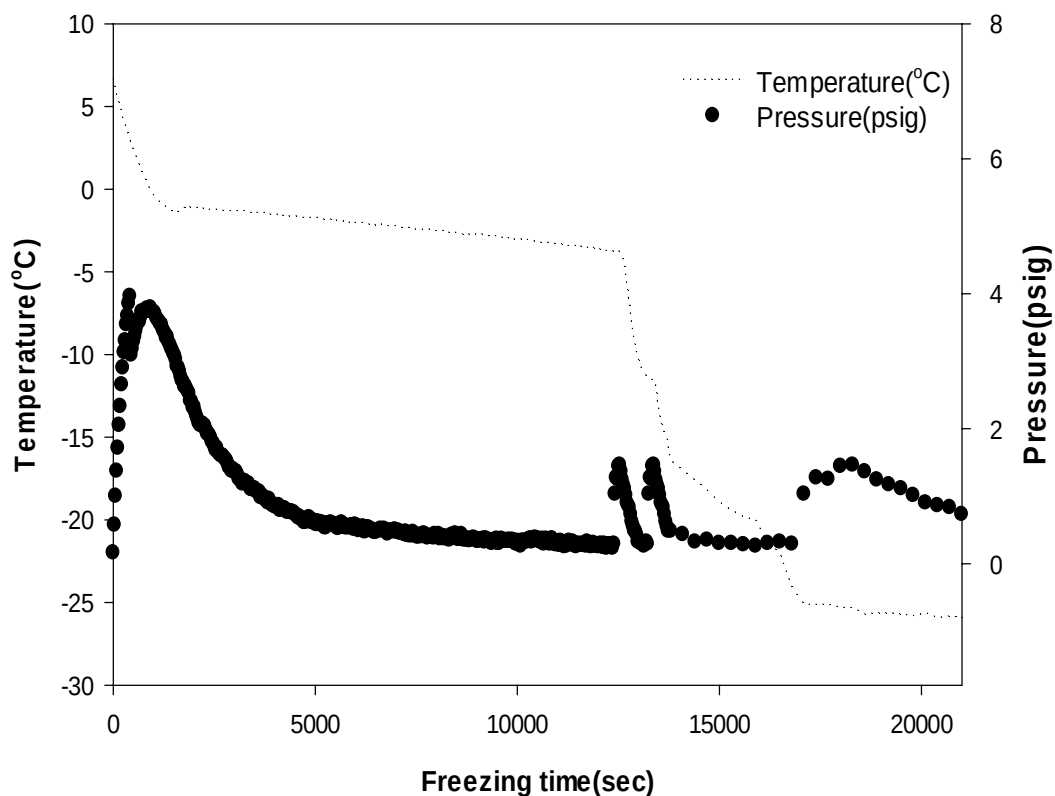


Fig. 2. Changes of internal pressure and temperature on pork loin by immersion freezing with thermal equalized treatment.

However, for the change in internal pressure of the pork with the thermal equalized treatment, as shown in Fig. 2, it showed the same tendency as the frozen pork without the process but appeared to be almost constant at about 1~2 psig until final freezing while showing a maximum pressure of about 4 psig just prior to freezing. The magnitude of the internal pressure was found to be reduced by more than 50% to be 1~4 psig, compared to that in the case without the process.

3.3. Observation of ice crystals and tissue according to freezing conditions

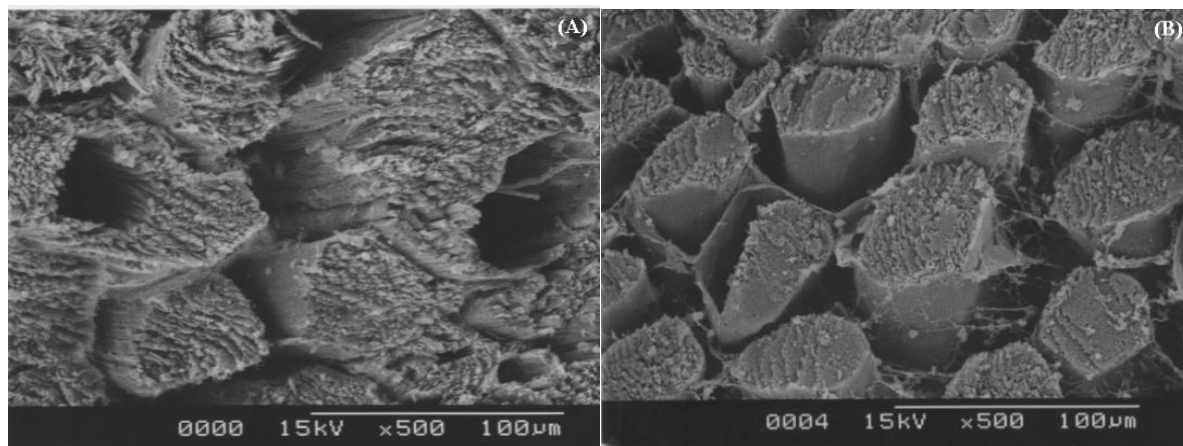


Fig. 3. Scanning electron microscopic (SEM) images of cross-section on frozen pork muscles fiber tissue without(A) or with(B) thermal equalized treatment by immersion freezing at -40°C .

Changes in the material temperature during freezing affect the size and location of ice crystals and tissue depending on the freezing rate. It is found that in the still air freezing at -20°C , as water-soluble substances within the muscle fiber tissue are slowly freeze, the tissue becomes irregularly shaped or distorted due to the dehydration of tissue by concentration.

Also, when immersing freezing type at -40°C , the tissue destruction was found to slightly occur during freezing. Grujic et al. (1993) have reported that the volume expansion caused by ice crystals created as temperature decreases pushes out muscle fibers resulting in myofibrils within the muscle fibers to become deformed by compression or cracks.

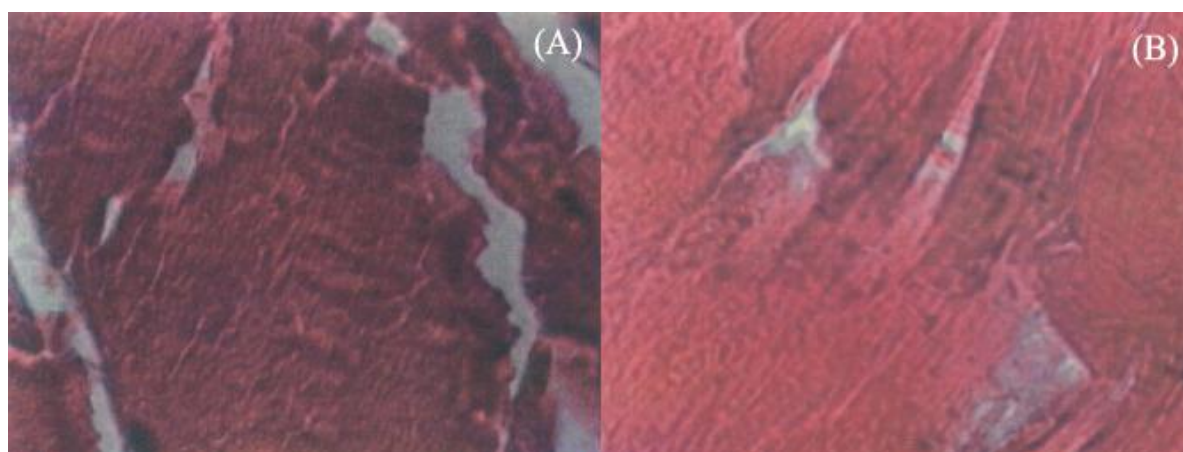


Fig. 4. Optical microscope image of cross-section on frozen pork muscles without(A) or with(B) thermal equalized treatment by immersion freezing at -40°C .

The microstructure on frozen pork tissue with and without thermal equalized treatment observed to scanning electron microscope and optical microscope. As shown in Fig. 3, the microstructure on frozen pork muscle fiber tissue assisted by thermal equalized treatment was observed to much less intercellular

disruption. Also, the comparison results of the degree of destruction in the specimen with the thermal equalized treatment and without the treatment, using the immersion freezing at -40°C shows that the destruction of muscle tissue was less observed in the specimen with the thermal equalized treatment (Fig. 4). This was attributed to the domination of intracellular small ice crystals.

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