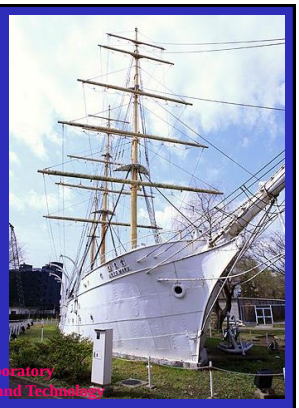
Final Congress of Freezewave Project
Congress Center of Nantes, 2018.11.5

Freezing assisted by magnetic field (4)

"Considerations to ensure the consistency in freezing experiment."



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Japan Society for Refrigerating and Air-conditioning Engineers (JSRAE) had run a research project entitled "Evaluation of the freezing method that utilizes electric and magnetic field" from 2006 to 2010.

10 researchers from 8 affiliations that includes 2 industries, 1 national institute and 4 universities were involved to the project.

We focused on to evaluate whether the applying alternating magnetic field during freezing generated significant difference on the quality of food materials.

How does freezing damage the tuna tissue?

Ice crystal structure,
e

Observation of ice crystals

Reactions in concentrated layer,
e.g., decayin
denaturation,

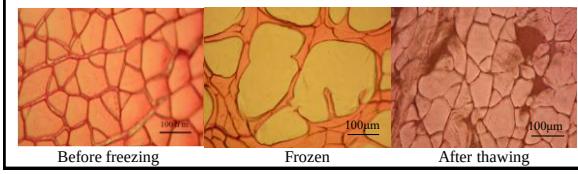
Quality evaluation after thawing

Magnetic field might
modify heat transfer.

Freezing temperature history

water molecules and
component molecules.

preserve cell wall and
olecules.



Before freezing | Frozen | After thawing

Experimental design

Typical food samples

- **Freezing without magnetic field (Control)**
- **Freezing with magnetic field**

Comparison of freezing temperature history
(super cooling, equilibrium freezing point, freezing time)

Observation of ice crystal by freeze substitution

Thawing in flowing water

Comparison of quality evaluation results
Physicochemical evaluation : Drip amount, color, structure, texture
Sensory evaluation : statistically processed questionnaire

Specification of the samples

Category	Sample	Comment
Vegetables	Japanese radish	Purchased at market
	Sweet potato	Purchased at market
	Spinatch	Purchased at market
Fishery products	Yellow tail	Never frozen, cultured
	Tuna	Never frozen
Others	Agar gel	1.5 wt% in concentration
	Purified water	Distilled

Test condition : Magnetic field

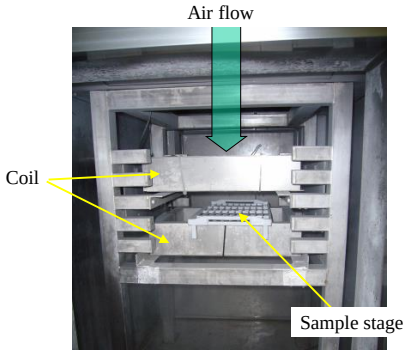
1. 1-dimensional Alternating magnetic field

   Intensity : 5 Gauss
   Frequency : 50 Hz

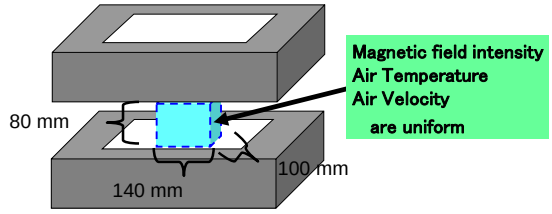
2. Nuclear Magnetic Resonance (NMR) condition

   Combination of static magnetic field of 200 Gauss and alternating magnetic field of 1 MHz in frequency and 1.2 Gauss in intensity

How to apply magnetic field

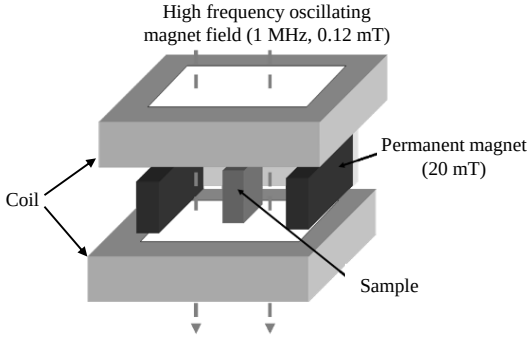


1-dimensional alternating magnetic field

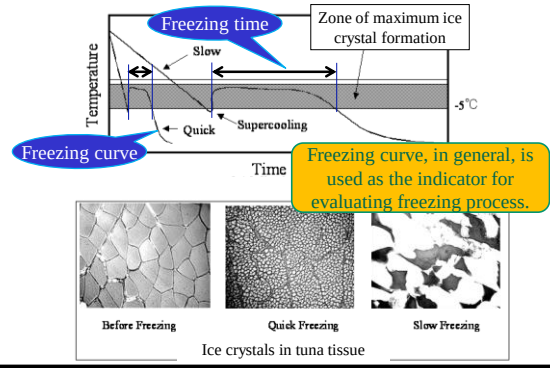


Air Temperature : -35 ± 2 deg.C
Direction of air : One dimensional downward
Velocity of air : 3.4 m/s
Magnetic field intensity : 5 Gauss
Frequency : 50 Hz

NMR condition

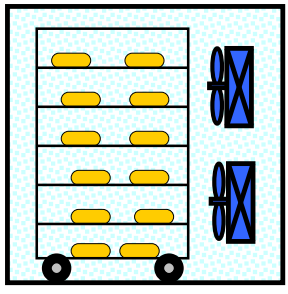


Temperature history during freezing dominates ice crystal structure, that strongly affects freezing damage.



Ice crystals in tuna tissue

Problem : Poor consistency of freezing curve



Air velocity is not uniform in the freezer

- Position of sample against a fan.
- Air flow generated by a propeller fan has complex flow structure.
- Influence of other sample.

Air temperature is not uniform nor constant.

- Non uniformity of the air flow induce uneven temperature.
- Mixing of fresh-cool air and stagnated air.

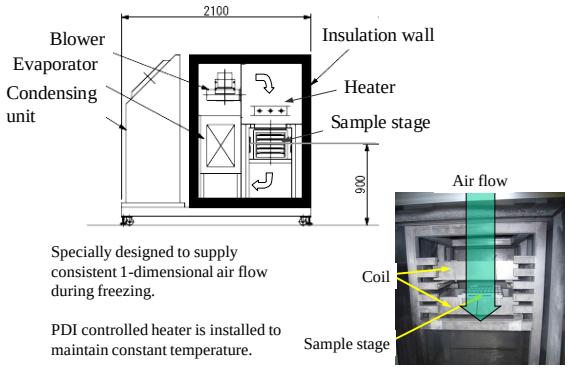
Inconsistency of samples

- Weight, dimension, component, microstructure etc. should be consistent.

Factors that have influence on heat transfer characteristics in food freezing

Factors	Required condition	Actual experimental condition
Samples		
Shape	Constant shape, 1-dimensional heat transfer	Cylindrical shape of ϕ40 x 40 mm with insulation
Composition	Take 2 samples from the same position of same individual to ensure that the 2 samples are as identical as possible.	Yellow tail: back meat not include blood meat Tuna: back meat not include fat Radish: central position Sweet potato: central position
Structure	If anisotropic because of muscle fiber, fix the fiber direction	Make the fiber direction parallel to heat transfer direction
Initial temperature	Constant and uniform	Long enough pre-cooling in the stocker at 7 deg.C
Cooling air flow		
Air velocity	Constant velocity against heat transfer surface	3.4 m/s , parallel to the heat transfer surface
Air temperature	Suppress fluctuation and positional distribution	Duct type chamber. Install an PDI controlled heater to keep –35 ± 2 deg.C.
Temperature measurement		
Position	Precise thermal center and surface	±1.0 mm in position accuracy
Sensor	Minimize the influence due to presence of sensor	T-type thermocouple of ϕ0.076 mm
Measuring Interval	Short enough to detect the ice nucleation from supercooling	1 second

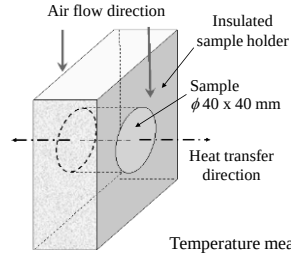
Details of test freezer



Specially designed to supply consistent 1-dimensional air flow during freezing.

PDI controlled heater is installed to maintain constant temperature.

Sample settings

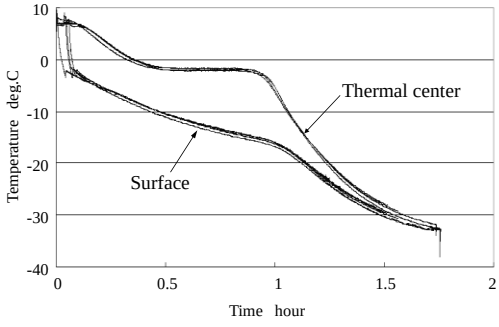


Temperature measurement

at the precise thermal center with accuracy of ± 1 mm

by T-type thermocouple of ϕ0.076 mm

Obtained freezing curve of tuna (n=4)



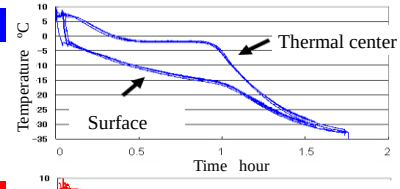
Physicochemical evaluation items and their method

Color	Spectrophotometer	L*, a*, b*
Drip amount	Centrifugal drip	Mass of sample : 1.5 **g** Centrifugal conditions : *for botanical materials* 2330*g* for 30 min. in 20 deg.C *for fish samples* 524*g* for 10 min. in 0 deg.C
Observation of structure	Optical microscope	Sliced by microtome, dyed, and observed
Texture	Maximum load in static displacement	Mass of sample : about 3 **g** Displacement rate : 1 mm/sec Plunger shape, final displacement ratio: *for botanical materials* cylinder of ϕ3 mm, 30 % *for fish samples* wedge of 20 mm, 80 %

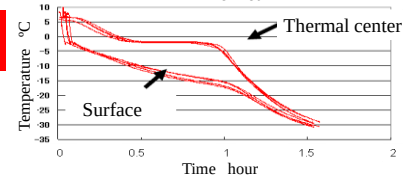
Experimental result

Freezing curves (n=4)

Control

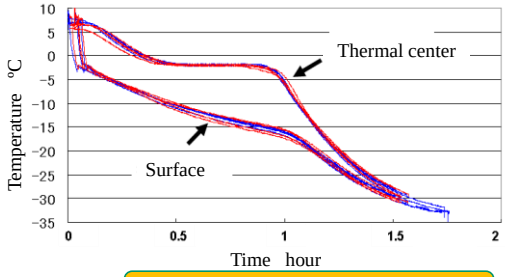


Magnetic field



We put 2 conditions together on the same graph

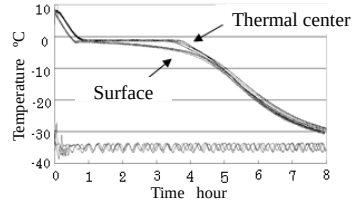
Quick frozen tuna



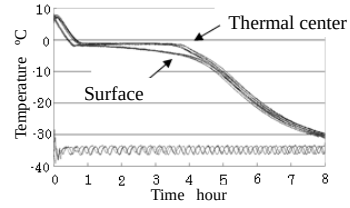
It is disclosed magnetic field has no effect on freezing curve at all.

Freezing curve during slow freezing of tuna (n=4)

Control



Magnetic field

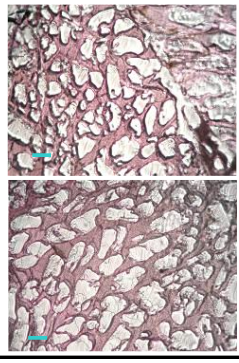


Quick frozen tuna

Microscopic images of frozen tuna tissue

Control

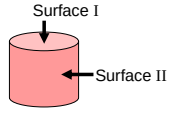
Magnetic field

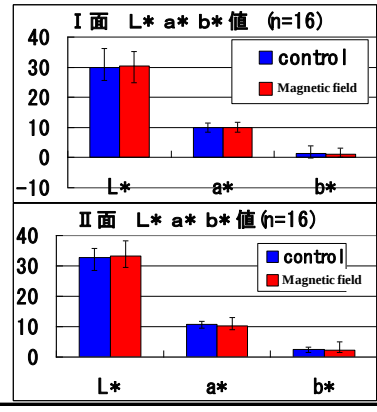


100 μm

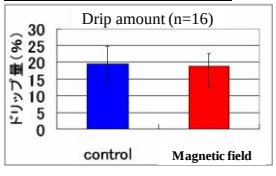
Quick frozen tuna

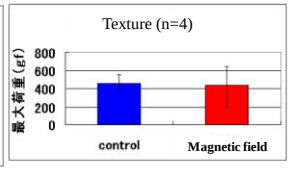
Color measurement





Quick frozen tuna





Before freezing | control | Magnetic field

Quick frozen tuna

Result of sensory evaluation

Evaluation item			MF freezing			Control			Differences
Side A	Redness	Relative evaluation	-0.30	±	0.35	0.30	±	0.35	Negative
	Brightness	Relative evaluation	-0.30	±	0.63	0.30	±	0.63	
	Color tone	Relative evaluation	-0.20	±	0.54	0.20	±	0.54	
	Wateriness	Relative evaluation	0.10	±	0.39	-0.10	±	0.39	
Side B	Redness	Relative evaluation	0.52	±	0.52	-0.52	±	0.52	
	Brightness	Relative evaluation	0.66	±	0.66	-0.66	±	0.66	
	Color tone	Relative evaluation	0.54	±	0.54	-0.54	±	0.54	
	Wateriness	Relative evaluation	0.49	±	0.49	-0.49	±	0.49	
Smelling	Smell	Relative evaluation	-0.10	±	0.47	0.10	±	0.47	
Hardness	Hardness	Relative evaluation	0.07	±	0.50	-0.07	±	0.50	
Tasting	Wateriness tasting	Absolute evaluation	1.07	±	1.10	1.13	±	1.13	

All test results indicate no significant difference between magnetic field freezing and control

Conclusion

In all evaluation items for all tested samples, no significant difference was observed between the sample frozen with weak magnetic field and control, within our experimental conditions. Therefore we can conclude that weak magnetic field do not have any significant effect on food freezing process.

It is found that we can have highly consistent freezing curve if we pay enough attention to make a constant heat transfer condition in freezing process. It means we can execute a reliable control experiments to evaluate the effect of something added supplementary to freezers.