CEI UPM | Centro de Electrónica Industrial

CSIC ictan
Instituto de Ciencia y Tecnología de Alimentos y Nutrición

Freezing assisted by Oscillating and Static Magnetic Field; recent advances

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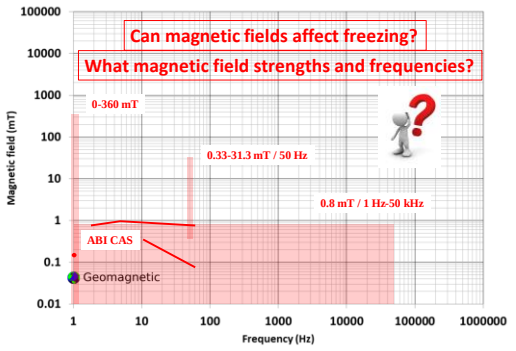
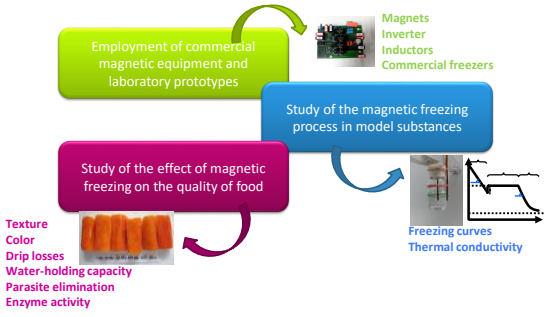
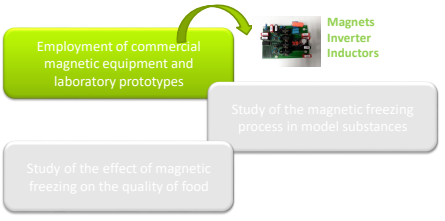
POLITÉCNICA

Magnetic field characteristics



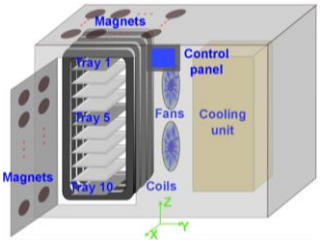
Objectives





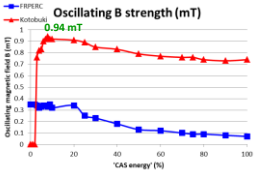
Commercial CAS freezers

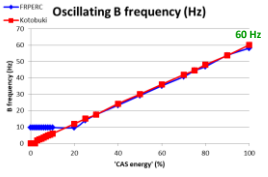
2 ABI CAS freezers
- Kotobuki in Madrid (Spain)
- Food Refrigeration and Process Engineering Research Centre (FRPERC) in Grimsby (UK)



CAS Energy 0-100%

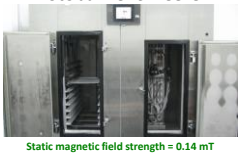
Commercial CAS freezers





FRPERC CAS freezer

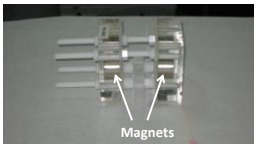
Kotobuki CAS freezer



Static magnetic field strength = 0.14 mT

Static magnetic field generator

Orientable polarities

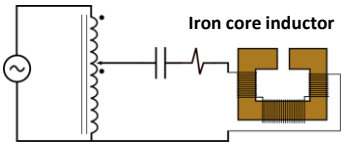


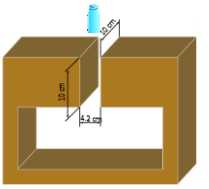
Neodymium $Nd_2Fe_{14}B$ permanent magnets

- Holding device made of Teflon and polymethyl methacrylate

Maximum static magnetic field strength = 359.6 mT

50-Hz oscillating magnetic field generator





Variac autotransformer

Iron core inductor

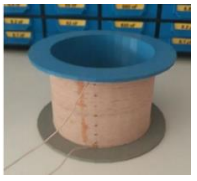
Oscillating magnetic field strengths:
- 0.33 mT
- 0.8 mT
- 1.5 mT
- 7 mT
- 31.3 mT

Frequency:
- 50 Hz

Oscillating magnetic field generator inverter

Design of the solenoid

High frequency coil



Constructive features

N = 75 turns
1 layer
Litz wire

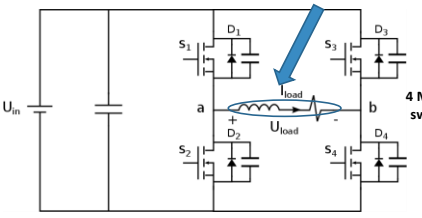
Measured impedance

L = 562 µH
R = 990 mΩ

Oscillating magnetic field generator inverter

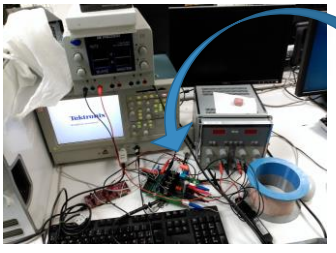
Design of the inverter

Full-bridge inverter

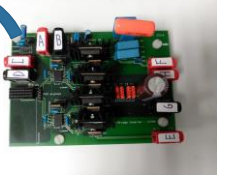


Main objective: obtain a purely sinusoidal current in the whole frequency range → minimize harmonics

Oscillating magnetic field generator inverter



Circuit generator of oscillating magnetic field

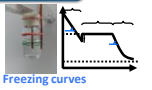


Full-bridge inverter

Employment of commercial magnetic equipment and laboratory prototypes

Study of the magnetic freezing process in model substances

Study of the effect of magnetic freezing on the quality of food



Freezing curves
Thermal conductivity

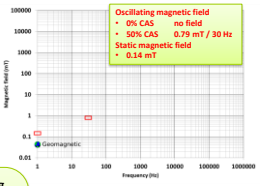
Ice thermal conductivity

Kotobuki CAS freezer

Pure water

Thermal properties analyzer

Hot-wire technique



CAS freezer

- 2 CAS conditions

Temperature
-50 °C
Air blast speed
3.8 m/s

Different freezing rates

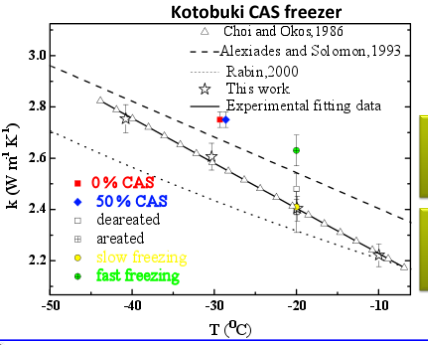
- Slow freezing
  In a thermostatic bath
- Fast freezing
  With liquid N_2

Different gas concentrations

- Aerated water
- Non-aerated water

Ice thermal conductivity

Kotobuki CAS freezer



CAS freezing does not change thermal conductivity

Thermal conductivity depends on the freezing speed

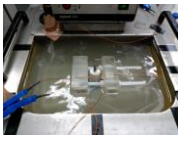
L. J. Bonales, A. C. Rodriguez, and P. D. Sanz, "Thermal conductivity of ice prepared under different conditions," International Journal of Food Properties, vol. 20, no. sup1, pp. S610-S619, 2017

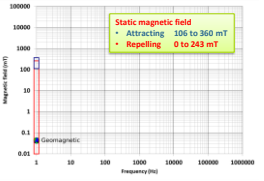
Freezing curves in static magnetic field

Static magnetic field generator

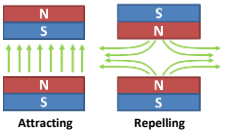
Pure water

NaCl solutions





Permanent magnets



Thermostatic bath

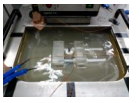
- Attracting magnets
- Repeling magnets
- No field applied

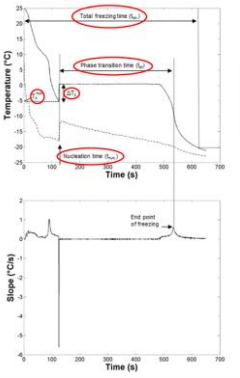
Temperature
-25 °C

Freezing curves in static magnetic field

Pure water

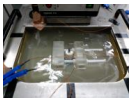
NaCl solutions





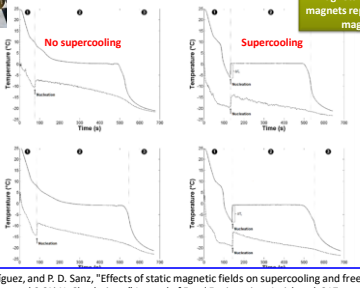
No significant differences among magnets attracting, magnets repelling or no magnets

Freezing curves in static magnetic field



Pure water

NaCl solutions



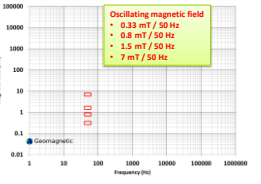
Similar proportion of occurrence of supercooling among magnets attracting, magnets repelling or no magnets

L. Otero, A. C. Rodriguez, and P. D. Sanz, "Effects of static magnetic fields on supercooling and freezing kinetics of pure water and 0.9% NaCl solutions," Journal of Food Engineering, Article vol. 217, pp. 34-42, 2018

Freezing curves at 50-Hz oscillating magnetic field

Iron core oscillating magnetic field generator

$FeCl_3$ solutions



Conventional freezer

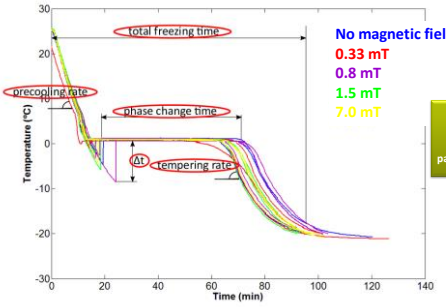
- 4 fields applied
- No field applied

Temperature
-22.7 °C
Air blast speed
0.24 m/s

Freezing curves at 50-Hz oscillating magnetic field

$FeCl_3$ solutions

Iron core oscillating magnetic field generator



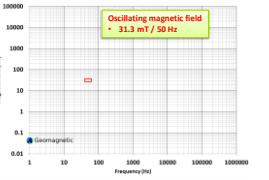
No magnetic field
0.33 mT
0.8 mT
1.5 mT
7.0 mT

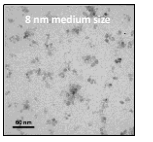
No significant differences in the freezing curve parameters for any field

Freezing curves at 50-Hz oscillating magnetic field

Iron core oscillating magnetic field generator

Magnetic nanoparticle (maghemite γ-Fe_2O_3) dispersion





Conventional freezer

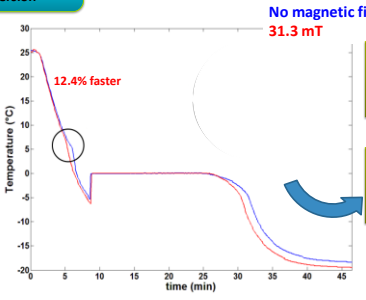
- 1 field condition (T = -17.6 °C)
- No field applied (T = -18.2 °C)

Air blast speed
0.51 m/s

Freezing curves at 50-Hz oscillating magnetic field

Magnetic nanoparticle (maghemite γ-Fe_2O_3) dispersion

Iron core oscillating magnetic field generator



No magnetic field
31.3 mT

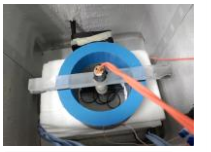
Acceleration in the precooling rate

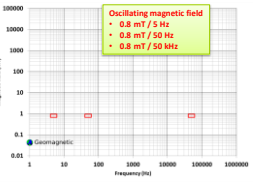
More studies at other frequencies

Freezing curves in the frequency-variable inverter

Air core oscillating magnetic field generator

Pure water



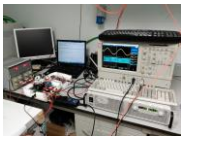


Conventional freezer

- 3 fields applied
- No field applied

Temperature
-28.3 °C

Air blast speed
0.25 m/s



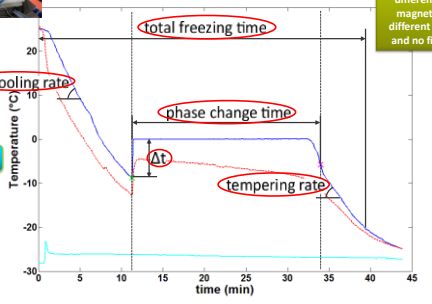
Freezing curves in the frequency-variable inverter

Air core oscillating magnetic field generator

5 Hz, 50 Hz, 50 kHz

No significant differences among magnetic fields at different frequencies and no field applied

Pure water



Employment of commercial magnetic equipment and laboratory prototypes

Study of the magnetic freezing process in model substances

Study of the effect of magnetic freezing on the quality of food

Texture
Color
Drip losses
Water-holding capacity
Parasite elimination
Enzyme activity

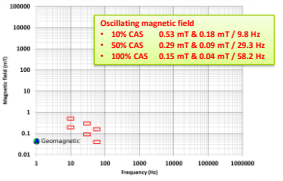
Food quality in commercial magnetic freezers

Freezing curves

Drip losses
Color
Texture

Pork loin

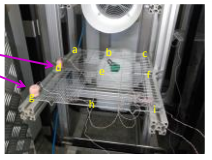
FRPERC CAS freezer



CAS freezer

- 3 CAS conditions at two locations
- No CAS applied

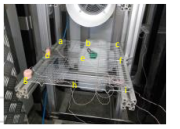
Temperature
-30 °C
Air blast speed
1-2 m/s

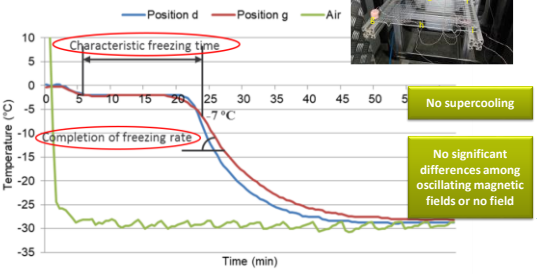


Food quality in commercial magnetic freezers

Pork loin

FRPERC CAS freezer





No supercooling

No significant differences among oscillating magnetic fields or no field

Food quality in commercial magnetic freezers

Pork loin

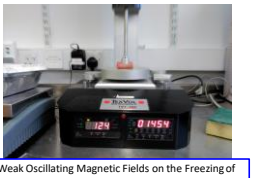
FRPERC CAS freezer

Drip losses

No significant differences among oscillating magnetic field strengths or no field

Color ΔL*, Δa*, Δb*

Texture density, hardness, force A, force B, and elasticity



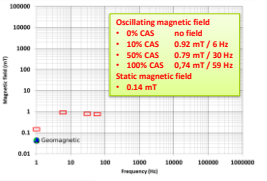
A. C. Rodríguez, C. James, and S. J. James, "Effects of Weak Oscillating Magnetic Fields on the Freezing of Pork Loin," Food and Bioprocess Technology, Article vol. 10, no. 9, pp. 1615-1621, 2017

Food quality in commercial magnetic freezers

Kotobuki CAS freezer

Drip losses
Water-holding capacity
Color
Texture

- After thawing
- After frozen storage for 1, 3, 6, 9 and 12 months



Crab sticks

Conventional freezer

CAS freezer

- 4 CAS conditions

Temperature
-25 °C
Air blast speed
3.8 m/s

Conventional freezer

- No field application

Temperature
-25 °C
Air blast speeds
4.8 m/s and 0 m/s

- Fresh non-frozen product

Food quality in commercial magnetic freezers

Kotobuki CAS freezer

Crab sticks

- Parameters after thawing

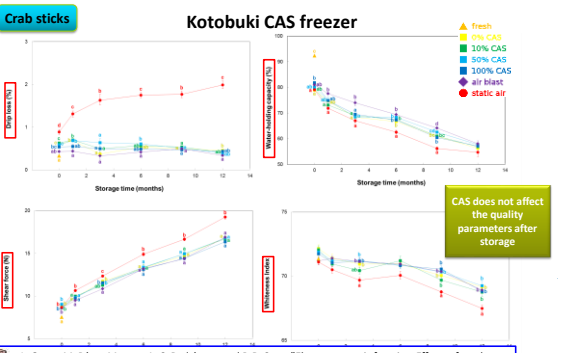
Drip losses	CAS > Fresh
Water holding capacity	CAS < Fresh
Whiteness	CAS ≈ Fresh
Toughness	CAS > Fresh

CAS freezer does not keep quality of fresh crab sticks

Food quality after frozen storage

Crab sticks

Kotobuki CAS freezer



CAS does not affect the quality parameters after storage

L. Otero, M. Pérez-Mateos, A. C. Rodríguez, and P. D. Sanz, "Electromagnetic freezing: Effects of weak oscillating magnetic fields on crab sticks," Journal of Food Engineering, Article vol. 200, pp. 87-94, 2017

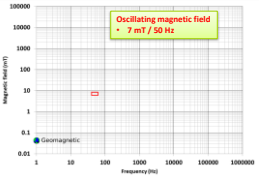
Enzymatic activity at 50-Hz oscillating magnetic field

Iron core oscillating magnetic field generator

Lactate dehydrogenase (LDH)

Freeze-labile enzyme

Plate reader spectrophotometer



2 cycles freezing-thawing

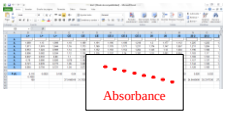
Fast freezing

- **With liquid N_2**

Conventional freezer

- **1 field condition**
- **No field applied**

Temperature
-23 °C
Air blast speed
0.24 m/s



Enzymatic activity at 50-Hz oscillating magnetic field

Iron core oscillating magnetic field generator

Lactate dehydrogenase (LDH)

Freeze-labile enzyme

Freezing procedure	LDH activity after 2 cycles of freezing/thawing
Non frozen	100%
Liquid N_2 (-196 °C)	2%
No magnetic field (-23 °C)	29.5%
7 mT (-23 °C)	28.2%

No significant differences in the LDH activity with or without magnetic field

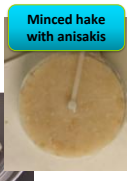
Food quality at 50-Hz oscillating magnetic field

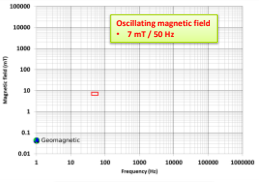
Iron core oscillating magnetic field generator

Anisakis inactivation

Water-holding capacity

Minced hake with anisakis





Conventional freezer

- **1 field condition**
- **No field applied**

Temperature
-23 °C
Air blast speed
0.24 m/s

Food quality at 50-Hz oscillating magnetic field

Iron core oscillating magnetic field generator

Minced hake with anisakis

No significant differences in the water holding capacity of the hake muscle

All anisakis larvae killed

M. Naito et al., "Effect of a Magnetic Field on Drosophila under Supercooled Conditions," PLoS ONE, vol. 7, no. 12, p. e51902, 2012

Conclusions

- By analyzing thermal conductivity and freezing curves, no effect of magnetic fields on freezing process has been proved.
- No changes in the quality parameters of foodstuff when subjected to magnetic-assisted freezing.
- Experiments have not been able to show any cryoprotective effect of magnetic fields.
- Only when oscillating magnetic fields were applied to dispersions of magnetic nanoparticles, a faster precooling rate was obtained but it did not affect freezing.

Future work

- The fast precooling rate obtained in magnetic nanoparticle dispersions could be used for energy saving in large-scale commercial freezing, for medicine and cryotherapy.
- The designed inverter opens up the possibility of applying a huge range of frequencies. This methodology could be adapted to scale up both the magnetic field strengths and frequencies as well as the dimensions of the coil to make it suitable for industrial purposes.

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Thank you for your attention

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