Isfahan University of Technology

Freezing assisted by RF (Radiofrequency) waves; state of the art and recent advances

PRESENTED BY:
NASSER HAMDAMI
MOHSEN DALVI NAVID HAFEZ-PARAST

32nd EFFoST International Conference

Table of Content

- Introduction
- Review of Recent Researches
- Case study: Radiofrequency assisted freezing of rainbow trout (*oncorhynchus mykiss*) fillet
- Possible mechanisms

Freezing

Introduction

- A phase transition in which a liquid turns into a solid when its temperature is lowered below its freezing point
- Most liquids freeze by crystallization
- Crystallization consists of nucleation and crystal growth

(Christian James et al., 2015)

Innovative Freezing Technologies

Introduction

- Pressure-assisted Freezing
- Ultrasound-assisted Freezing
- Electrostatic Field-assisted Freezing
- Magnetic Resonance-assisted Freezing
- ✓ Radiofrequency and Microwave-assisted Freezing

(Stephen J. James et al., 2015)

Major differences between RF and MW

Introduction

Both processes are similar in mechanisms, but RF has:

- Lower frequency (The microwave range is from 300 MHz to 300 GHz, and RF electromagnetic waves have frequencies of around 300 kHz ~ 300 MHz)
- Lower thermal energy creation
- Higher penetration depth

Review of Recent Researches

Anese et al., 2012	Lower drip loss and Smaller ice crystals
Xanthakis et al., 2014	The quality of the frozen product improved
Hafez -Parast et al., 2018	The size of ice crystals was decreased

CASE STUDY:

EFFECTS OF RADIOFREQUENCY-ASSISTED FREEZING ON MICROSTRUCTURE AND QUALITY OF RAINBOW TROUT (*ONCORHYNCHUS MYKISS*) FILLET

7

Objectives

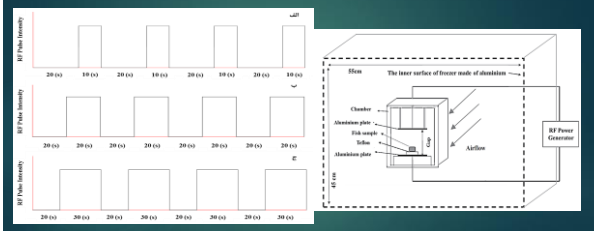
Case study

- **Effect of Radiofrequency assisted freezing on technological parameters (Freezing time, freezing rate)**
- **Impact of Radiofrequency assisted freezing on quality attributes and microstructure of fish**

8

Experimental Set up

Case study



Radiofrequency pulse application patterns during air-blast freezing

9

Materials and Methods

Performed Tests

Case study

- **Time –Temperature Profiles**
- **Drip Loss Measurement**
- **Texture Analysis**
- **Colour Measurement**
- **Histological Analysis**

10

Materials and Methods

Time – Temperature Profiles

Case study

- Freezing Time
- Freezing Rate
- Freezing Point

11

Materials and Methods

Histology Analysis

Case study

- **Carnoy solution (60% absolute ethanol, 30% chloroform, and 10% glacial acetic acid, v/v)**
- **Samples dehydrated with absolute ethanol and toluene bath**
- **Immersed in a pure paraffin bath kept at 60 °C**
- **Using a microtome in 10 µm to cut musle fiber**
- **For coloration immersed in orange G and blue aniline**
- **Slides were observed with a microscope fitted with camera**

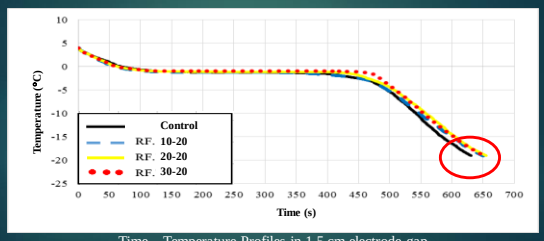
(Alizadeh et al., 2007)

12

Results

Time – Temperature Profiles

Case study

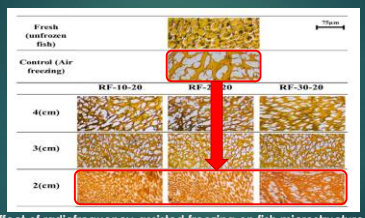


Time – Temperature Profiles in 1.5 cm electrode gap

Results

Microstructure

Case study



Effect of radiofrequency assisted freezing on fish microstructure

Results

Ice crystal size

Case study

Effect of radiofrequency assisted freezing on ice crystal size

Electrode spacing (cm)	Radiofrequency application pattern	Equivalent diameter (μm)
2	10–20	14.29 ± 2.19[c]
	20–20	13.19 ± 2.25[c]
	30–20	16.81 ± 3.19[c]
3	10–20	[illegible]
	20–20	[illegible]
	30–20	[illegible]
4	10–20	[illegible]
	20–20	31.14 ± 4.88[b]
	30–20	31.03 ± 5.89[b]
Control (frozen without RF)		52.02 ± 7.16[a]

Size reduction 75%

The research highlights

Case study

- No significant increase in freezing time
- **Size of ice crystals** was decreased by **75%** in comparison with control
- Quality attributes (**drip loss, hardness and color**) were better maintained in compared with control

Comparison between different assisted freezing methods

Case study

Method	Radiofrequency (rainbow trout)	Microwave (pork meat)	Electrostatic (lamb meat & pork meat)
Ice crystal size reduction (Eq. Diameter) (%) (treated vs control)	75 [1]	62 [2]	60 [3] 56 [4]
Drip loss	↓ (statistically significant)	-	↓ (statistically significant)
Hardness	Not influenced	-	Not influenced
Color	Not influenced	-	Not influenced

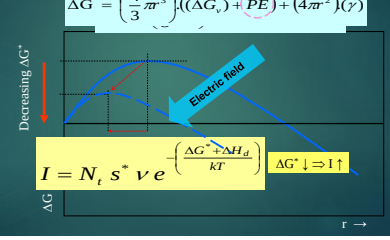
RF caused more size reduction and less product quality reduction

pork meat. Innovative Food Science & Emerging Technologies, 20(0), 115–120.

Effect of Electrostatic field (Thermodynamic Aspect)

Possible mechanism

$$\Delta G = \left(\frac{4}{3}\pi r^3\right).((\Delta G_v) + PE) + (4\pi r^2).(\gamma)$$

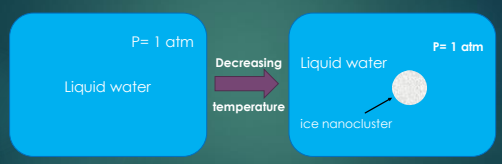


$$I = N_t\, s^*\, \nu\, e^{-\left(\frac{\Delta G^* + \Delta H_d}{kT}\right)}$$

$\Delta G^* \downarrow \Rightarrow I \uparrow$

The thermodynamic of ice nucleation

Possible mechanism



19

Possible mechanism

- Gibbs free energy of a nano-system according to Hill's theory:

$$G = N\hat{\mu} = Nf(p,T) + a(p,T)N^{\frac{2}{3}} + b(T)\ln T + C(P,T)$$

- Gibbs free energy of a bulk system

$$G = N\mu$$

So by some Simplification

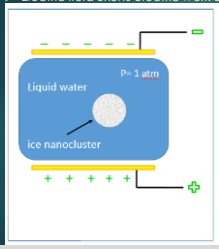
$$\Delta\mu = \hat{\mu}_s - \mu_L = (f(p,T) + a(p,T)N^{-\frac{1}{3}}) - \frac{G}{N}$$

Hill, T.L. 1962. Thermodynamics of Small Systems. J. Chem. Phys. 36, 3182.

20

Possible mechanism

- Electric field exerts electric work on the system



The electric work on liquid system:

$$W_{LE} = \frac{1}{6}\epsilon_m E^2 R^3$$

The electric work on ice cluster:

$$W_{s,E} = \frac{3\epsilon_c\epsilon_m^2}{2(\epsilon_c+2\epsilon_m)^2}E^2 r_c^3 + \frac{1}{6}\epsilon_m E^2(R^3 - r_c^3) + \frac{\epsilon_m(\epsilon_c-\epsilon_m)^2}{3(\epsilon_c+2\epsilon_m)^2}E^2 r_c^3\left[1-\left(\frac{r_c}{R}\right)^3\right]$$

Where ϵ_c & ϵ_m: dielectric permeabilities of the ice and water
R & r_c: radius of water and ice cluster
E: strength of electric field

21

Kashchiev, D. 1972. On the Influence of the Electric Field on Nucleation Kinetics. Philos. Mag. 25, 459–470.

- Therefore the chemical potential energy of liquid and solid changes when electric fields are present

Possible mechanism

$$\hat{\mu}_{s,E} = \hat{\mu}_s + W_{s,E} \qquad \mu_{L,E} = \mu_L + W_{L,E}$$

$$\Delta\mu_E = \Delta\mu + \Delta W_E$$

where $\Delta W_E = W_{s,E} - W_{L,E}$

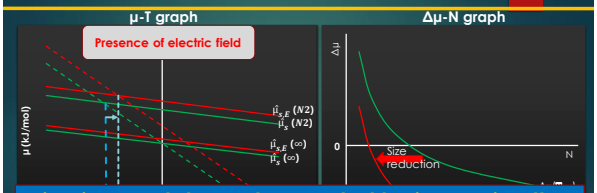
- Electric work on ice-cluster is smaller than liquid and depend on size of cluster

$\Delta\mu_E$ ↓ with ↑ strength of electric field and ↓ cluster size

22

Kashchiev, D. 1972. On the Influence of the Electric Field on Nucleation Kinetics. Philos. Mag. 25, 459–470.

Possible mechanism



Fine ice crystals can be created by increasing the strength of electric field

23