Freezewave

FREEZEWAVE FINAL CONGRESS
NANTES
5th Nov 2018

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Freezewave

1 BACKGROUND

2 FREEZEWAVE PROJECT

3 ORAL PROGRAM

4 DISCUSSION

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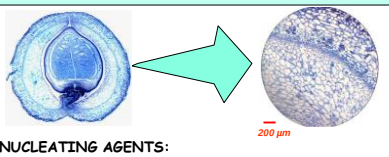
CRYSTALLISATION & CRYSTAL SIZE

TARGETS …
FOOD FREEZING = NUMEROUS and FINE ICE CRYSTALS
FRREZING FOR FREEZE DRYING = MEDIUM SIZE ICE CRYSTALS
FREEZE CONCENTRATION = BIG ICE CRYSTALS



→ ICE NUCLEATING AGENTS:
- Proteins, Ice Nucleating Bacteria,… challenging for sold foods app.

→ ULTRASOUND, HIGH PRESSURE, …:
- Challenging for solid foods (US),
- Costy and complex

→ ULTRA FAST FREEZING; CRYOGENIC etc
- Costy and also risk of internal cracks

ENERGY

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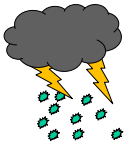
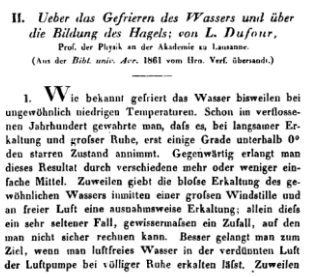
ELECTRICAL CHARGES & CRYSTALLISATION

DUFOUR, 1861
CLIMATE SCIENCE




II. *Ueber das Gefrieren des Wassers und über die Bildung des Hagels; von L. Dufour,*
Prof. der Physik an der Akademie zu Lausanne.
(Aus der *Bibl. univ. Arch.* 1861 vom Hrn. Verf. übersandt.)

1. Wie bekannt gefriert das Wasser bisweilen bei ungewöhnlich niedrigen Temperaturen. Schon im verflossenen Jahrhundert gewahrte man, dafs es, bei langsamer Erkaltung und grofser Ruhe, erst einige Grade unterhalb 0° den starren Zustand annimmt. Gegenwärtig erlangt man dieses Resultat durch verschiedene mehr oder weniger einfache Mittel. Zuweilen giebt die blofse Erkaltung des gewöhnlichen Wassers inmitten einer grofsen Windstille und an freier Luft eine ausnahmsweise Erkaltung; allein diefs ein sehr seltener Fall, gewissermafsen ein Zufall, auf den man nicht sicher rechnen kann. Besser gelangt man zum Ziel, wenn man luftfreies Wasser in der verdünnten Luft der Luftpumpe bei völliger Ruhe erkalten läfst. Zuweilen

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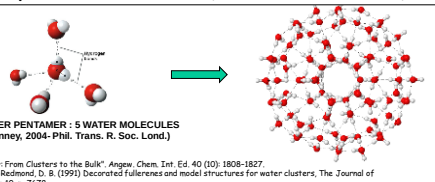
FROM LIQUID WATER TO ICE

LIQUID WATER is made of Water clusters
→ n =2 to 36 water molecules interacting on each other
-Water clusters are hydrogen bonded assemblies
-Ice crystals originate from water clusters

Pentamers of water → 5 water molecules
→ 85% of liquid water @ 298 K (Ohtomo et al. 1982)



WATER PENTAMER : 5 WATER MOLECULES
(Finney, 2004- Phil. Trans. R. Soc. Lond.)

Rudolf Ludwig (2001). "Water: From Clusters to the Bulk". Angew. Chem. Int. Ed. 40 (10): 1808–1827.
-Fowler, P. W., Quinn, C. M., Redmond, D. B. (1991) Decorated fullerenes and model structures for water clusters, The Journal of Chemical Physics, Vol. 95, No 10, p. 7678.
-Ignatov, I., Mosin, O. V. (2013) Structural Mathematical Models Describing Water Clusters, Journal of Mathematical Theory and Modeling, Vol. 3, No 11, pp. 72-87.

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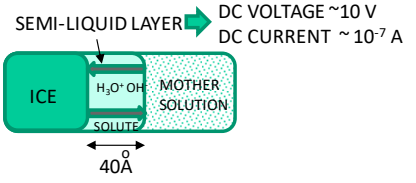
FROM LIQUID WATER TO ICE



Fletcher, N. H. (1970). The chemical physics of ice. (A. Herzenberg, M. M. Woolfson, & J. M. Ziman, Eds.). Cambridge: Cambridge University Press.

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CRYSTALLISATION & ELECTRICAL DISTURBANCES
2 STRATEGIES

1 STATIC FIELD → MAGNETIC FIELD / ELECTRIC FIELD

2 OSCILLATING FIELD

- OSC. MAGNETIC FIELD
  - → INDUCED E-M FIELD
  - → LOW FREQUENCY
  - → LOW POWER
- POWER E-M WAVES
  - → MICRO WAVES (2450 MHz)
  - → RF WAVES (27 MHz)

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ELECTRICAL DISTURBANCES & CRYSTALLISATION
2 STRATEGIES

1 STATIC MAGNETIC or ELECTRIC FIELD

- → IMPACT ON WATER MOLECULES (POLAR) ?
- → IMPACT ON HYDROGEN BONDS ?
- → TEMPERATURE OF CRYSTALLISATION ?

2 OSCILLATING ELECTROMAGNETIC FIELD

- → CONTINUOUS or PART TIME EMISSION
- → DIFFERENT WAVELENGTH (MICROWAVE, RF ….)
- → IMPACT ON WATER/ICE TRANSITION
- •

⇒ →APPLICATIONS: FOOD, BIOLOGICAL TISSUES, POLYMERS …

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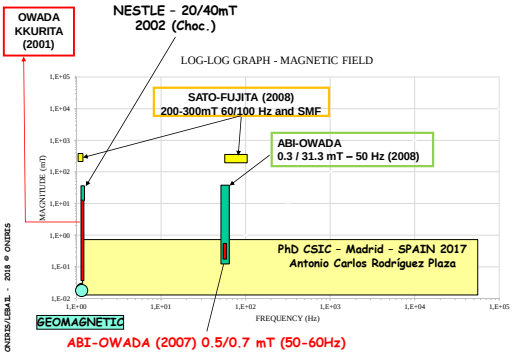
MAGNETIC FIELD – OSCILLATING → OSC. E-M FIELD



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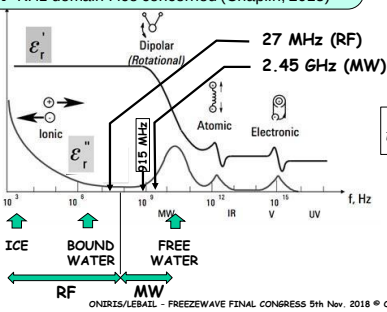
« POWER » ELECTRO MAGNETIC FIELD

- → MW at 2.45GHz enhances water mobility
- → GHz domain : Free water concerned
- → MHz domain : bound water also concerned
- → KHz domain : ice concerned (Chaplin, 2015)



$$tg(\delta) = \frac{\varepsilon''}{\varepsilon'}$$

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Freezewave

1 BACKGROUND

2 FREEZEWAVE PROJECT

ELECTROFREEZING @ ONIRIS: STARTED 2005
STATIC ELECTRIC FIELD
2012-2014 → MW ASSISTED FREEZING = **MAF**

Innovative Food Science and Emerging Technologies 26 (2014) 176–181

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Development of an innovative microwave assisted food freezing process

E. Xanthakis [a,b], A. Le-Bail [a,b,*], H. Ramaswamy [c]

Freezewave

1 BACKGROUND

2 FREEZEWAVE PROJECT

ERANET-SUSFOOD
SUSTAINABLE FOODS

Funding organizations

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FREEZE WAVE PROJECT (2015 – 2018)

FREEZEWAVE CONCEPT:
-APPLICATION OF LOW ENERGY MICROWAVES DURING FREEZING
→ REFINEMENT OF ICE CRYSTALS
→ HIGHER QUALITY FROZEN FOODS

FREEZEWAVE CHALLENGES:
-OPTIMIZING QUALITY vs ENERGY…

FREEZEWAVE OBJECTIVES:
-UNDERSTANDING FREEZING WITH µWAVES
-BATCH PROCESS DEVELOPMENT
-CONTINUOUS PROCESS DEVELOPMENT
-INDUSTRY CONCEPTS & TESTINGS

- Oniris: *MODELLING (1 PhD) EMULSIONS FRUITS & VEG. (1 PhD)*
- *RTE MEALS (FISH) (1 Eng.)*
- RISE: *MEAT (1 Post Doc)*
- Dairem

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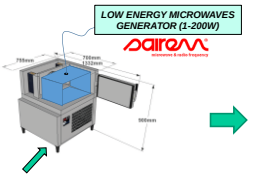
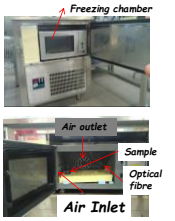
PROTOTYPE MULTIMODE MICROWAVES FREEZER



COMMERCIAL FREEZER BATCH MW-OVEN



Inner view

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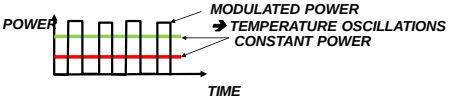
Freezewave

SUSFOOD

FREEZE WAVE EUROPEAN PROJECT (2015-2018)

MICROWAVE ASSISTED FREEZING

CHALLENGES OF FREEZEWAVE:
- OPTIMISATION OF MW POWER
- OPTIMISATION OF MODE OF EMISSION



→ *→ FROZEN FOOD QUALITY ?*

Oniris RISE TTZ Bremerhaven Dairem

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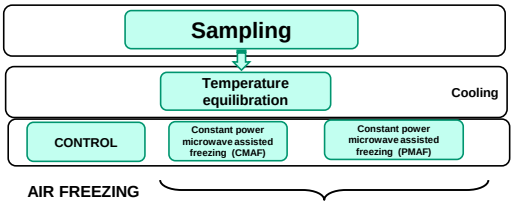
Experimental Design for MAF



AIR FREEZING

MW ASSISTED FREEZING

MAF POWER 100 / 250 W/kg

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4. DISCUSSION

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Freezewave

FINAL CONGRESS

5th Nov 2018 (10h-18h)

NANTES CONGRESS CENTER - FRANCE

SUSFOOD

PROGRAM

MORNING (10h00 / 12h30) : FREEZEWAVE RESULTS

10h00-10h15	Welcome	
10h15-10h30	Introduction FREEZEWAVE	Pr A LEBAIL-ONIRIS-France
10h30-10h50	Fruits and vegetables applications	P.K. JHA-ONIRIS-France
10h50-11h10	Seafood applications	J. HUEN-TTZ-Germany
11h10-11h30	Meat applications	E. XANTHAKIS-RISE-Sweden
11h30-11h50	Modelling and process upscale	M. SADOT-ONIRIS-France
11h50-12h10	Sensory evaluation	I.MATULLAT-TTZ-Germany
12h10-12h30	Discussion	Pr A LEBAIL-ONIRIS-France

LUNCH (12h30-13h30)
Sandwich choice – soft drinks - coffee

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Freezewave

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NANTES CONGRESS CENTER - FRANCE

AFTERNOON (13h30 / 17h30) : FREEZING ASSISTED WITH ELECTRIC & MAGNETIC FIELD

13h30-13h40	Introduction of session	Pr A LEBAIL-ONIRIS-France
13h40-14h00	Freezing assisted by Radio Frequency (1)	Dr M. ANESE (Univ. Udine-ITALY)
14h00-14h20	Freezing assisted by Radio Frequency (1)	Pr N. HAMDAMI (IUT-IRAN)
14h20-14h40	Freezing assisted by static electric field	Dr E. XANTHAKIS-RISE-Sweden
14h40-15h00	Modelling of static electric field	Pr M. HAVET-ONIRIS-France
15h00-15h20	Freezing assisted by magnetic field (1)	Pr Liu BIN, Tianjin Key Lab of Refrigeration, CHINA
15h20-15h40	Freezing assisted by magnetic field (2)	Pr Changqing TIAN, Chinese Academy of Science, CHINA
15h40-16h00	Freezing assisted by magnetic field (3)	Dr A.C. RODRIGUEZ, Dr L. OTERO - ICTAN-CSIC-SPAIN
16h00-16h20	Freezing assisted by magnetic field (4)	Pr M. WATANABE, Tokyo Univ. Marine Science – JAPAN
16h20-17h00	Coffee break – open discussion	
17h30	Conclusions – summary of the presentations	Pr A LEBAIL-ONIRIS

Oniris RISE IU Bremerhaven airem

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FREEZEWAVE OBJECTIVES:
-ASSESSMENT OF FREEZE DAMAGE
-UNDERSTANDING FREEZING WITH μWAVES
-BATCH PROCESS DEVELOPMENT
-CONTINUOUS PROCESS DEVELOPMENT

Oniris → *MODELLING (1 PhD) EMULSIONS FRUITS & VEG (1 PhD)*

IU → *RTE MEALS (FISH) (1 Eng.)*

RISE → *MEAT (1 Post Doc)*

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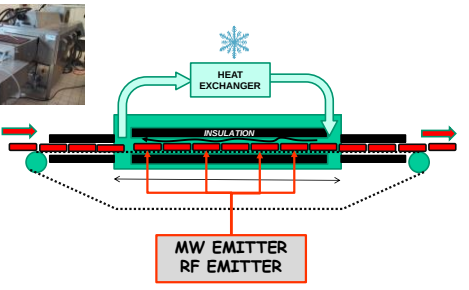
4 OUTLOOK
DESIGN OF A CONTINUOUS FREEZING PROCESS

- MW ASSISTED FREEZER
- RF ASSISTED FREEZER



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DESIGNING a CONTINUOUS MWAF or RFAF is doable

RF tunnel 120 kW,
3 Generators 40kW - 27,12 MHz
CHICKEN THAWING -20°C to -2°C

airem Votre partenaire en solution professionnelle Micro-ondes & Haute Fréquence
12 porte du Grand Lyon, 01700 NEYRON, France / Tel: +33 (0)472 018 160 / Fax: +33 (0)472 018 179 www.airem.com

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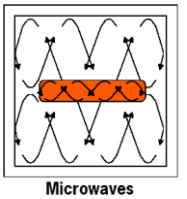
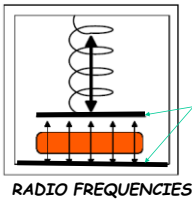
DESIGN OF A CONTINUOUS FREEZING PROCESS





Microwaves
2450 MHz or 915 MHz

RADIO FREQUENCIES
27,12 MHz or 13,56 MHz

PARAMETERS:
- POWER
- TIME
- LOAD SPEC.

PARAMETERS:
- POWER
- TIME
- LOAD SPEC.
- LOAD-EMITER COUPLING

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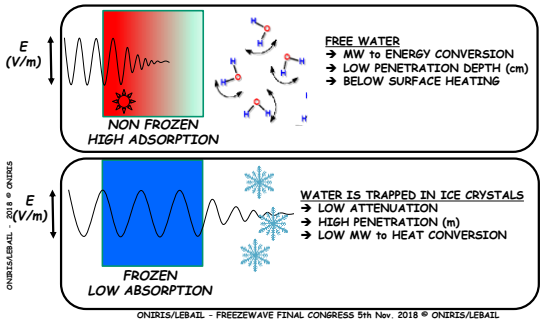
DESIGN OF A CONTINUOUS FREEZING PROCESS



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ATTENUATION: DEPTH OF PENETRATION

3 x DEPTH OF PENETRATION
→ 95 of MW POWER CONVERTED TO HEAT

$$\Delta = \frac{\lambda_0}{2.\pi.\sqrt{(\varepsilon'.tan(\delta))}}$$

T = 20-25°C
2,450 MHz

Dielectric properties of materials at 20–25°C and 2450 MHz

Material		Dielectric constant ($F\,m^{-1}$)	Loss factor	Penetration depth (cm)
Banana (raw)		62	17	0.93
Beef (raw)		51	16	0.87
Bread	BREAD	4	0.005	1170
Brine (5%)		67	71	0.25
Butter	BUTTER	3	0.1	30.5
Carrot (cooked)		71	18	0.93
Cooking oil		2.6	0.2	19.5
Distilled water	WATER	77	9.2	1.7
Fish (cooked)	FISH	46.5	12	1.1
Glass		6	0.1	40
Ham		85	67	0.3
Ice	ICE	3.2	0.003	1162
Paper		4	0.1	50
Polyester tray		4	0.02	195
Potato (raw)	POTATO	62	16.7	0.93

Adapted from Mudget (1982), Buffler (1993) and Mohsenin (1984).

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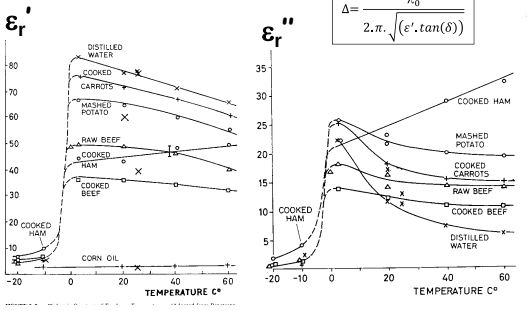
Tan(δ)=$\varepsilon_r''/\varepsilon_r'$= LOSS FACTOR
ENERGY CONVERSION FACTOR

FROZEN → Δ ↗

$$\Delta = \frac{\lambda_0}{2.\pi.\sqrt{(\varepsilon'.tan(\delta))}}$$



POWER (W/m³) = $5.56.10^{-11}.f.E^2.\varepsilon''_r.tg\delta$

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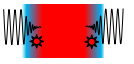
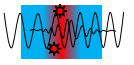
MWAF PROCESS

→ IMPACT OF FOOD THICKNESS and GEOMETRY

START OF FREEZING
→ HEATING CLOSE TO SURFACE = FREEZING FRONT
→ TEMPERATURE OSCILLATION ON FREEZING FRONT



TOWARS END OF FREEZING
→ FOOD SURFACE IS FROZEN
→ WAVES CAN PENETRATE THE FROZEN PARTS
→ HEAT RELASE AT FREEZING FRONT
→ TEMPERATURE OSCILLATION



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MW ASSISTED FREEZING

TWO ASSUMPTIONS MAY EXPLAIN THE OBSERVED REDUCTION OF THE SIZE OF ICE CRYSTALS WITH MICROWAVE ASSISTED FREEZING (MAF)

NITOM Effect;
The "NITOM" concept (Nucleation Induced by Temperature Oscillation caused by Microwaves) is supported by a theory based on the impact of a fluctuating temperature on secondary nucleation during MAF freezing.

NICMIW Effect:
A second concept called "NICMIW" (Nucleation Induced by Constant MIcroWaves power) based on constant power emission will also be presented; it is supported by the impact of MW on hydrogen bonds between water molecules, which may affect water clusters during freezing.

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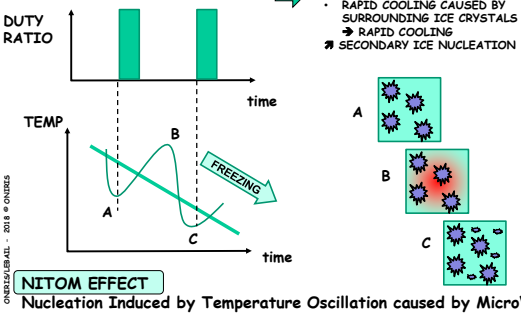
INTEREST OF PULSED MW vs CRYSTALLISATION



PULSED MW:
- TEMP. OSCILLATIONS
- RAPID COOLING CAUSED BY SURROUNDING ICE CRYSTALS
  → RAPID COOLING
  ↗ SECONDARY ICE NUCLEATION

NITOM EFFECT
Nucleation Induced by Temperature Oscillation caused by MicroWave

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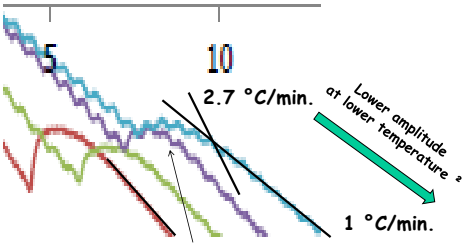
NITOM EFFECT

Nucleation Induced by Temperature Oscillation caused by Microwave



Real time – temperature plots obtained during conventional freezing (red curve) and under different power levels of microwave radiation of pork tenderloin samples (40% - green curve, 50% - purple curve, 60% - blue curve).

Development of an innovative microwave assisted food freezing process, E. XANTHAKIS, A. LE-BAIL & H. RAMASWAMY - IFSET - 2014; INNFOO_IFSET-D-14-00057

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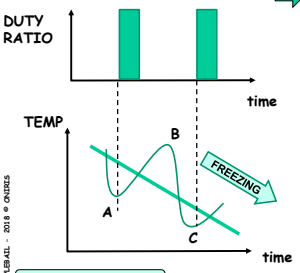
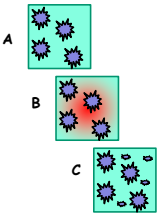
INTEREST OF PULSED MW vs CRYSTALLISATION



PULSED MW:
- TEMP. OSCILLATIONS
- RAPID COOLING CAUSED BY SURROUNDING ICE CRYSTALS
  → RAPID COOLING
  → SECONDARY ICE NUCLEATION



NITOM EFFECT

Nucleation Induced by Temperature Oscillation caused by MicroWave

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14h00-14h20	Freezing assisted by Radio Frequency (1)	Pr N. HAMDAMI (IUT-IRAN)
14h20-14h40	Freezing assisted by static electric field	Dr E. XANTHAKIS-RISE-Sweden
14h40-15h00	Modelling of static electric field	Pr M. HAVET-ONIRIS-France
15h00-15h20	Freezing assisted by magnetic field (1)	Pr Liu BIN, Tianjin Key Lab of Refrigeration, CHINA
15h20-15h40	Freezing assisted by magnetic field (2)	Pr Changqing TIAN, Chinese Academy of Science, CHINA
15h40-16h00	Freezing assisted by magnetic field (3)	Dr A.C. RODRIGUEZ, Dr L. OTERO - ICTAN-CSIC-SPAIN
16h00-16h20	Freezing assisted by magnetic field (4)	Pr M. WATANABE, Tokyo Univ. Marine Science – JAPAN
16h20-17h00	Coffee break – open discussion	
17h30	Conclusions – summary of the presentations	Pr A LEBAIL-ONIRIS

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OUTLOOK

1 STATIC FIELD → MAGNETIC FIELD, ELECTRIC FIELD

2 OSCILLATING FIELD →
- OSC. MAGNETIC FIELD
  → INDUCED E-M FIELD
  → LOW FREQUENCY
  → LOW POWER
- POWER E-M WAVES
  → MICRO WAVES (2450 MHz)
  → RF WAVES (27 MHz)

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OUTLOOK

1 STATIC FIELD → ELECTRIC FIELD, MAGNETIC FIELD

ELECTRIC FIELD:
- WORKS
- CHALLENGE vs HIGH VOLTAGE

MAGNETIC FIELD:
- CERTAIN CONDITIONS SEEM TO WORK
- RESEARCH STILL NEEDED

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OUTLOOK

2 OSCILLATING FIELD →
- POWER E-M WAVES
  → MICRO WAVES (2450 MHz)
  → RF WAVES (27 MHz)
- OSC. MAGNETIC FIELD
  → INDUCED E-M FIELD
  → LOW FREQUENCY
  → LOW POWER

POWER E-M WAVES:
- WORKS (PULSED MODE)
- OPTIMISATION / FREQUENCY
- OPTIMISATION / DUTY RATIO
- RESEARCH STILL NEEDED

OSC. MAGNETIC FIELD:
- WORKS FOR SOME APPLICATIONS
- OPTIMISATION SEEMS CHALLENGING
- RESEARCH STILL NEEDED ?

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OUTLOOK

- « FREEZEWAVE-CLUB » LINKEDIN GROUP
- « FREEZEWAVE » CONGRESSES

➔ attached to bigger congress as parallel session

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