FREEZEWAVE, Microwave assisted Freezing Modelling

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November 5th 2018

Introduction

Purpose :

- The development of a model which describes the interactions between microwaves and matter.
- The study of the microwaves behaviour within the product during the phase change.

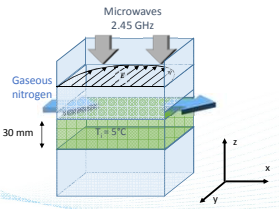
➔ Preliminary study in simple conditions

➔ Validation on a laboratory scale prototype

Geometry

- Study of matter-microwaves interaction in controlled conditions:

  ➔ Model product filling the waveguide section dimensioned for a TE10 monomode electric field distribution at 2.45 GHz.



COMSOL MULTIPHYSICS

Equations

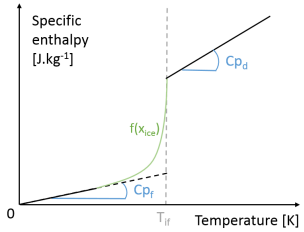
- **Heat Equation :**

$$\frac{\partial H}{\partial T}\frac{\partial T}{\partial t}\rho - \nabla . k\, \nabla T = Q_e$$

$$Q_e = \frac{1}{2}\omega\varepsilon_0\varepsilon_r''|E|^2$$

$$H = f(T, x_{ice})$$

$$x_{ice} = \frac{m_{ice}}{m_{product}}$$



Equations

- **Ice fraction**

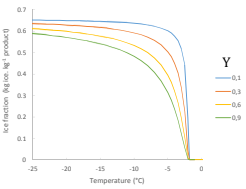
At -20°C, 89% of frozen water for red meat vs 54% for carrot [1]

➔ Adaptable parameter needed

$$x_{ice} = f[r(T)]$$

$$r(T) = \left(1 + \frac{Y}{T - T_{if} - Y}\right) . r_{fin}$$

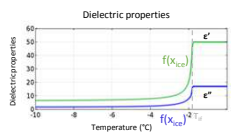
With Y a constant specific at the system.

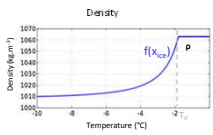


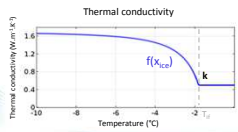
[1] L. Wang, C.L. Weller, Thermophysical Properties of Frozen Foods, in: D.-W. Sun (Ed.), Handb. Frozen Food Process. Packag., Boca Raton, 2012: pp. 101–127.

Equations

- **Dielectric and thermophysical properties as a function of temperature :**





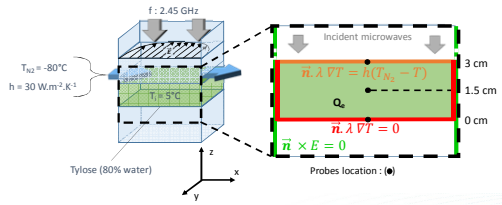


➔ Non linear equations

Model interest :

- x_{ice} governs all the properties

Boundary conditions



- Homogeneous heat transfer coefficient on the top surface
- Product thermally insulated
- Waveguide walls conductor of electricity

Model validation

- No experimental data in controlled conditions.

  ✓Thermal - phase change validation from a cryogenic freezing [2].

  ✓Coupling electromagnetism – thermal – phase change validation from a microwave thawing [3].

➔ The model is adapted to a microwave assisted freezing.

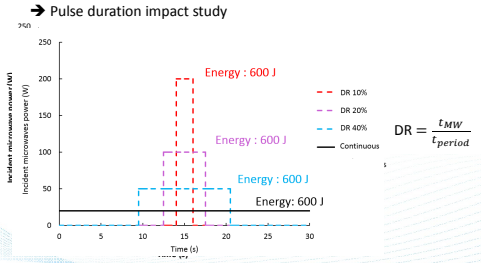
[2] Rouaud, O., Le Bail, A., De Pellegrin, R., 2013. Transfert de chaleur et de masse lors de la congélation de produits non emballés. Rev. générale du froid du Cond. l'air 1137, 42–47.

[3] S. Curet, Traitements micro-ondes et transferts de chaleur en milieu multiphasique, Thèse de l'Université de Nantes, 2008.

Model exploitation

- Experimental studies performed a microwave – RF treatment by pulses.

  ➔ Pulse duration impact study

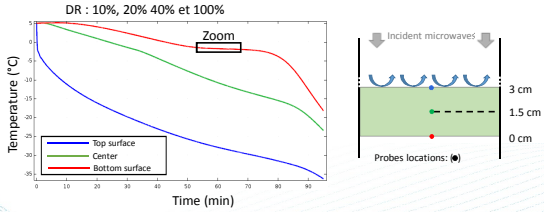


$$DR = \frac{t_{MW}}{t_{period}}$$

Results

- Temperature evolution during pulsed microwave assisted freezing

DR : 10%, 20% 40% et 100%

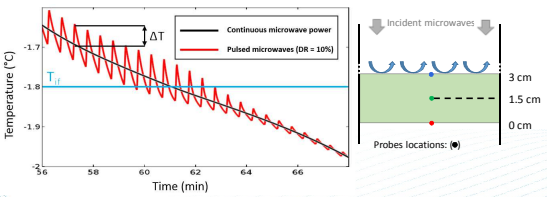


➔ Superimposed curves for different duty ratios

➔ Oscillation amplitude diminution in frozen phase

Results

- Temperature evolution during pulsed microwave assisted freezing

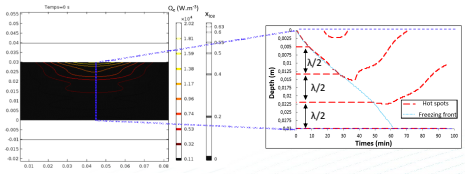


➔ Superimposed curves for different duty ratios

➔ Oscillation amplitude diminution in frozen phase

Results

- Generated heat during microwave assisted freezing



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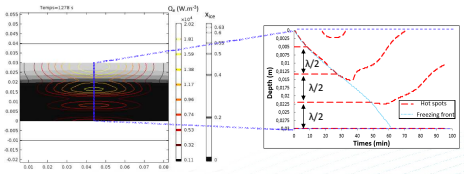
- Generated heat during microwave assisted freezing



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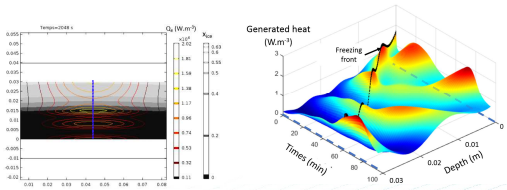
Results

- Generated heat during microwave assisted freezing



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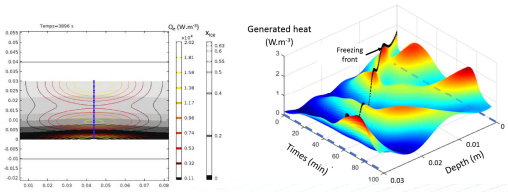
Results

- Generated heat during microwave assisted freezing



➔ Identification of hot spots with variable location and intensity in space and time.

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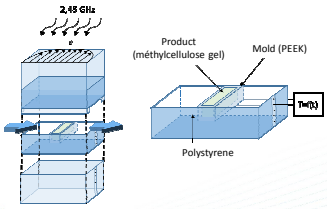
Prototype development

- Microwave assisted freezing:



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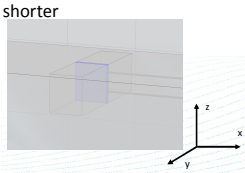
Experimental - Simulation

- Solid state microwave generator SAIREM
- Pulses generated with a switch
- Power measured with directional coupler
- Temperature measured with sheathed thermocouples

- COMSOL Multiphysics
- Hybrid model:
  - 2D heat equation
  - 3D Maxwell equations

➔ Identical solution with a computational time 20 times shorter



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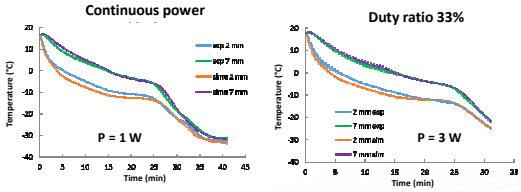
Model validation

- Microwave assisted freezing



- Good concordance of temperature curves
- Temperature oscillations amplitude similar (~ 1°C)
- Oscillation decrease after phase change

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Conclusion

- Experimental validation of developed model
- Visualisation of non experimentally measurable phenomena
- Help of the modelling in prototype design

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Thank you for listening