Physics in Food Manufacturing Challenges

3rd Edwards Symposium
New Horizons in Soft Matter

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PepsiCo Global Snacks R&D

6th Sep 2018

IOP Institute of Physics
Physics in Food Manufacturing Group

PepsiCo R&D

John Bows is an employee of PepsiCo Inc. The views expressed in this presentation are those of the author and do not necessarily reflect the position or policy of PepsiCo Inc.

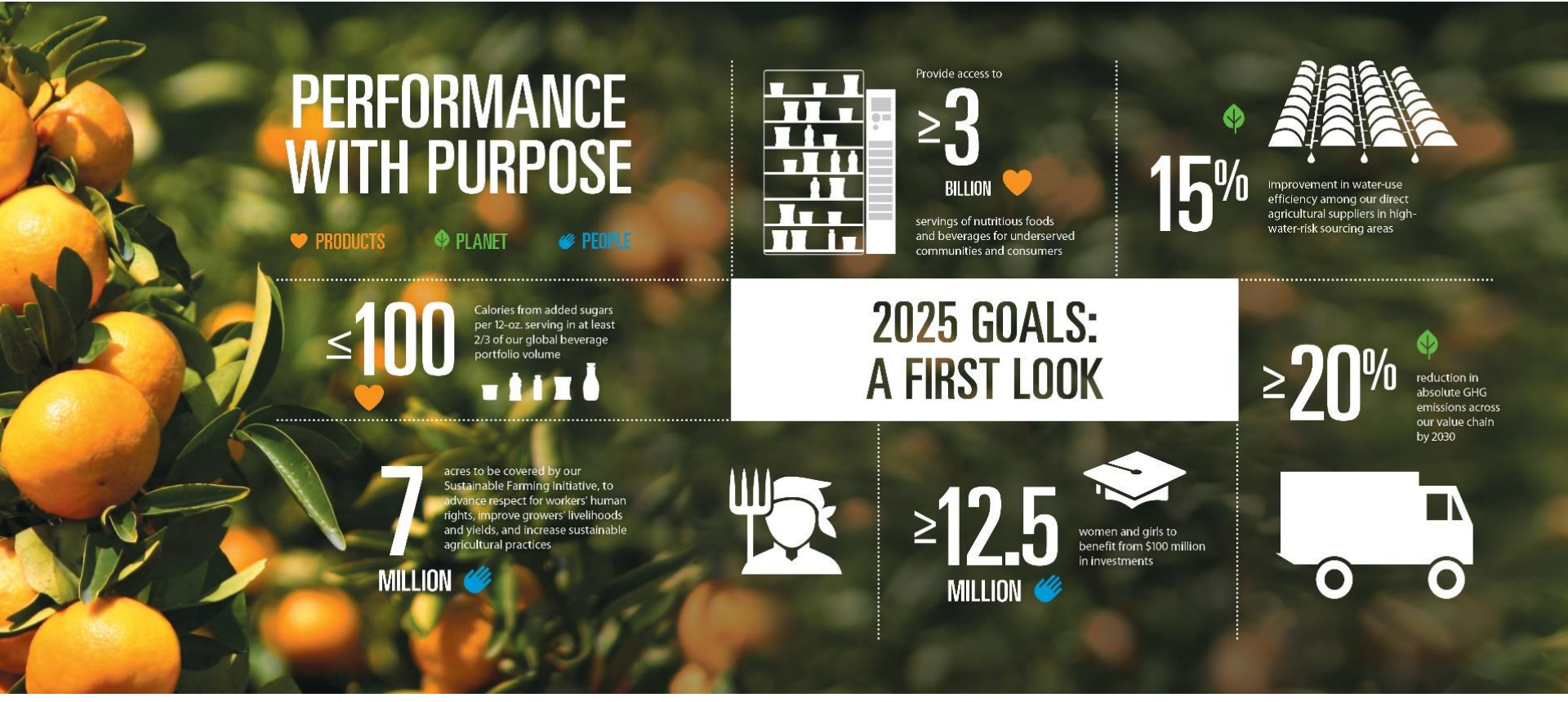
PepsiCo brands consumed 1 bn times a day

22 brands with more than $1 billion annual retail sales in 2017

More than 40 brands
$250 mn – $1 bn sales

$64bn net revenue in 2017

PepsiCo has public commitments on sustainability, many of which require significant R&D innovation

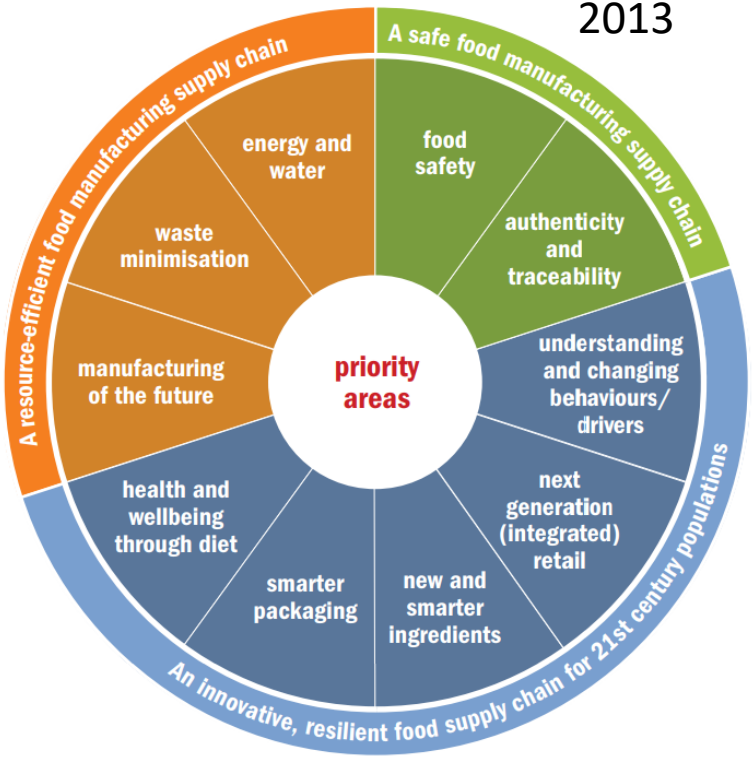


Food & Drink is UK's largest manufacturing sector

- Receives <2% of total R&D spend in UK (2014)

- Challenges facing Food & Drink industry need improved industry / academia / government partnerships to solve for:
  - Population growth
  - Food security
  - Environmental impact
  - Water / energy
  - Health and nutrition concerns

2013



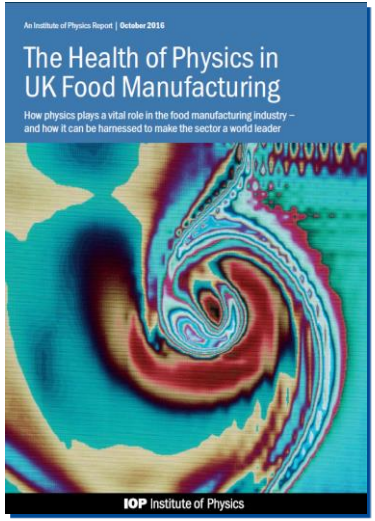
https://www.fdf.org.uk/events/Pre-Comp-Food-Booklet-Final.pdf

Physics in Food Manufacturing group inaugurated in May 2017 after 2 years of national engagement

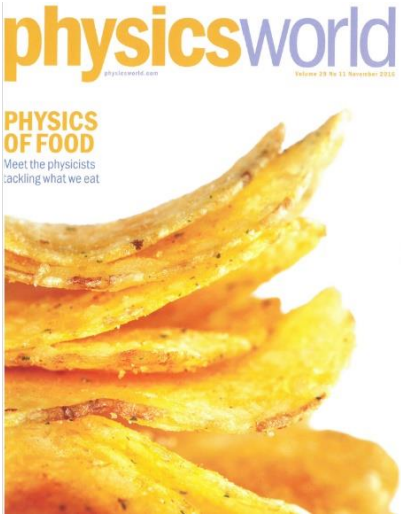
- **Champion role of physics in food manufacturing**
- **Inspire physics students on careers in food industry**
- **Engage physics academia to address sector challenges**
- **Catalyse partnerships**

IOP Institute of Physics
Physics in Food Manufacturing Group

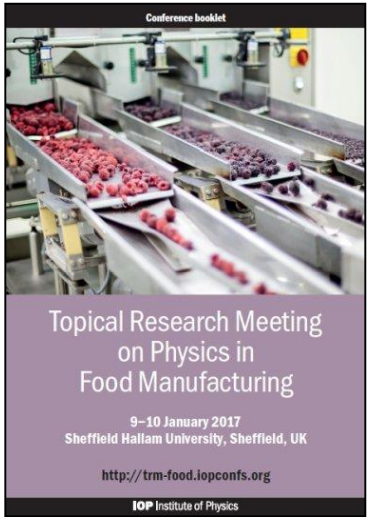
Oct 2016



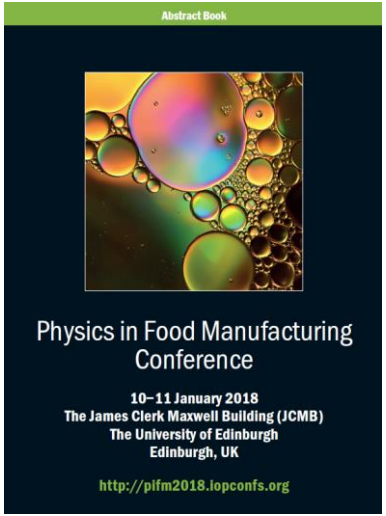
Nov 2016



Jan 2017



Jan 2018



Mar 2018

PiFM committee comprised on industrial and academic physicists

John Bows (chair)
PepsiCo

Dr Rob Farr (treasurer)
J. Douwe Egberts

Dr Anne Pawsey (early years champion)
Edinburgh University

Dr John Melose (secretary)
Retired (ex JDE)

Dr Becky Smith
Mondelez

Prof Thomas Krauss
York University

Prof Doug Cleaver
Sheffield Hallam

Dr Felix Oppong
Unilever

Dr M. Whitworth
Campden BRI

Prof Megan Povey
Leeds Uni

Prof Sarah Bridle
Manchester Uni

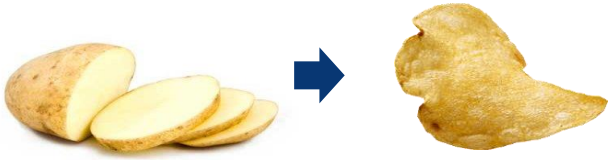
Prof Wilson Poon
Edinburgh Uni

Food manufacturing challenges context

- "Cook & Look" is traditional approach to product development
  - Rarely creates sustainable competitive advantage nor product innovation

- Material science approach increasingly important
  - "New" food ingredients
  - Advantaged processing / minimal thermal treatments
  - Improved nutritional / health delivery
  - New appliances (food service, in-home, on-the-go)

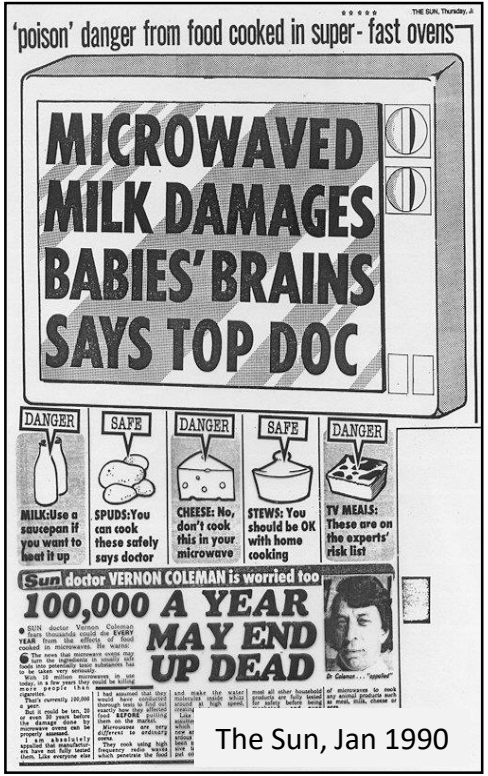
- "Soft matter transitions" critical for final texture, appearance
  - Material science tools (TFS, CDS, state diagrams …)
  - Predictive design (modelling, dimensionless numbers)
  - *Real-time* imaging, measurement, characterisation
  - Physicists mind set!



Selected food manufacturing challenges

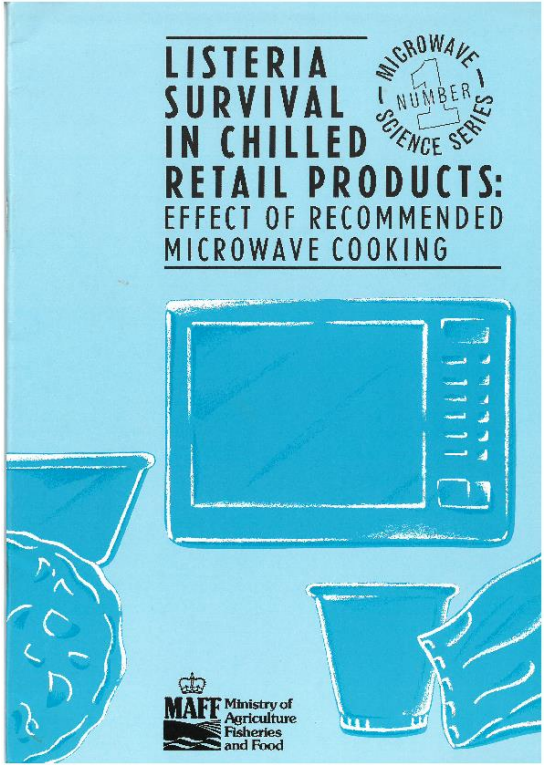
- Measure product microstructure evolution during it's creation
- Measure (T, P, ε^* …) in hostile EM closed environments
- Advantaged / hybrid processing
- Nutrient-retentive processing
- "Coffee Time" / App-based computer modelling & simulation
- Predictive product design
- Food safety

In-situ time-temperature validation of advantaged processing technologies remains key challenge

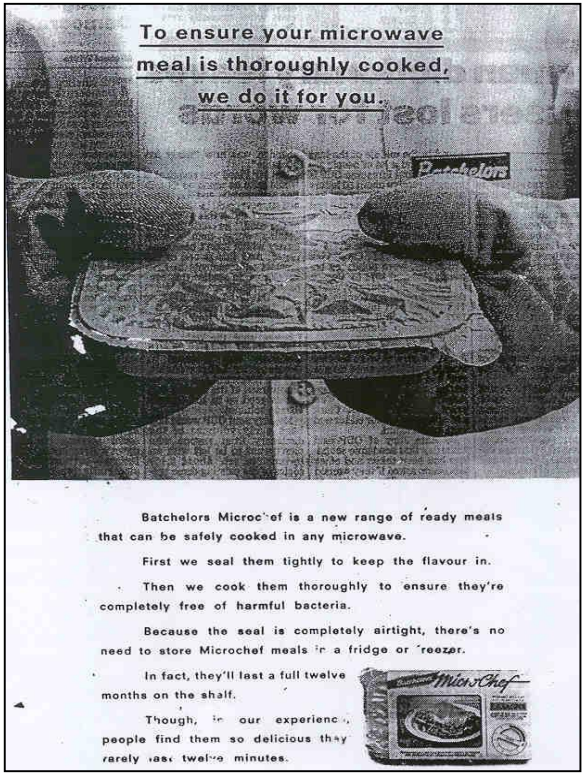


The Sun, Jan 1990

Technology reputation



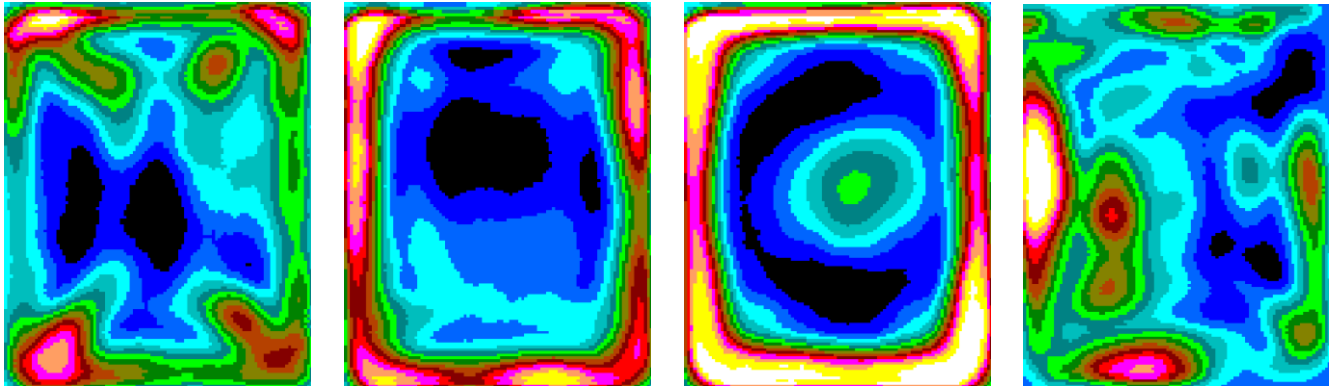
All domestic microwaves vary

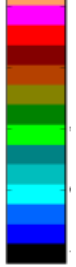


Not a reliable thermal kill step

Thermal imaging used to understand dominant field distribution in microwave ovens

Oven 1	Oven 2	Oven 3	Oven 4
Corner over-heating	Edge over-heating	Edge & Centre	Corner under-heating

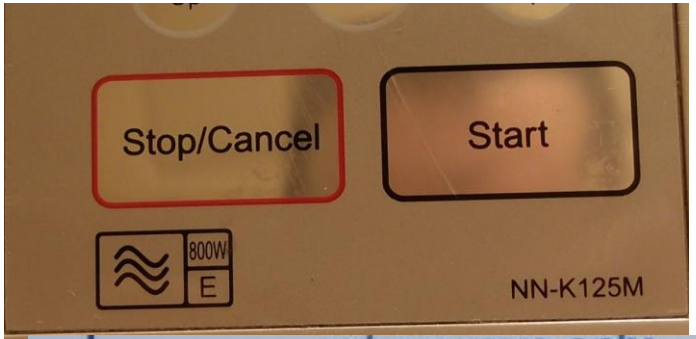


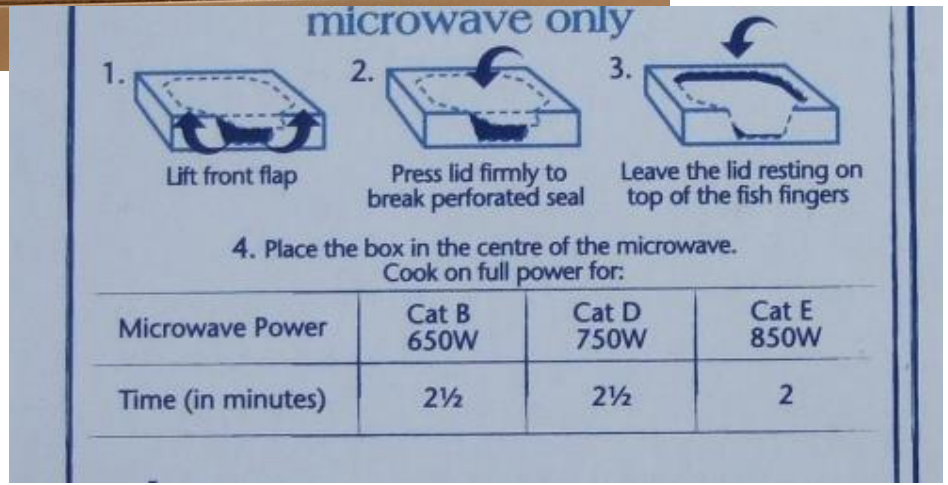


FLIR ONE Pro
-20 to 400°C
£332

Centre plane thermal images of trays of model food gel after 1 min heating at full power in different domestic ovens

2 bn domestic ovens globally – only UK has harmonised solution for consistent power delivery (but not uniformity!)





microwave only

1. Lift front flap

2. Press lid firmly to break perforated seal

3. Leave the lid resting on top of the fish fingers

4. Place the box in the centre of the microwave. Cook on full power for:

Microwave Power	Cat B 650W	Cat D 750W	Cat E 850W
Time (in minutes)	2½	2½	2

How / when will solid state microwave technology generate new material science opportunities?

IBEX One

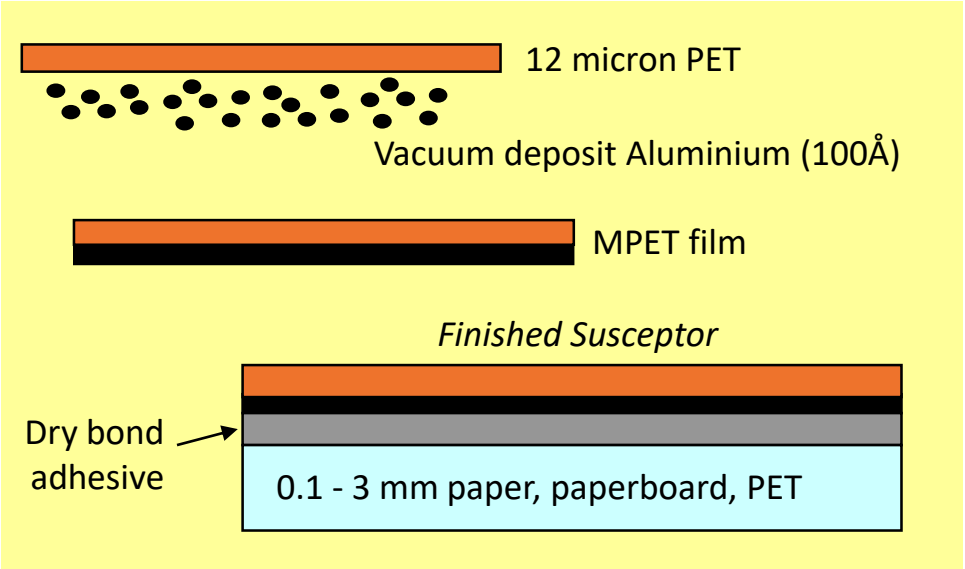
Wayv Adventurer $200

Bows (1990). Domestic Microwave Oven Characterisation and its Relation to the Reheating Performance of Ready Meals. Campden TM 564.

Susceptors enable crisping / cooking

- Susceptors first used around 1980
  - Optical Density = log (1 / Light Transmission Coefficient)
  - Typical OD for food use is 0.2 to 0.3

Susceptors can achieve 200°C within 2s



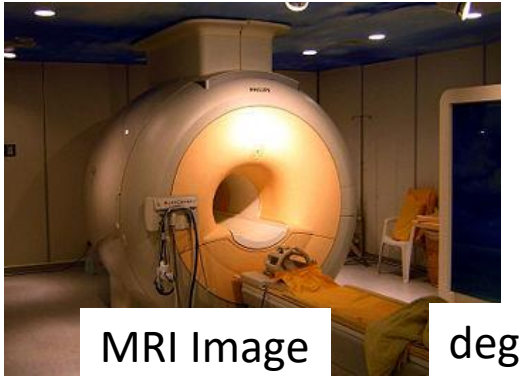
Antennae unlock cook-from-raw

- Electric field in home ovens up to 15 c. kV/m
- Continuous metal loops can lead to voltage breakdown in abuse conditions (e.g. no food load)
- Abuse-tolerant metal loops are resonant when perimeter is (n/2) $\lambda_o/\sqrt{\varepsilon'}$
- Food load (ε') capacitively couples elements to create a resonant loop, power transmission line or reflection sheet

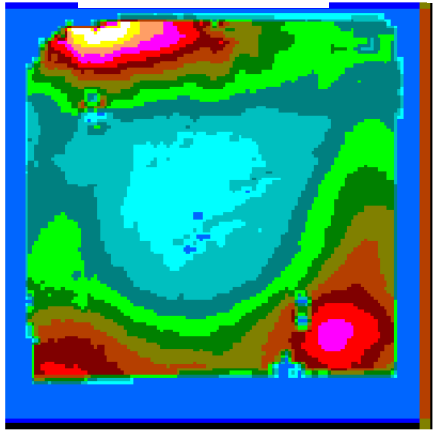
Iceland Microwave Pie (UK, 1998)

Birds Eye Ireland & Belgium (2002)
World's first raw rising dough microwave pizza

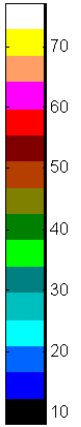
Challenge – measuring temperature during “field processing”



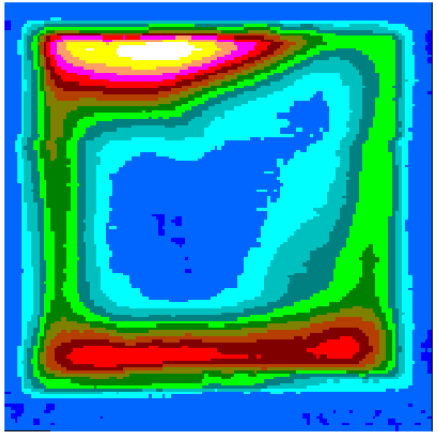
MRI Image



deg C



Thermal Image

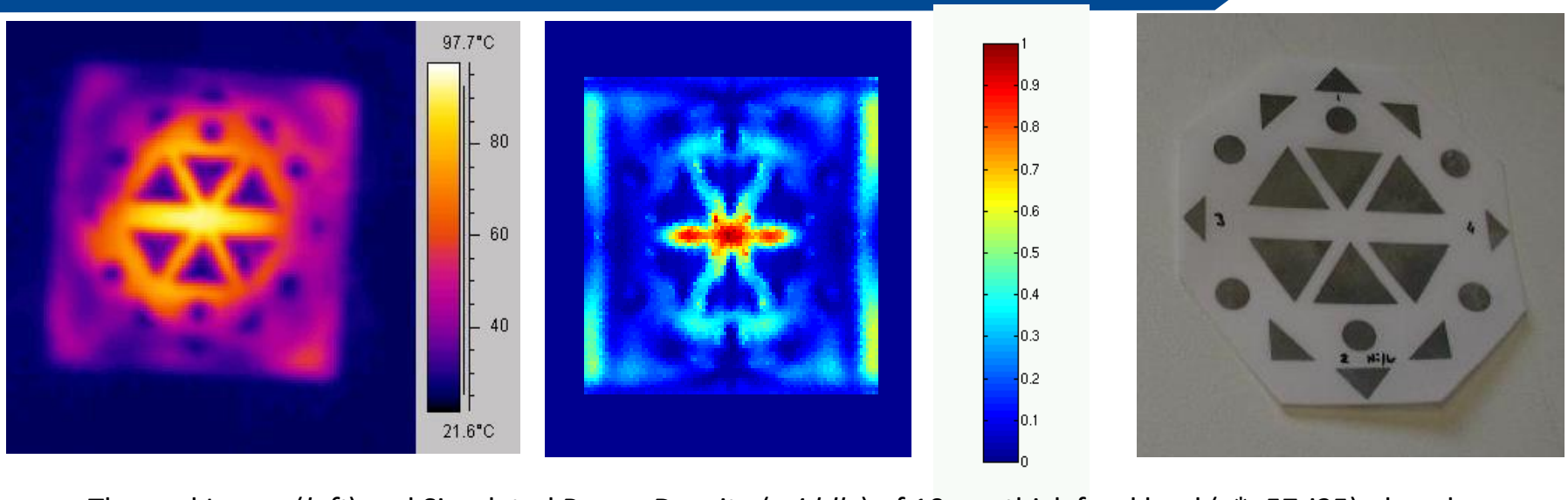


Fibre optic probe

Doneness Indicator

Bows et al (2001). Three-dimensional MRI mapping for assurance of minimum temperatures achieved in microwave and conventional food processing. IJFST, 36, 1-10.

Challenge – “coffee time” modelling



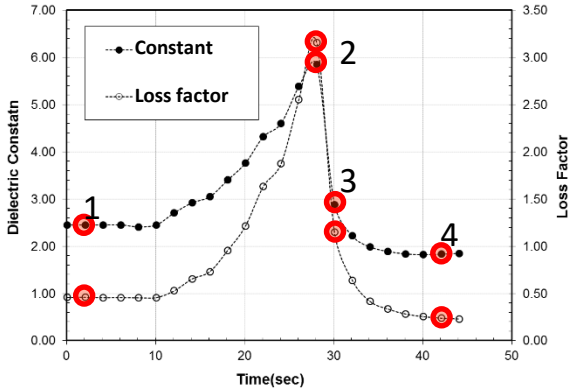
Thermal Image (*left*) and Simulated Power Density (*middle*) of 10mm thick food load (ε^*=57-j25) placed on top of antennae array (*right*) after 60 secs microwave heating

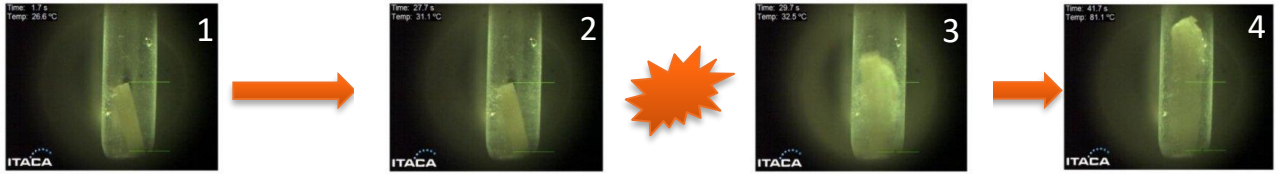
DoF 855k, time step =71 nm, run time 30 hrs on 450 MHz Pentium II processor

Validation of numerical codes for the simulation of microwave heating and associated gas discharge phenomena, Proceedings of The IEE Validation of Computational Electromagnetics Seminar, BAE Systems, Farnborough, 29 March 2004, pp. 27-30.

Dielectric measurements during “soft matter” state of starch pellets essential for optimising pellet expansion

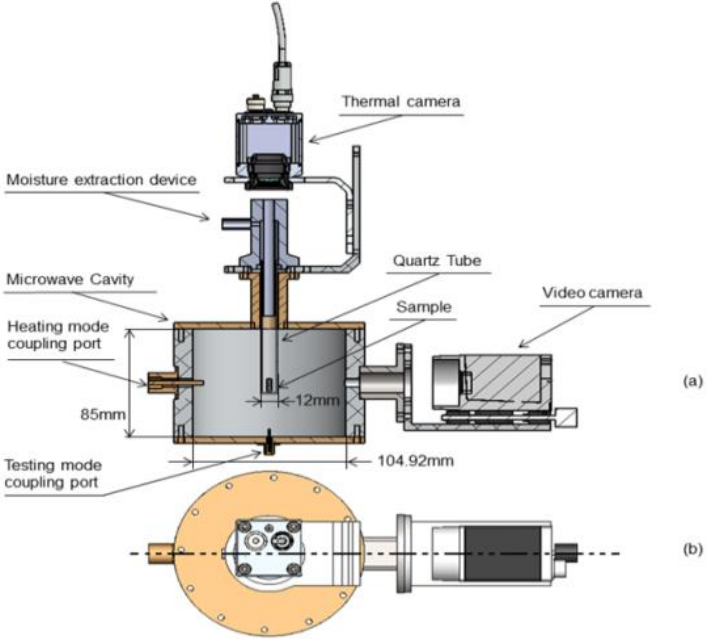
- Correlate pellet formulation to microwave expansion behaviour
- Design pellets (starch, protein, minors, geometry …) to control expansion
- Ingredient functionality can improve expansion performance



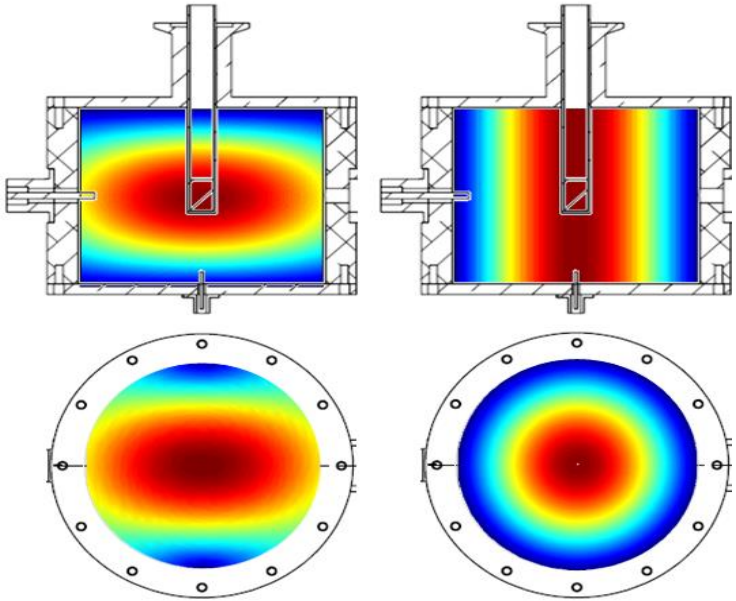


Gutierrez, J.D., Catala-Civera, J.M., Bows, J. & Penaranda-Foix, F.L. (2017). *Dynamic measurement of dielectric properties of food snack pellets during microwave expansion*. Journal of Food Engineering, 202, 1-8.

Real-time dielectric measurements during microwave expansion



Schematic view of the cylindrical microwave cavity (a) Front view (b) top view



Analytical E-field magnitude in the dual-mode cylindrical microwave cavity. TE111 mode (left) and TM010 mode (right).

Can we model length (μ – cm) and time (ns – sec) scales …

8%

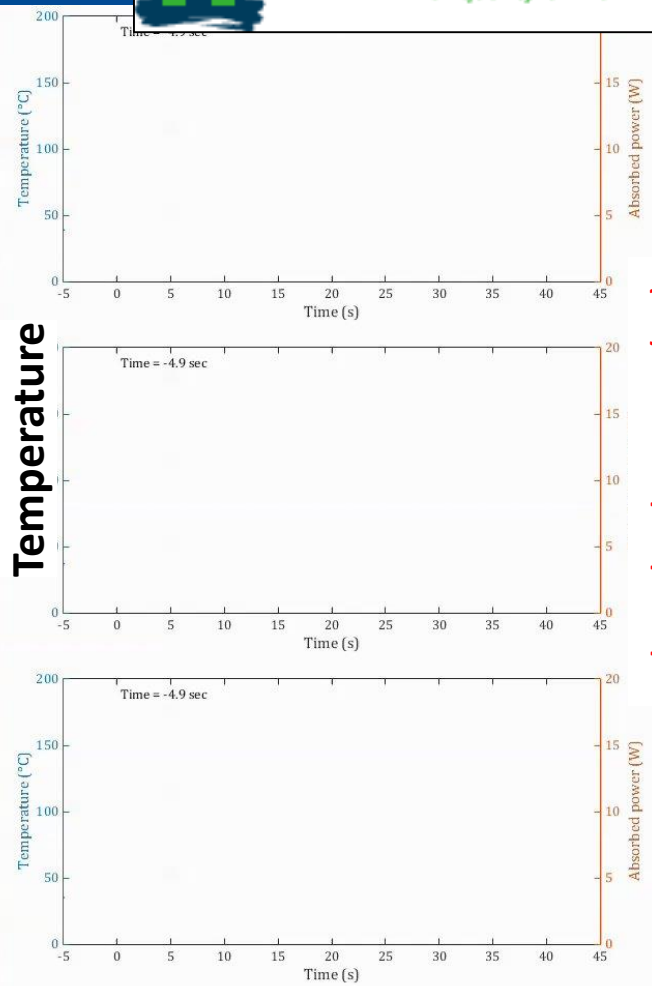
Predictive Design

- Continuous, discrete, filler phases
- Starch / protein functionality
- Minors (salt, emulsifiers)
- Moisture content
- Water binding (chem, ε*)
- Melt phase transition

11%

15%

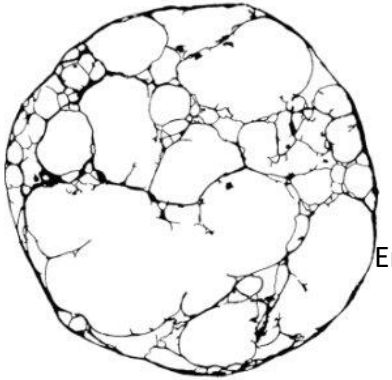
moisture content



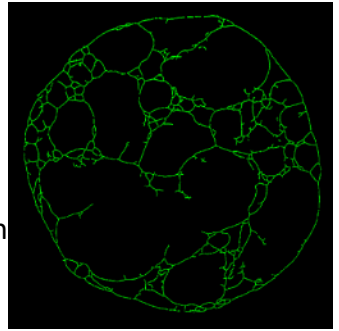
Esveld, E. at al (2017). *In-situ single mode dielectric measurements of microwaveable snack pellets.* Proc. 16th International Conference on Microwave and High Frequency Heating, Delft, The Netherlands, September 18-21, 2017

X-Ray tomography during expansion reveals how attributes of texture develop

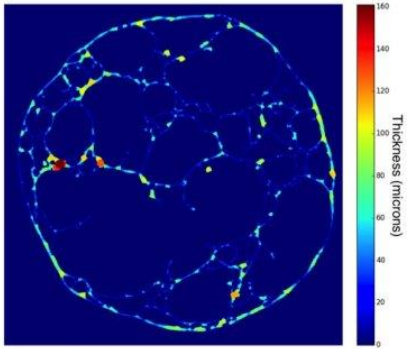
3 µm slice through pellet



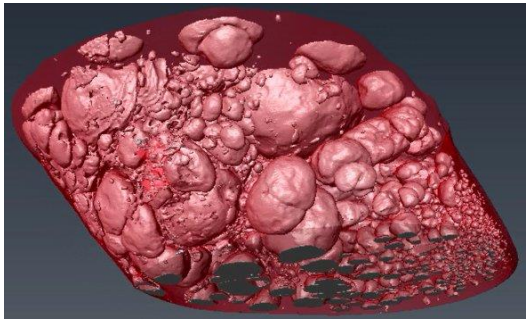
Erosion



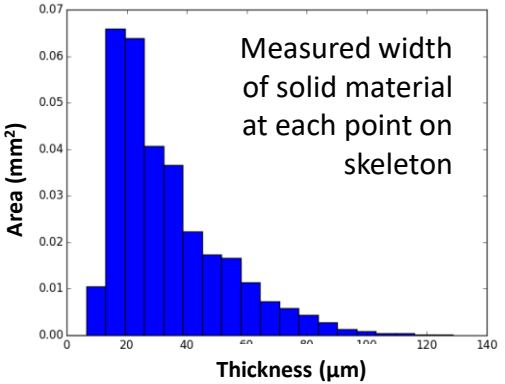
1-pixel skeleton



50 slices



3D movie reconstruction from 500 slices (1.5 mm vertical segment)



Pacold, J.I. et al. (2016). *Tomographic imaging of expanding pore structures in starch materials*. Advanced Light Source 2016 User Meeting 3-5 Oct, Berkeley Lab, US.

Advantaged processing to deliver nutritional benefit

Quadram Institute
Science Health Food Innovation

- Clinical trials showed equivalent bio-availability of bioactives in vegetable mix processed within a baked potato snack vs the fresh veg mix
- Need full understanding of how phytochemicals interact with snack base during processing, oral breakdown and transit through gut wall

75g Baked snacks = 460g fresh veg mix

Comparative bio-accessibility, bioavailability and bioequivalence of quercetin, apigenin, glucoraphanin and carotenoids from freeze-dried vegetables incorporated into a baked snack versus minimally processed vegetables: Evidence from in vitro models and a human bioavailability study. Journal of Functional Foods, 48, 410-419, 2018.

Selected food manufacturing challenges

- Measure product microstructure evolution during it’s creation
- Measure temperature in hostile (EM) closed environments
- Advantaged / hybrid processing
- Nutrient-retentive processing
- “Coffee Time” / App-based computer modelling & simulation
- Predictive product design
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