Gary Tucker, Campden BRI

Work Experience / History

- Chemistry teacher from 1985 to 1989
- Campden BRI from 1989 to present
- Thermal processing of foods, both in-pack and continuous
- Preservation methods for foods
- Baking processes
- Process validation and calculation methods
- Food rheology

Education

- Chemical Engineering graduate
- Masters in food rheology
- PhD in biochemical time-temperature integrators

Hobbies

- Wood turning, various woodworking projects
- Gardening, fruit tree grafting
- Sports – squash playing, watching most others
- Walking

100 years of thermal processing research

Gary Tucker

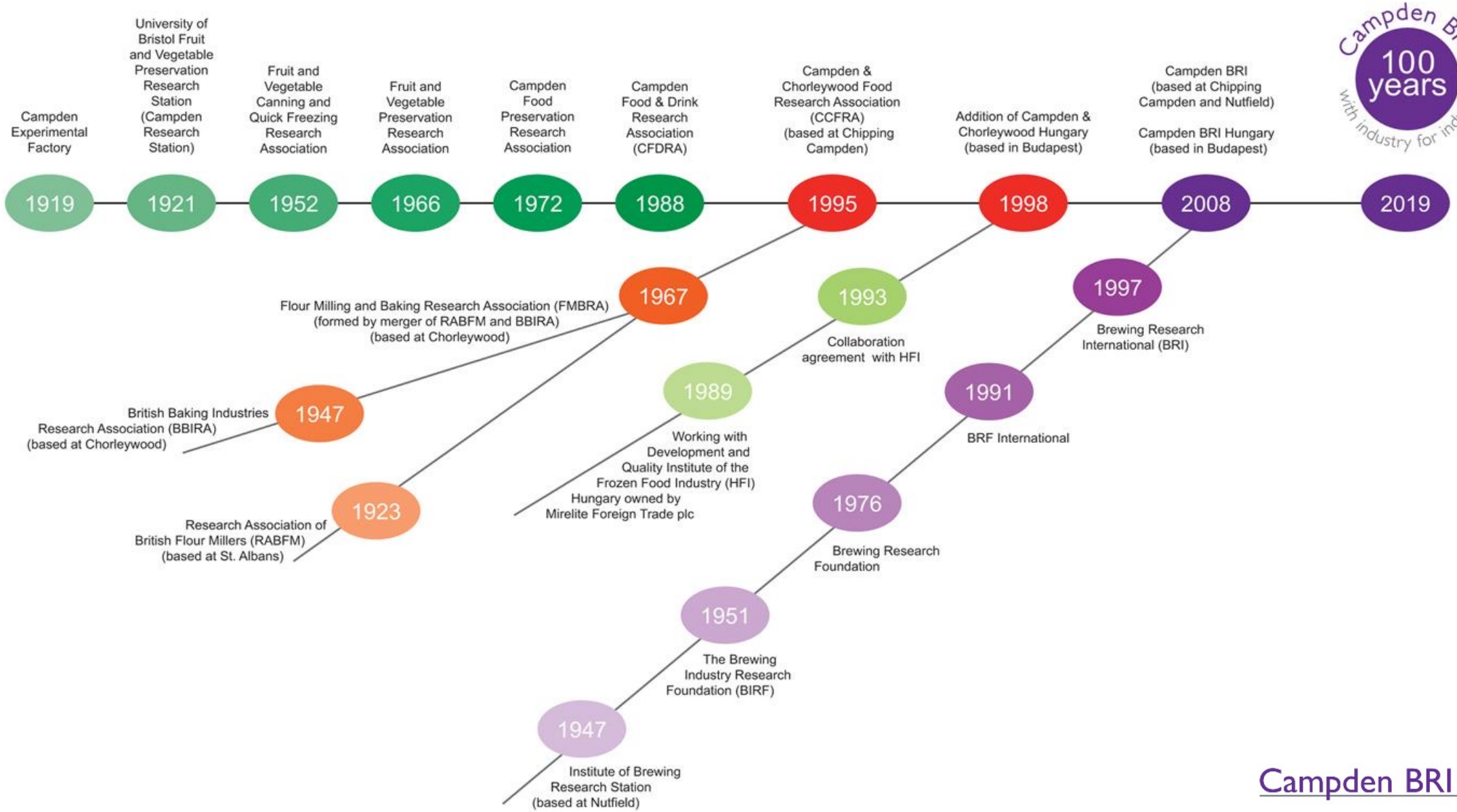
IFTPS, New Orleans, 2023

Campden BRI
food and drink innovation

1. Brief Campden BRI update
2. Origins of the botulinum cook
3. Other relevant botulinum work
4. Selected achievements at Campden BRI

Campden BRI

1. Brief Campden BRI update -



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- During the WW1 the UK government funded methods to preserve foods for transport to the troops in Europe
- Vale of Evesham was a major area for fruit and vegetable production - a pheasant feed mill by Chipping Campden railway station was selected as a base for the University of Bristol to investigate options
- Campden Experimental Factory opened in 1919

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- Canning was the preservation method - most of the pioneering scientific studies in the UK canned food industry were performed here
- Work began into frozen food production, and in the 1960s expanded rapidly into all areas of food and drink preservation

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What are Campden BRI known for publicly?

- Campden tablets (1920s) - Fruit and Vegetable Preserving Research Station
- Chorleywood Bread Process (1961) – British Baking Industries Research Association

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Interesting differences in US and UK thermal processing

°F in US v °C in UK

C. bot. pH growth below 4.6 in US v 4.5 in UK

US billion is 10^9.
In the UK it was 10^{12}.
Since 1974 the UK Government adopted the US billion.

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2. Origins of the '*Botulinum Cook*'

What we know:

- F_0 3
- 3 minutes at 121.1°C (250°F)
- 12 log kill of *C. bot.* spores
- Food safety process – it has worked for 100 years
- But…..
  - Thermophiles need higher levels, F_0 20+
  - The container must protect the product
  - Pre-process spoilage must be avoided

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Esty, J.R. and Meyer, K.F. (1922). The heat resistance of the spores of B. botulinus and allied anaerobes. The Journal of Infectious Diseases, 31 (6), 650-664.

The original set of data on *Clostridium botulinum* spores

THE HEAT RESISTANCE OF THE SPORES OF B. BOTULINUS AND ALLIED ANAEROBES. XI

J. R. Esty and K. F. Meyer

From the George Williams Hooper Foundation for Medical Research, University of California Medical School, San Francisco, and the Research Laboratory of the National Canners Association, Washington, D. C.

As a part of a broad study dealing with the bacteriology and biochemistry of B. botulinus, the heat resistance of the spores of this and allied anaerobes has been investigated. A brief analysis of the accumulated data made on 1804 spore suspensions and 65 soil specimens naturally or artificially contaminated with the spores of B. botulinus, has revealed a number of important scientific and practical facts. As the detailed preparation and publication of the numerous experiments embracing over 42,807 cultures may be delayed for several months, it is deemed advisable to report the main tentative conclusions. The technic used in these studies is in principle identical with that employed by Bigelow and Esty [1] in their work on the heat resistance of thermophilic bacteria. In the course of the investigation minor modifications in the preparation of the cultures and the subcultures of the heated spore suspensions have been adopted in order to eliminate the danger of laboratory contaminations. Extensive experience has definitely proved the broad applicability and absolute reliability of this standard method.

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Summary of their botulinum experiments

- 109 strains of *B. botulinus*
- 78 type A, 30 type B, 1 non-toxic strain
- From soils, vegetables, botulism outbreaks
- Spores concentrated by centrifugation and sedimentation
- Phosphate buffer pH 7.0-7.12
- 2cc and 1cc amounts into sealed, glass tubes and vials
- Heated in an electric oil bath
- Type A more heat resistant than B

Log reduction concept: botulinum spores

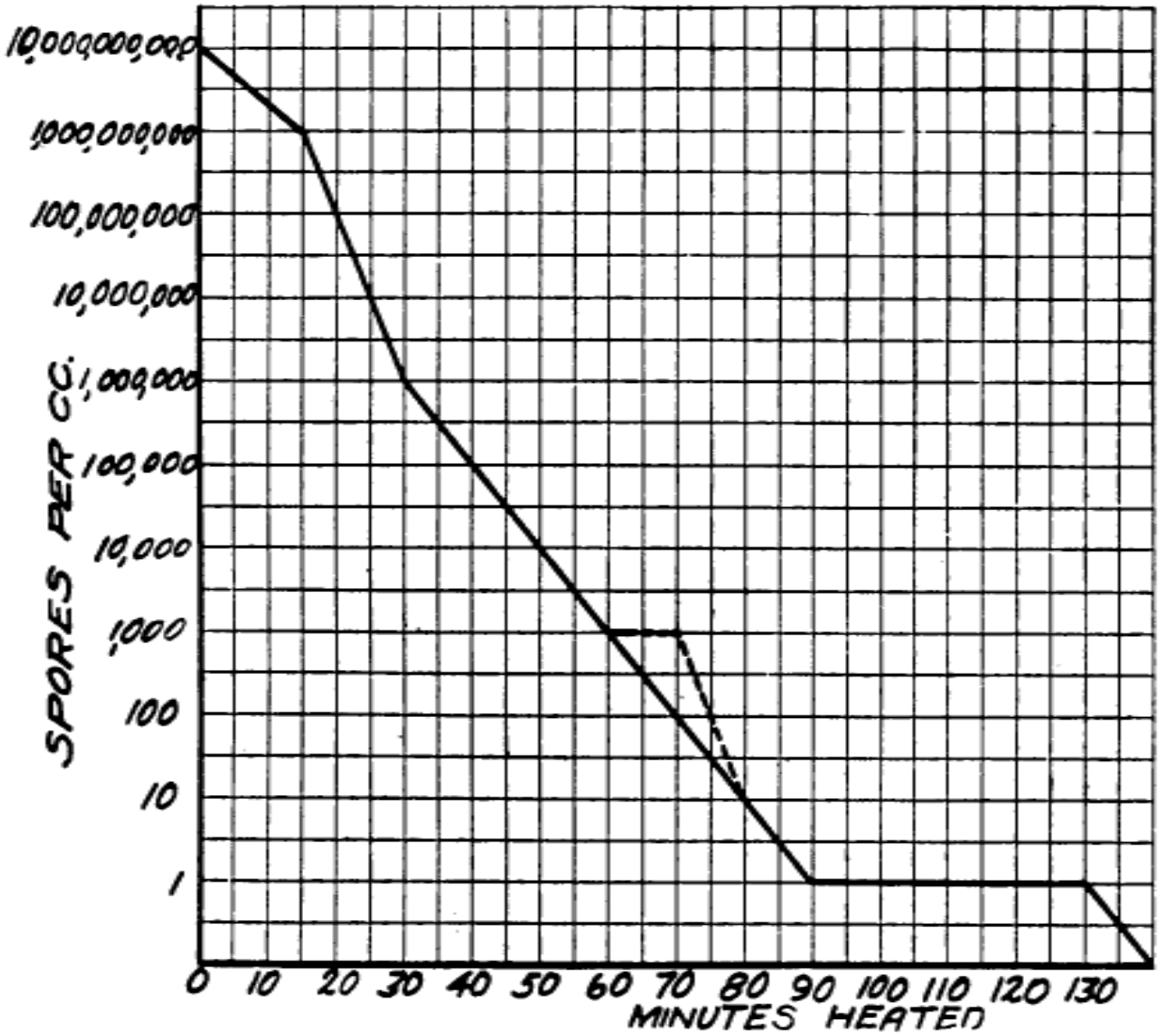

Chart 3.—Death rate of B. botulinus spores in phosphate M/15 KH_2PO_4 and NA_2HPO_4 at 100 C.

Reduction in numbers of *B. botulinus* spores follows a log-linear decay

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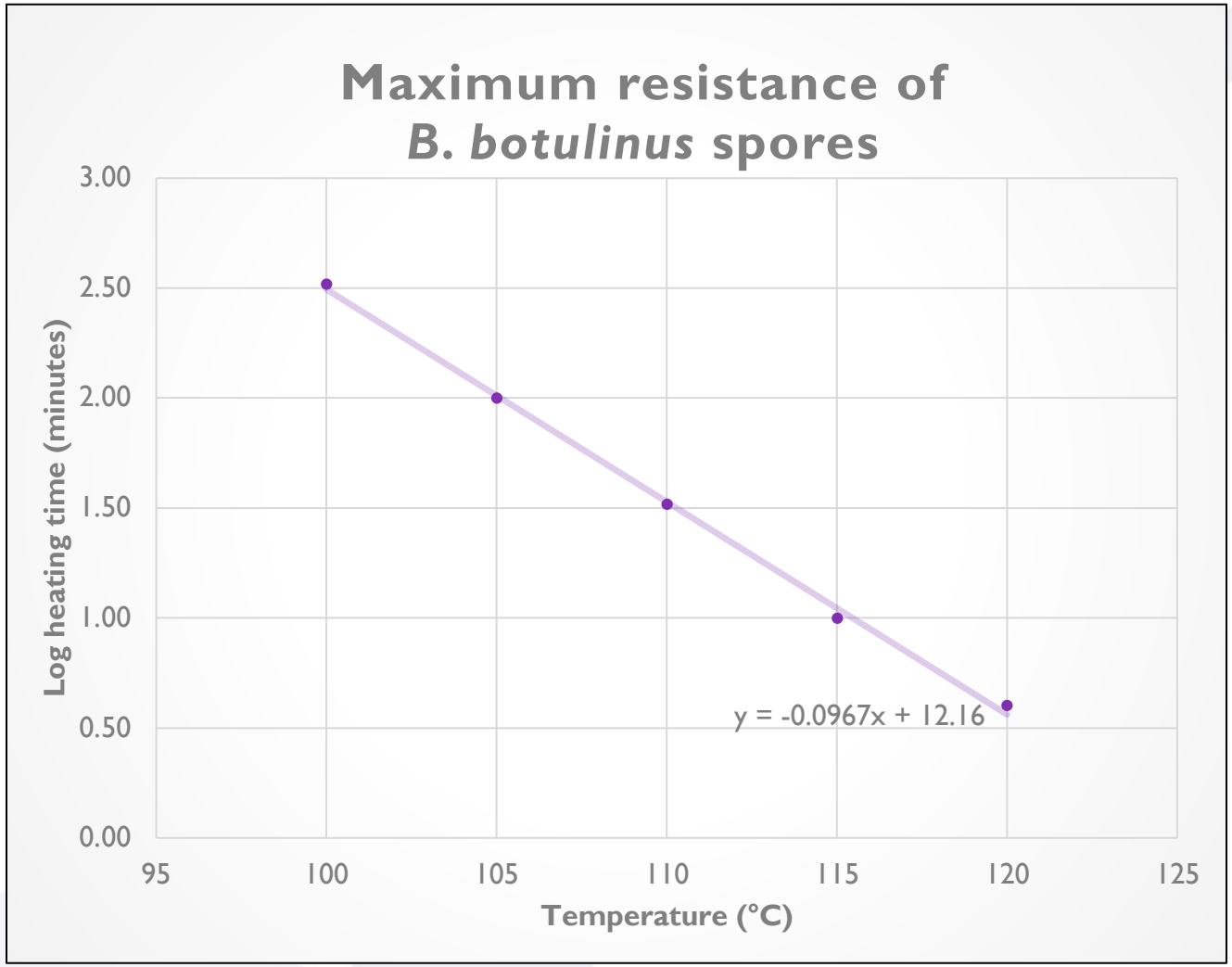
Maximum Resistance Time

Maximum resistance:

- 4 mins at 248°F (120°C)
- 10 mins at 239°F (115°C)
- 33 mins at 230°F (110°C)
- 100 mins at 221°F (105°C)
- 330 mins at 212°F (100°C)

2.82 minutes at 250°F (121.1°C) is the time required to eradicate all spores



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Why are ‘log reductions’ so important?

- We talk about 12-log reductions but why?
- The maximum practically achievable log reduction will eliminate every viable spore
- So how many spores per g could there be in a food?
- How big are *C bot* spores?
- How many *C bot* spores can squash into a small space such as 1cc?

This is interesting because it is effectively what was done around 100 years ago by Esty and Meyer in 1922

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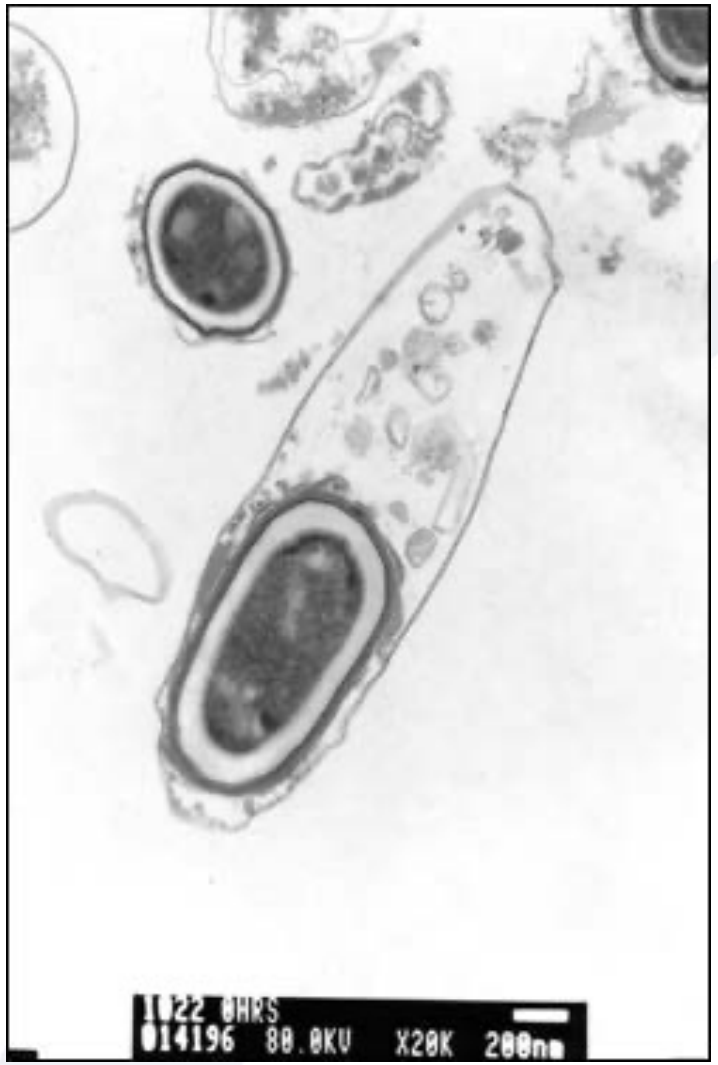
C bot spore diameter?

- Micrographs of *C bot* spores (with scales) and estimated various sizes from 600nm to over 1,000nm
- A colleague found other information sources and estimated spore diameter towards the lower end
- For the purposes of these calculations, I took 750nm as my spore diameter or **7.5×10^{-7}m** in SI units



From trigger to toxin – Clostridium botulinum exposed. Life Sciences and Chemistry (2005). Sandra Stringer

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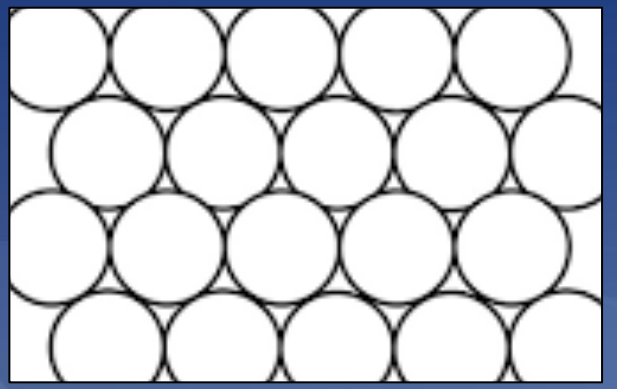
How many spores will fit into a 1cc glass vial?

- Volume of a 7.5×10^{-7} m diameter *C bot* spore is **2.21×10^{-19} m^3**
- If they are tight-packed into a 1mL sphere, like the glass vials used by Esty and Meyer, it is possible to theoretically fit in **4.53×10^{12}** spores
- More likely they pack randomly, which means a max packing density of 64%, which takes the number down to **2.9×10^{12}**



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How many spores will fit into a 1cc glass vial?

- The maximum number of *C bot* spores that can be squeezed into a 1mL glass vial is **2.9×10^{12} (±?)**
- Assumes there is only spores and water in the vial:
  - The spores are more oval than spherical, taking up more room
  - There will be numerous *C bot* cells as well
  - Substrate will be left
- Esty and Meyer got a maximum of **1.92×10^{10}** per 1mL - impressive

What does this mean for F_0?

- The widely accepted decimal reduction time for *C bot* spores is 0.21 minutes at 121.1°C (250°F)
- F_0 3 process, or minimum botulinum process, achieves sufficient log reductions to kill all the *C bot* spores
- **It is not possible to squash *C bot* spores into a food product and still get survivors after F_0 3**

Number of viable spores	Number of viable spores	Decimal reductions	F_0 value (min)
2.9×10^{12}	2,900,000,000,000	0	0
2.9×10^{11}	290,000,000,000	1	0.21
2.9×10^{10}	29,000,000,000	2	0.42
2.9×10^{9}	2,900,000,000	3	0.63
2.9×10^{8}	290,000,000	4	0.84
2.9×10^{7}	29,000,000	5	1.05
2.9×10^{6}	2,900,000	6	1.26
2.9×10^{5}	290,000	7	1.47
2.9×10^{4}	29,000	8	1.68
2.9×10^{3}	2,900	9	1.89
2.9×10^{2}	290	10	2.10
2.9×10^{1}	29	11	2.31
2.9×10^{0}	2.9	12	2.52
2.9×10^{-1}	0.29	13	2.73

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Spore concentration resistance

‘It is a common experience to encounter cultures with less than one million spores, although their resistance surpasses that of others containing several billion organisms per cc’

Esty, J.R. and Meyer, K.F. (1922)

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3. Other relevant botulinum work

Appert

Circumstantial evidence indicates that Appert's (1810) water-bath processes of 180 or 210 minutes at 100°C, in use from 1900 to 1930, were able to control *C. botulinum* spores.

Consequently, a thermal-process F_0 of the order of 1.0 minute must be able to control *C. botulinum* spores on products with natural contamination.

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Stumbo

- Raw food products, especially vegetables, contain a resistant mesophilic, non-pathogenic microbial population with $D_{121.1}$-value of 1.0 to 1.5 minutes, more than five times as resistant as *C. botulinum* spores
- When there is a process failure (the delivered F_0 is less than the target F_0), resistant non-pathogenic, mesophilic spore-forming microorganisms are likely to spoil the food
- The numbers of spores of mesophilic bacteria more resistant than those of *C. botulinum* seldom is greater than one spore per gram of food

Stumbo, C. R., Purohit, K. S., and Ramakrishnan, T. V. (1975) Thermal process lethality guide for low-acid foods in metal containers. J. Food Science

Pflug

- Survival is measured in probabilities
- The ability of any bacterial-spore species to survive a heat process is not constant but variable; determined by the species, how the spores were grown, testing method, and the post-heating environment
- In preserving LACFs, we have three microbial groups, heat resistance-wise:
  (a) *C. botulinum* ($D_{121.1}$-value about 0.21 min)
  (b) Resistant, mesophilic, spore-forming organisms ($D_{121.1}$-value about 1 min)
  (c) Thermophilic, spore-forming organisms ($D_{121.1}$-value about 3 to 6 min)

Irwin Pflug (2010). Science, Practice and Human Errors in Controlling *Clostridium botulinum*. Heat-Preserved Food in Hermetic Containers. J. Food Prot. 73(5), 993-1002.

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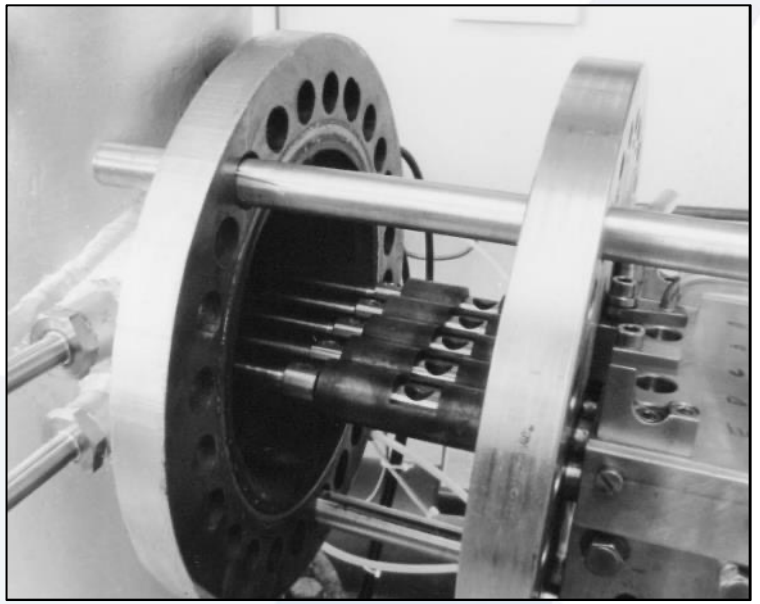
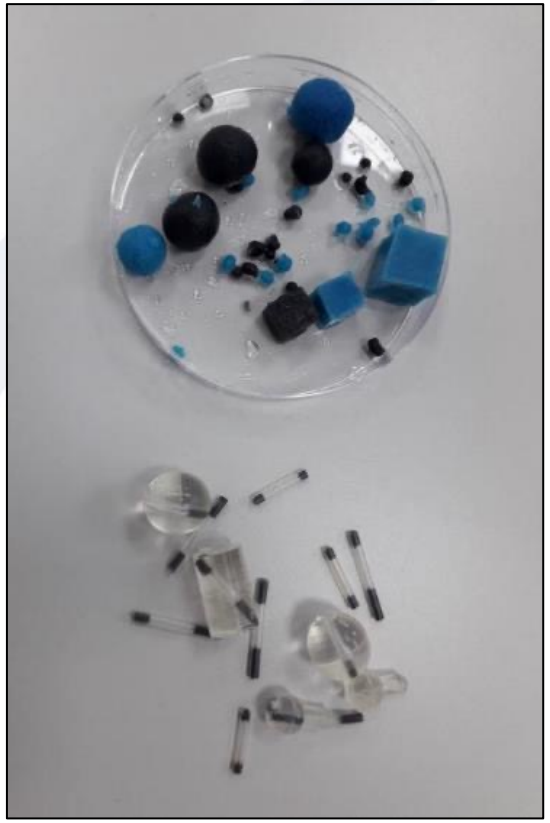
4. Selected thermal processing achievements at Campden BRI

- Thermoresistometer
- Amylase time-temperature integrators
- E-learning





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Thermoresistometer

- 3 x Thermoresistometers built
- Similar designs to resistometers from Stumbo and Pflug
- MK1 used for initial data
- MK2 for Valencia Food Research Institute
- MK3 improved on MK1 design
- Heat resistance of *Clostridium botulinum* spores, strain 213B, heated in phosphate buffer (pH 7.0) measured over 120 to 140°C

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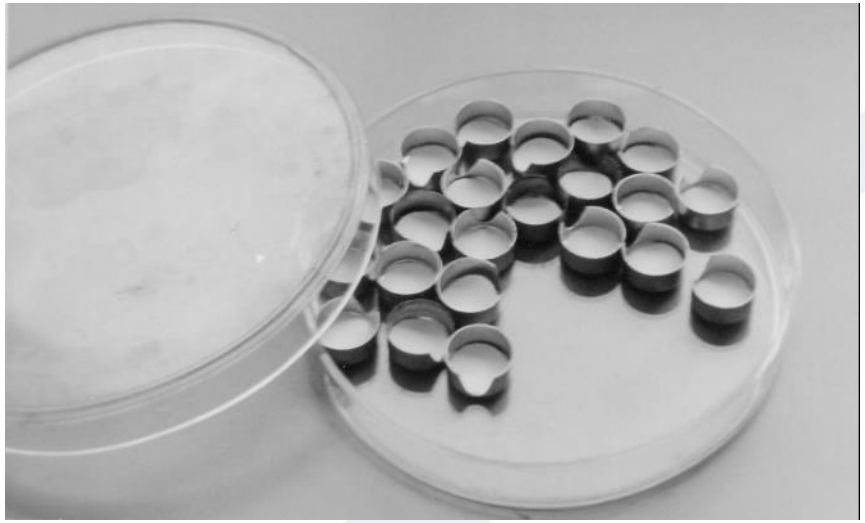
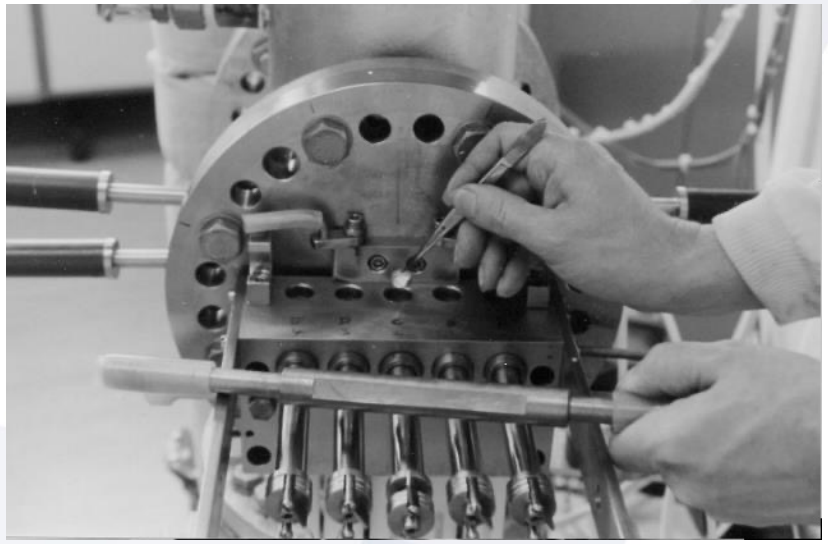
MK3 Thermoresistometer





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D and z-value graphs for *C. botulinum* 213B

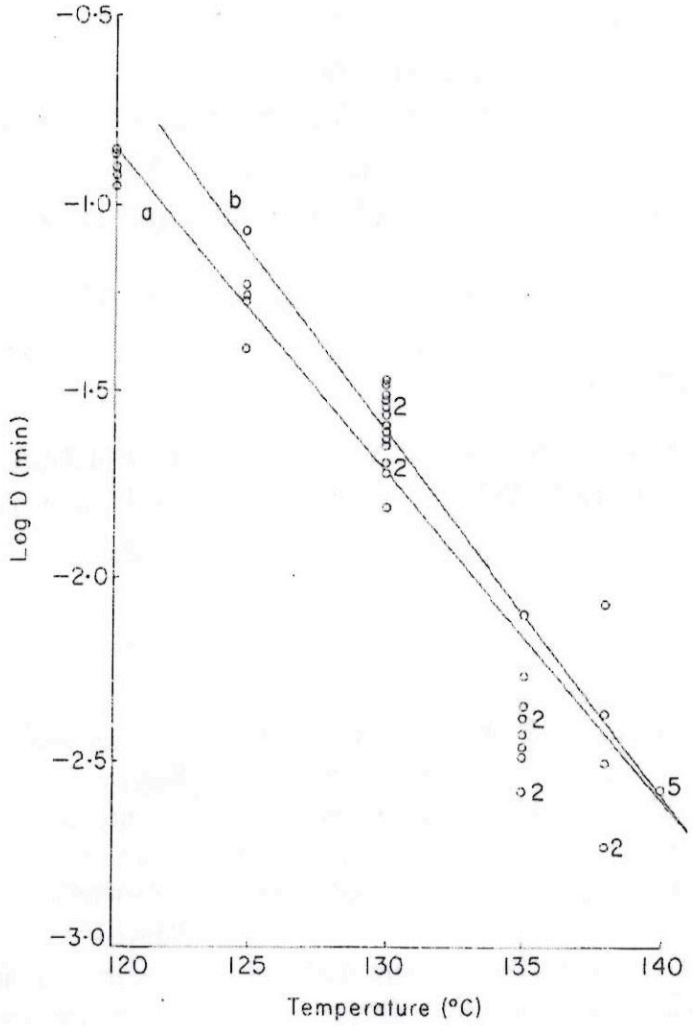

Figure 2. Thermal death time curve for spores of *C. botulinum* (213B) heated in M/15 phosphate buffer, pH 7.0. Line a refers to the result of linear regression analysis of the *C. botulinum* 213B data, and line b to the classical Esty and Meyer studies.

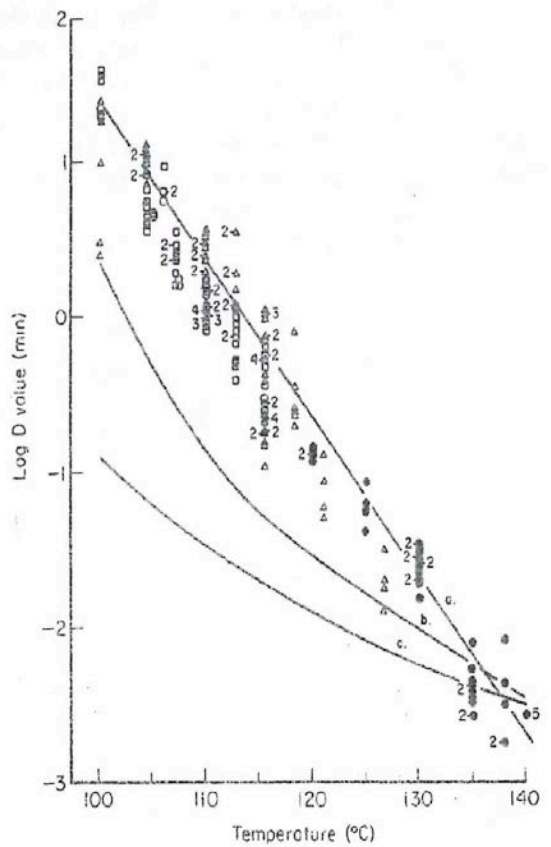

Figure 3. Comparative heat resistance data for *C. botulinum* over the temperature range 100 to 140°C; Pflug & Odlaug review (1978) 213B buffer (○), 213B product (□), other strains (△); this report (●). The lines indicate: (a) classical Esty & Meyer (1922) line, (b) Neaves & Jarvis (1978) capillary tube data, and (c) Neaves & Jarvis (1978) MISTRESS data.

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C. bot. data at 140°C measured and F_0 3 confirmed

- D_{121}-value of approximately 0.13 min and z value of 11.0°C (obtained by linear regression)
- Values were close to the classical D_{121} of 0.2 min and z value of 10°C used in process calculations
- The z value of *C. botulinum* can be considered constant over 120 to 140°C
- Provided support for the classical process calculations, using a z value of 10°C extrapolated to 140°C

Gaze, J.E. and Brown, K.L. (1988). The heat resistance of spores of *Clostridium botulinum* 213B over the temperature range 120 to 140°C. International Journal of Food Science & Technology 23.4: 373-378.

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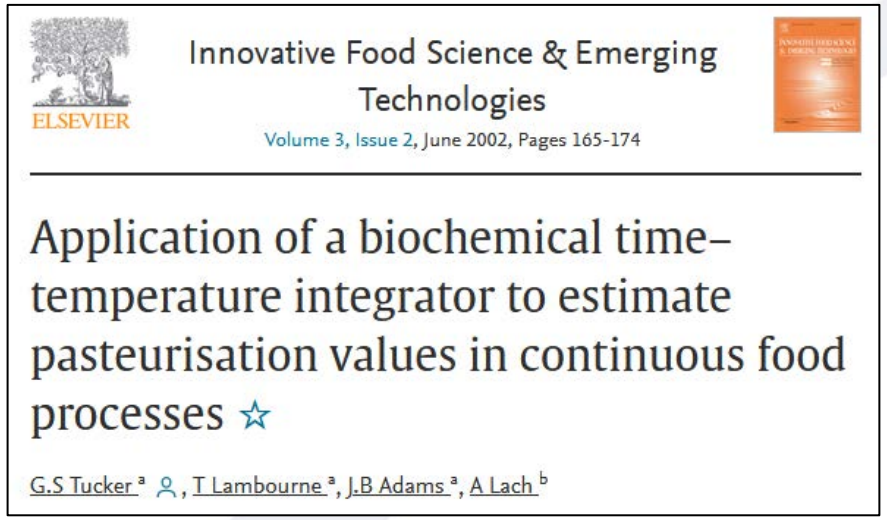
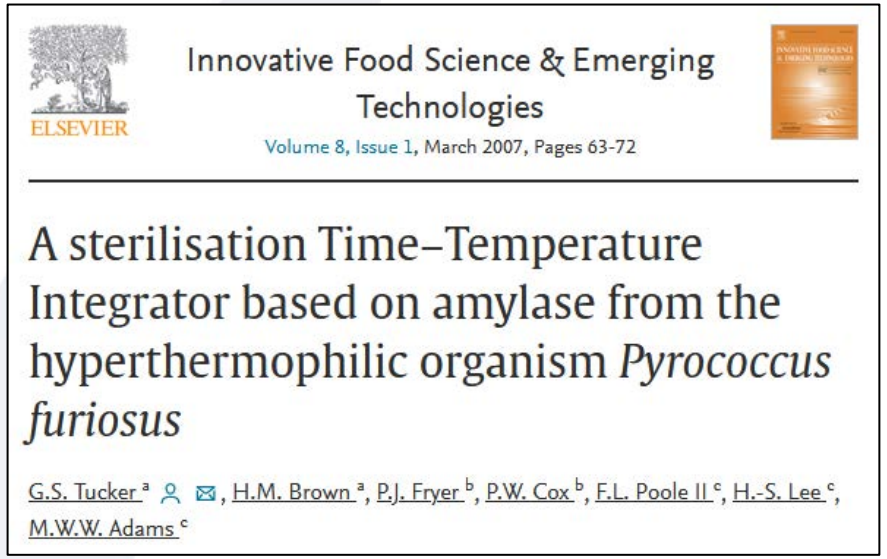
Amylase time-temperature integrators

- Time and temperature integrator (TTI)
- Amylase structure denatures on heating
- Commercial amylase preparations used
- Purity of samples varies - caution
- 10-20 ml sample size
- 2-log reduction in amylase can be measured
- Sterilisation - *Pyrococcus furiosus* amylase has exceptional heat stability


Innovative Food Science & Emerging Technologies
Volume 3, Issue 2, June 2002, Pages 165-174

Application of a biochemical time–temperature integrator to estimate pasteurisation values in continuous food processes ☆

G.S Tucker [a], T Lambourne [a], J.B Adams [a], A Lach [b]


Innovative Food Science & Emerging Technologies
Volume 8, Issue 1, March 2007, Pages 63-72

A sterilisation Time–Temperature Integrator based on amylase from the hyperthermophilic organism *Pyrococcus furiosus*

G.S. Tucker [a], H.M. Brown [a], P.J. Fryer [b], P.W. Cox [b], F.L. Poole II [c], H.-S. Lee [c], M.W.W. Adams [c]

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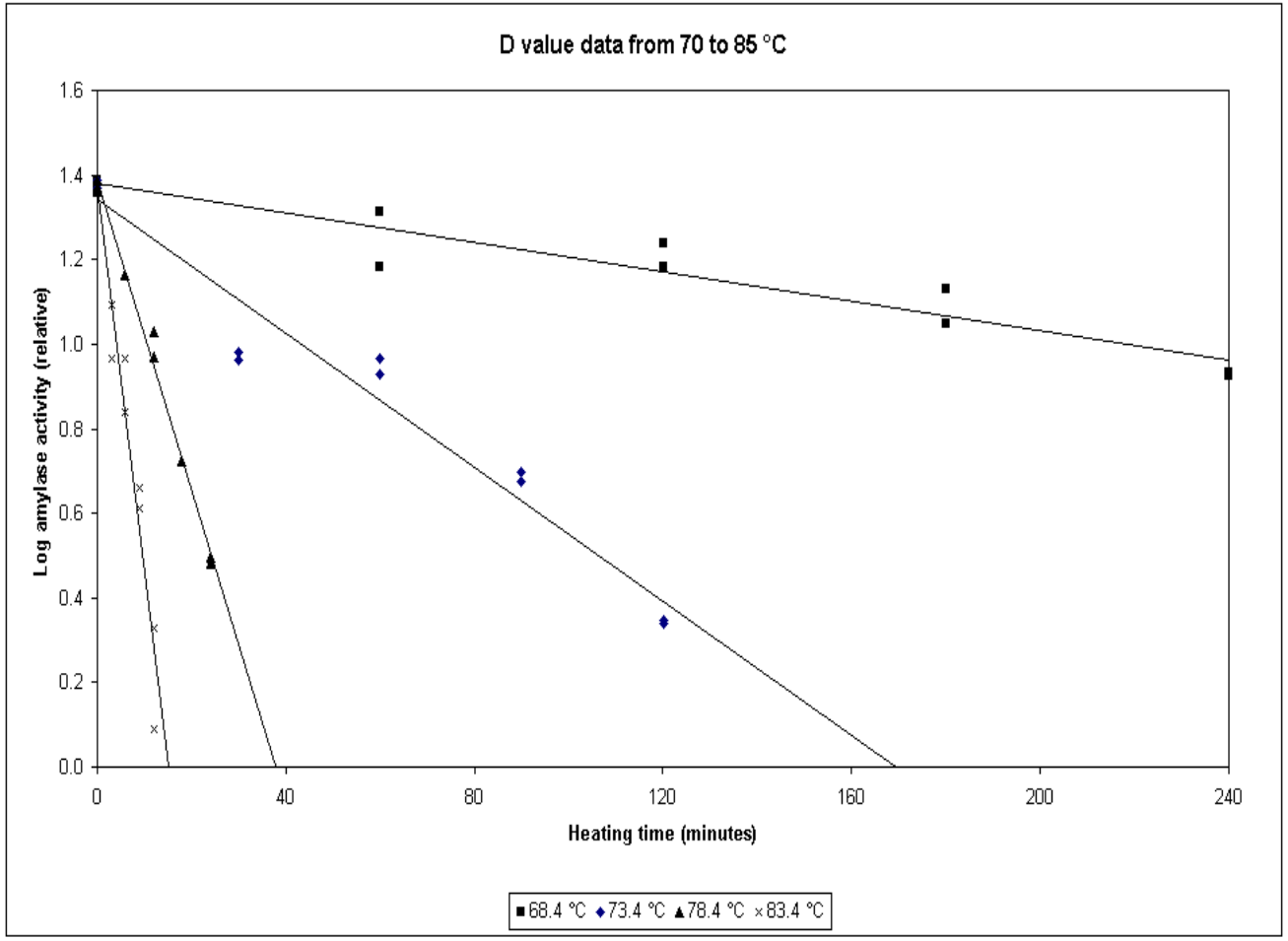
Amylase thermal stability



- *B. Amyloliquefaciens amylase:* 16 minutes at 85°C (z-value 8.6°C, D_{85} 8.1 minutes)
- *B. Licheniformis amylase:* 17 minutes at 93°C (z-value 9.1°C, D_{93} 8.8 minutes)
- Changing the buffer pH and Ca^{2+} concentration enables amylase thermal stability to be tailored

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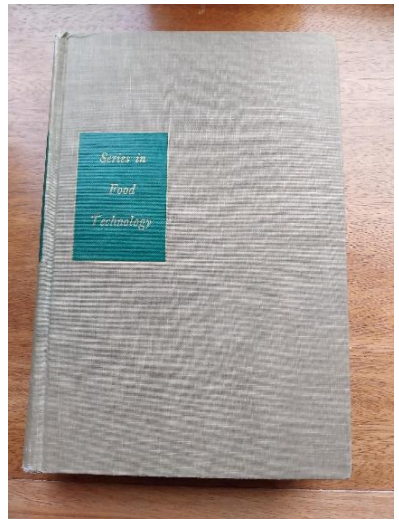
Applications to particulates



Geometry	Heating factor term ($\alpha.f_h=$)
Sphere (1D)	$0.233a^2$
Cylinder (2D)	$0.398 / (1/a^2 + 0.427/b^2)$
Brick (3D)	$0.933 / (1/a^2 + 1/b^2 + 1/c^2)$

α *(silicone)* $1.02 \times 10^{-7}\ m^2s^{-1}$

α *(foods)* $1.4 \times 10^{-7}\ m^2s^{-1}$

10 mm silicone cube (f_h 76 s) $\Rightarrow$ 11.7 mm food cubes

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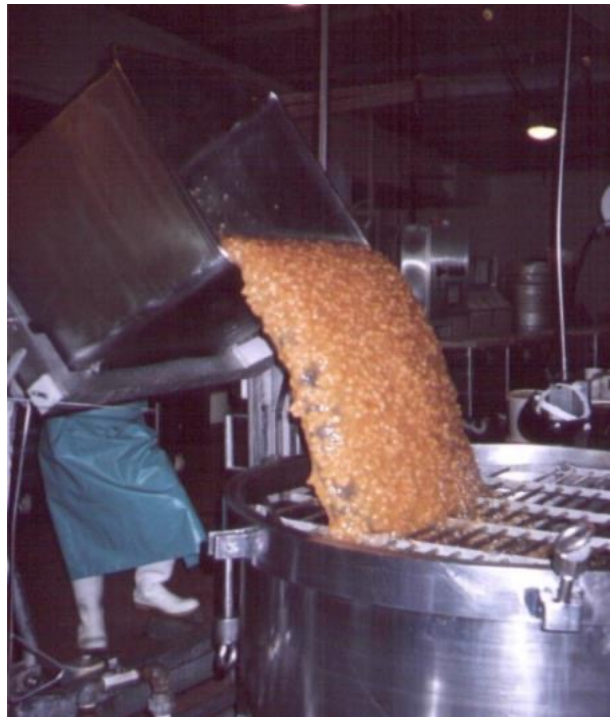
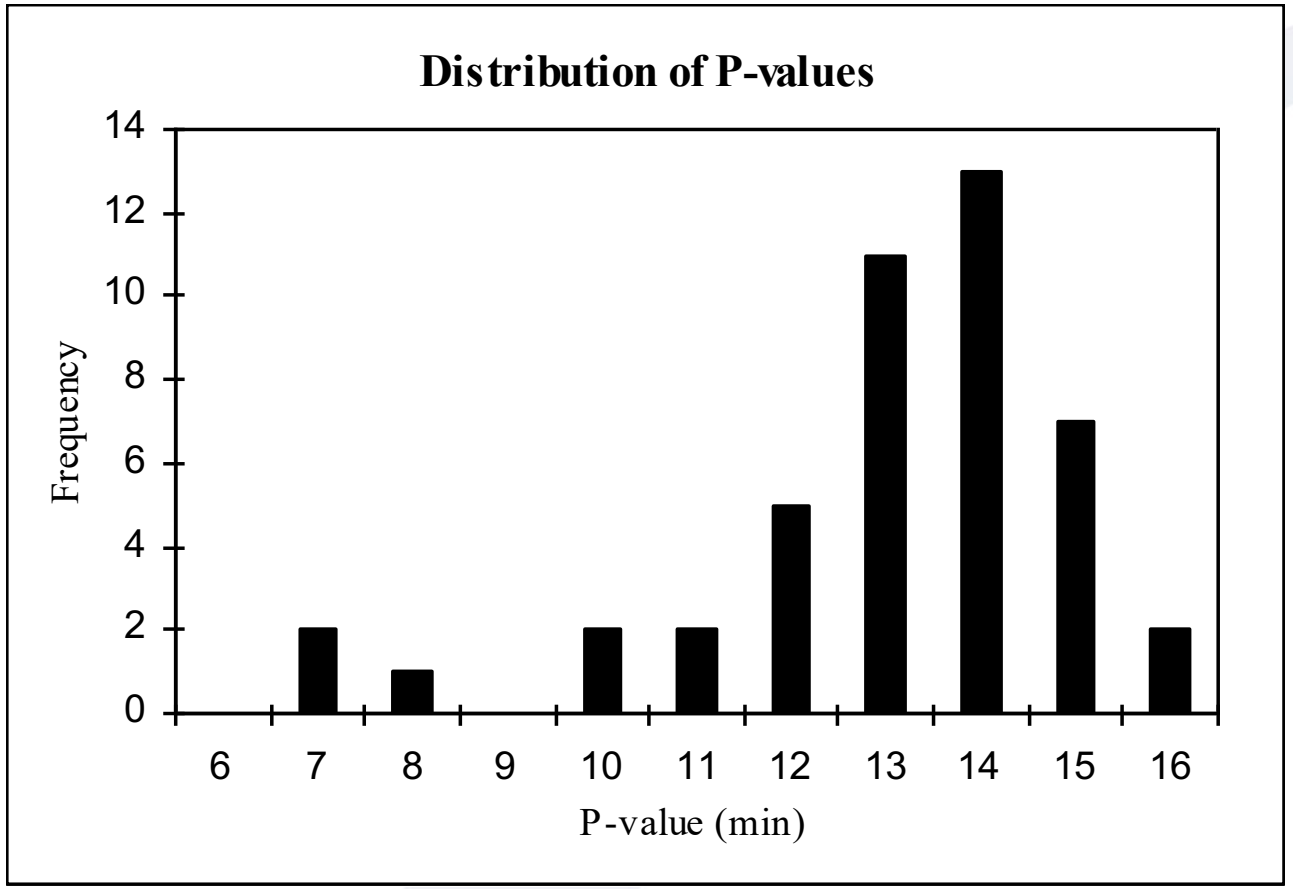
P value distribution data





Target process: 5 minutes at 85°C (z 8.3°C)

B. amyloliquefaciens amylase: D_{85} 8.1 minutes, z-value 8.6°C

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E-learning course on thermal processing

https://www.campdenbri.co.uk/training/onDemand/thermal-processing-foundation.php

- New concept for Campden BRI
- Builds on existing training courses
- Different way of structuring the learning experience
- Modular – 'ladder of learning'
- Interactive

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Demonstration

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CAMPDEN
LEARNING

PROCESS ESTABLISHMENT

X

THERMAL PROCESS SCHEDULE

INTRO TO TP.

1 - Target process times and temperatures.

INTRO TO MICROBIOLOGY

MICROHEAT RESISTANCE

2 - Temperature (heat) distribution.

CF PROCESSING EQUIPMENT

IN-PACK PROCESSING EQUIPMENT

3 - Heat penetration.

4 - Process Values.

PROCESS VALUES

5 - Safety margins.

ESTABLISHMENT

6 - Scheduled process.

DEVIATIONS

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Summary

- 12-log reductions has served the industry for 100 years
- The past 50 years have seen immense innovation in the process, product, and package
- We are entering the ‘electric’ era – what does this mean for thermal processing?
- There is still a lot to know and develop

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