TEKNOLOGI PENGOLAHAN PANGAN
SEMESTER GENAP 2010 / 2011

PRO & BIN

Pertemuan	Tanggal	Materi	Dosen
1	7 | 11 .03	Introduction	PRO
2	14 | 18 .03	Blanching | Pasteurisation | Sterilisation	PRO
3	21 | 25 .03	Freezing & Chilling	PRO
4	28 .03 | 01 .04	Drying (1)	PRO
5	04 | 08 .04	Drying (2)	PRO
6	11 | 15 .04	Frying	PRO
7	18 | 22 .04*	Microwave	PRO
	28.04 – 06.05	UTS	PRO
8	9 | 13 .05	Distilasi	BIN
9	16 | 20 .05	Evaporasi	BIN
10	23 | 27 .05	Ekstraksi	BIN
11	30 .05 | 03 .06	Ekstrusi	BIN
12	06 | 10 .06	Kristalisasi	BIN
13	13 | 17 .06	Baking	BIN
14	20 | 24 .06	Presentasi Tugas	PRO + BIN
	27.06 – 08.07	UAS	BIN

Catatan : * 22.04 Libur Paskah (kuliah pengganti Senin 25.04?)

Pustaka

- Utama

  Fellows, PJ., 2000. *Food Processing Technology; Principles and Practice*. Woodhead Publ. Cambridge, England

- Pendukung

  Semua pustaka (buku, artikel) terkait teknologi pengolahan pangan

Generic Contents

- Introduction
- Theory/Principle of The Process
- Unit operation (for few extent, when necessary; otherwise this will be discussed further in the course Unit Operation)
- Equipment/Machineries, also in a brief
- Effects on Foods

Introduction

Reminding Few Basic Principles

- **Heat Transfer**
- **D and z value**

Ch. 1 of Fellows

Aims of food industry

- Extending period of wholesomeness (shelf life).
- Increasing variety in the diet (*eating quality*, *sensory quality*)
- Changing the form of food to allow further processing.
- Providing required nutrients for health (*nutritional quality*).
- Generating income for the manufacturing company.

- All food processing involves a combination of procedures.

  → *unit operations*
- specific, identifiable & predictable effect on a food.

- Movies; how is made: peanut butter (04:44), chewing gum (04:55)

Objectives of the course

- To understand the wide range of processing techniques that are used in food processing, including:
  - Basic principle of each processing unit
  - Processing design & control

- To analyse food processing technologies appropriate for specific properties of raw materials and the effect of processing on quality & safety of food products

Basic knowledge requirement:

- Basic knowledge on the properties of foods (incl. physico-chemistry and microbiology of food & raw materials)

Heat Transfer

- *Radiation*

  by electromagnetic waves, e.g. in an electric grill.

- *Conduction*

  by direct transfer of molecular energy within solids, e.g. through metal containers or solid foods.

- *Convection*

  by groups of molecules move as a result of differences in density (e.g. in heated air) or agitation (e.g. in stirred liquids).

- Majority all occur simultaneously but one type may be more important than others in particular applications.

Energy balances

- ‘the amount of heat or mechanical energy entering a process = the total energy leaving with the products & wastes + stored energy + energy lost to the surroundings’
- If heat losses are minimised, energy losses to the surroundings may be ignored
- For more accurate solutions, compensation should be made for heat losses.

Mechanisms of heat transfer

Steady-state **heat transfer**

- constant temperature difference between two materials.
- amount of heat entering = amount of heat leaving & no change in temperature of material.
- E.g. when heat is transferred through the wall of cold store if the store temperature & ambient temperature are constant, & in continuous processes once operating conditions have stabilised.
- Majority of food-processing, *unsteady-state* is more common

Steady-state conduction

- rate of heat transfer, influenced by

  → temperature difference between food & heating or cooling medium,

  → total resistance to heat transfer.

- Resistance to heat transfer

  → conductance of a material (*thermal conductivity*)

$$Q = \frac{kA(\theta_1 - \theta_2)}{x}$$

- Q (J s^{-1}) : rate of heat transfer,
- k ($Jm^{-1}s^{-1}K^{-1}$ or $Wm^{-1}K^{-1}$) : thermal conductivity,
- A (m^2) : surface area,
- $\theta_1 - \theta_2$ (^oC or K) : temperature difference
- x (m) : thickness of the material.
- $(\theta_1 - \theta_2)/x$ = temperature gradient.

- E.g. stainless steel conducts heat 10x less well than aluminium,

  the difference is small compared to the low thermal conductivity of foods (20 to 30x smaller than steel)

  and does not limit the rate of heat transfer.

- Stainless steel is much less reactive than other metals, particularly with acidic foods

  → used in most food-processing equipment that comes into contact with foods.

- Thermal conductivity of foods is influenced by
  - nature of the food
  - temperature & pressure of the surroundings.

- A reduction in moisture content causes a substantial reduction in thermal conductivity.

  → implications in unit operations involve conduction of heat through food to remove water (e.g. drying, frying & freeze drying).

Thermal conductivity of selected foods and other materials

Type of material	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	Temperature of measurement (°C)
Construction materials		
Aluminium	220	0
Copper	388	0
Stainless steel	21	20
Other metals	45–400	0
Brick	0.69	20
Concrete	0.87	20
Foods		
Olive oil[a]	0.17	20
Whole milk[a]	0.56	20
Freeze-dried foods	0.01–0.04	0
Frozen beef[b]	1.30	−10
Pork (lean)[b]	0.48	3.8
Frozen cod	1.66	−10
Apple juice	0.56	20
Orange	0.41	0–15
Green beans	0.80	−12.1
Cauliflower	0.80	−6.6
Egg	0.96	−8
Ice	2.25	0
Water[a]	0.57	0
Packaging materials		
Cardboard	0.07	20
Glass, soda	0.52	20
Polyethylene	0.55	20
Poly(vinyl chloride)	0.29	20
Insulating materials		
Polystyrene foam	0.036	0
Polyurethane foam	0.026	0
Other types	0.026–0.052	30

[a] Assuming convection currents are absent.

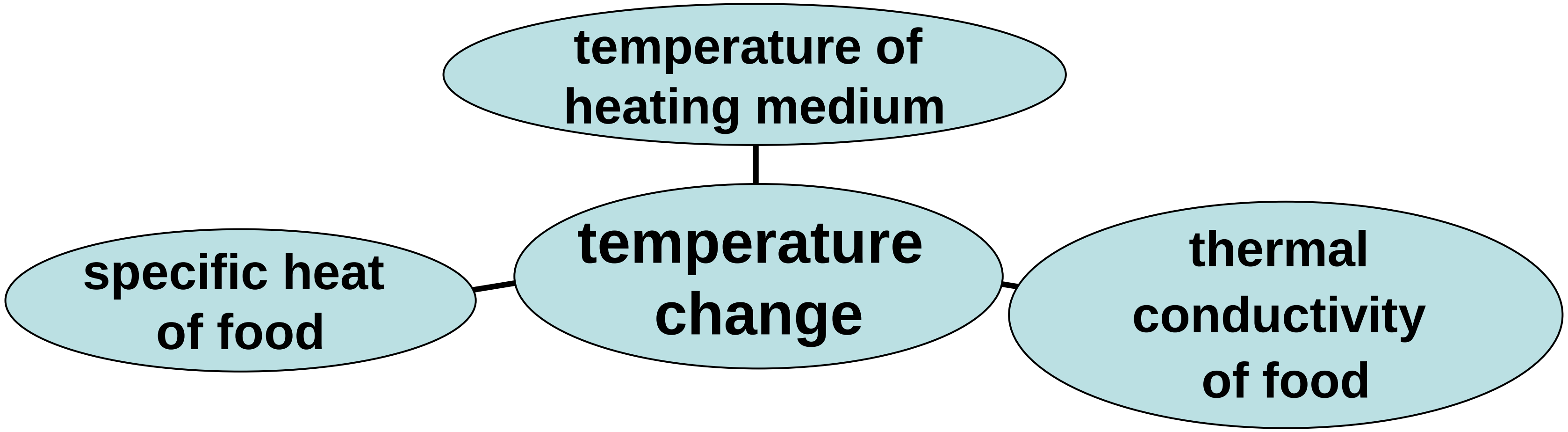
[b] Heat flow parallel to fibres.

From Earle (1983), Lewis (1987) and Woodams and Nowrey (1968).

Unsteady-state conduction

- During processing, temperature at a given point within a food depends on rate of heating or cooling & the position in the food.

- Temperature changes continuously.



temperature of heating medium

temperature change

specific heat of food

thermal conductivity of food

Specific heat of selected foods and other materials

Food/material	Specific heat (kJ kg^{-1} K^{-1})	Temperature (°C)
Aluminium	0.89	20
Apples	3.59	ambient
Apples	1.88	frozen
Cod	3.76	ambient
Cod	2.05	frozen
Copper	0.38	20
Ice	2.04	0
Lamb	2.80	ambient
Lamb	1.25	frozen
Potatoes	3.43	ambient
Potatoes	1.80	frozen
Stainless steel	0.46	20
Water	4.18	15
Water vapour	2.05	100

Adapted from data of Peleg and Bagley (1983), Jowitt *et al*. (1983) and Polley *et al*. (1980).

- Thermal diffusivity is related to thermal conductivity, specific heat & density of a food

$$a = \frac{k}{\rho . c}$$

- a ($m^2 s^{-1}$): thermal diffusivity,
- ρ ($kg\ m^{-3}$): density,
- c ($J\ kg^{-1} K^{-1}$): specific heat capacity,
- k ($W m^{-1} K^{-1}$): thermal conductivity.

- unsteady-state heat transfer in a single direction (*x*)

$$\frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{k}{\rho c}\frac{\mathrm{d}^2\theta}{\mathrm{d}x^2}$$

- d*θ*/d*t* : change in temperature with time.

Convection

- When a fluid changes temperature → changes in density → natural convection currents.
- E.g. natural-circulation evaporators, air movement in chest freezers, & movement of liquids inside cans during sterilisation.

- Forced convection

  → a stirrer or fan is used to agitate the fluid.

  → reduces boundary film thickness to produce higher rates of heat transfer & a more rapid temperature redistribution.
- Forced convection is more common than natural.
- E.g. mixers, fluidised-bed driers, air blast freezers & liquids pumped through heat exchangers.

- When liquids or gases are used as heating or cooling media, the rate of heat transfer from the fluid to the surface of a food

$$Q = h_s A(\theta_b - \theta_s)$$

- Q (J s^{-1}): rate of heat transfer,
- A (m^2): surface area,
- θ_s (K): surface temperature,
- θ_b (K): bulk fluid temperature,
- h_s ($Wm^{-2}K^{-1}$): surface (or film) heat transfer coefficient.

- *Surface heat transfer coefficient* h_s

  → measure of the resistance to heat flow, caused by the boundary film

  → = k/x in the conduction equation
- higher in turbulent flow than in streamline flow.

- Heat transfer through air < through liquids
- Rates of heat transfer of moving air > still air.
- Larger heat exchangers, when air is used for heating or cooling compared to liquids.
- Rates of heat transfer of condensing steam > hot water, at the same temperature
- Presence of air in steam reduces rate of heat transfer.
- Implications for canning: any air in the steam → lowers amount of heat received by the food.

Surface heat transfer coefficient is related to

- physical properties of a fluid (e.g. density, viscosity, specific heat),
- gravity (causes circulation due to changes in density),
- temperature difference,
- length or diameter of the container under investigation.

$$\text{Nusselt number Nu} = \frac{h_c D}{k}$$

$$\text{Prandtl number Pr} = \frac{c_p \mu}{k}$$

$$\text{Grashof number Gr} = \frac{D^3 \rho^2 g \beta \Delta\theta}{\mu^2}$$

- h_c ($\mathrm{Wm^{-2}K^{-1}}$) : convection heat transfer coefficient at solid-liquid interface,
- D (m) : dimension (length or diameter),
- k ($\mathrm{Wm^{-1}K^{-1}}$) : thermal conductivity of the fluid,
- c_p ($\mathrm{J\ kg^{-1}K^{-1}}$) : specific heat at constant pressure,

- ρ (kg m-3) : density,
- μ (N sm-2) : viscosity,
- g ($\mathrm{m\ s^{-2}}$) : acceleration due to gravity,
- β ($\mathrm{m\ m^{-1}K^{-1}}$) : coefficient of thermal expansion,
- $\Delta\theta$ (K) : temperature difference
- v ($\mathrm{ms^{-1}}$) : velocity.

- Streamline flow through pipes,

$$\mathrm{Nu} = 1.62(\mathrm{Re}\ \mathrm{Pr}\frac{D}{L})^{0.33}$$

- *L* (m) : length of pipe,
- when Re Pr *D/L* > 120 & all physical properties are measured at the mean bulk temperature of fluid.

- Turbulent flow through pipes,

$$\mathrm{Nu} = 0.023(\mathrm{Re})^{0.8}(\mathrm{Pr})^{n}$$

- *n* = 0.4 for heating or *n* = 0.3 for cooling,
- when Re > 10,000, viscosity is measured at the mean *film* temperature & other physical properties are measured at the mean bulk temperature of fluid.
- Grashof number is used for natural convection.

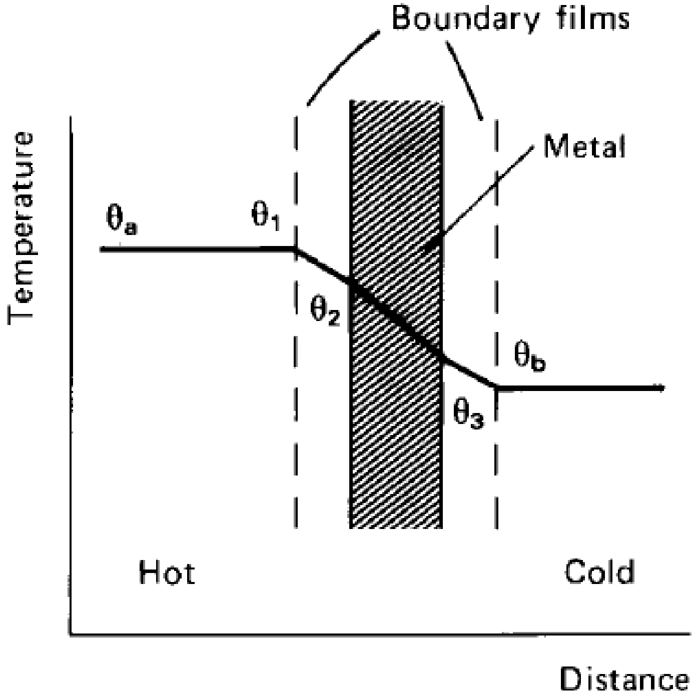
Values of surface heat transfer coefficients

	Surface heat transfer coefficient h_s ($W\ m^{-2}\ K^{-1}$)	Typical applications
Boiling liquids	2400–60 000	Evaporation
Condensing saturated steam	12 000	Canning, evaporation
Condensing steam		
With 3% air	3500	Canning
With 6% air	1200	
Condensing ammonia	6000	Freezing, chilling
Liquid flowing through pipes		
low viscosity	1200–6000	Pasteurisation
high viscosity	120–1200	Evaporation
Moving air ($3\ m\ s^{-1}$)	30	Freezing, baking
Still air	6	Cold stores

Adapted from Loncin and Merson (1979) and Earle (1983).

- Most cases of heat transfer in food processing involve heat transfer through a number of different materials.

- E.g. heat transfer in a heat exchanger from a hot fluid, through the wall of a vessel to a 2nd fluid



Temperature changes from a hot liquid through a vessel wall to a cold liquid.

- Overall temperature difference

$$\theta_{\mathrm{a}} - \theta_{\mathrm{b}} = \frac{Q}{A}\left(\frac{1}{h_{\mathrm{a}}}\frac{x}{k} + \frac{1}{h_{\mathrm{b}}}\right)$$

- Sum of the resistances to heat flow = *overall heat transfer coefficient* (OHTC), *U*

- Rate of heat transfer

$$Q = UA(\theta_{\mathrm{a}} - \theta_{\mathrm{b}})$$

- OHTC, e.g to indicate effectiveness of heating or cooling in different types of processing equipment.

OHTCs in food processing

Heat transfer fluids	Example	OHTC ($W\ m^{-2}\ K^{-1}$)
Hot water–air	Air heater	10–50
Viscous liquid–hot water	Jacketed vessel	100
Viscous liquid–hot water	Agitated jacketed vessel	500
Viscous liquid–steam	Evaporator	500
Non-viscous liquid–steam	Evaporator	1000–3000
Flue gas–water	Boiler	5–50
Evaporating ammonia–water	Chilled water plant	500

Adapted from Lewis (1990).

- Liquids flow → same or opposite directions in a heat exchanger.

- Heat transfer efficiency of counter-current flow > co-current (or ‘parallel’) flow; so, widely used in heat exchangers

- Temperature difference varies at different points in the heat exchanger

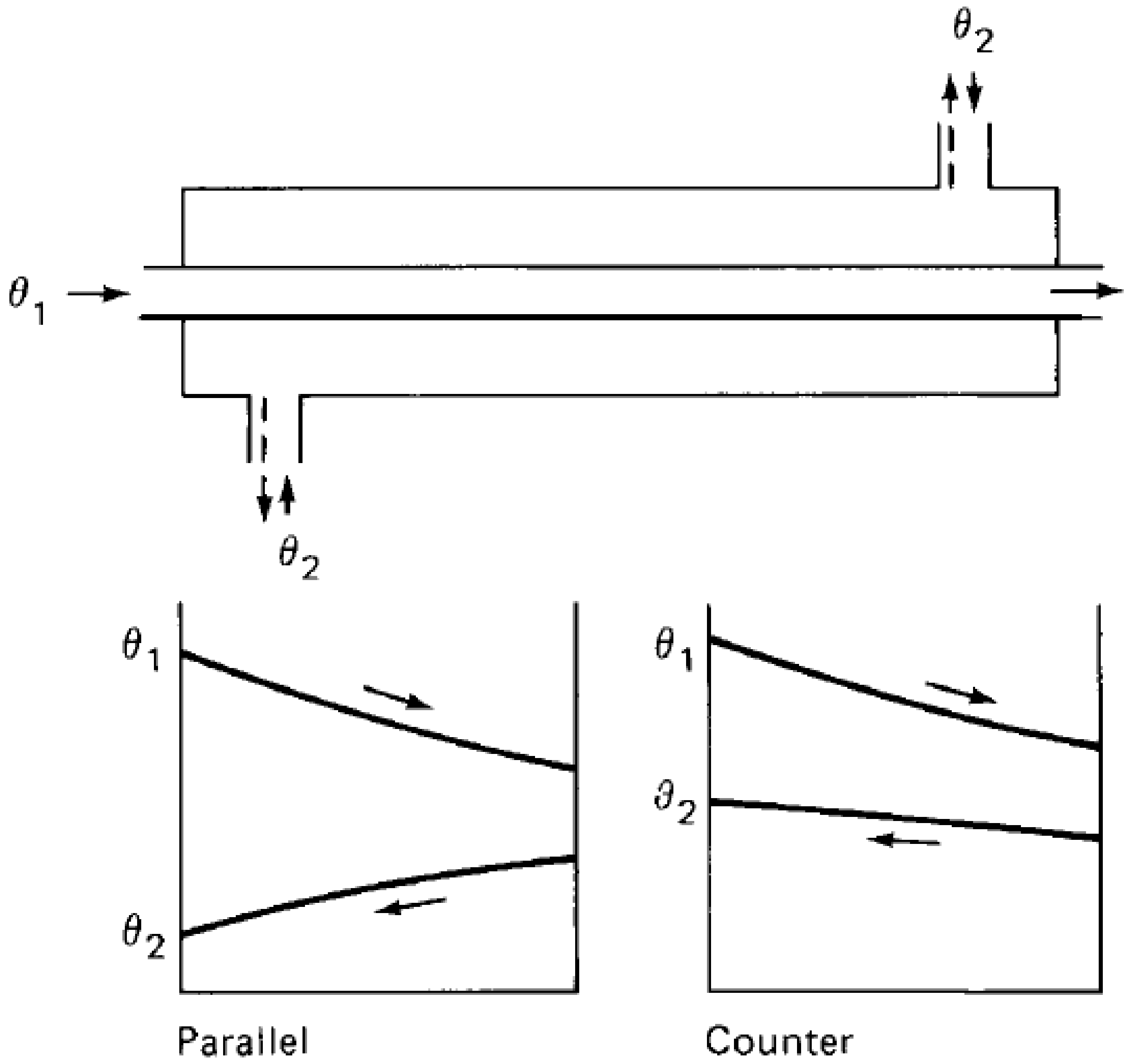
$$\Delta\theta_{\mathrm{m}} = \frac{\Delta\theta_1 - \Delta\theta_2}{\ln(\Delta\theta_1/\theta_2)}$$

- $\theta_1 > \theta_2$.

- The heading time in batch processing

$$t = \frac{mc}{UA} \ln\left(\frac{\theta_{\mathrm{h}} - \theta_{\mathrm{i}}}{\theta_{\mathrm{h}} - \theta_{\mathrm{f}}}\right)$$

- m (kg): mass,
- c (J kg^{-1} ^{o}K^{-1}): specific heat capacity,
- θ_h (^{o}C): temperature of heating medium,
- θ_i (^{o}C): initial temperature,
- θ_f (^{o}C): final temperature,
- A (m^{2}): surface area
- U (W m^{-2} K^{-1}): OHTC.



Parallel and counter-current flow through a heat exchanger.

Unsteady-state heat transfer by conduction & convection

- solid piece is heated or cooled by a fluid,
- resistances to heat transfer are surface heat transfer coefficient & thermal conductivity of food.

→ *Biot Number*

$$\mathrm{Bi} = \frac{h\delta}{k}$$

- h (W m^{-2} K^{-1}): heat transfer coefficient,
- δ: 'half dimension' (e.g. radius of a sphere or cylinder, half thickness of a slab)
- k (W m^{-1}K^{-1}): thermal conductivity.

- At small *Bi* (< 0.2)

  → surface film is main resistance to heat flow

  → time to heat solid food = previous equation

  (t = …),

  → use film heat transfer coefficient *h*s; not *U*.

- In most applications, thermal conductivity of food limits rate of heat transfer (*Bi* > 0.2).

  → Calculations are complex

  → series of charts

- The charts relate

  \- Biot number (Bi),

  \- *temperature factor*

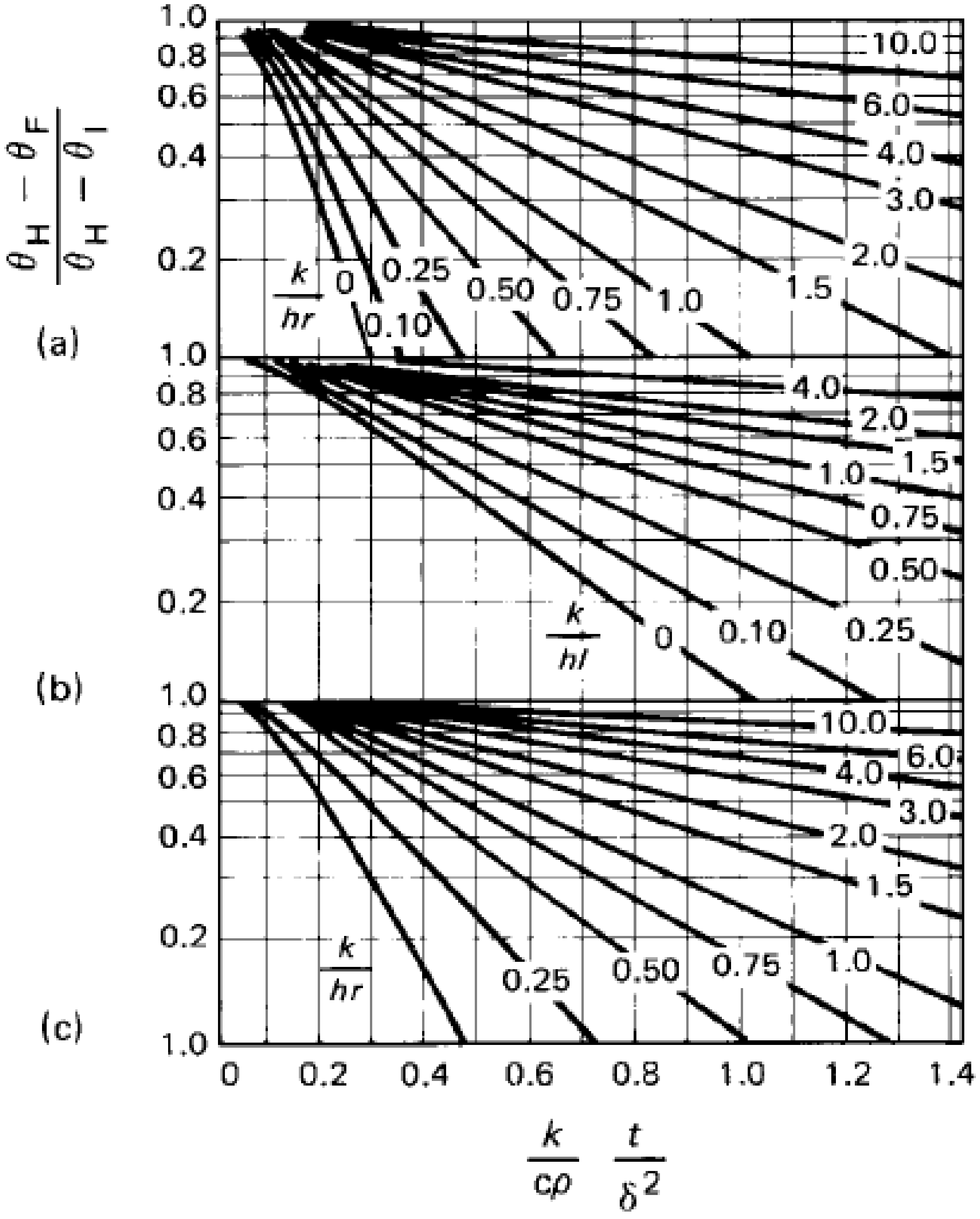
  (the fraction of the temperature change that remains to be accomplished)

  \- *Fourier number* Fo

  (a dimensionless number which relates the thermal diffusivity, the size of the piece and the time of heating or cooling)

$$\frac{\theta_{\mathrm{h}} - \theta_{\mathrm{f}}}{\theta_{\mathrm{h}} - \theta_{\mathrm{i}}}$$

h → heating medium,
f → final value,
i → initial value.



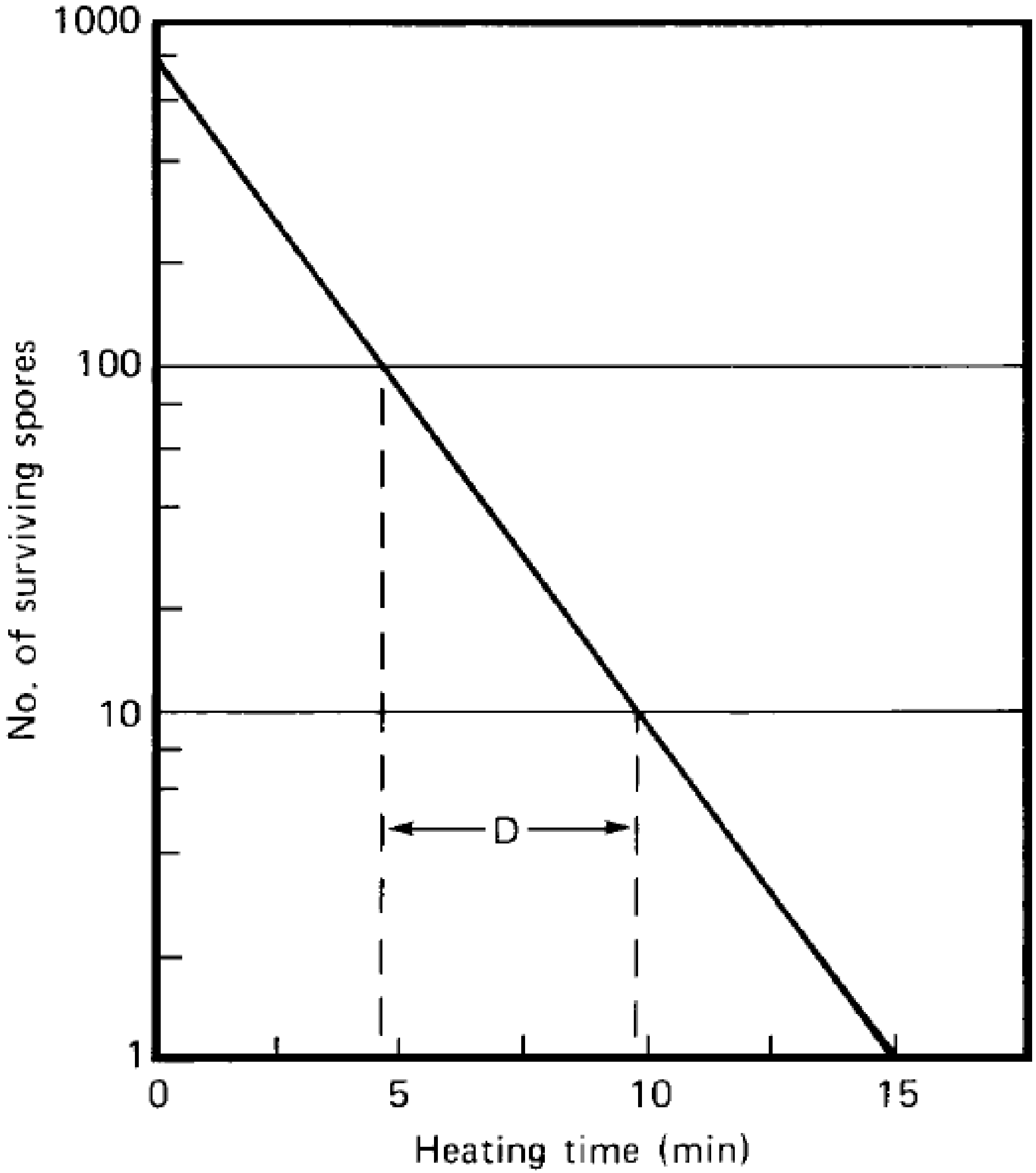
$$\text{Fo} = \frac{k}{c\rho}\frac{t}{\delta^2}$$

Chart for unsteady-state heat transfer: (a) sphere; (b) slab; (c) cylinder. (After Henderson and Perry (1955).)

decimal reduction time
***D* value**

- Time to destroy 90% of the micro-organisms (to reduce their numbers by a factor of 10).
- differ for different microbial species
- higher *D* value indicates greater heat resistance.

- The destruction of micro-organisms is temperature dependent; cells die more rapidly at higher temperatures



Death rate curve.

Thermal properties of selected nutritional and sensory components of foods in relation to heat-resistant enzymes and bacteria

Component	Source	pH	z (°C)	D_{121} (min)	Temperature range (°C)
Thiamin	Carrot purée	5.9	25	158	109–149
Thiamin	Pea purée	Natural	27	247	121–138
Thiamin	Lamb purée	6.2	25	120	109–149
Lysine	Soya bean meal	–	21	786	100–127
Chlorophyll a	Spinach	6.5	51	13.0	127–149
Chlorophyll a	Spinach	Natural	45	34.1	100–130
Chlorophyll b	Spinach	5.5	79	14.7	127–149
Chlorophyll b	Spinach	Natural	59	48	100–130
Anthocyanin	Grape juice	Natural	23.2	17.8*	20–121
Betanin	Beetroot juice	5.0	58.9	46.6*	50–100
Carotenoids	Paprika	Natural	18.9	0.038*	52–65
Peroxidase	Peas	Natural	37.2	3.0	110–138
Peroxidase	Various	–	28–44	–	–
Clostridium botulinum spores type A + B	Various	>4.5	5.5–10	0.1–0.3*	104
Bacillus stereothermophilus	Various	>4.5	7–12	4.0–5.0	110+

* *D* values at temperatures other than 121°C.

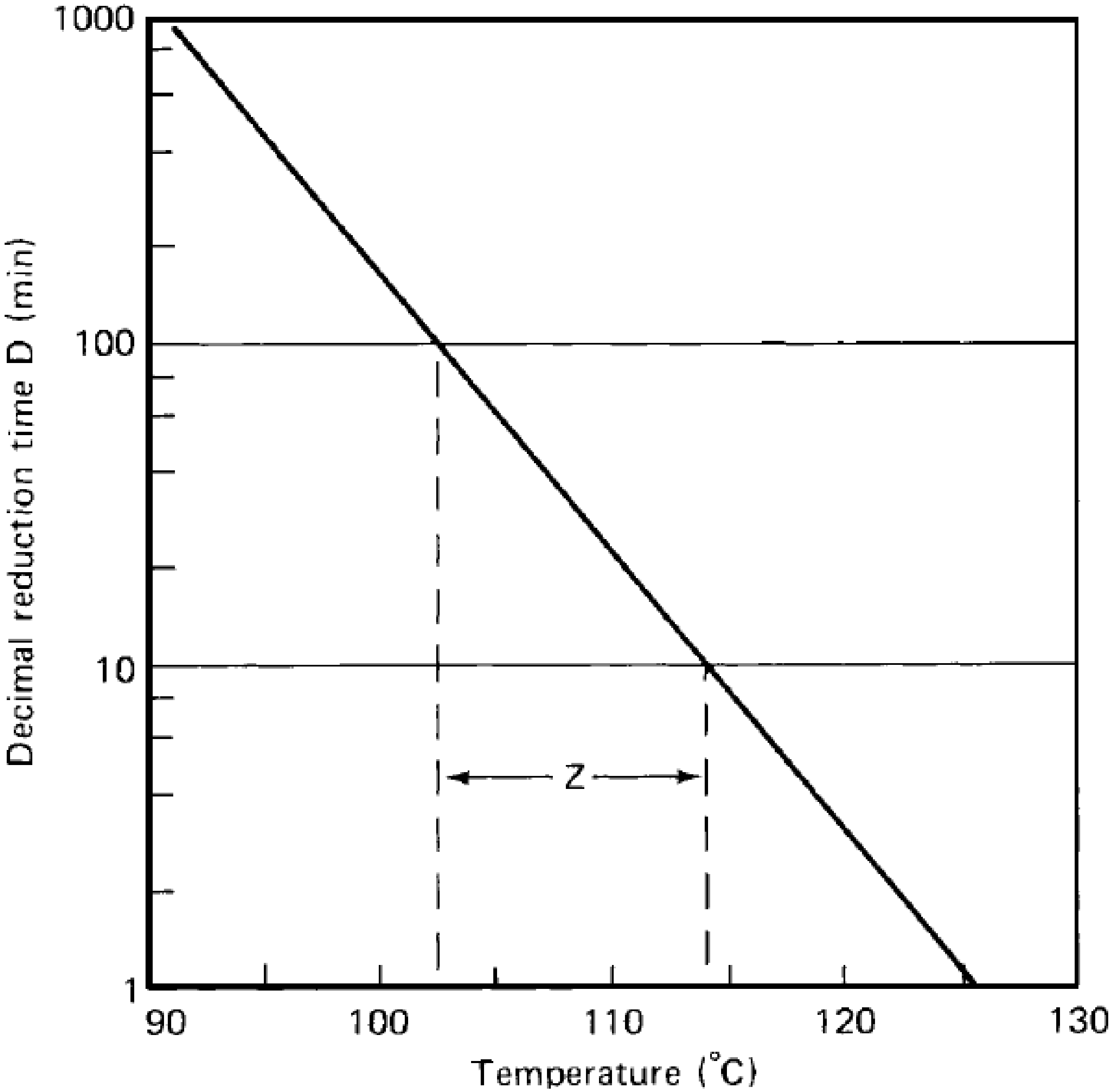
Adapted from Felliciotti and Esselen (1957), Taira *et al*. (1966), Gupta *et al*. (1964), Ponting *et al*. (1960), von Elbe *et al*. (1974), Adams and Yawger (1961), Esselen and Anderson (1956) and Stumbo (1973).

z value

- *thermal death time* (TDT) curve

  → collating *D* values at different temperatures
- *Z* value = slope of the TDT curve
- number of degrees Celsius required to bring about a 10x change in decimal reduction time
- The *D* & *z* values

  → to characterise heat resistance of a micro-organism & its temperature dependence, respectively.



TDT curve. Microbial destruction is faster at higher temperatures (for example 100 min at 102.5ºC has the same lethal effect as 10 min at 113ºC).

Thank you