Blanching | Pasteurisation | Heat Sterilisation

PRO

Ch. 10 – 12 of Fellows

Heat Processing Overview

Heat processing using steam or water

- Blanching | Pasteurisation | Heat sterilisation | Evaporation & Distillation | Extrusion

Heat processing using hot air

- Dehydration | Baking and roasting

Heat processing using hot oils

- Frying

Heat processing by direct and radiated energy

- Dielectric | Ohmic | Infrared

Processing by The Removal of Heat

- Chilling | Controlled- or modified-atmosphere storage and packaging | Freezing | Freeze drying

General Introduction

Heat treatment in food processing

+ eating quality
+ preservative
+ simple control of processing conditions
+ shelf-stable foods
+ destruction of anti-nutritional factors
+ availability of some nutrients

- alters or destroys components of foods

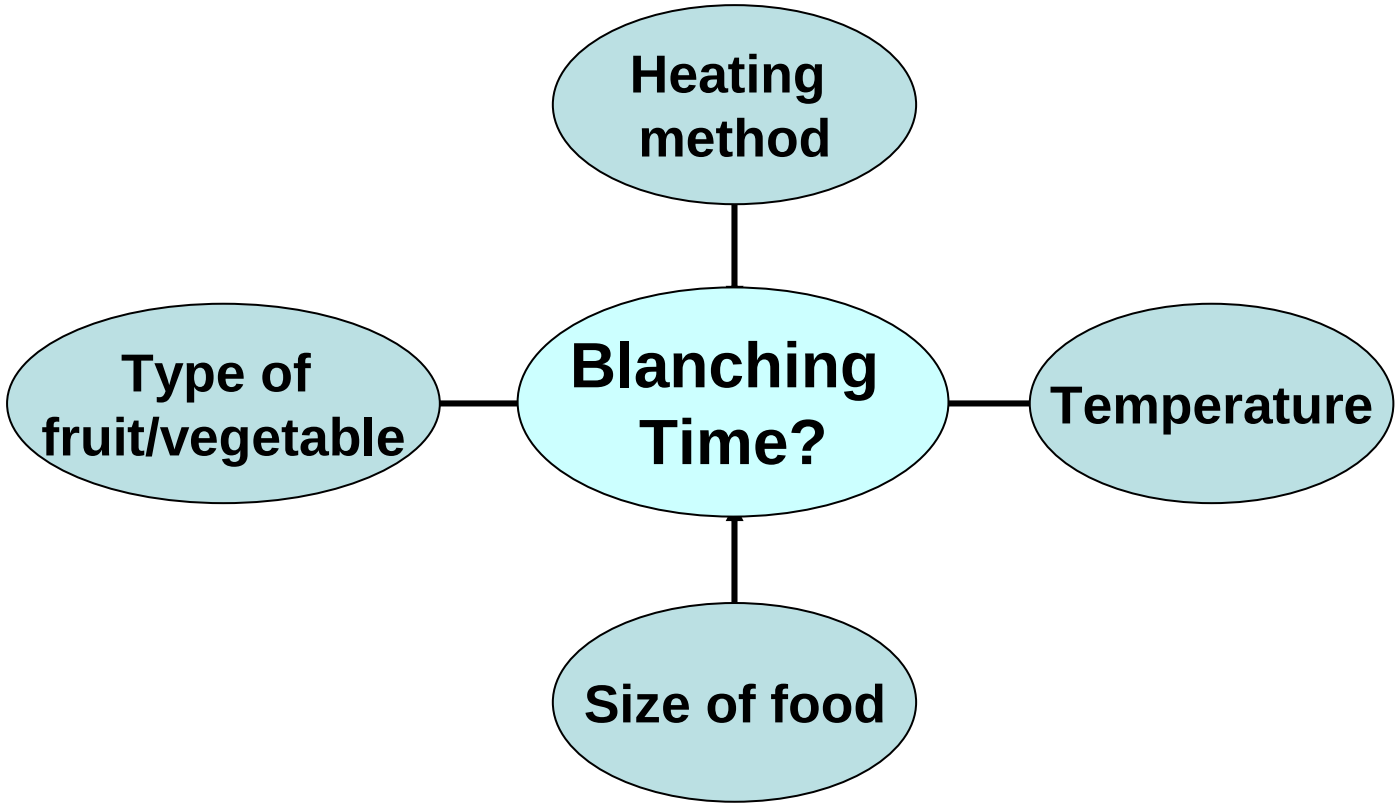
Blanching

- to destroy enzymic activity in many vegetables and fruits, prior to further processing.
- Not a sole method of preservation
- A pre-treatment
- When combined with peeling / cleaning

  → savings energy consumption, space & equipment costs.

To achieve adequate enzyme inactivation

- food is heated rapidly to a pre-set temperature,
- held for a pre-set time,
- cooled rapidly to near ambient temperatures.



Theory – Principle

- Unsteady-state heat transfer by conduction & convection
- Max. processing temperature in freezing & dehydration

  → insufficient to inactivate enzymes.

  → undesirable changes during storage.
- Canning (particularly in large cans)

  → enzyme activity inactivation?
- Heat - sufficient to disrupt tissues and release enzymes - but not inactivate them; only some enzymes may be destroyed.

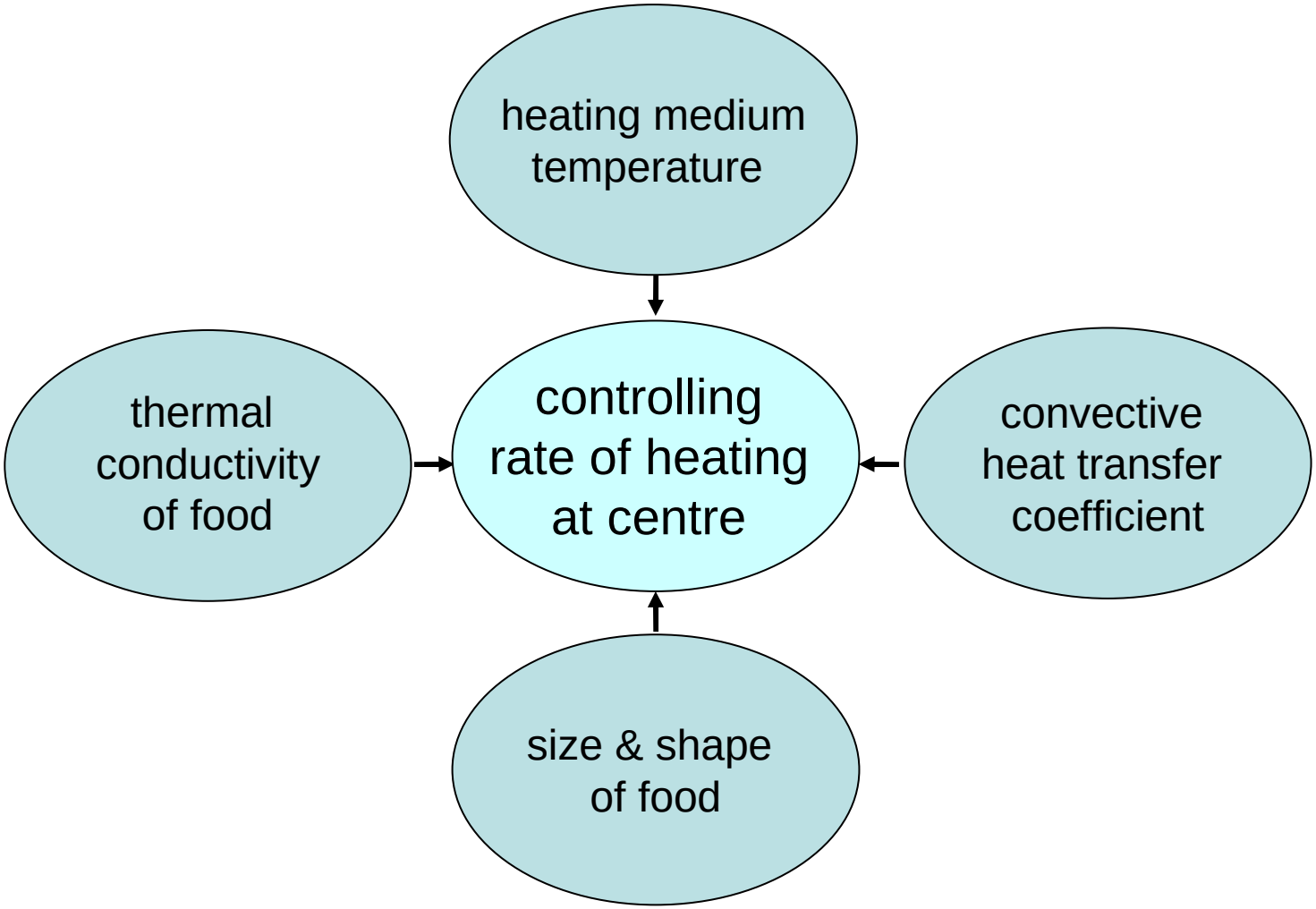
- The heat resistance of enzymes

  → *D* and *z* values.
- Enzymes:
  - lipoxygenase,
  - polyphenoloxidase,
  - polygalacturonase,
  - chlorophyllase.

- Heat-resistant enzymes: catalase & peroxidase.

  → not to cause deterioration during storage;

  → used as marker enzymes to determine the success of blanching.


heating medium temperature
thermal conductivity of food
controlling rate of heating at centre
convective heat transfer coefficient
size & shape of food

- Adequate blanching also reduces numbers of contaminating micro-organisms on surface of foods

  = preservation aid, e.g. in heat sterilisation.

- Freezing & drying do not substantially reduce number of micro-organisms in un-blanched foods

  → grow on thawing or rehydration.

- Blanching can soften vegetable tissues

  → facilitate filling into containers

  → removes air from intercellular spaces

    → increases density of food

    → assisting formation of a head-space vacuum in cans

Equipment

- Commercially common:
  by passing food through
  (1) an atmosphere of saturated steam or
  (2) a bath of hot water.
- relatively simple and inexpensive.

- Developments
  → reduce the energy consumption & loss of soluble components.

- “Commercially” success indicator: *yield* of food
  → consider blanching & cooling

Steam blanching

→ higher nutrient retention, provided cooling is by cold-air or cold-water sprays.

- Cooling with running water (fluming)
  → increases leaching losses,
  but product may gain weight.

- Cooling with air
  → weight loss; nutrient retention.

- Differences in yield & nutrient retention also due to differences in
  - type of food
  - method of preparation (e.g. slicing & peeling).

- Recycling of water

  does not affect product quality or yield but

  reduces volume of effluent.

- Needs for adequate hygienic in cooling water.

Equipment: *Steam blanchers*

- Esp. for foods with a large area of cut surfaces
  → leaching losses < hot-water blanchers.

- Mesh conveyor carries food through a steam atmosphere in a tunnel (typically 15m x 1–1.5m).
- Water sprays at the inlet and outlet to condense escaping steam.

- Alternatively, food may enter & leave blancher through rotary valves or hydrostatic seals
  → reduce steam losses
  → increase energy efficiency
  → or steam may be re-used.

- Conventional steam blanching
  → often poor heating uniformity in multi-layers' food.
- overheating at food's edges → loss of texture & others

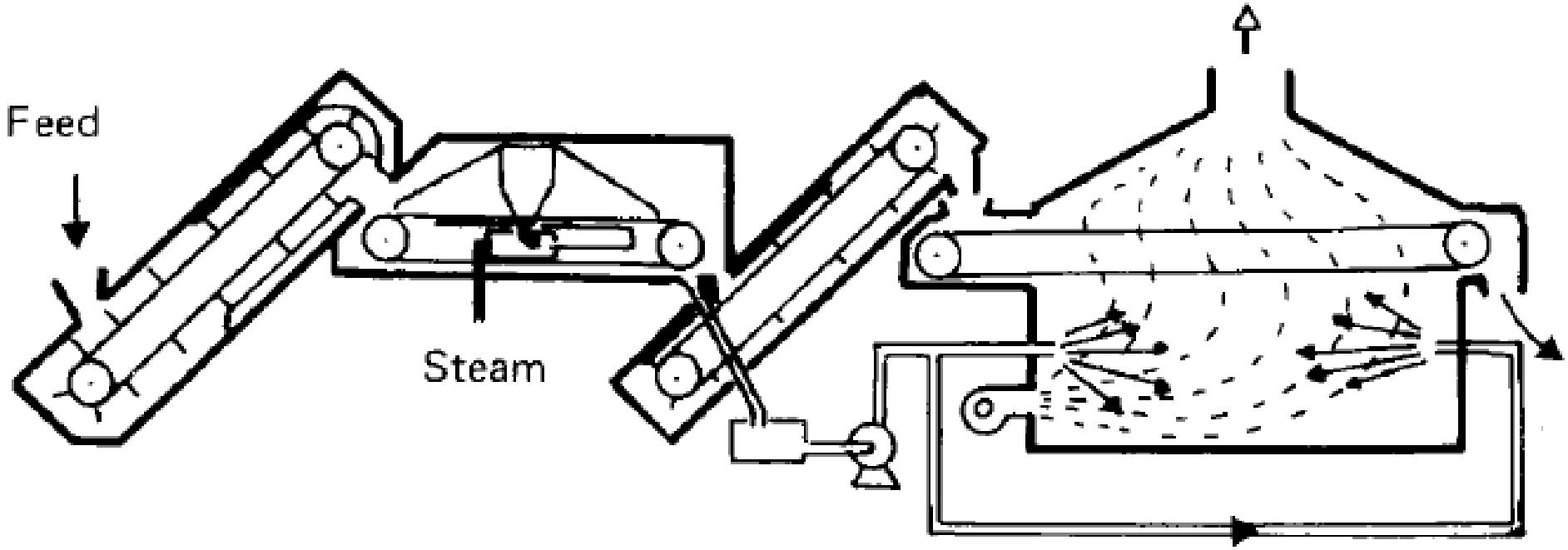
Individual quick blanching (IQB)

→ blanching in two stages.

1st : food is heated in a single layer to a sufficiently high temperature to inactivate enzymes.

2nd (*adiabatic holding*) : a deep bed of food is held for sufficient time to allow temperature at centre of each piece to increase to that needed for enzyme inactivation.

- E.g. 25 s for heating and 50 s for holding 1 cm diced carrot compared with 3 min for conventional blanching.



IQB steam blancher (after Timbers *et al.* (1984))

IQB

- Nutrient losses during steam blanching are reduced by exposing the food to warm air (65ºC) in a short preliminary drying operation (‘*pre-conditioning’*).

- Surface moisture evaporates & surfaces then absorb condensing steam during IQB.

- Pre-conditioning + IQB

  → reduce nutrient losses by 81% for green beans, 75% for Brussels sprouts, 61% for peas & 53% for lima beans

  → no reduction in the yield of blanched food.

- Complete inactivation of peroxidase & minimum loss in quality → retention of 76–85% of ascorbic acid.

Batch ***fluidised-bed blanchers***

→ a mixture of air & steam

→ fluidises & heats product simultaneously.

- advantages:
  - faster, more uniform heating
  - good mixing of product
  - reduction of effluent volume
  - shorter processing times; smaller losses of vitamins & other soluble heat sensitive components.

Equipment: *Hot-water blanchers*

- holds food in hot water (70-100ºC) for a specified time,
- removes it to a dewatering-cooling section.

reel blancher

- food enters a slowly rotating cylindrical mesh drum (with internal flight) partly submerged in hot water.

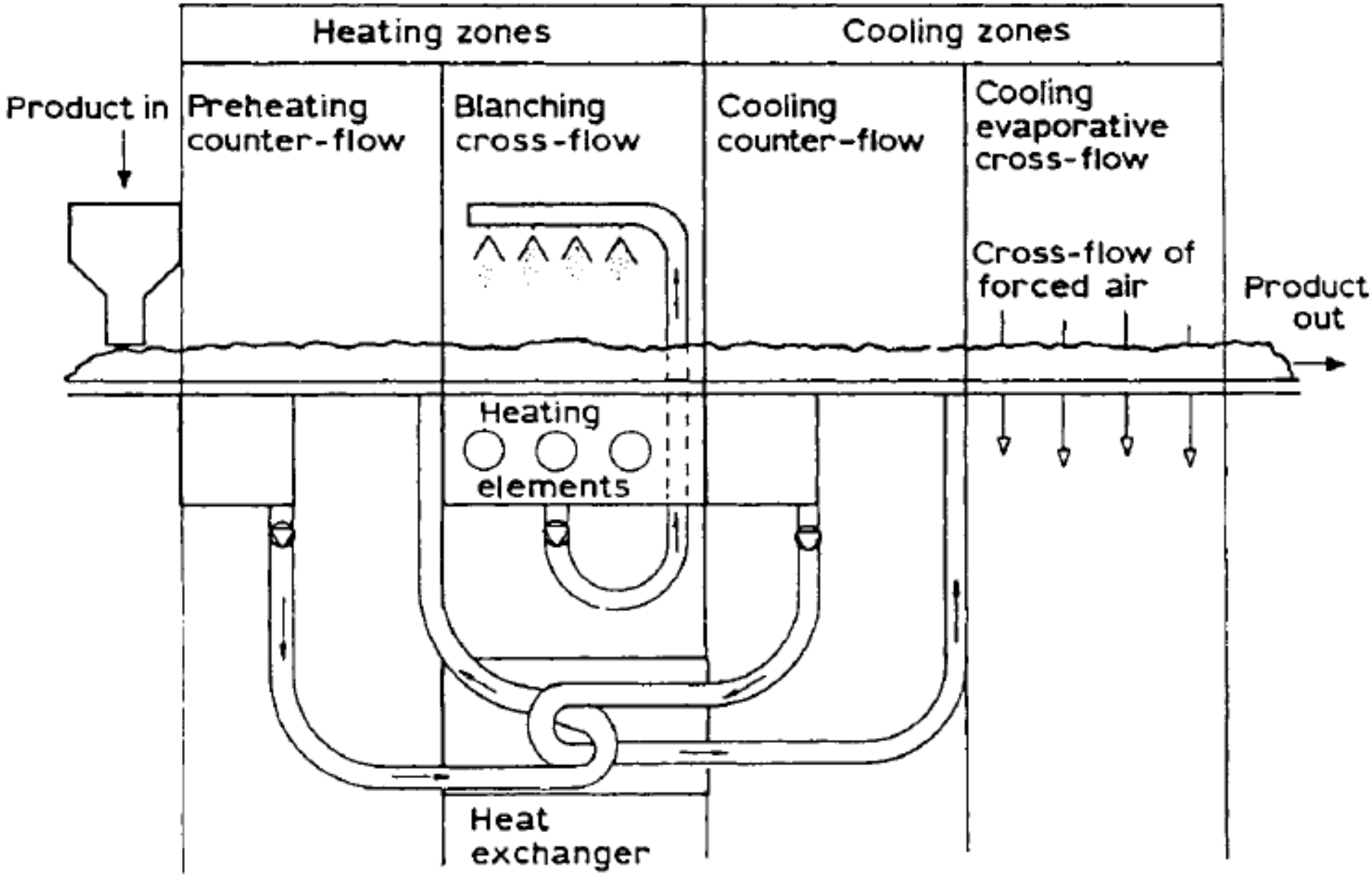
Pipe blanchers

- a continuous insulated metal pipe fitted with feed & discharge ports.
- Hot water is re-circulated through pipe & food is metered in.
- Large capacity while occupying a small floor space.

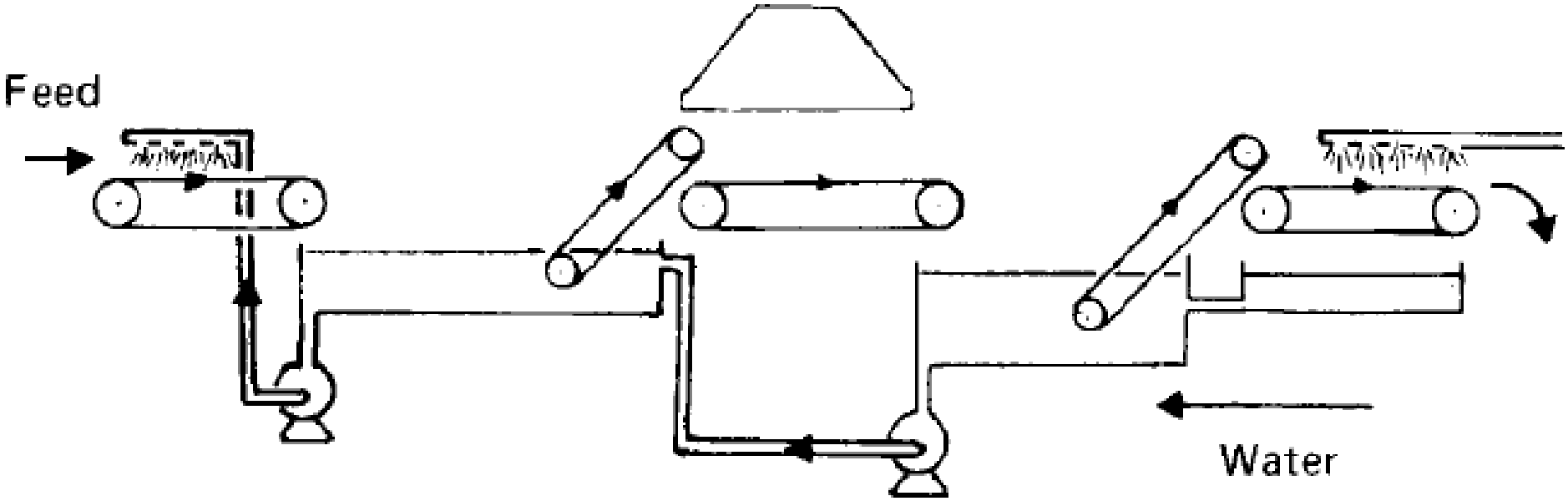
blancher-cooler

- pre-heating, blanching, cooling sections.

- Food on a single conveyor belt throughout each stage
  → not to suffer from physical damage due to turbulence of conventional hot water blanchers.
- Food is pre-heated with water (re-circulated through a heat exchanger / HE).
- After blanching, 2nd recirculation system cools the food.
-
- The two systems pass water through the same HE
- Heats the pre-heat water & simultaneously cools the cooling water.
- A re-circulated water-steam mixture to blanch food, & final cooling is by cold air.



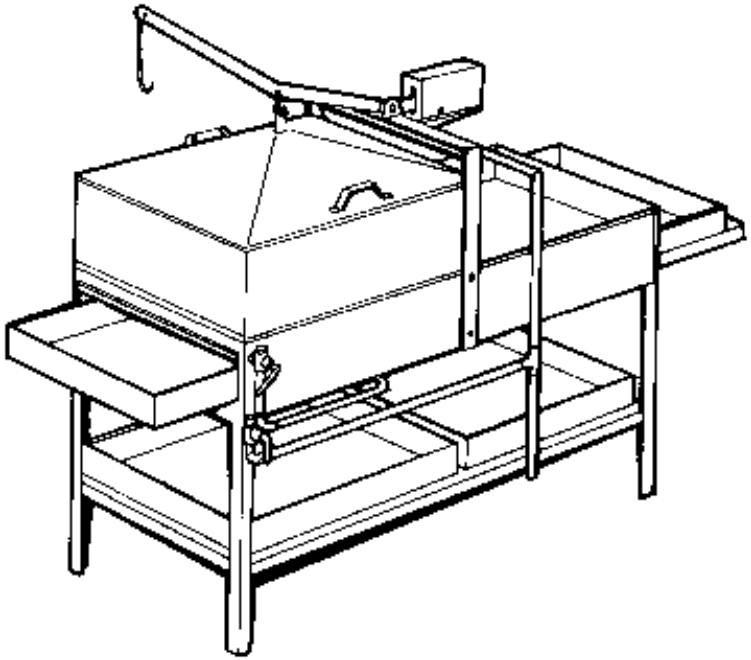
blancher–cooler (from Hallstrom *et al.* (1988))



counter-current blancher (after Wendt *et al.* (1983))

Advantages and limitations of conventional steam and hot-water blanchers

Equipment	Advantages	Limitations
Conventional steam blanchers	Smaller loss of water-soluble components. Smaller volumes of waste and lower disposal charges than water blanchers, particularly with air cooling instead of water. Easy to clean and sterilise	Limited cleaning of the food so washers also required. Uneven blanching if the food is piled too high on the conveyor. Some loss of mass in the food.
Conventional hot-water blancher	Lower capital cost and better energy efficiency than steam blanchers	Higher costs in purchase of water and charges for treatment of large volumes of dilute effluent . Risk of contamination by thermophilic bacteria.




FMT

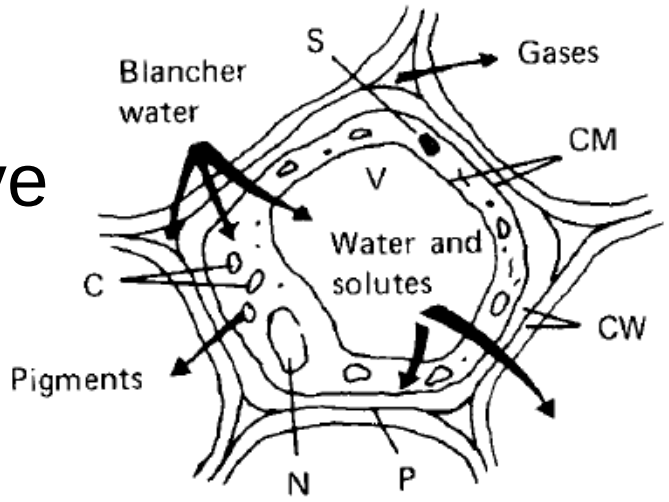

Steam Section
Cool Section

Effect on foods

- changes to sensory & nutritional qualities < heat sterilisation
- time–temperature combination is a compromise

  → ensuring adequate enzyme inactivation

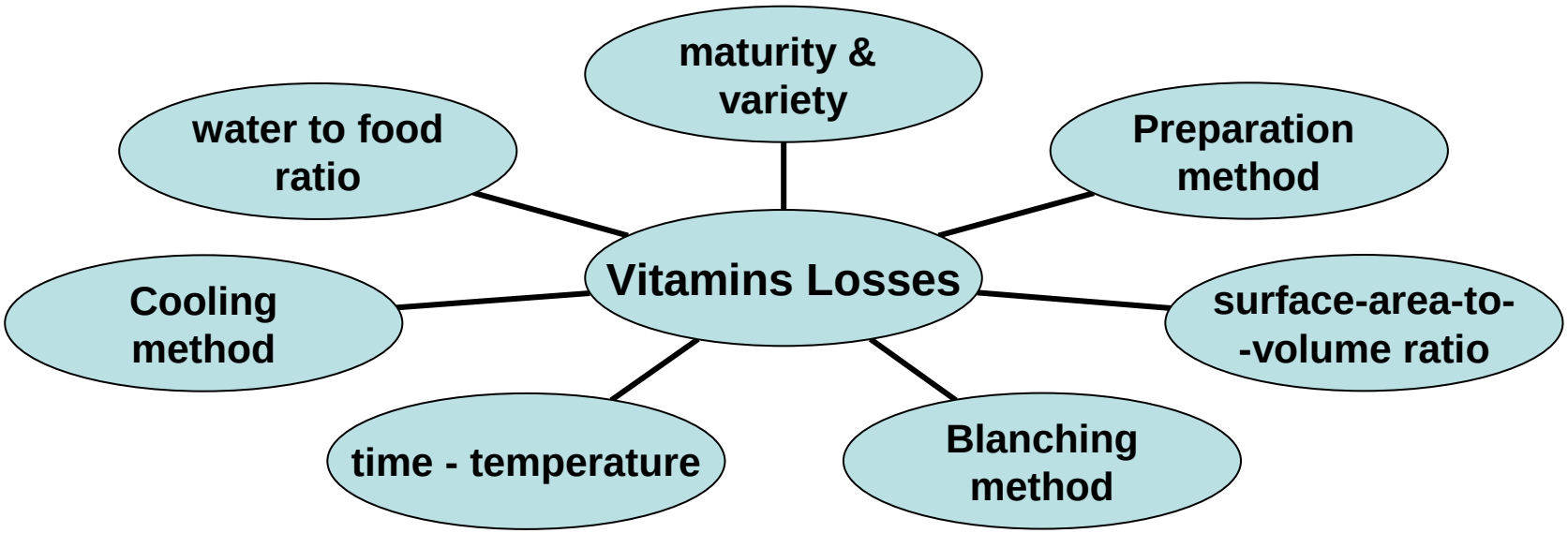
  → prevents excessive softening & loss of flavour



Effect of blanching on cell tissues: S, starch gelatinised; CM, cytoplasmic membranes altered; CW, cell walls little altered; P, pectins modified; N, nucleus and cytoplasmic proteins denatured; C, chloroplasts and chromoplasts distorted.

Effect: *Nutrients*

- Some minerals, water-soluble vitamins & other water-soluble components are lost.
- Losses of vitamins are mostly due to leaching, thermal destruction & oxidation.



- Losses of ascorbic acid

  → indicator of food quality.

Effect of blanching method on ascorbic acid losses in selected vegetables

Treatment	Loss (%) of ascorbic acid		
	Peas	Broccoli	Green beans
Water blanch–water cool	29.1	38.7	15.1
Water blanch–air cool	25.0	30.6	19.5
Steam blanch–water cool	24.2	22.2	17.7
Steam blanch–air cool	14.0	9.0	18.6

Differences in both steam versus water blanching and air versus water cooling are significant at the 5% level. Adapted from Cumming *et al.* (1981).

Effect: *Colour and flavour*

- brightens colour of some foods
  → removing air & dust on surface → altering λ of reflected light.
- change in food pigments according to their *D* value.
- Na_2CO_3 or CaO (+) to blancher water
  → protect chlorophyll; retain colour of green vegetables
  → increase in pH may increase losses of ascorbic acid.
- cut apples & potatoes → in dilute brine prior to blanching.
- correct blanching → mostly no sig. changes to flavour or aroma
- under-blanching → off-flavours during storage of dried or frozen foods.

Effect: *Texture*

- when used for freezing or drying,
  time–temperature conditions
  needed to achieve enzyme inactivation
  cause an excessive loss of texture
  in some types of food

- $CaCl_2$ (+) to blancher water
  → to form insoluble calcium pectate complexes
  → maintain firmness in the tissues.

Pasteurisation

- a relatively mild heat treatment; to < 100ºC.
- low acid foods (pH > 4.5, e.g. milk)

  → minimise pathogenic micro-organisms hazards

  → extend shelf life for several days.
- acidic foods (pH < 4.5, e.g. bottled fruit)

  → destruction of spoilage micro-organisms (yeasts or moulds) and/or enzyme inactivation

  → extend shelf life for several months

Theory

- *Sensible heat* to raise liquid temperature during pasteurisation

$$Q = mc(\theta_A - \theta_B)$$

- Q (W): specific rate of heat transfer,
- m (kg s^{-1}): mass flow rate,
- c (kJ kg^{-1} $^oC^{-1}$): specific heat capacity
- θ_A - θ_B (^oC): temperature change.

- Independent study: Unit Operation part; Chapter 1 (Sample problems 1.7 and 1.8) and in Section 11.2.2 of Fellows.

- Heat treatment level required to stabilise a food

  → *D* value of the most heat-resistant enzyme or micro-organism which may be present.

- E.g. - milk pasteurisation is based on D_{60} & a 12 logarithmic cycle reduction in numbers of *C.burnetii*

  - liquid whole egg is treated to produce a 9*D* reduction in numbers of *S. seftenberg*.

- HTST optimises retention of nutritional & sensory quality → 'flash pasteurisation'.

- E.g. milk processing at 63ºC for 30 min (*holder* process) causes greater changes to flavour & a slightly greater loss of vit.s than HTST processing at 71.8ºC for 15 s.

Purpose of pasteurisation for different foods

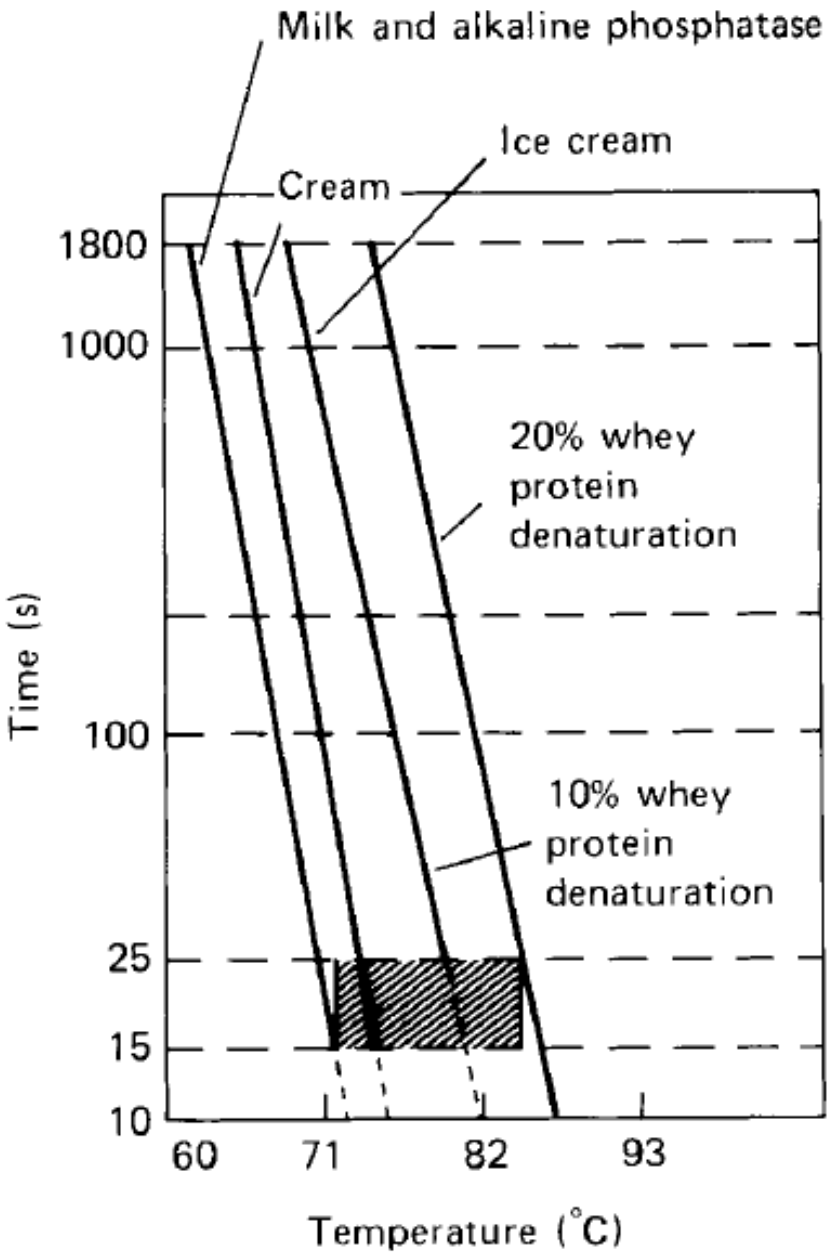
Food	Main purpose	Subsidiary purpose	Minimum processing conditions[a]
pH < 4.5			
Fruit juice	Enzyme inactivation (pectinesterase and polygalacturonase)	Destruction of spoilage micro-organisms (yeasts, fungi)	65°C for 30 min; 77°C for 1 min; 88°C for 15 s
Beer	Destruction of spoilage micro-organisms (wild yeasts, *Lactobacillus* species), and residual yeasts (*Saccharomyces* species)	–	65–68°C for 20 min (in bottle); 72–75°C for 1–4 min at 900–1000 kPa
pH > 4.5			
Milk	Destruction of pathogens: *Brucella abortis*, *Mycobacterium tuberculosis*, (*Coxiella burnettii*[b])	Destruction of spoilage micro-organisms and enzymes	63°C for 30 min; 71.5°C for 15 s
Liquid egg	Destruction of pathogens *Salmonella seftenburg*	Destruction of spoilage micro-organisms	64.4°C for 2.5 min 60°C for 3.5 min
Ice cream	Destruction of pathogens	Destruction of spoilage micro-organisms	65°C for 30 min; 71°C for 10 min; 80°C for 15 s

[a] Followed by rapid cooling to 3–7°C.
[b] Rickettsia organism which causes Q fever.
Adapted from Fricker (1984), Wiggins and Barclay (1984), Lund (1975) and Hammid-Samimi and Swartzel (1984).

- Alkaline phosphatase,
  naturally occurring enzyme in raw milk
  has a similar *D* value to heat-resistant pathogens.

- If phosphatase activity is found,
  heat treatment was inadequate to destroy the pathogenic bacteria or
  unpasteurised milk has contaminated the pasteurised product.

- A similar test for the effectiveness of liquid-egg pasteurisation is based on residual α-amylase activity.



Time–temperature relationships for pasteurisation. The hatched area shows the range of times and temperatures used in commercial milk pasteurisation.
(After Harper (1976).)

Equipment

Pasteurisation of packaged foods

- Some liquid foods (e.g. beers & fruit juices) are pasteurised after filling into containers.

- Hot water
  → glass container
  → max. temperature differences between container & water, 20ºC (heating) & 10ºC (cooling).

- Steam–air mixtures or hot water
  → metal or plastic containers.

- Food is cooled to appr. 40ºC to evaporate surface water
  → minimise external corrosion to container or cap
  → accelerate setting of label adhesives.

- Hot-water pasteurisers → batch or continuous.

Batch

→ a water bath,

→ crates of packaged food are heated to a pre-set temperature & held for the required length of time.

→ cold water is pumped in to cool product.

Continuous

(1) → a long narrow trough (+) a conveyor belt

→ containers through heating & cooling stages.

(2) → a tunnel divided into heating zones.

→ very fine (atomised) water sprays heat containers through each zone on a conveyor,

→ incremental rises in temperature until pasteurisation is achieved.

→ water sprays cool containers.

- Savings in energy & water consumption

  → water recirculation between preheat sprays,

  → cooled by the incoming food between cooling zones

  → heated by the hot products.

Steam tunnels

  → faster, shorter, & smaller.

- Temperatures in heating zones are gradually increased

  → by reducing amount of air in steam–air mixtures.

- Cooling takes place using fine sprays of water or by immersion in a water bath.

Pasteurisation of unpackaged liquids

Swept surface heat exchangers (HEs) or **open boiling pans**

→ small-scale batch of some liquid foods.

Plate HEs

→ large scale of low viscosity liquids (e.g. milk, milk products, fruit juices, liquid egg, beers & wines).

- Some products (e.g. fruit juices, wines) also require de-aeration to prevent oxidative changes during storage.

  → sprayed into a vacuum chamber

  → dissolved air is removed by a vacuum pump, prior to pasteurisation.

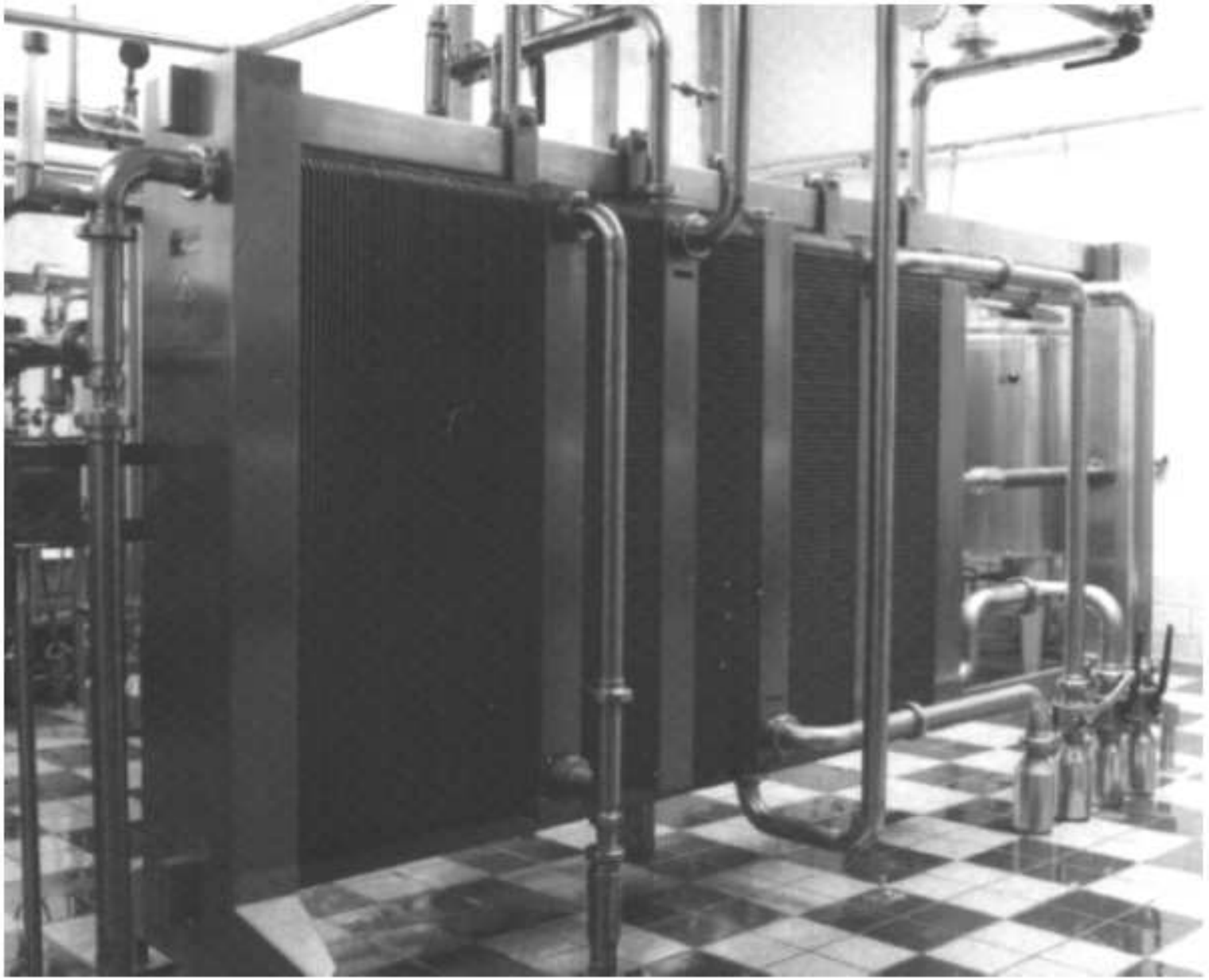
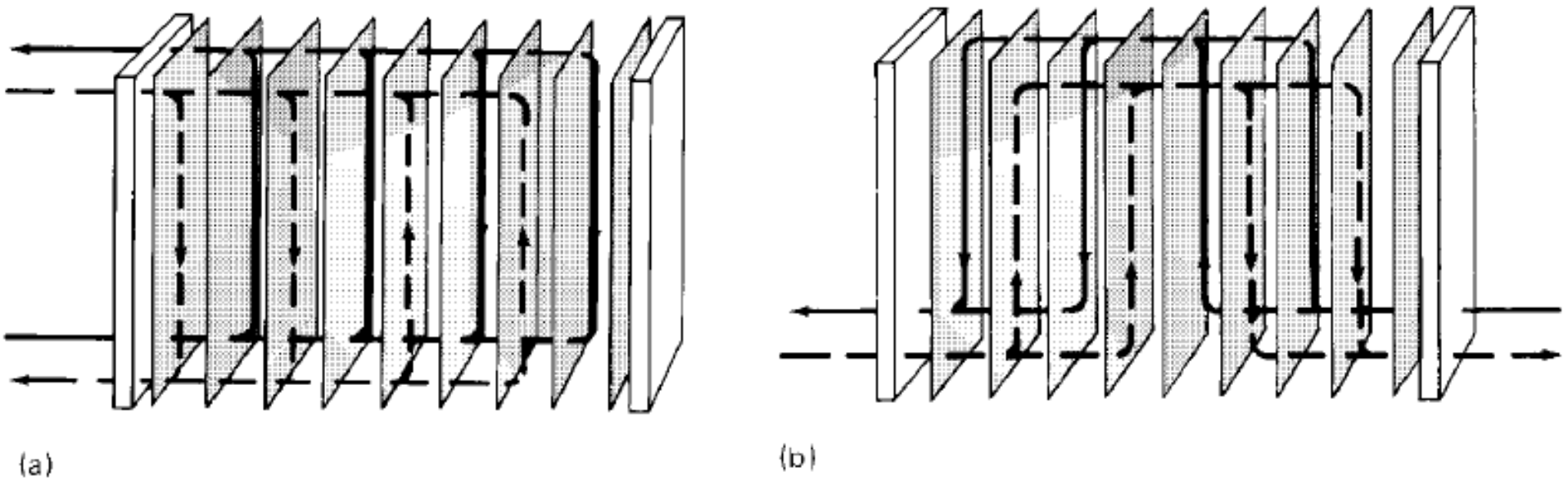


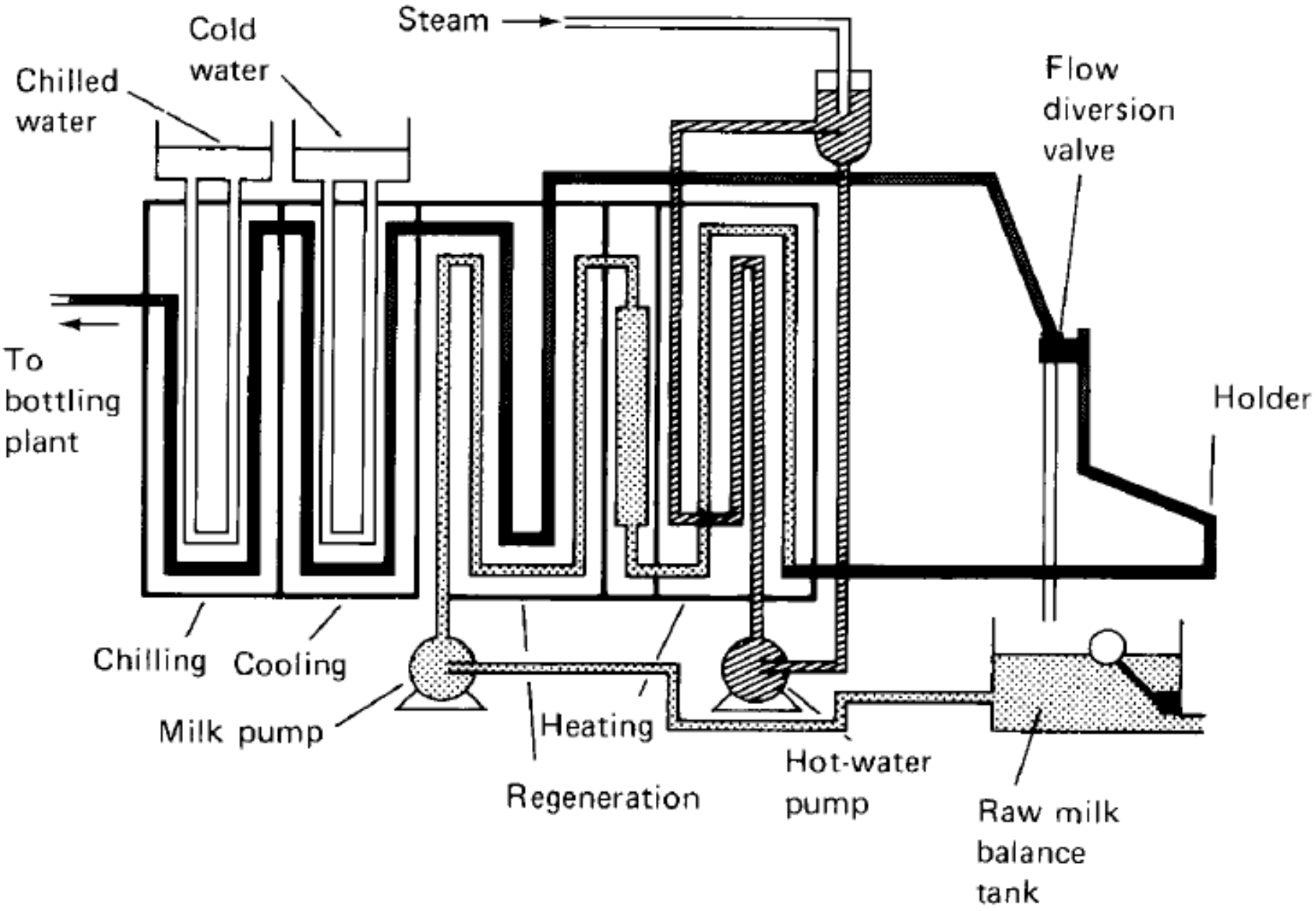
Plate heat exchanger.
(Courtesy of Wincanton Engineering Ltd.)



Counter-current flow through plate heat exchanger: (a) one pass with four channels per medium; (b) two passes with two channels per pass and per medium.
(Courtesy of HRS Heat Exchangers Ltd.)

- Each plate is fitted with a synthetic rubber gasket
- The plates are corrugated to induce turbulence in the liquids

  → turbulence + high velocity induced by pumping reduces thickness of boundary films → high heat transfer coefficients.



Pasteurising using a plate heat exchanger.
(Courtesy of APV Ltd.)

- If the pasteurising temperature is not reached
  → a flow diversion valve automatically returns food to balance tank to be re-pasteurised

$$\text{heat recovery } (\%) = \frac{\theta_2 - \theta_1}{\theta_3 - \theta_1} \times 100$$

- θ_1 (ºC): inlet temperature,
- θ_2 (ºC): pre-heating temperature
- θ_3 (ºC): pasteurisation temperature.

- Advantages of HEs over in-bottle processing:
  - more uniform heat treatment
  - simpler equipment & lower maintenance costs
  - lower space & labour costs
  - greater flexibility for different products
  - greater control over pasteurisation conditions.

Concentric tube HE

→ for more viscous foods; dairy products, mayonnaise, tomato ketchup & baby foods.

→ a number of concentric stainless steel coils

→ each made from double- or triple-walled tube.

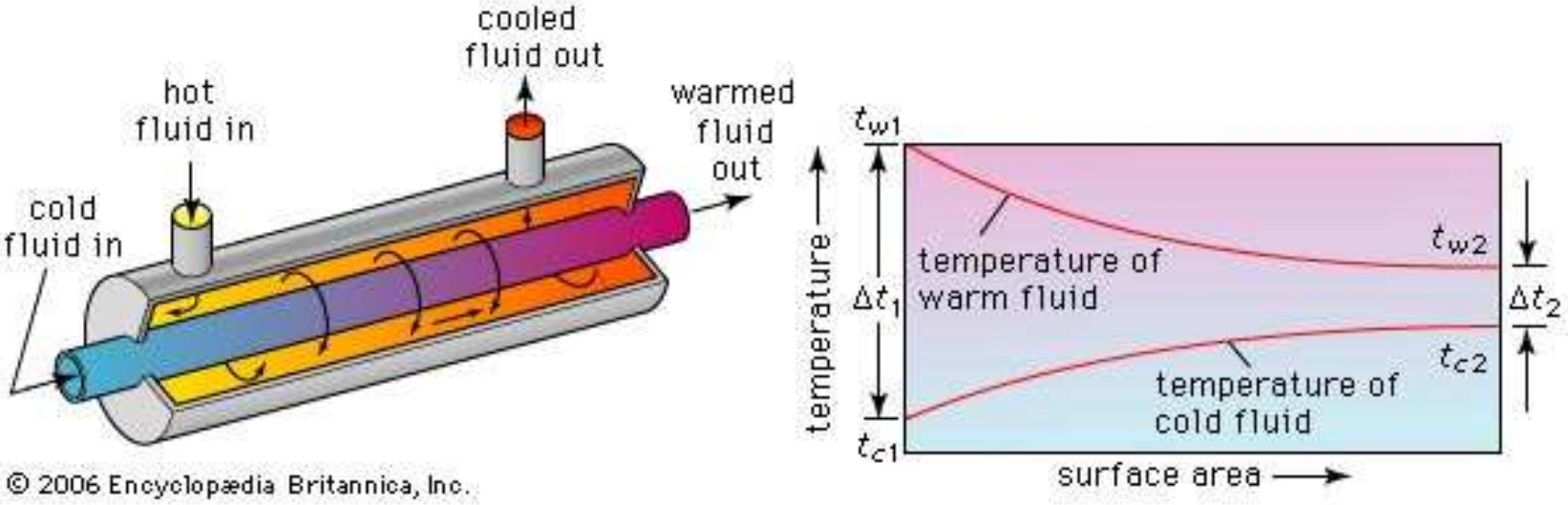
→ Food passes through the tube

→ heating or cooling water is re-circulated through the tube walls.

→ Liquid food is passed from one coil to the next for heating & cooling

→ heat is regenerated to reduce energy costs.

→ Pasteurised food is immediately filled into cartons or bottles & sealed.


cooled
fluid out
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t_{w1}
temperature
Δt_1
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temperature of
warm fluid
t_{w2}
Δt_2
t_{c2}
temperature of
cold fluid
surface area
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- spoilage & risks from pathogens

  → from post-pasteurisation contamination,

  → when foods (e.g. milk) are not re-heated before consumption

  → cleaning & hygiene

- Products should be stored at refrigerated temperature until consumption.

Effect on foods

- minor changes to nutritional & sensory characteristics of most foods.
- shelf life: few days or weeks

Effect: *Colour, flavour and aroma*

- Fruit juices
  → colour deterioration
  → enzymic browning by PPO.
  → promoted by the presence of oxygen
  → fruit juices are de-aerated prior to pasteurisation.

- Whiteness of raw milk & pasteurised milk differs
  → due to homogenisation
  → pasteurisation alone → no measurable effect.
- Other pigments in plant & animal products are mostly unaffected.
- Small loss of volatile aroma compounds during pasteurisation of juices.
- Volatile recovery may be used to produce high quality juices.
- Loss of volatiles from raw milk removes a hay-like aroma & produces a blander product.

Effect: *Vitamin loss*

- In fruit juices, losses of vitamin C & carotene are minimised by de-aeration.
- Changes to milk are confined to a 5% loss of serum proteins & small changes to vitamin content.

Vitamin losses during pasteurisation of milk

Vitamin	Method of pasteurisation	
	HTST	Holder
Vitamin A		
Vitamin D		
Riboflavin		
Vitamin B_6	0	0
Pantothenic acid		
Nicotinic acid		
Biotin		
Folic acid		
Thiamin	6.8	10
Vitamin C	10	20
Vitamin B_{12}	0	10

From Ford *et al.* (1969).

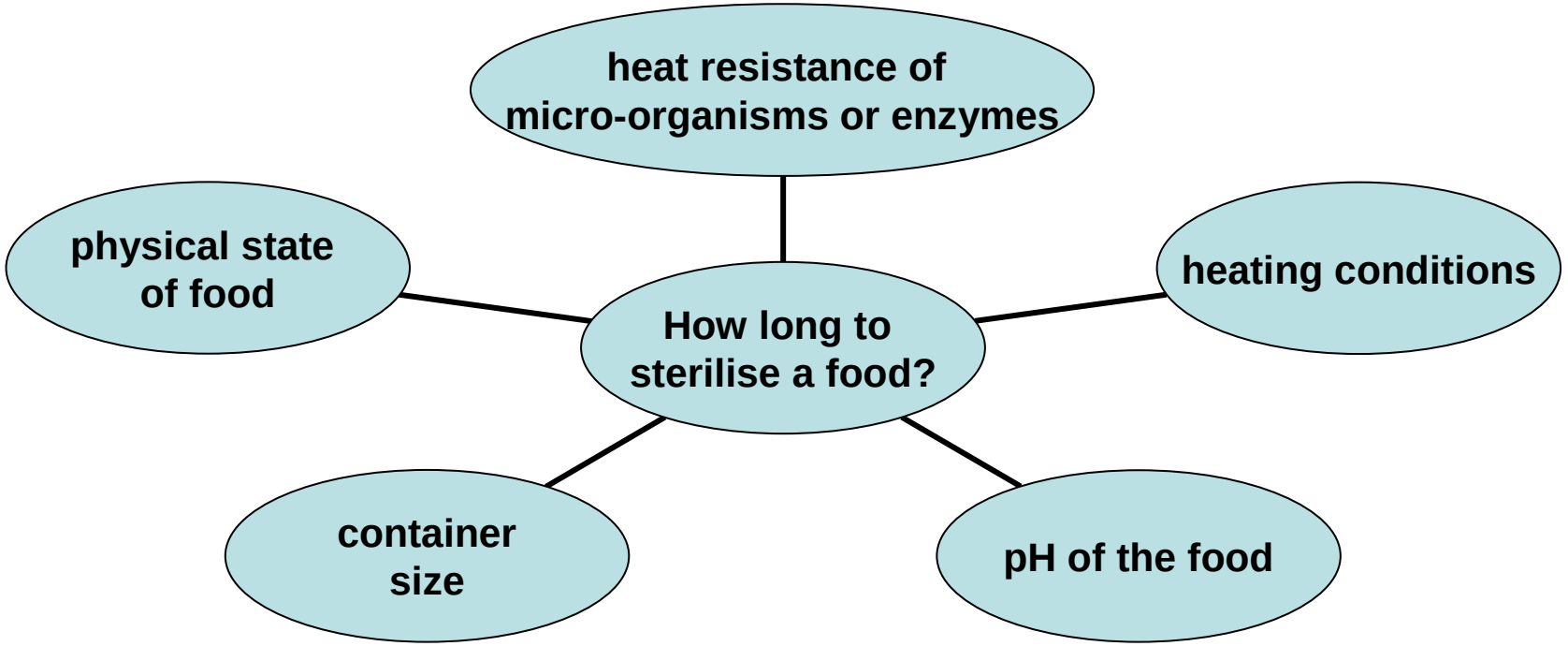
Heat sterilisation

- unit operation; foods are heated sufficiently at high temperature & for long time to destroy microbial & enzyme activity.
- a shelf life > 6 mo at ambient temperatures.

- Severe heat treatment during the older process of in-container sterilisation (canning) may produce substantial changes in nutritional and sensory qualities of foods.
- Developments → to reduce damage to nutrients & sensory components.

- Part 1: in-container heat sterilisation
- Part 2: UHT processes.

1. In-container sterilisation



- process time

→ heat resistance of micro-organisms (spores) or enzymes

→ rate of heat penetration into the food.

Heat resistance of micro-organisms

- Most heat resistant spores have a *z* value of around 10ºC.

Low-acid foods (pH>4.5)

- Destruction of *C. botulinum* is a *minimum* requirement of heat sterilisation.
- Normally, foods receive more than minimum treatment as other more heat-resistant spoilage bacteria may also be present.

More acidic foods (pH 4.5–3.7)

- other micro-organisms (e.g. yeasts and fungi) or heat-resistant enzymes are used to establish processing times and temperatures.

Acidic foods (pH < 3.7)

- enzyme inactivation (*pasteurisation*).

- Thermal destruction of micro-organisms

  → logarithmically

  → a sterile product cannot be produced with certainty no matter how long the process time.

- The *probability* of survival of a single micro-organism can be predicted

  → using details of heat resistance of micro-organism &

  → temperature & time of heating.

  ➔ *commercial sterility*.

- E.g. a process that reduces cell numbers by 12 decimal reductions (a 12*D* process), applied to a raw material contains 1000 spores per container would reduce microbial numbers to 10^{-9} per container, or the probability of one microbial spore surviving in one billion containers processed.

- Commercial sterility → inactivates substantially all micro-organisms & spores which, if present, would be capable of growing in food under defined storage conditions.

- The level of survival is determined by type of micro-organism that is expected to contaminate raw material.

- A 12*D* process → *C. botulinum* is likely to be present in low acid foods

Heat resistance of some spore-forming bacteria[a] used as a basis for heat sterilisation of low acid foods

Micro-organism	z value (°C)	D_{121} value (min)	Typical foods
Thermophilic (35–55°C)			
Bacillus stearothermophilus	9–10	3.0–4.0	Vegetables, milk
Clostridium thermosaccharolyticum	7.2–10	3.0–4.0	Vegetables
Mesophilic (10–40°C)			
Clostridium sporogenes	8.8–11.1	0.7–1.5	Meats
Bacillus subtilis	4.1–7.2	0.3–0.76	Milk products
Cl. botulinum toxins A and B	5.5	0.1–0.3	Low-acid foods
B. coagulans	6–9	0.01–0.07	Milk
B. cereus	36	3.8	Milk
Psychrophilic (−5−1.5°C)	10	3.0 (60°C)	Low-acid foods
Cl. botulinum toxin E			

[a] Note: the data is intended to be indicative only as the thermal resistance of micro-organisms is influenced by the nature of the food. Original literature gives precise information for particular products.
Adapted from Lund (1975), Burton (1988), Brennan *et al.* (1990), Heldman and Hartel (1997) and Licciardello *et al.* (1967).

- In practice a 2*D* to 8*D* process → most economical level of food spoilage consistent with adequate food quality & safety.

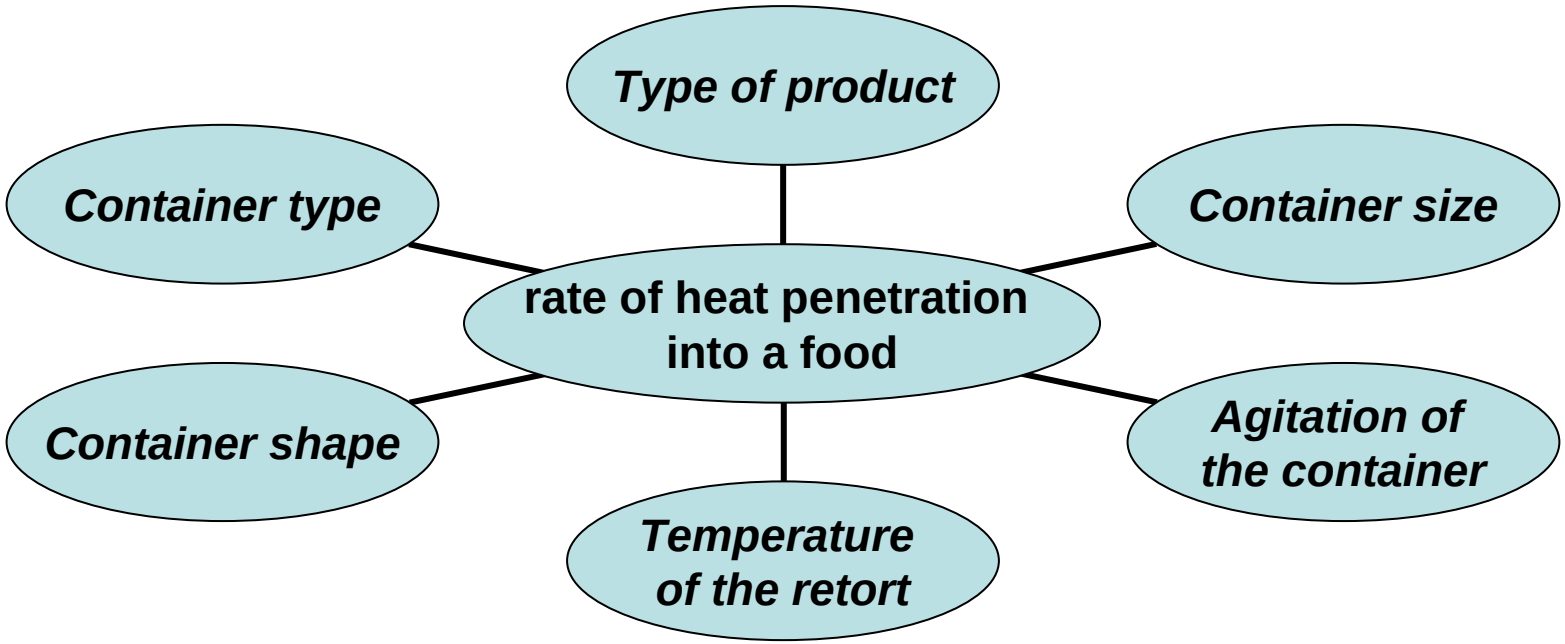
  → microbial load on raw materials must be kept at a low level.

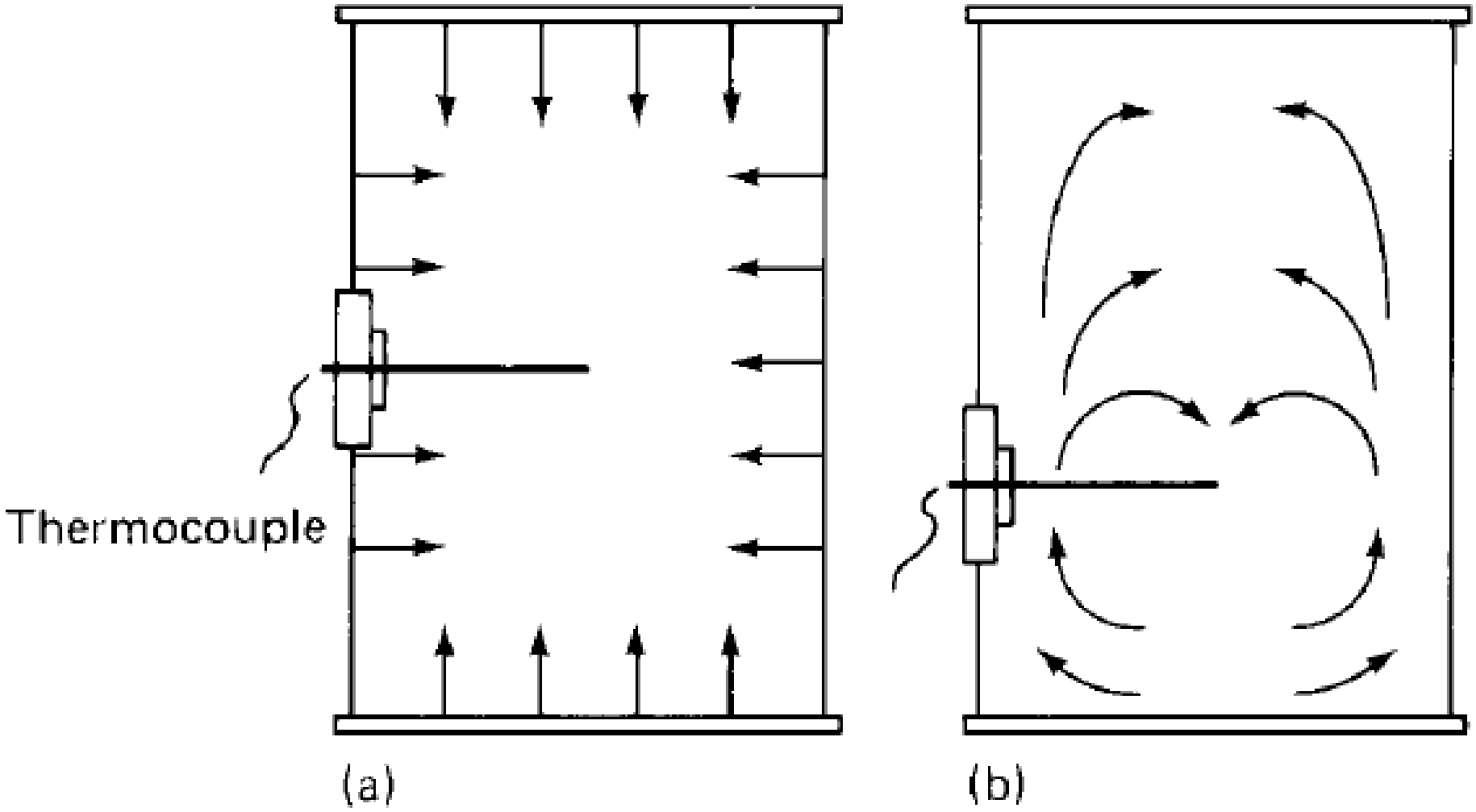
- When *C. botulinum* grows & produces toxin in a sealed container there is characteristic production of gas which can cause visible swelling of the container

  (not the only cause of swelling).

Rate of heat penetration

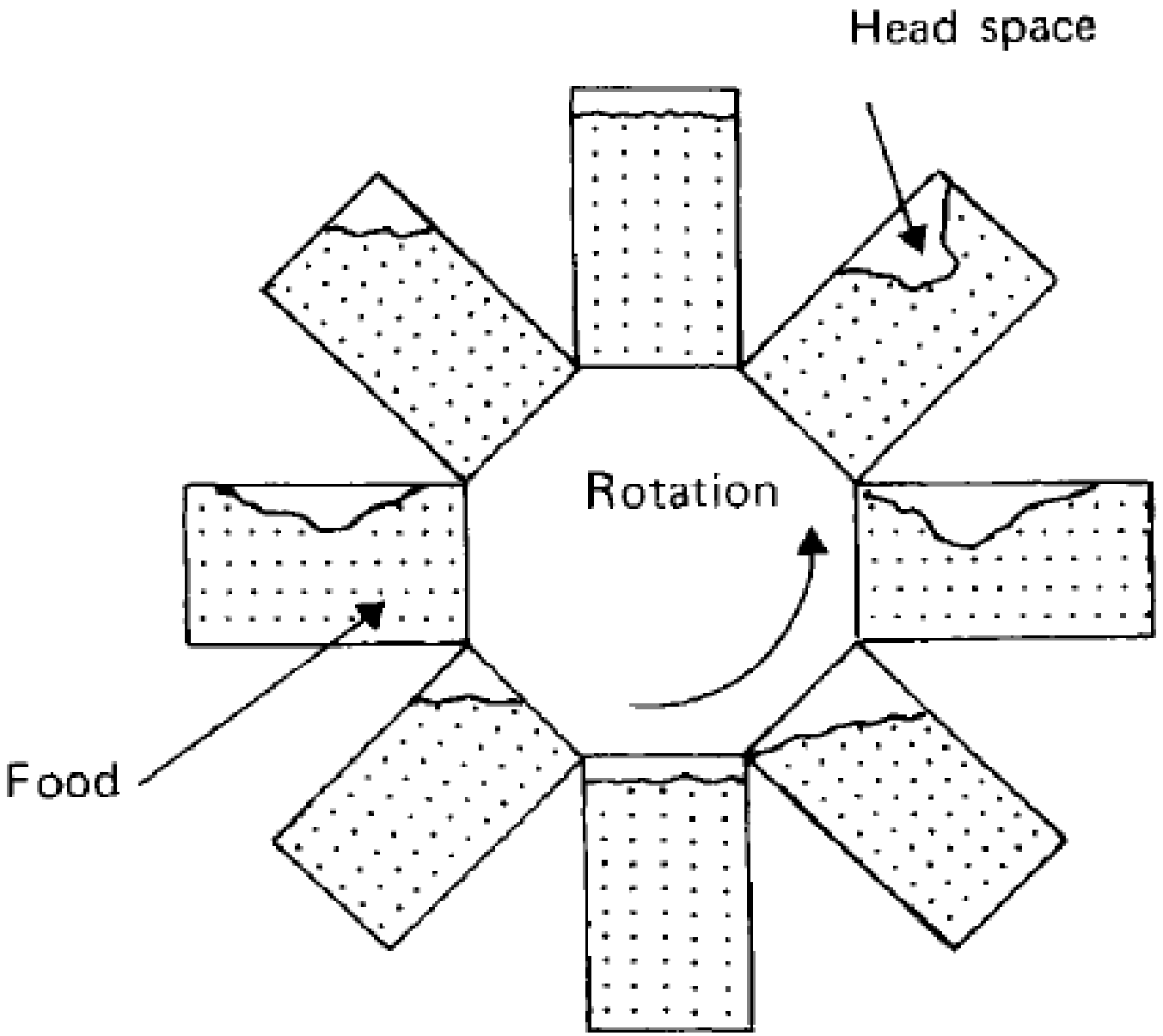
- Heat is transferred from steam or pressurised water through the container & into food.
- Generally the surface heat transfer coefficient is very high and is not a limiting factor in heat transfer.





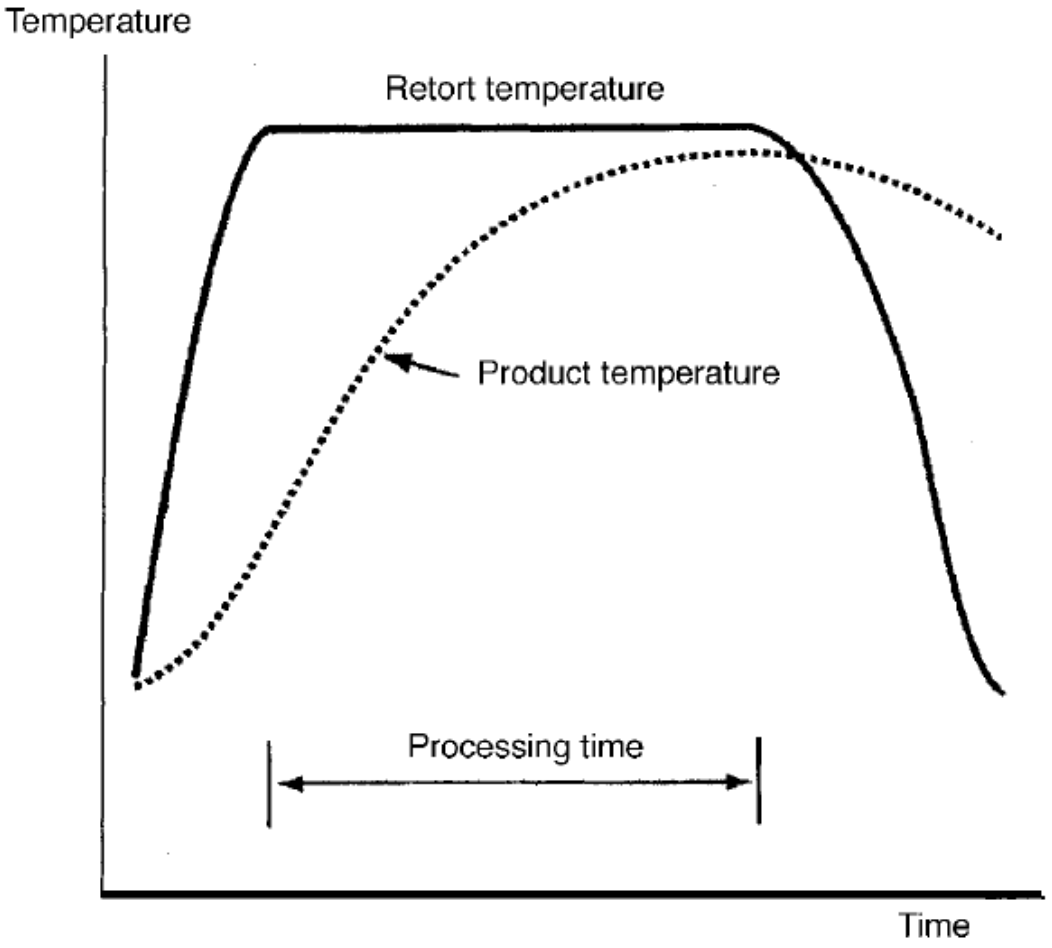
Heat transfer into containers by (a) conduction and (b) convection.

- In cylindrical containers, the thermal centre is
  at the geometric centre for conductive heating foods
  appr 1/3 up from the base of container for convective heating foods.
- In convective heating, the exact position varies & should be found experimentally.
- Convective heating is more rapid than conductive heating & the rate depends mostly on viscosity of food.
- In commercial processing, containers of viscous food may be agitated to increase the rate of convective heating.



End-over-end agitation of containers.
(After Hersom and Hulland (1980).)

- A typical heating curve → plotting temperature vs. time on semi logarithmic graph paper.



Heat penetration into a can of conductive heating food: (a) = retort temperature; (b) = temperature at the slowest heating point.

- A broken heating curve occurs when a food is initially heated by convective heating but then undergoes a rapid transition to conductive heating (e.g. in foods which contain a high concentration of starch which undergoes a sol-to-gel transition).

- The thermal death time (TDT) or *F value*
  → basis for comparing heat sterilisation procedures.
  → time required to achieve a specified reduction in microbial numbers at a given temperature
  → the total time–temperature combination received by a food.

- a process operating at 115ºC based on a micro-organism with a *z* value of 10ºC → F^{10}_{115}

- *F* value → time to reduce microbial numbers by a multiple of the *D* value.

$$F = D(\log n_1 - \log n_2)$$

- n_1; n_2 = initial; final number of micro-organisms.
- A reference *F* value (F_0) → to describe processes that operate at 121ºC which are based on a micro-organism with a *z* value of 10ºC.

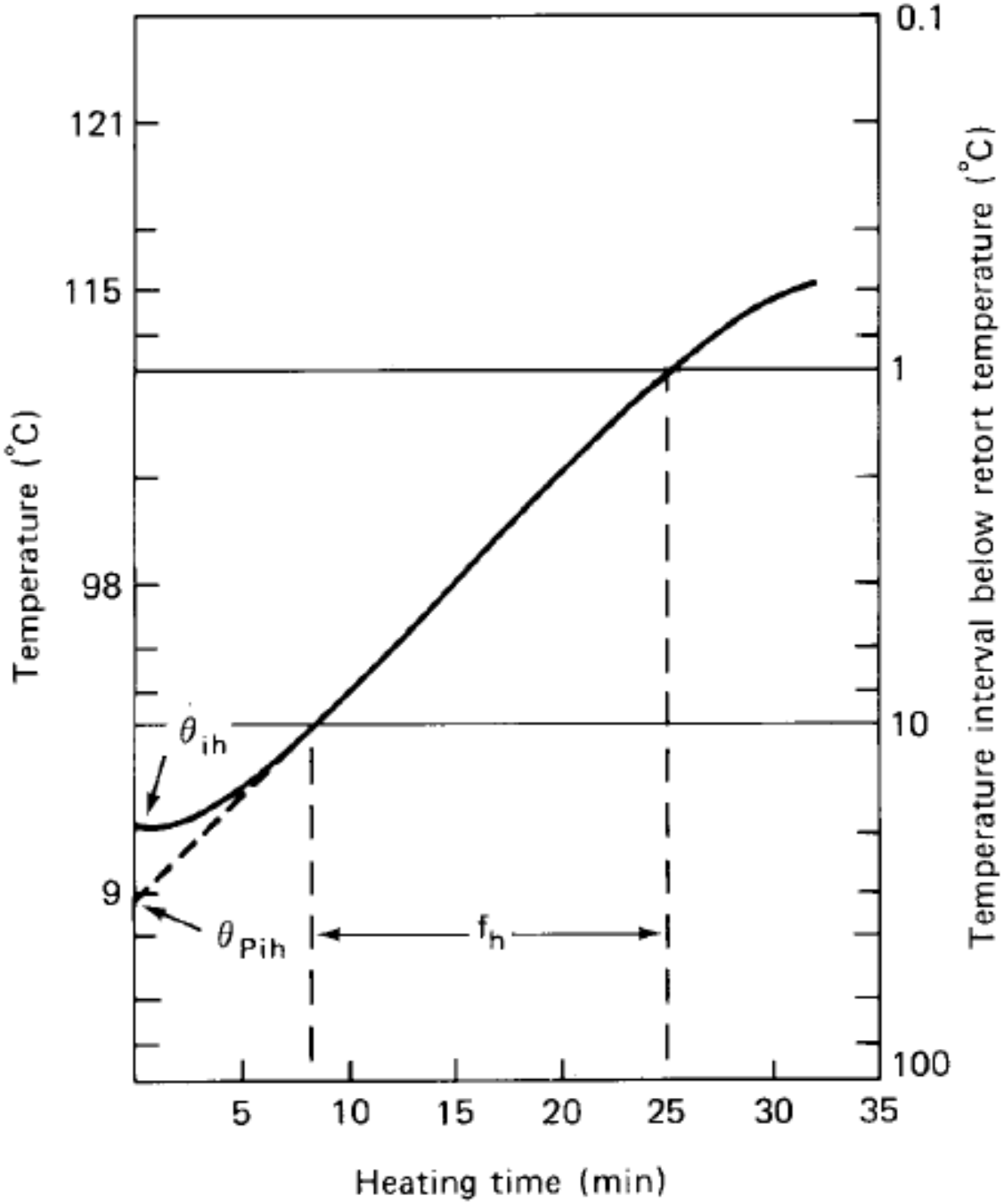
Calculation of process times

subject for independent study

- The slowest heating point in a container may not reach processing temperature,

  but once the temperature of food rises > appr. 70ºC → thermal destruction of micro-organisms.

- Purpose → how long a food in a given can size should be held at a set processing temperature in order to achieve the required thermal destruction at the slowest heating point in the container.
- Methods:
  - mathematical
  - graphical



Heating curve.

Mathematical method

- Rapid calculation for different retort temperatures or container sizes
- limited by the assumptions about the nature of heating process.

$$B = f_h \log\left(\frac{j_h I_h}{g}\right)$$

- *B* (min): time of heating,
- f_h (min): heating rate constant = time for the heat penetration curve to cover one log. cycle
- j_h: thermal lag factor

$$j_h = \frac{\theta_r - \theta_{pih}}{\theta_r - \theta_{ih}}$$

- pseudo-initial product temperature (θ_{ih}).
- I_h (=$\theta_r - \theta_{ih}$) (ºC): difference between retort & initial product temperature,
- *g*: difference between retort & final product temperature at the slowest heating point,
- θ_r (ºC): retort temperature
- θ_{ih} (ºC): initial product temperature.

- Heating rate constant varies according to
  - surface area : volume ratio of the container
  - shape & size of the pack.
  - whether the product heats by convection or conduction.

- Cooling rate data are plotted in a similar way.

- Value of *g* is influenced by:
  - TDT of micro-organism on which process is based
  - slope f_h of heating curve
  - *z* value of target micro-organism
  - difference between retort temperature & temperature of cooling water.

- Concept of comparing the *F* value at the retort temperature (F_1) with a reference *F* value of 1 min at 121ºC (*F*).
- The TDT at the retort temperature (*U*) :

$$U = FF_1$$

- If the reference *F* value is known

  → calculate *U* by consulting F_1 tables.
- The value of *g*

  → f_h/u *& g* tables.

  → difference between retort temperature & temperature of cooling water.

- Conductive heating foods

  → a lag before cooling water begins to lower product temperature

  → significant amount of heating after steam has been turned off.

➔ a cooling lag factor j_c:

- 'time taken for the cooling curve to cover one log. cycle'

  → analogous to j_h (heating lag factor).

$$j_c = \frac{\theta_c - \theta_{pic}}{\theta_c - \theta_{ic}}$$

- θ_c (ºC) = cooling water temperature
- θ_{ic} (ºC) = actual product temperature at the start of cooling.

- Batch retorts

  → only 40% of the time taken for retort to reach operating temperature (come-up time, *I*)

  → at a sufficiently high temperature to destroy microorganisms.

  → The calculated time of heating (*B*)

  → adjusted to give corrected processing time:process time

$$\text{process time} = B - 0.4I$$

- More complex formulae to calculate processing times where the product displays a broken heating curve.

F_1 values for selected z values at retort temperatures below 121°C

$121-\theta_r$ (°C)	z value					
	4.4°C	6.7°C	8.9°C	10°C	11.1°C	12°C
5.6	17.78	6.813	4.217	3.594	3.162	2.848
6.1	23.71	8.254	4.870	4.084	3.548	3.162
6.7	31.62	10.00	5.623	4.642	3.981	3.511
7.2	42.17	12.12	6.494	5.275	4.467	3.899
7.8	56.23	14.68	7.499	5.995	5.012	4.329
8.3	74.99	17.78	8.660	6.813	5.623	4.806
8.9	100.0	21.54	10.00	7.743	6.310	5.337
9.4	133.4	26.10	11.55	8.799	7.079	5.926
10.0	177.8	31.62	13.34	10.00	7.943	6.579
10.6	237.1	38.31	15.40	11.36	8.913	7.305

Adapted from Stumbo (1973).

Selected f_h/U and g values when $z = 10$ and $j_c = 0.4$–2.0

	Values of g for the following j_c values					
f_h/U	0.40	0.80	1.00	1.40	1.80	2.00
0.50	0.0411	0.0474	0.0506	0.0570	0.0602	0.0665
0.60	0.0870	0.102	0.109	0.123	0.138	0.145
0.70	0.150	0.176	0.189	0.215	0.241	0.255
0.80	0.226	0.267	0.287	0.328	0.369	0.390
0.90	0.313	0.371	0.400	0.458	0.516	0.545
1.00	0.408	0.485	0.523	0.600	0.676	0.715
2.00	1.53	1.80	1.93	2.21	2.48	2.61
3.00	2.63	3.05	3.26	3.68	4.10	4.31
4.00	3.61	4.14	4.41	4.94	5.48	5.75
5.00	4.44	5.08	5.40	6.03	6.67	6.99
10.0	7.17	8.24	8.78	9.86	10.93	11.47
20.0	9.83	11.55	12.40	14.11	14.97	16.68
30.0	11.5	13.6	14.6	16.8	18.9	19.9
40.0	12.8	15.1	16.3	18.7	21.1	22.3
50.0	13.8	16.4	17.7	20.3	22.8	24.1
100.0	17.6	20.8	22.3	25.4	28.5	30.1
500.0	26.0	30.6	32.9	37.5	42.1	44.4

Adapted from Stumbo (1973).

Graphical method

- Basis: different combinations of temperature & time have the same lethal effect on micro-organisms.
- Temperature increases → logarithmic reduction in time needed to destroy the same number of micro-organisms.
- The *lethal rate* (the reciprocal of TDT)

$$\text{Lethal rate} = 10^{(\theta - 121)/z}$$

- θ (ºC) = temperature of heating.
- The TDT at a given processing temperature is compared to a reference temperature (T) of 121ºC.
- E.g. if a product is processed at 115ºC and the most heat-resistant micro-organism has a z value of 10ºC,

  Lethal rate = $10^{(115-121)/10} = 0.25$

- As temperature of food increases during processing; higher rate of microbial destruction.

- Initial heating part of process contributes little towards total lethality until the retort temperature is approached
- Most of accumulated lethality takes place in last few minutes, before cooling begins.

- Lethal rate depends on the *z* value of micro-organism on which process is based & product temperature

- Conduction heating foods

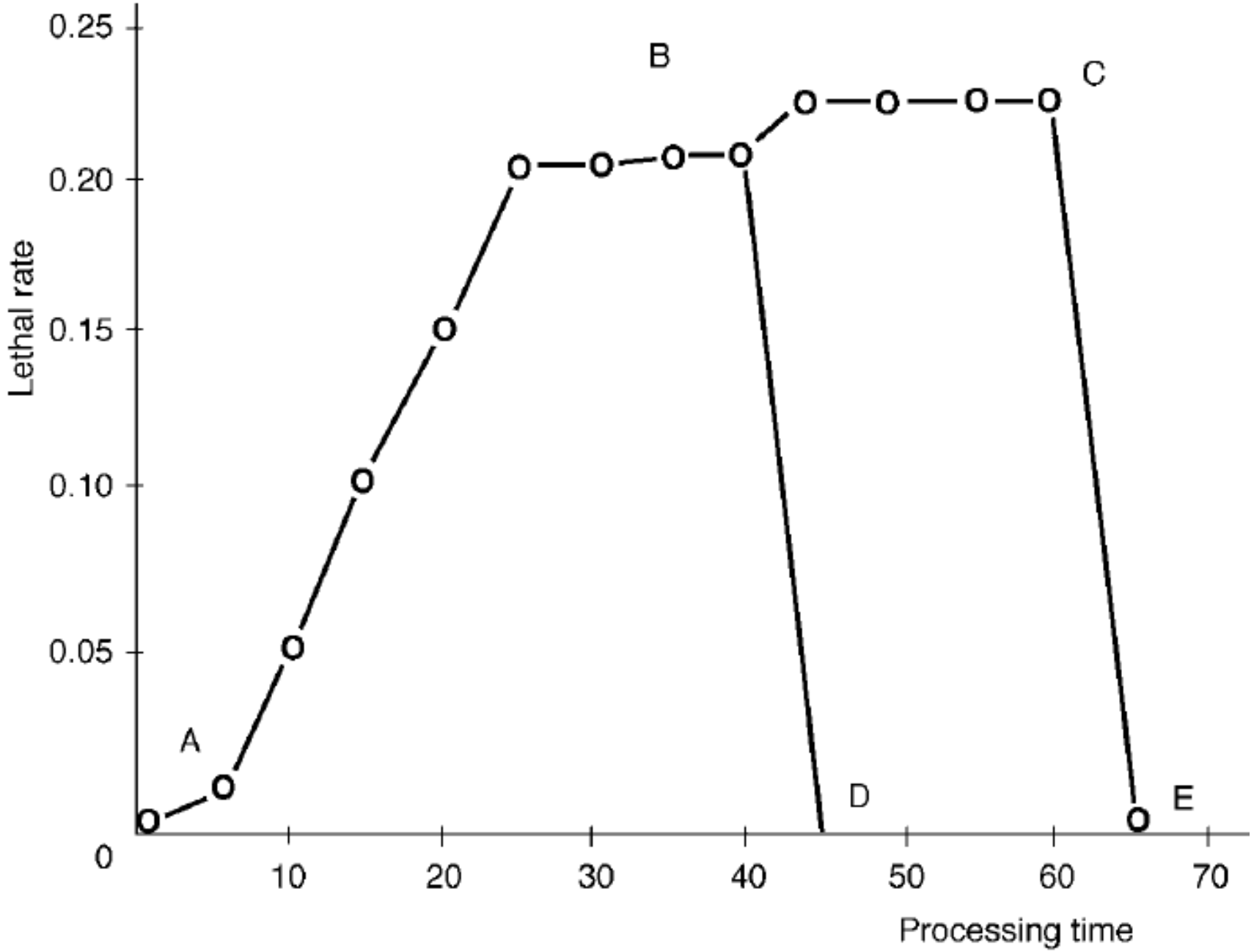
  → temperature at the centre of container may continue to rise after cooling commences because of low rate of heat transfer.

- it is necessary to determine lethality after a number of trials in which heating is stopped at different times.

Lethal rates for z = 10°C

Temperature (°C)	Lethal rate (min[a])	Temperature (°C)	Lethal rate (min)
90	0.001	108	0.049
92	0.001	110	0.077
94	0.002	112	0.123
96	0.003	114	0.195
98	0.005	116	0.308
100	0.008	118	0.489
102	0.012	120	0.774
104	0.019	122	1.227
106	0.031	124	1.945

[a] At 121°C per minute at θ_r.
Adapted from Stumbo (1973).



Lethal rate curve.

F_0 values for selected commercial processes

Product	F_0 values
Carrots in brine	3–4
Beans in tomato sauce	4–6
Herrings in tomato sauce	6–8
Meat in gravy	12–15

Retorting (heat processing)

- Shelf life of sterilised foods depends in part on the ability of the container to isolate food completely from environment.

- Heat-sterilisable container:

- Removing air (exhausting) before filled containers are processed

  → prevents air expanding with the heat

  → reduces strain on container.

  → prevents internal corrosion & oxidative changes in some foods.

- Steam replaces the air & on cooling forms a partial vacuum in the head space.

Exhausting containers:

- hot filling food into container (also pre-heats food reduces processing times)

- cold filling food then heating container & contents to 80–95ºC with the lid partially sealed (clinched)

- mechanical removal of air using a vacuum pump

- steam flow closing; a blast of steam carries air away from the surface of food immediately before container is sealed.
  - to liquid foods where little air trapped, surface is flat & does not interrupt the flow of steam.

Heating by saturated steam

- Latent heat is transferred to food when saturated steam condenses on the outside of container.
- If air is trapped inside the retort, it forms an insulating boundary film around the cans which prevents steam from condensing → under processing.
- Produces a lower temperature than that obtained with saturated steam.
- All air is removed from retort by incoming steam (*venting*).

- Problem with processing solid or viscous foods → low rate of heat penetration to the thermal centre.
- Over-processing → damage to nutritional & sensory characteristics of food near the walls of container
- To increase rate of heat transfer → thinner profile containers & agitation of containers.
- Increase retort temperature → reduce processing times & protect nutritional & sensory qualities, but impractical;
- higher pressures → require substantially stronger & more expensive containers & processing equipment.

- After sterilisation the containers are cooled by sprays of water.
- Steam is rapidly condensed in retort, but food cools more slowly & pressure in containers remains high.
- Compressed air to equalise pressure to prevent strain on container seams (pressure cooling).
- When food has cooled to < 100ºC, the over-pressure of air is removed & cooling continues to appr. 40ºC.
- At this temperature, moisture on container dries which prevents surface corrosion & allows label adhesives to set more rapidly.

Temperatures of saturated steam at gauge pressures from 0 kPa to 199 kPa (0–29 lb ft^{-2})

Temperature (°C)	Pressure (lb ft^{-2})	Pressure (kPa)	Temperature (°C)	Pressure (lb ft^{-2})	Pressure (kPa)
100.0	0	0	121.0	15	103.4
101.9	1	6.9	122.0	16	110.3
103.6	2	13.8	123.0	17	117.2
105.3	3	20.7	124.1	18	124.1
106.9	4	27.6	125.0	19	131.0
108.4	5	34.5	126.0	20	137.9
109.8	6	41.4	126.9	21	144.8
111.3	7	48.3	127.9	22	151.7
112.6	8	55.2	128.7	23	158.6
113.9	9	62.1	129.6	24	165.5
115.2	10	68.9	130.4	25	172.4
116.4	11	75.8	131.2	26	179.3
117.6	12	82.7	132.1	27	186.2
118.8	13	89.6	133.0	28	193.1
119.9	14	96.5	133.6	29	199.9

Heating by hot water

- Foods are processed in glass containers or flexible pouches under hot water with an overpressure of air.
- Glass containers; thick & lower thermal conductivity of glass → slower heat penetration, longer processing times, higher risk of thermal shock than cans.
- Foods in rigid polymer trays or flexible pouches heat more rapidly → thinner material & smaller cross-section of container.
- Liquid or semi-liquid foods are often processed horizontally to ensure thickness of food is constant across the pouch.
- Vertical packs promote better circulation of hot water in retort, but special frames are necessary to prevent pouches from bulging at the bottom.

Heating by flames

- High rates of heat transfer are possible at flame temperatures of 1770ºC.
- Short processing times → foods of high quality & reduce energy consumption

- No brine or syrup is used in the can & smaller cans may be used.
- High internal pressures (275 kPa at 130ºC) limit to small cans.
- E.g. to process mushrooms, sweetcorn, green beans, pears & cubed beef.

Equipment

- Batch or continuous.

Batch retorts

- Vertical or horizontal
- Horizontal: easier to load & unload and have facilities for agitating containers, but require more floor space.

Continuous retorts

- permit close control over processing conditions
- produce more uniform products.
- produce gradual changes in pressure inside cans
- less strain on can seams.

- high in-process stock → lost if a breakdown occurred
- problems with metal corrosion & contamination by thermophilic bacteria if adequate preventative measures are not taken.

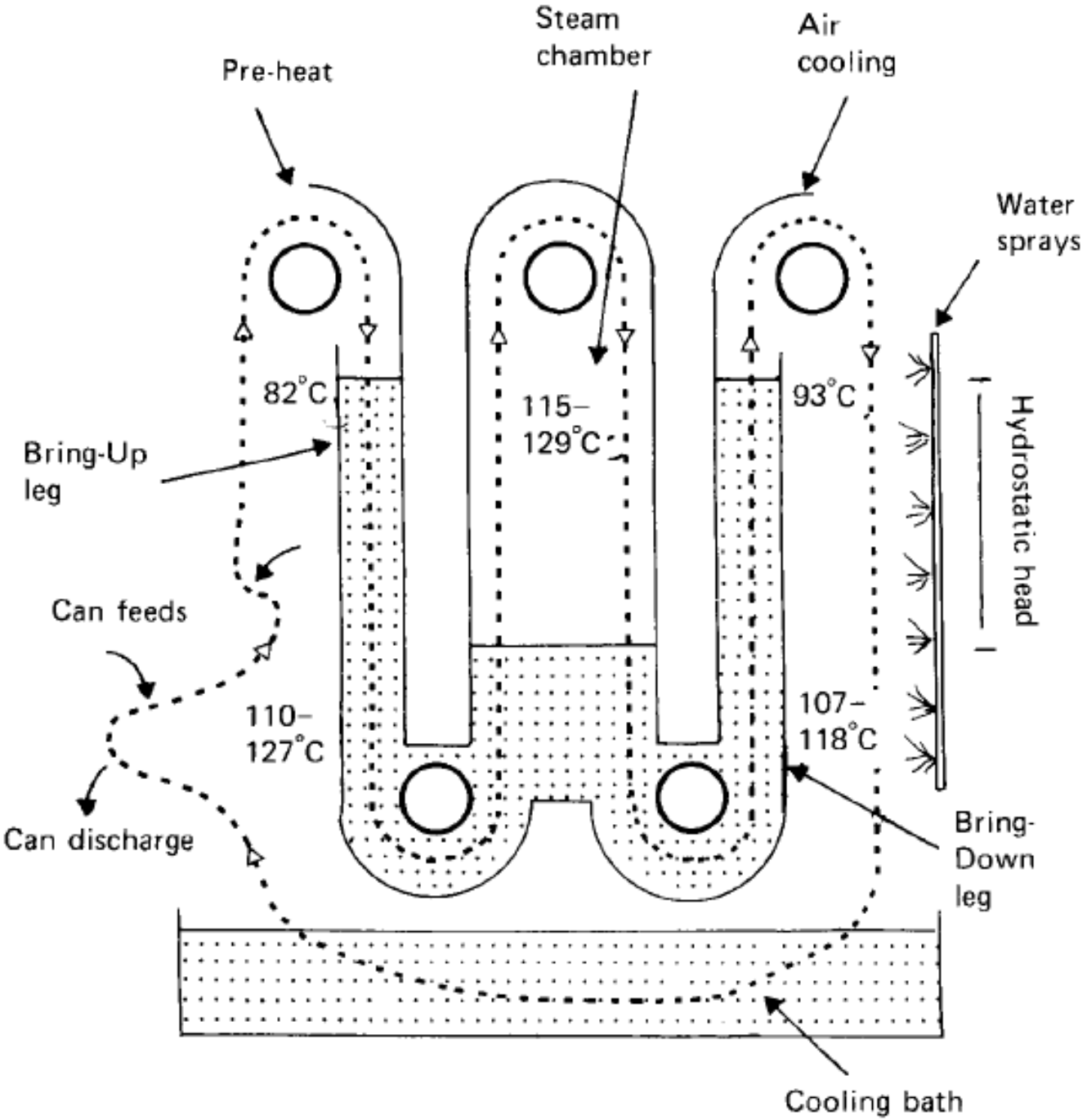
- Types:

  cooker-coolers,

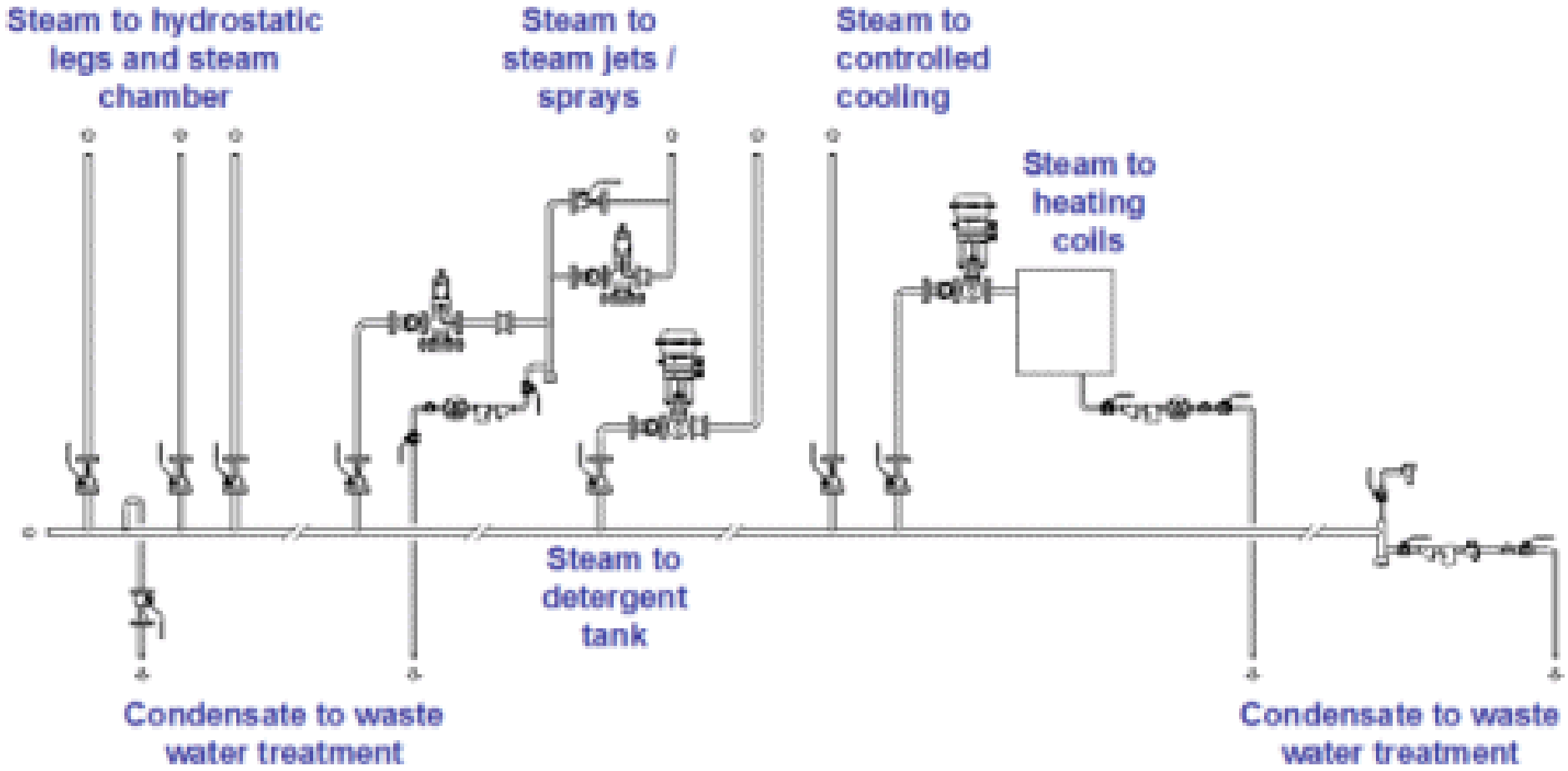
  rotary sterilisers,

  hydrostatic sterilisers.

- In practice, large continuous sterilisers are used for the production of high-volume products (e.g. 1000 cans per min)



Continuous hydrostatic steriliser.


Steam to hydrostatic legs and steam chamber
Steam to steam jets / sprays
Steam to controlled cooling
Steam to heating coils
Steam to detergent tank
Condensate to waste water treatment
Condensate to waste water treatment

- process variables monitored:
  - temperature of raw material
  - temperature of cooling water
  - temperature of steam
  - time of processing
  - heating & cooling rates.

2. UHT | aseptic processes

- Higher processing temperatures for a shorter time are possible if the product is sterilised before it is filled into pre-sterilised containers in a sterile atmosphere.

- Liquid foods: milk, fruit juices and concentrates, cream, yoghurt, wine, salad dressing, egg & ice cream mix.
- Foods with small discrete particles: cottage cheese, baby foods, tomato products, fruit & vegetables, soups & rice desserts.

- High quality of UHT foods ~ chilled & frozen foods
- Shelf life of at least 6 mo without refrigeration.

- UHT conditions are independent of container size.

- E.g. - conventional retorting of A2 cans of vegetable soup requires 70 min at 121ºC to achieve F_0 value 7 min, followed by 50 min cooling,

  - aseptic processing in a scraped-surface heat exchanger at 140ºC for 5 s gives F_0 value of 9 min.

  - Increasing the can size to A10 increases the processing time to 218 min, whereas with aseptic processing the sterilisation time is the same.

Main limitations of UHT processing

- cost & complexity of the plant

  → necessity to sterilise packaging materials, associated pipework & tanks,

  → maintenance of sterile air & surfaces in filling machines,

  → higher skill levels required by operators & maintenance staff.

Theory

- Given increase in temperature

  → rate of destruction of micro-organisms & many enzymes increases faster than rate of destruction of nutrients & sensory components

- Some enzymes, e.g. proteases & lipases are more heat resistant.

  → not destroyed by some UHT treatments & may cause changes to flavour of products during prolonged storage.

Comparison of conventional canning and aseptic processing and packaging

Criteria	Retorting	Aseptic processing and packaging
Product sterilisation		
Delivery	Unsteady state	Precise, isothermal
Process calculations		
Fluids	Routine – convection	Routine
Particulates	Routine – conduction or broken heating	Complex
Other sterilisation required	None	Complex (process equipment, containers, lids, aseptic tunnel)
Energy efficiency	Lower	30% saving or more
Sensory quality	Unsuited to heat sensitive foods	Superior – suitable for homogenous heat sensitive foods
Nutrient loss	High	Minimal
Value added	Lower	Higher
Convenience	Shelf stable	Shelf stable
Suitability for microwave heating	Glass and semi-rigid containers	All non-foil rigid and semi-rigid containers
Production rate	High (600–1000/min)	Medium (500/min)
Handling/labour costs	High	Low
Downtime	Minimal (mostly seamer and labeller)	Re-sterilisation needed if loss of sterility in filler or steriliser
Flexibility for different container sizes	Need different process delivery and/or retorts	Single filler for different container sizes
Survival of heat resistant enzymes	Rare	Common in some foods (e.g. milk)
Spoilage troubleshooting	Simple	
Low acid particulate processing	Routine	Not in practice (data from high acid systems being used to design low acid systems)
Post-process additions	Not possible	Possible to add filter sterilised enzymes or probiotics after heat processing

Adapted from David (1996).

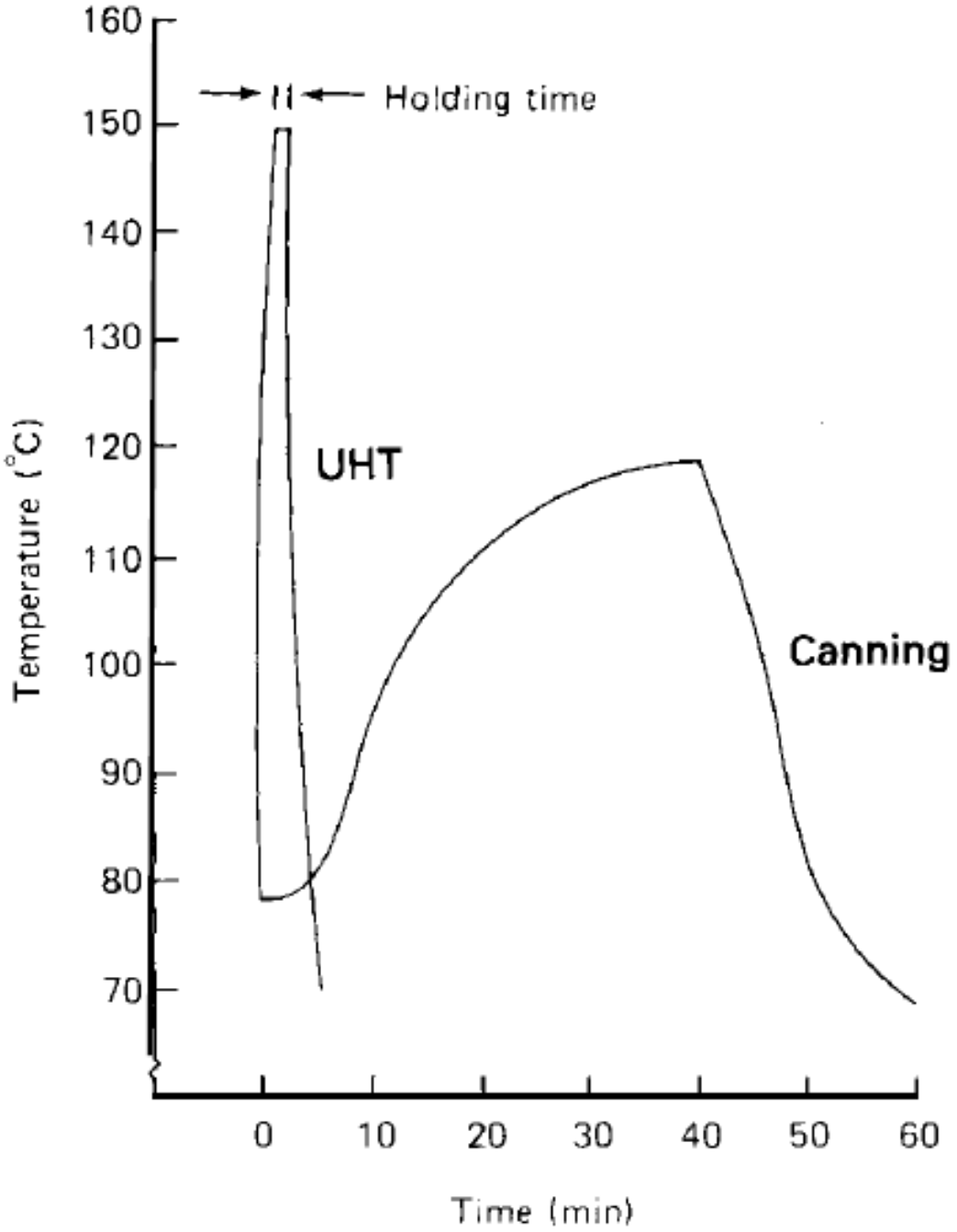
- UHT processes heat food rapidly to holding temperature & major part of lethality accumulates at a constant temperature.

- Sterilising value = lethal rate at the holding temperature * holding time.
- The come-up time & cooling periods are very short

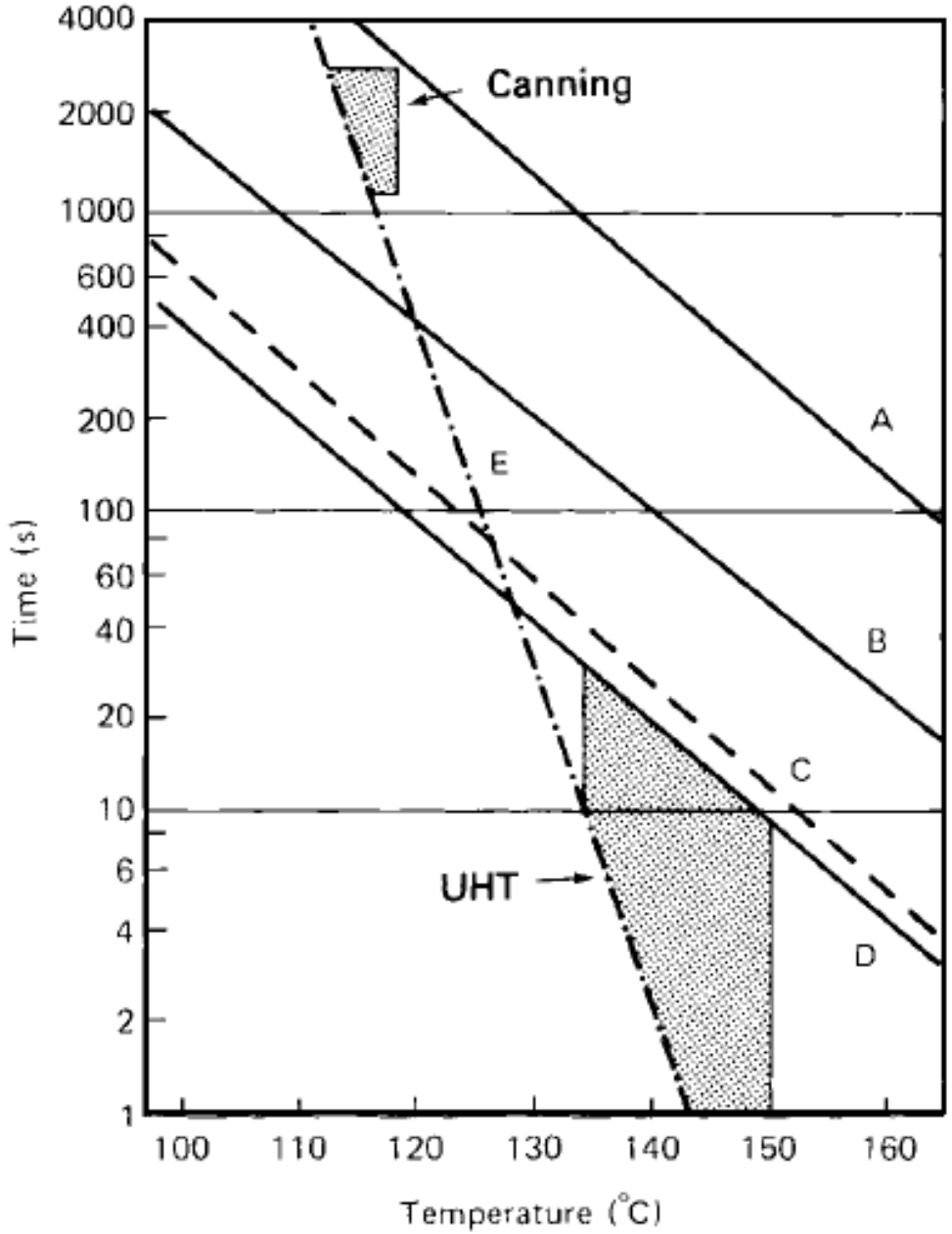
- Time-temperature to achieve required F_0 value?

  → flow rate for the fastest moving particle

  → longest time needed for heat transfer from liquid to the centre of particle
- criteria = canning → attainment of commercial sterility.
- Typical minimum time–temperature conditions to destroy *C. botulinum* (F_0 = 3) = 1.8 s at 141ºC.



Time–temperature conditions for UHT and canning



rates of microbial and nutrient destruction in UHT processing: line A, 40% thiamin; line B, 10% thiamin; line C, 1% lysine; line D, 3% thiamin; line E, microbial.

- Beside F_0 to assess microbial destruction, in dairy UHT processing

  → *B** value → total integrated lethal effect of a process

  → *C** value → total chemical damage taking place during a process.

- The reference temperature 135ºC.

- A process that is given a *B** value = 1 will result in a 9*D* reduction in spores (*z* = 10.5ºC) and would be equivalent to 10.1 s at 135ºC.

- A process given a *C** value = 1 will cause 3% loss of thiamine and would be equivalent to 30.5 s at 135ºC.

- holding time: $B^* = 10^{(\theta-135)/10.5}.t/10.1$

  $C^* = 10^{(\theta-135)31.4}.t/30.5$

- θ (ºC): processing temperature
- t (s): holding time.

- Ideally a process should maximise B^* and minimise C^*,
- unless a specific chemical (e.g. an enzyme or natural toxin such as trypsin inhibitor) is to be destroyed or vegetable tissues are required to be softened.

Processing

- Food is heated in relatively thin layers in a continuous HE with close control over the sterilisation temperature & holding time.

- ensuring microbial spores cannot survive the process?
  → shortest time any particle to pass through the holding section & rate of heat transfer

- achieve turbulent flow if possible
  → spread of residence times is smaller.
- viscous foods → flow is likely to be streamline
  → wider spread of residence times; the minimum may be only half the average time.

→ minimum time > specified for the product to avoid under-processing.

→ close control over particle size range in particulate products.

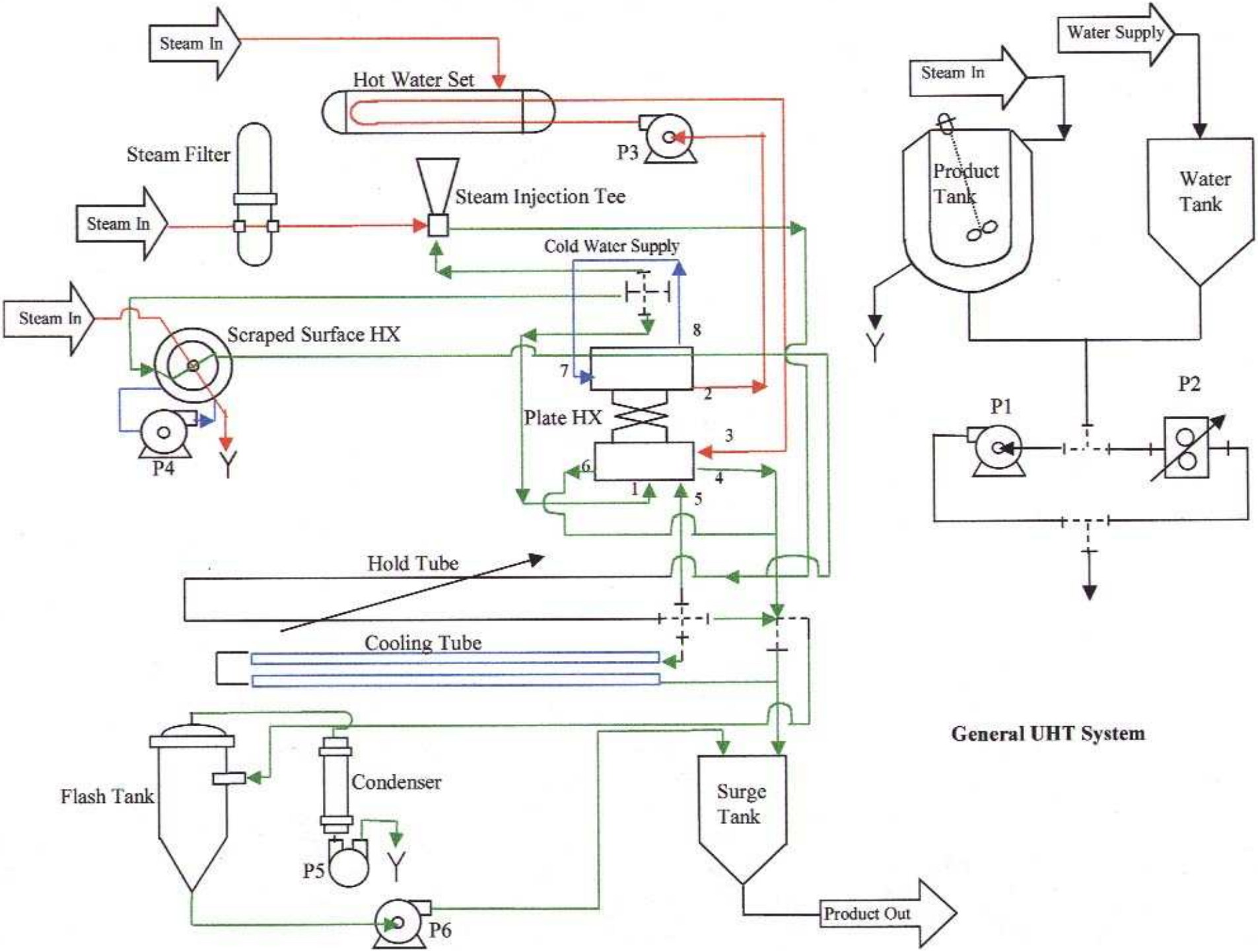
- E.g. if a process is designed to sterilise 14 mm particles to $F_0 = 6$ → the holding tube should be 13 m long. If a 20 mm particle passes through under these conditions, it will only reach $F_0 = 0.5$ → under-processed.

  a 10mm diameter particle will reach $F_0 = 20$ → over-processed.

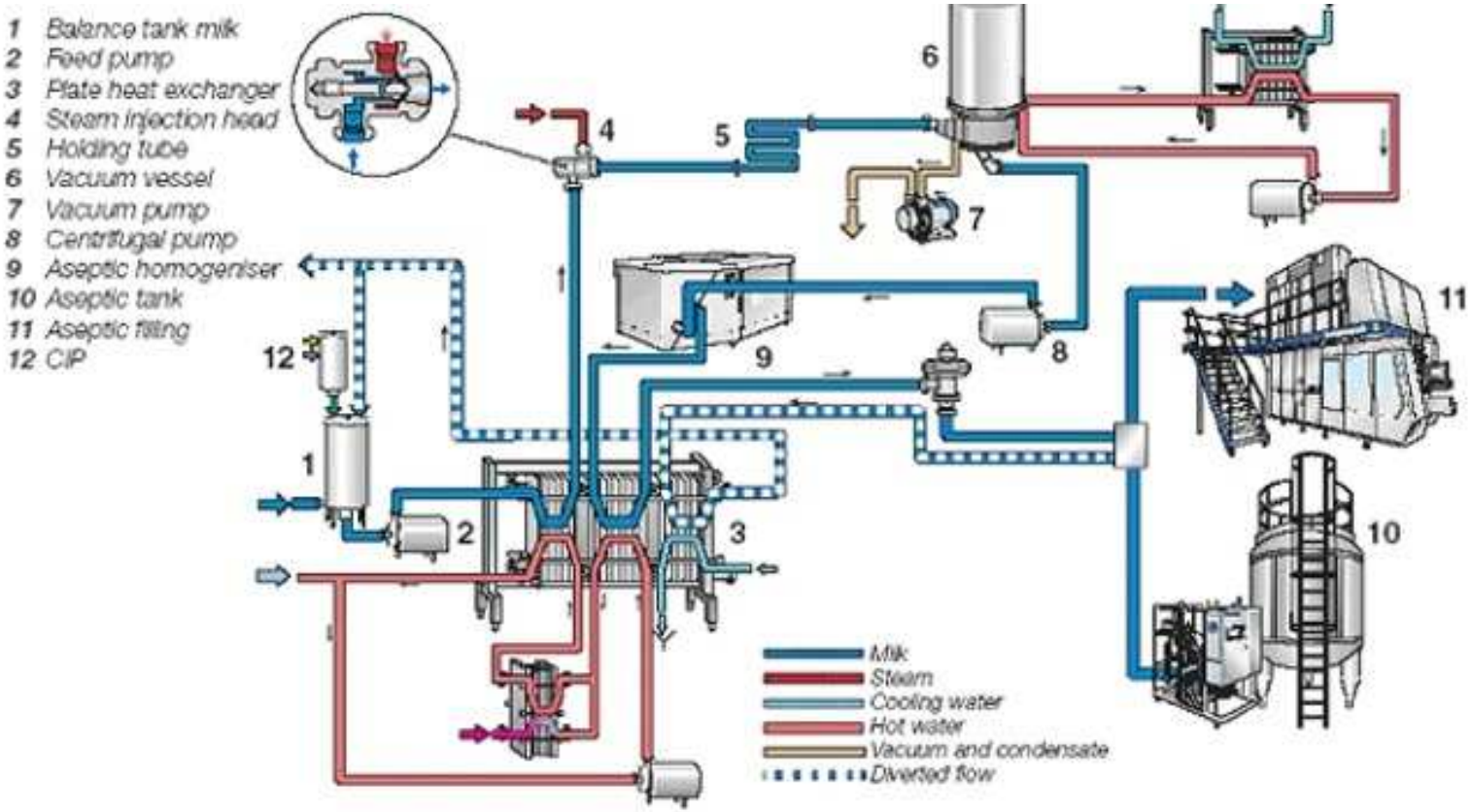
- Sterilised product is cooled in a 2nd HE or in a vacuum chamber if de-aeration is also required.
-
- Containers are not required to withstand sterilisation conditions → laminated cartons OK
- Cartons are pre-sterilised with H_2O_2,
- Filling machines are enclosed & maintained in a sterile condition by ultraviolet light & filtered air.
- A positive air pressure is maintained in filling machine to prevent entry of contaminants.

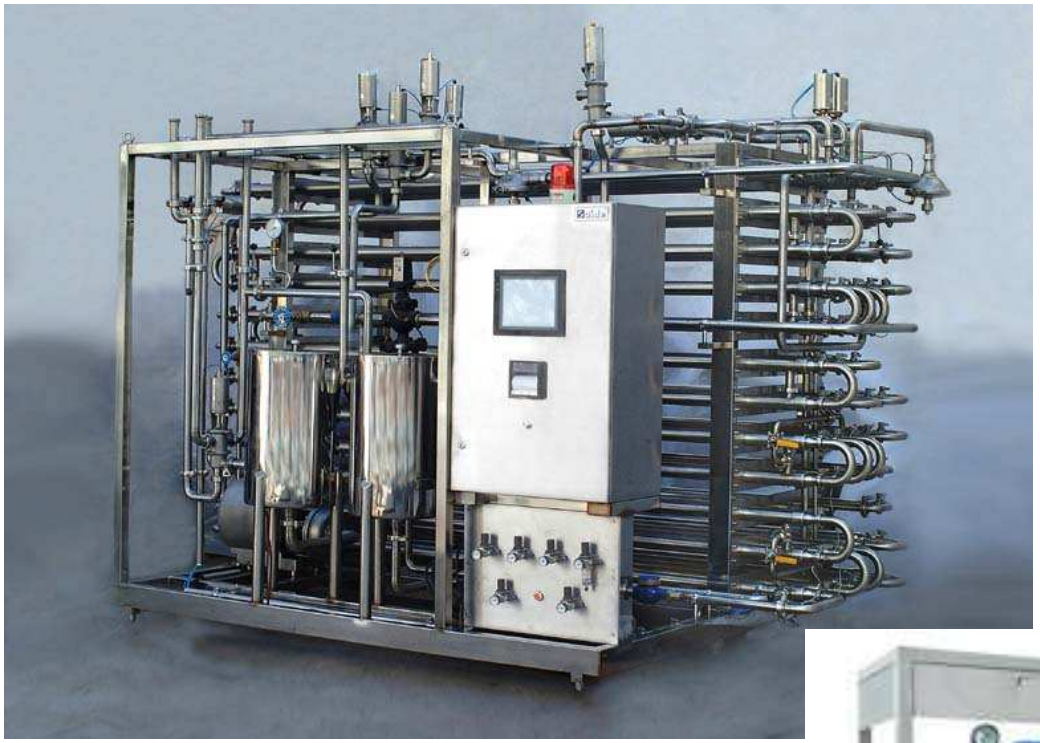
- OK to liquid & small-particulate foods but problems in larger pieces of solid food.

- Major difficulties:
  - enzyme inactivation at centre of the pieces of food causes overcooking of surfaces; limiting particle sizes
  - agitation is necessary to improve the rate of heat transfer and to aid temperature distribution, but this causes damage to product
  - lack of suitable equipment for processing & filling
  - settling of solids is a problem if the equipment has a holding tube.
    - uncontrolled and overlong holding times and variable proportions of solids in the filled product.



General UHT System


1 Balance tank milk
2 Feed pump
3 Plate heat exchanger
4 Steam injection head
5 Holding tube
6 Vacuum vessel
7 Vacuum pump
8 Centrifugal pump
9 Aseptic homogeniser
10 Aseptic tank
11 Aseptic filling
12 CIP
Milk
Steam
Cooling water
Hot water
Vacuum and condensate
Diverted flow



Equipment

- Ideal UHT process
  → heat product instantly to the required temperature,
  → hold it at that temperature to achieve sterility &
  → cool it instantly to filling temperature.

- In practice, depends on
  → the method used to heat food
  → sophistication of control (cost of equipment).
  → properties of the food (e.g. viscosity, presence of particles, heat sensitivity & tendency to form deposits on hot surfaces).

- UHT processing equipment (except ohmic heating):
  - operation > 132ºC
  - exposure of a relatively small volume of product to a large surface area for heat transfer
  - maintenance of turbulence in the product as it passes over the heating surface
  - use of pumps to give a constant delivery of product against pressure in heat exchanger
  - constant cleaning of heating surfaces to maintain high rates of heat transfer & to reduce burning-on of product.

- according to the method of heating:
  - direct systems

    (steam injection & steam infusion)

  - indirect systems

    (plate HE, tubular HE (concentric tube or shell-and-tube) & scraped surface HE)

  - other systems

    (microwave, dielectric, ohmic & induction heating).

Direct methods

- Steam injection (uperisation) & Steam infusion

Steam injection

- Steam at 965 kPa into a pre-heated liquid product in fine bubbles by a steam injector & rapidly heats product to 150ºC.

- After a suitable holding period (e.g. 2.5 s) product is flash cooled in a vacuum chamber to 70ºC; condensed steam & volatiles in product are removed.

- Moisture content of product returns to appr. the same level as raw material.

- Advantages:
  - one of the fastest methods of heating & cooling; suitable for more heat-sensitive foods
  - volatile removal is an advantage with some foods (e.g. milk).

- Limitations:
  - only suitable for low-viscosity products
  - relatively poor control over processing conditions
  - requirement for potable steam, more expensive to produce than normal processing steam
  - regeneration of energy is less than indirect systems
  - flexibility for changing to different types of product is low.

Steam infusion

- Food is sprayed in a free-falling film into high-pressure (450 kPa) potable steam in a pressurised vessel.
- Heated to 142–146ºC in 0.3 s, held for 3 s in a holding tube before flash cooling in a vacuum chamber to 65–70ºC.
- Heat from the flash cooling is used to pre-heat the feed material.
- Advantages
  - over injection methods

    → liquid does not contact hotter surfaces & burning-on is reduced.

- almost instantaneous heating of food to the temperature of steam & very rapid cooling

  → high retention of sensory characteristics & nutritional properties

- greater control over processing conditions than steam injection

- lower risk of localised overheating of product

- suitable for higher viscosity foods compared to steam injection.

- Other disadvantages
  - blockage of the spray nozzles
  - separation of components in some foods.

Indirect systems

Plate HE (described formerly)

- limitations due to the higher temperatures & pressures.

Tube and shell HEs (will be in meeting 9 Evaporation), e.g:

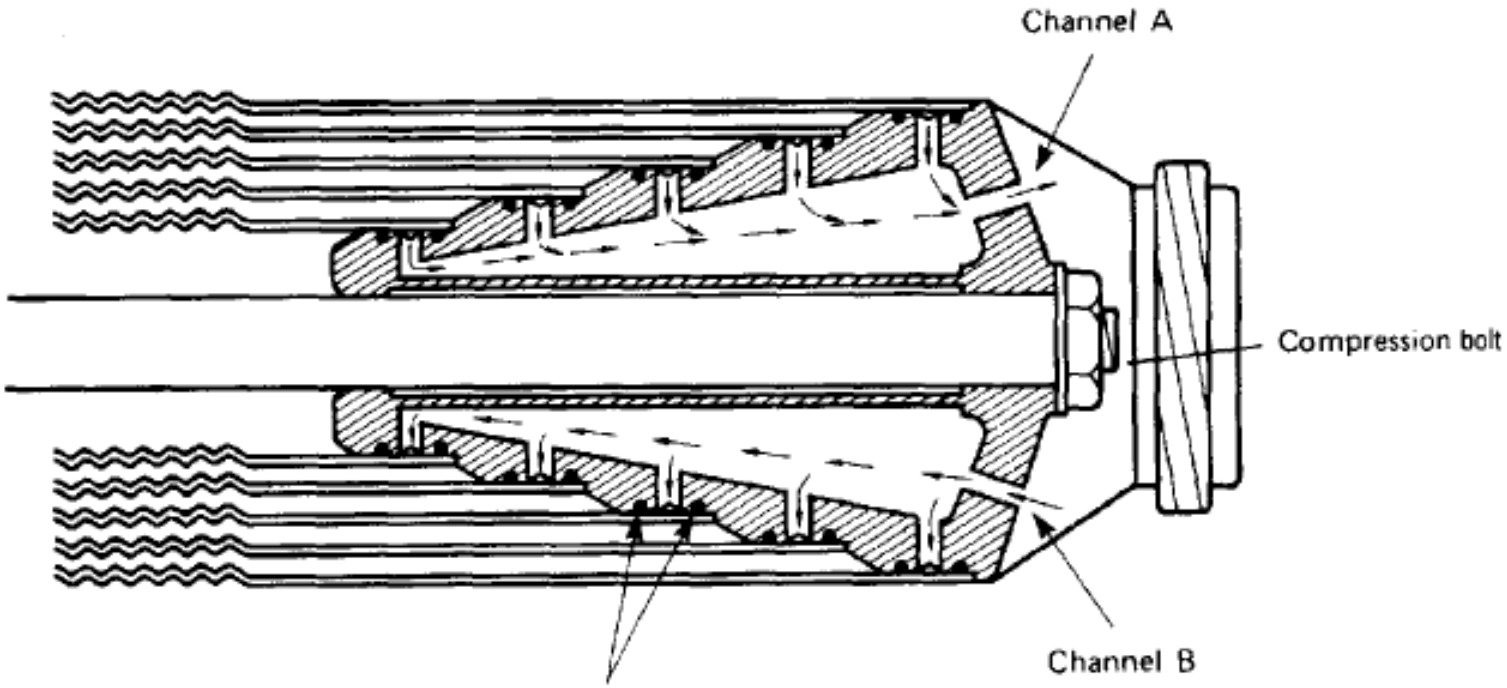
concentric tube HE

→ Combination of plate & tubular designs.

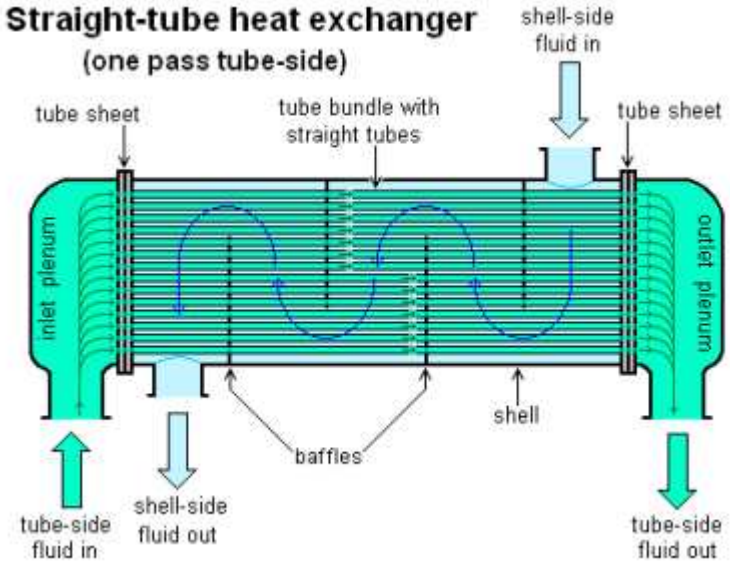
→ Counter-current flow & helical corrugations → to generate turbulence & to increase rate of heat transfer.

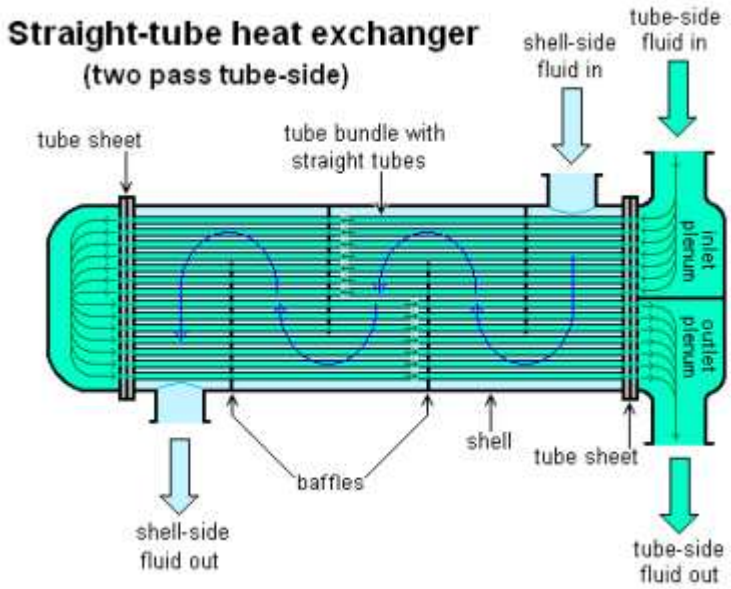
→ Able to operate at high pressures with viscous liquids.

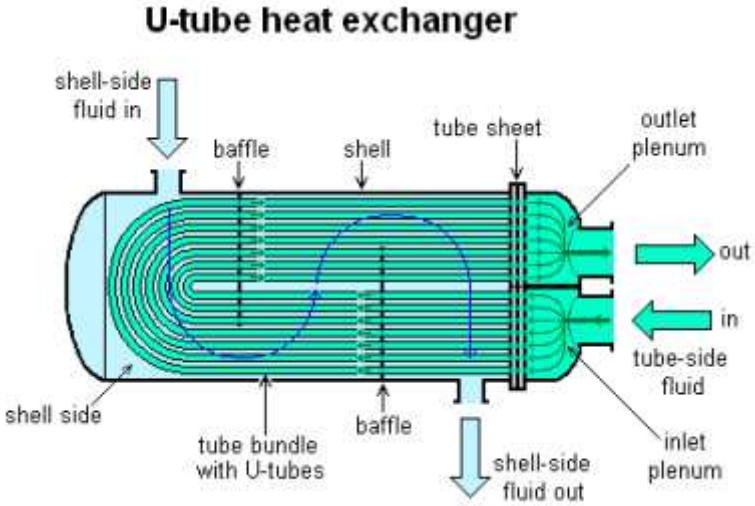
→ Turbulence can be increased

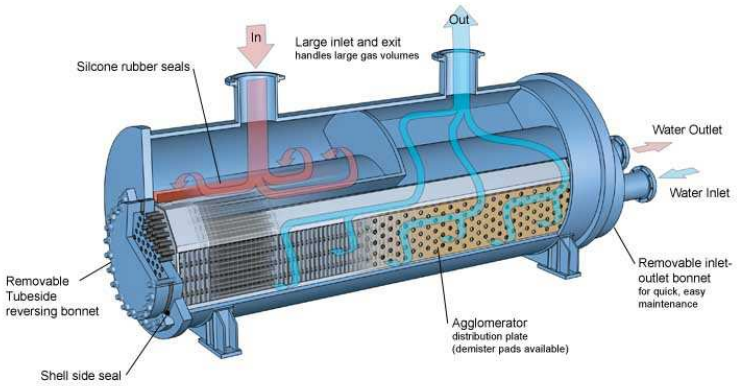


Concentric tube heat exchanger: (a) cross-section; (b) effect of rotation of tubes.
(Courtesy of HRS Heat Exchangers Ltd.)


Straight-tube heat exchanger
(one pass tube-side)
shell-side
fluid in
tube sheet
tube bundle with
straight tubes
tube sheet
inlet plenum
outlet plenum
shell
baffles
tube-side
fluid in
shell-side
fluid out
tube-side
fluid out


Straight-tube heat exchanger
(two pass tube-side)
shell-side
fluid in
tube-side
fluid in
tube sheet
tube bundle with
straight tubes
inlet plenum
outlet plenum
shell
tube sheet
baffles
shell-side
fluid out
tube-side
fluid out


U-tube heat exchanger
shell-side
fluid in
baffle
shell
tube sheet
outlet
plenum
out
in
tube-side
fluid
shell side
tube bundle
with U-tubes
baffle
shell-side
fluid out
inlet
plenum


In
Large inlet and exit
handles large gas volumes
Out
Silcone rubber seals
Water Outlet
Water Inlet
Removable
Tubeside
reversing bonnet
Removable inlet-
outlet bonnet
for quick, easy
maintenance
Agglomerator
distribution plate
(demister pads available)
Shell side seal

Comparison of plate and tube-and-shell heat exchangers for UHT processing

Plate heat exchanger		Tube-and-shell heat exchanger	
Advantages	Limitations	Advantages	Limitations
• Relatively inexpensive • Economical in floor space and water consumption • Efficient in energy use (> 90% energy regeneration) • Flexible changes to production rate, by varying the number of plates • Easily inspected by opening the plate stack	• Operating pressures limited by the plate gaskets to approximately 700 kPa • Liquid velocities at relatively low pressure also low (1.5–2 $m\,s^{-1}$) • Low flow rates can cause uneven heating and solids deposits on the plates which require more frequent cleaning • Gaskets susceptible to high temperatures and caustic cleaning fluids and are replaced more regularly than in pasteurisation • Limited to low viscosity liquids (up to 1.5 $N\,s\,m^{-2}$) • Careful initial sterilisation of the large mass of metal in the plate stack is necessary for uniform expansion to prevent distortion and damage to plates or seals • Liable to fouling	• Few seals and easier cleaning and maintenance of aseptic conditions • Operation at higher pressures (7000–10 000 kPa) and higher liquid flow rates (6 $m\,s^{-1}$) than plate heat exchangers • Turbulent flow at tube walls due to higher flow rates • Hence more uniform heat transfer and less product deposition	• Difficulty in inspecting heat transfer surfaces for food deposits • Limited to relatively low-viscosity foods (up to 1.5 $N\,s\,m^{-2}$) • Lower flexibility to changes in production capacity • Larger-diameter tubes cannot be used because higher pressures needed to maintain the liquid velocity and large-diameter pipes have a lower resistance to pressure • Any increase in production rate requires duplication of the equipment

Scraped-surface HEs

→ for freezing; evaporation by boiling; for continuous production of margarine & butter.

→ suitability for viscous foods & particulates (< 1 cm),

→ flexibility for different products by changing the geometry of rotor assembly.

→ high capital & operating costs

→ heat recovery is not possible.

- to process fruit sauces & fruit bases for yoghurts & pies.

Effect on foods

- extend shelf life, minimising changes in nutritional value & eating quality.

Effect: *Colour*

- Time–temperature combinations in canning → e.g. Meat
  - oxymyoglobin (red) → metmyoglobin (brown)
  - myoglobin (purplish) → myohaemichromogen (red–brown)
  - Maillard & caramelisation → colour of sterilised meats.
    - acceptable change in cooked meats.

  - Na-nitrite & Na-nitrate (+) to some meat products to reduce the risk of growth of *C. botulinum*.
  - red–pink coloration is due to nitric oxide myoglobin & metmyoglobin nitrite.

- Fruits & vegetables
  - chlorophyll → pheophytin,
  - carotenoids are isomerised from 5, 6-epoxides to less intensely coloured 5, 8-epoxides
  - anthocyanins are degraded to brown pigments.

  → (+) permitted synthetic colourants.

- Canned foods during storage
  - iron or tin react with anthocyanins → purple pigment
  - colourless leucoanthocyanins form pink anthocyanin complexes in some varieties of pears & quinces.

- Sterilised milk
  - slight colour changes

    → caramelisation, Maillard browning & changes in the reflectivity of casein micelles.

- In UHT processing
  - meat pigments change colour; little caramelisation or Maillard browning.
  - carotenes & betanin are virtually unaffected
  - chlorophyll & anthocyanins are better retained.
  - an increase in whiteness in colour of milk.

Effect: *Flavour & aroma*

- Canned meats, e.g.
  - pyrolysis, deamination & decarboxylation of amino acids,
  - degradation, Maillard reactions & caramelisation of carbohydrates to furfural & HMF,
  - oxidation & decarboxylation of lipids.
  - Interactions between these components produce more than 600 flavour compounds in ten chemical classes.

- Fruits and vegetables,
  - changes are due to complex reactions

    → degradation, recombination & volatilisation of aldehydes, ketones, sugars, lactones, amino acids & organic acids.

- Milk,
  - Development of cooked flavour

    → denaturation of whey proteins to form hydrogen sulphide

    → formation of lactones & methyl ketones from lipids.

- Aseptically sterilised foods,
  - changes are less severe; the natural flavours of milk, fruit juices and vegetables are better retained.

Effect: *Texture or viscosity*

- Canned meats,
  - Coagulation
  - Loss of WHC of proteins
    → shrinkage & stiffening of muscle tissues.
  - Softening
    → hydrolysis of collagen,
    → solubilisation of the resulting gelatin,
    → melting & dispersion of fats through the product.

- Polyphosphates (+) to some products to bind water.
  → increases the tenderness of product & reduces shrinkage.

- Fruits & vegetables,
  - Softening
    → hydrolysis of pectic materials,
    → gelatinisation of starches
    → partial solubilisation of hemicelluloses
    → loss of cell turgor.
  - Calcium salts (+) to blancher water or to brine or syrup, to form insoluble calcium pectate → increase the firmness of canned product.
  - Different salts for different fruit (e.g. CaOH for cherries, $CaCl_2$ for tomatoes & Ca-lactate for apples) → differences in the proportion of dimethylated pectin in each product.

- Small changes in the viscosity of milk → modification of K-casein leading to an increased sensitivity to calcium precipitation & coagulation.

- Aseptically processed milk & fruit juices
  - viscosity is unchanged.
  - texture of solid fruit & vegetable pieces is softer than the unprocessed food
    → solubilisation of pectic materials
    → loss of cell turgor (firmer than canned products).

- The relatively long time required for collagen hydrolysis & the relatively low temperature needed to prevent toughening of meat fibres are conditions found in canning but not in UHT processing.
- Toughening of meat is likely under UHT conditions.
- The texture of meat purees is determined by size reduction & blending operations; is not substantially affected by aseptic processing.

Loss of vitamins in canned and bottled foods (including losses due to preparation and blanching)

Food	Loss (%)														
	Carotene		Thiamin		Riboflavin		Niacin		Vitamin C		Panto-thenic acid	Vitamin B_6	Folacin	Bio-tin
Low-acid foods														
Carrots	0–9	(6)	67		38–60		32		75		54	80	59	40
Beef	—		67		100		100		—		—	—	—	—
Green beans	22–52		62		54–63		40		79		61	50	57	—
Mackerel	4		60		39		29		—		—	46	—	—
Milk	0		35		0		0		50–90		0	50	10–20	—
Mushrooms	—		80		46		52		33		54	—	84	54
Peas	0–30	(3)	75	(84)	47	(67)	71	(91)	67	(80)	80	69	59	78
Potatoes	—		56		44		56		28		—	59	—	—
Salmon	9		73		0		0		—		58	57	—	—
Spinach	0–32	(9)	80	(84)	45	(47)	50	(50)	72	(79)	78	75	35	67
Tomatoes	0	(2)	17	(22)	25	(59)	0	(1)	26	(26)	30	10	54	55
Acid foods														
Apple	0–4		31		48		—		74		15	0		
Cherries (sweet)	41		57		64		46		68		—	6		
Peaches	65	(70)	49	(57)	39		39	(38)	56	(58)	71	21		
Pears	—		45		45		0		73		69	18		
Pineapple	25		7	(10)	30		0		57	(57)	12	—		

The values in parentheses indicate the vitamin loss after storage for 12 months at 10–15°C.
Adapted from De Ritter (1982), Rolls (1982), Burger (1982) and March (1982).

Changes in nutritive value of milk after UHT and in-bottle sterilisation

Nutrient	Loss (%) on processing	
	UHT	In-bottle
Thiamin	10	35
Ascorbic acid	25	90
Vitamin B_{12}	10	90
Folic acid	10	50
Pantothenic acid	0	0
Biotin	0	0
β-carotene	0	0
Pyridoxine	10	50
Vitamin D	0	0
Whey proteins (denaturation)	12–40[a]	87
Lysine	–	10
Cystine	–	13
Biological value	–	6

[a] Direct UHT at 135°C for 2 s (12.3%) and indirect UHT at 135°C for 2 s (40.3%).
Adapted from Rolls (1982), Kiesker (1972) and Ford *et al.* (1969).

Effect: *Nutritional value*

- Canning
  - Hydrolysis of carbohydrates & lipids (nutrients remain available & nutritional value of food is not affected).
  - Proteins are coagulated; in canned meats, losses of amino acids are 10–20%.
  - Reductions in lysine content are proportional to the severity of heating but rarely > 25%.
  - Loss of tryptophan &, to a lesser extent, methionine, reduces the biological value of proteins by 6–9%.
  - Vitamin losses → thiamin (50–75%) & pantothenic acid (20–35%).

- In canned fruits and vegetables, significant losses may occur in all water soluble vitamins, particularly ascorbic acid.

  → large variations

    → differences in the types of food,

    → presence of residual oxygen in container,

    → methods of preparation (peeling & slicing) or blanching.

- In some foods, vitamins are transferred into the brine or syrup, which is also consumed.

- Sterilised soya–meat products → increase in nutritional value → decreases the stability of trypsin inhibitor in soy beans.

- Aseptically processed meat & vegetable products lose thiamin & pyridoxine.
-
- Negligible vitamin losses in aseptically processed milk & lipids, carbohydrates & minerals are unaffected.

- Riboflavin, pantothenic acid, biotin, nicotinic acid & vitamin B6 are unaffected.

- Nutrient losses also occur during periods of prolonged storage.

Thank you