New technologies for sterilisation of milk

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Outline

Some important basic bacteriological facts

Requirements of a sterile product; concept of commercial sterility

Traditional sterilisation and effects on milk

Non-traditional thermal processes

Alternative (non-thermal) sterilisation technologies

Other alternatives – any candidates

Summary

Bacteria

Some important basic bacteriological facts

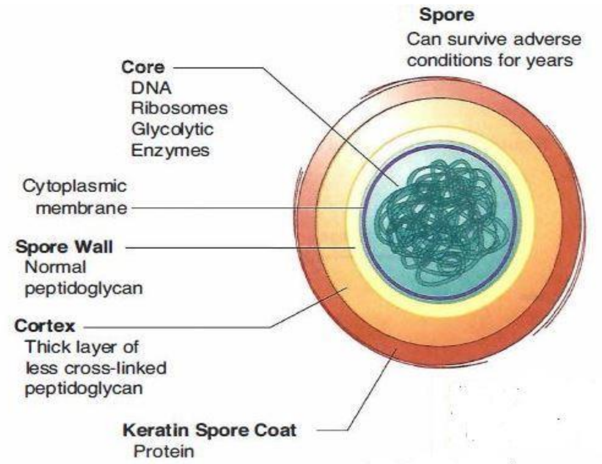
There are 2 major types of bacteria: **Vegetative** (or non-sporeforming) and **sporeforming**

Non-sporeforming (or vegetative)

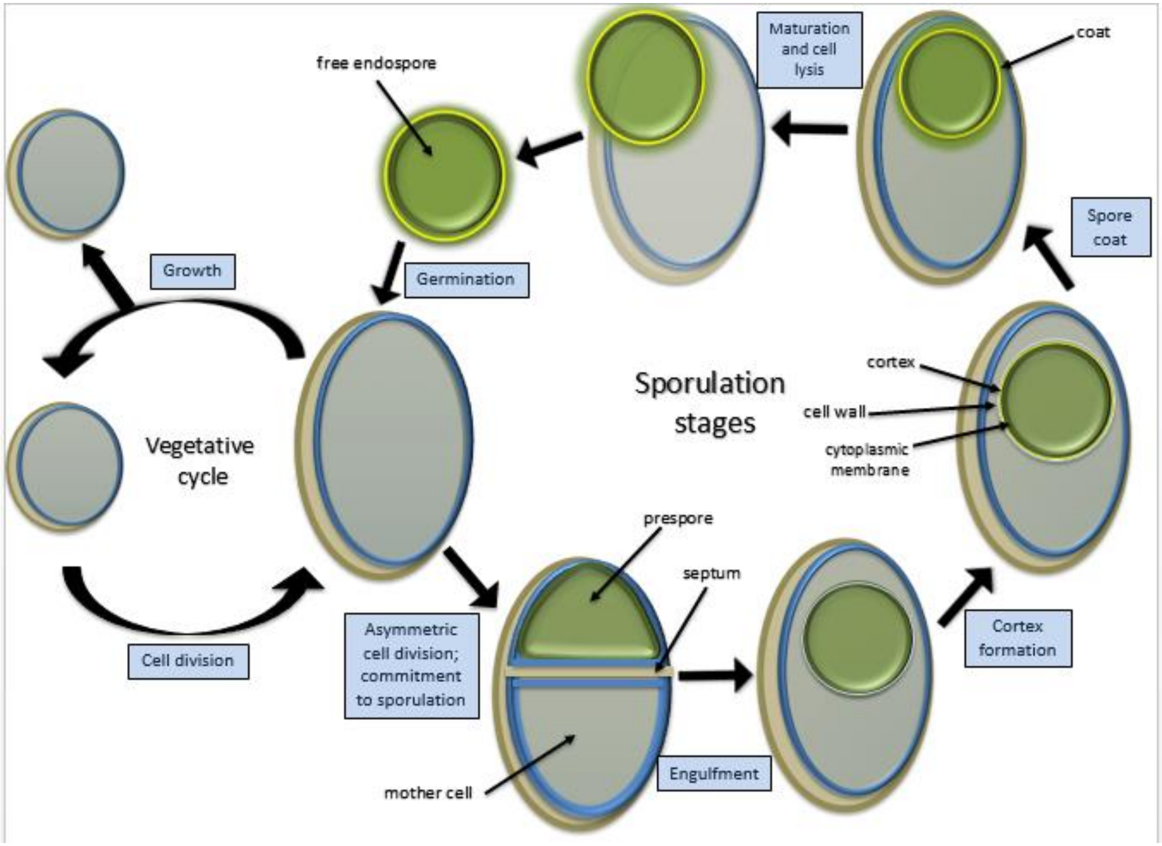
- Most bacteria in milk are non-sporeforming, e.g., *Pseudomonas*
- Most are easily killed by pasteurisation at ~72°C for 15 s
  - Some, e.g., corynebacteria, some streptococci, survive pasteurisation but are readily killed at ≤ 100°C for a few seconds

Sporeforming bacteria

- Bacteria that produce spores. A spore is:
  - dormant [non-growing] state which forms when growth conditions become unfavourable
  - Spores are multi-layered



  - very dry
  - very heat-resistant – not affected by pasteurisation
  - the target of sterilisation treatments
- When a spore germinates, it turns into a vegetative form, it can “grow” (think of plant seed), i.e., divide & multiply
- The vegetative form is relatively easy to kill


free endospore
Maturation and cell lysis
coat
Spore coat
Growth
Germination
Vegetative cycle
Sporulation stages
cortex
cell wall
cytoplasmic membrane
prespore
septum
Cell division
Asymmetric cell division; commitment to sporulation
Cortex formation
Engulfment
mother cell

Sporeformer under the microscope

Commercially sterile products

The concept of commercial sterility

- A “commercially sterile” product is one in which bacteria will not grow during storage **under normal conditions**
  - It may contain bacteria but these will not grow during storage
- Commercial sterility is achieved when the spores which are likely to germinate and grow during storage (under normal conditions) are destroyed (or removed)
- Hence the aim of sterilisation is to **GET RID OF SPORES**

Note: Sterilisation here is about a liquid product, not surfaces as in packaging material or equipment where several technologies exist (steam, hydrogen peroxide with or without UV light, various gases, cold plasma)

Traditional sterilisation

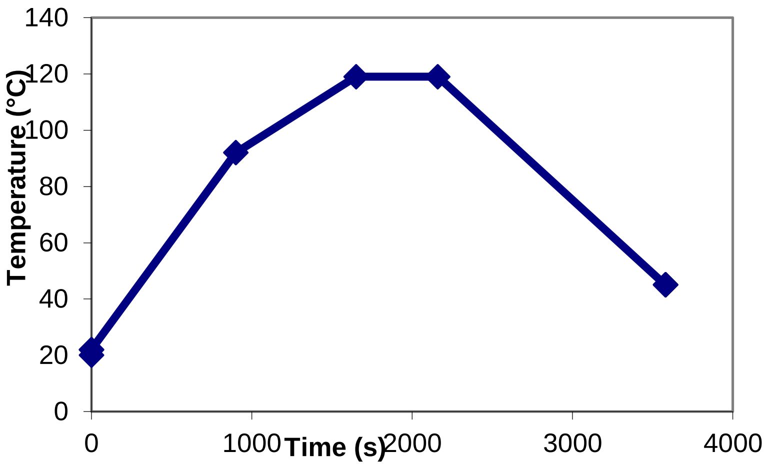
Traditional sterilisation processes

Two major types, both thermal:

- in-container (batch) sterilisation and ultra-high temperature (UHT) processing
- both cause the same level of spore inactivation and produce commercially sterile products

In-container (batch) sterilisation

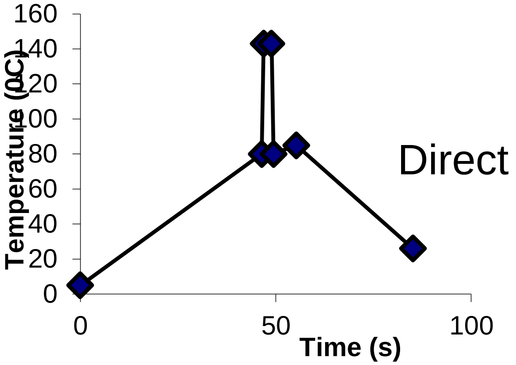
- Uses a retort into which packaged product is placed
- Heats product to 110-120°C/10-20 min under pressure
- Heat-up and cool-down are usually slow – faster in some retorts, e.g., shaking, rolling



- In milk, causes brown colour and strong cooked flavour

UHT processing

- A continuous flow process
- The standard method for sterilising milk
- Heats product to 135-145°C and holds for 1-10 s
- Heat-up and cool-down are much faster than for in-container sterilisation



- Heating is by steam, either directly in contact with milk or indirectly through heat exchangers
- Causes little change in colour and much less cooked flavour than in-container sterilisation

Non-traditional thermal processes

Non-traditional thermal processes

Includes ohmic, electrically heated tube and microwave technologies

Ohmic

- Also called Joule heating or electrical resistance heating
- Heats by passage of electricity through the product –the product acts as the resistor
- No heated tubes
- Is efficient, close to 100%
- Rapid heating to sterilisation temperature - but not rapid cooling
- Suitable for all liquid products including ones with particulates

Electrically heated tube heating

- Also called Current Passage Tube Technology or Actijoule heating (after company Actini)
- Heats the stainless steel tubes by passage of electricity through the tubes – by electrical resistance heating
- Can heat up to 400°C
- No steam is required
- Rate of heating can be controlled – slower for viscous products
- Can heat milk rapidly to sterilisation temperature - but not rapid cooling
- Has been used for UHT milk and desserts in France since 1992
- Electricity cost is an important factor

Microwave heating

- Dielectric heating – heats materials with molecular dipoles - water is main substance heated
- Uses frequencies of 915 MHz (domestic) and 2450 MHz (industrial) – other frequencies are used for communications
- Volumetric heating – but non-uniform, hot and cold spots
- Heats by passage of microwaves through the product
- Not as efficient as ohmic heating, ~65%
- Rapid heating to sterilisation temperature - but not rapid cooling

Microwave heating 2

Two types for sterilisation: Batch and continuous

<u>Batch sterilisation</u>

- Patented process called **Microwave Assisted Thermal Sterilisation (MATS™)**
- Operates at 915 MHz (commercialised by *915 Labs* coy)
- Treats packaged food in pouches in pressurized hot water.
- Process was approved by the US FDA for production of shelf-stable food in 2010
- Interest for military foods

Microwave heating 3

Continuous sterilisation

- Milk can be UHT treated using microwave technology in a continuous mode
- Uses a cylindrical microwave applicator operating at 915 MHz
- In comparison with milk processed in a traditional UHT plant with same heating rate (& same F_0), microwave-treated milk had better flavour
- Does not seam to have been adopted commercially
    - Pilot plants have been available for 20 years

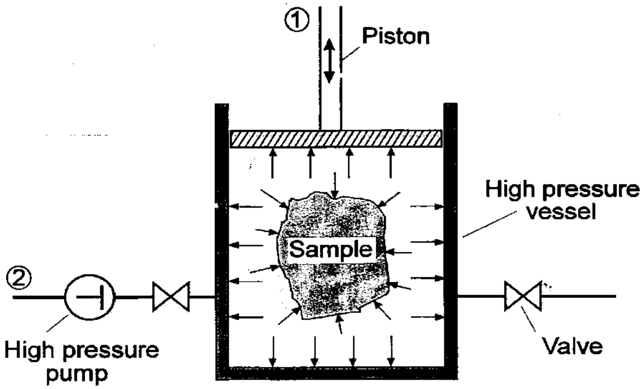
Alternative (non-thermal) sterilization technologies

Non-thermal technologies

- Several non-thermal technologies exist as possible alternatives to thermal technologies
- Almost all are capable of killing vegetative bacteria (to some extent) but hardly any can kill spores
  - that is, without the help of some heat
- Currently only 2, **high pressure processing & high pressure homogenisation** have potential for use in sterilising milk
  - both need to operate at elevated temperature to kill spores
- Some others, e.g., ultrasonication, can weaken spores to enable them to be killed at lower temperatures – improves flavour of sterilised (UHT) product

High pressure processing (HPP)

- Uses high pressures (100 to 800 MPa)
- Usually ~500 MPa at 40-60ºC for 2-30 min
- Mostly batch processing in cylinders up to 525 L



- The benefits
  - Little effect on flavour, colour, nutrients
  - Does not inactivate bioactive components, e.g., immunoglobulins, which are sensitive to heat
  - Pressurisation occurs uniformly (Pascal’s Principle) and rapidly

HPP products

- Used commercially to process yoghurts, sauces, fruit juices, meats, seafood, prepared meals, guacomole and milk

NSW 2016

Mexico 2014

- Products processed to date are "pasteurized" not sterilised, i.e., spores not killed
- So can it be used for sterilisation?

Can HPP be used for sterilisation?

- Yes, with high pressures and high temperatures
  - at 600-800 MPa & 60-90°C for ~15 min
- Process is called Pressure Assisted Thermal Sterilisation (PATS) or High-Pressure, High-Temperature (HPHT)
- Enables products to be sterilised at lower temperatures than when using heat alone
- Heat is generated during pressurization (3-5°C/100 MPa)
  - Called adiabatic heating or compression heating
  - With initial temperatures of 60-90°C, the temperature can reach 90-130°C in PATS
  - Temperature returns to initial temp when pressure is released
- Effect of PATS on spores depends on bacterial species and strain

PATS – advantages and disadvantages

Advantages:

- Quality of product higher than for thermally sterilised
- Uniformity of treatment effect
- Suitable for shelf-stable, small-volume, high-value products, e.g., infant formula

Disadvantages:

- High pressures and temperatures put huge demand on equipment
- Mostly batch processing, hence only small volumes can be treated

High Pressure Homogenisation (HPH)

- Homogenisation at 100 to 400 MPa
  - At ≥ 300 MPa, sometimes called “Ultra-High Pressure Homogenisation”
  - Milk is normally homogenised ~10-30 MPa
- Should not be confused with high pressure processing
- Used commercially in the pharmaceutical and chemical industries
- Pressure is applied only during homogenisation - for much less than 1 second
- Heat is generated during homogenisation, ~20°C per 100 MPa (i.e., a 60°C rise at 300 MPa)
  - due to turbulence, cavitation, shear stress and impact speed
  - product remains at highest temperature reached until cooling applied
- Can be used for sterilisation of milk at 300 MPa at an initial temperature of 75 or 85°C
  - final temperatures:133 and 139 °C; residence time 0.5 s (+).

Advantages and disadvantages of HPH

Advantages:

- Is a continuous process
- Is currently being used commercially in non-dairy industries
- Sterilisation occurs at lower temperature and/or shorter holding time than thermal sterilisation, i.e., UHT processing
- Causes effective homogenisation of fat in milk

Disadvantages

- Equipment limitations
  - Limitations due to high pressures generated
  - Capacity of high-pressure homogenisers

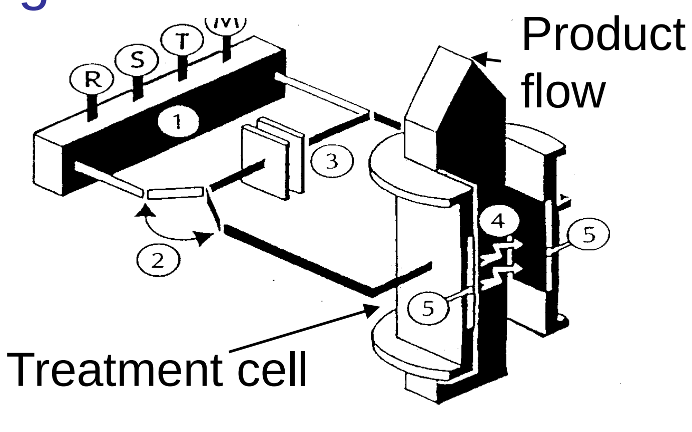
Other alternatives – any candidates?

Other non-thermal technologies?

- Several non-thermal technologies are able to kill bacteria
- Some could be used for “pasteurising” milk
- Very few are capable of killing spores, and hence sterilising milk
- Some weaken spores and enable them to be killed at lower temperature than when using heat alone

1. Pulsed electric field technology

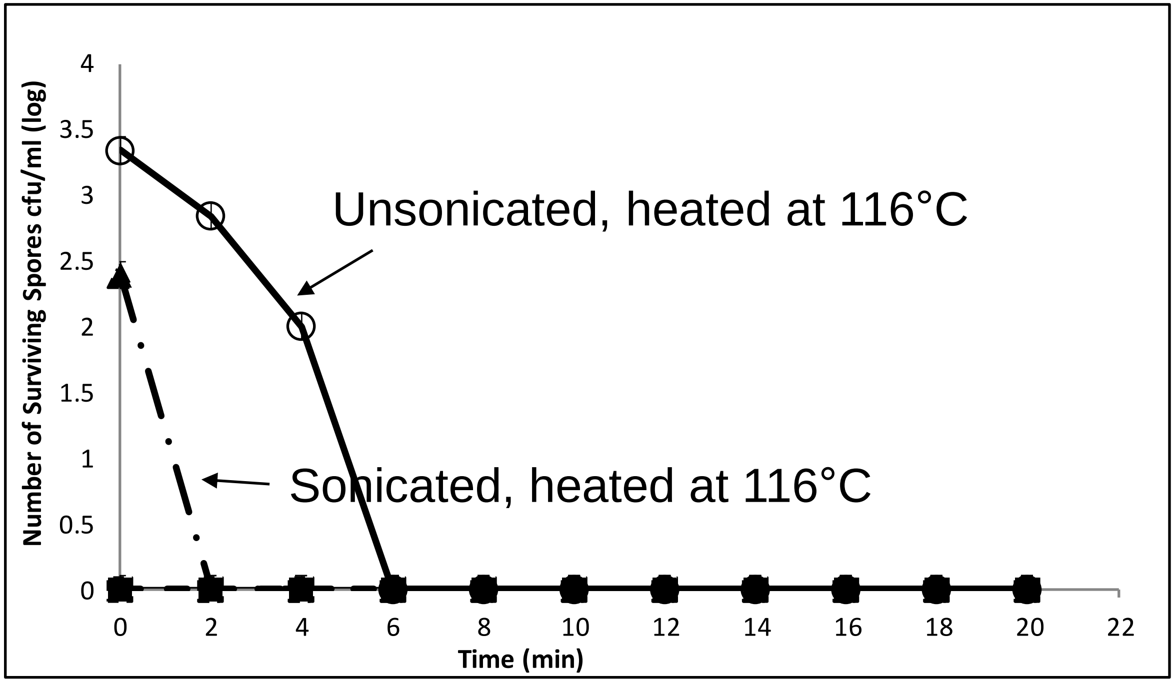
- Destroys most non-sporeforming bacteria at ~ 30 kV/cm, 50°C, 10-20 pulses (total treatment time < 1 sec)
  - Equivalent to **pasteurization**
- When combined with HTST pasteurization (72°C/15 s) produces **ESL** (extended shelf-life) milk
- When combined with heating at 112 °C for 31.5 s produced shelf-stable (sterile) milk
- No commercial plants for sterilising milk



2. Ultrasonication

- Uses high intensity ultrasound at 20 kHz-2.5 MHz - beyond range of human ear (<16kHz)
- Kills vegetative bacteria by cavitation - formation and collapse of microscopic bubbles which destroy bacterial cells by shear forces
- More effective in combination with heat and slight pressure
- Ultrasonication at 20 kHz/80°C/4 bar (0.4 MPa) caused 1 log reduction of *Bacillus licheniformis* in 120 min
  - but made it more susceptible to inactivation by heat
- Long treatment times prelude its use for milk

Bacillus licheniformis – *effect of ultrasonication on heat stability*



3. Ionising radiation

- Gamma radiation at 1 to > 10 kGy
  - Causes pasteurization at 1-2 kGy
  - Causes sterilisation at >10 kGy
- Causes off-flavour development in milk
  - from breakdown of fat and protein
  - noticeable at 0.07 kGy in whole; 0.2 kGy in skim
- Large loss of vitamins - up to 100% of thiamine at 10 kGy
- Bleaches milk fat
- Consumer opposition
- Unlikely to be used

4. UV irradiation

- Irradiation with UVC light (200-280 nm wavelength) is effective in killing most microorganisms.
- Has been used for many years for decontaminating air, surfaces of packaging materials and equipment, and water
- Has limited penetration into opaque liquids (e.g., milk)
- Approved for commercial pasteurisation of milk by the European Food Safety Association for pasteurised milk (EFSA, 2016).
- Causes unclean, off-flavour after irradiation at levels less than those needed even for pasteurisation
- Could not be used for sterilisation

Summing up

Some non-traditional thermal technologies could be used to replace traditional steam-based processes, with some advantages

- Ohmic
- Microwave
- Electrically heated tube (Actijoule)

No non-thermal technologies can be used alone to sterilise milk

With additional heat, some are capable of sterilising milk

- High pressure
- High pressure homogenisation
- High voltage pulsed electric field technology

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Thank you for your attention ☺

Any questions?