ESL milk processing

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What is ESL milk?

- Extended-shelf-life milk: keeps longer than pasteurised milk but not as long as UHT milk
- Can be produced by non-thermal technologies, with or without some thermal treatment, or by thermal treatment alone
- Non-thermal technologies used:
  - Microfiltration – widely commercialized
  - Bactofugation – has been commercialised, e.g. in South Africa
  - Pulsed electric field (PEF) technology – proven effective in research only
- Microfiltration and bactofugation remove bacteria while thermal processing and PEF destroy the bacteria (and leave the dead bacteria in the milk)

About ESL milk

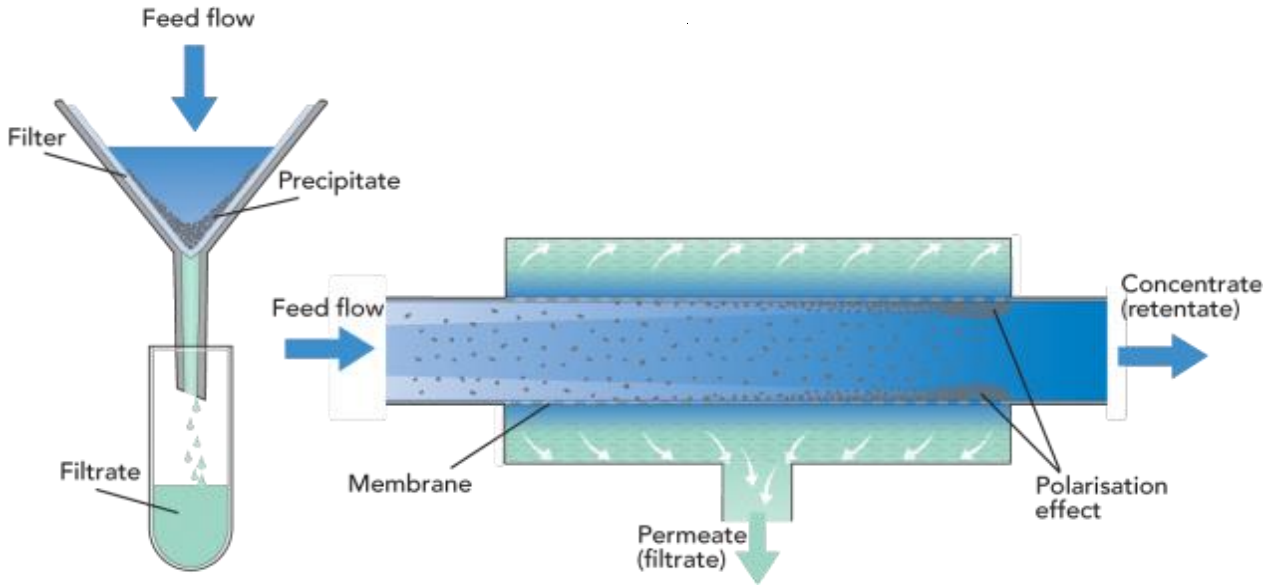
- Must be stored refrigerated
- Should have a similar taste to pasteurised milk
- Mostly packaged under ultra-clean conditions but can be packaged aseptically
- Keeps for 30 days or longer

ESL milk by microfiltration

Microfiltration – a membrane filtration technology

Some points about membrane technologies:

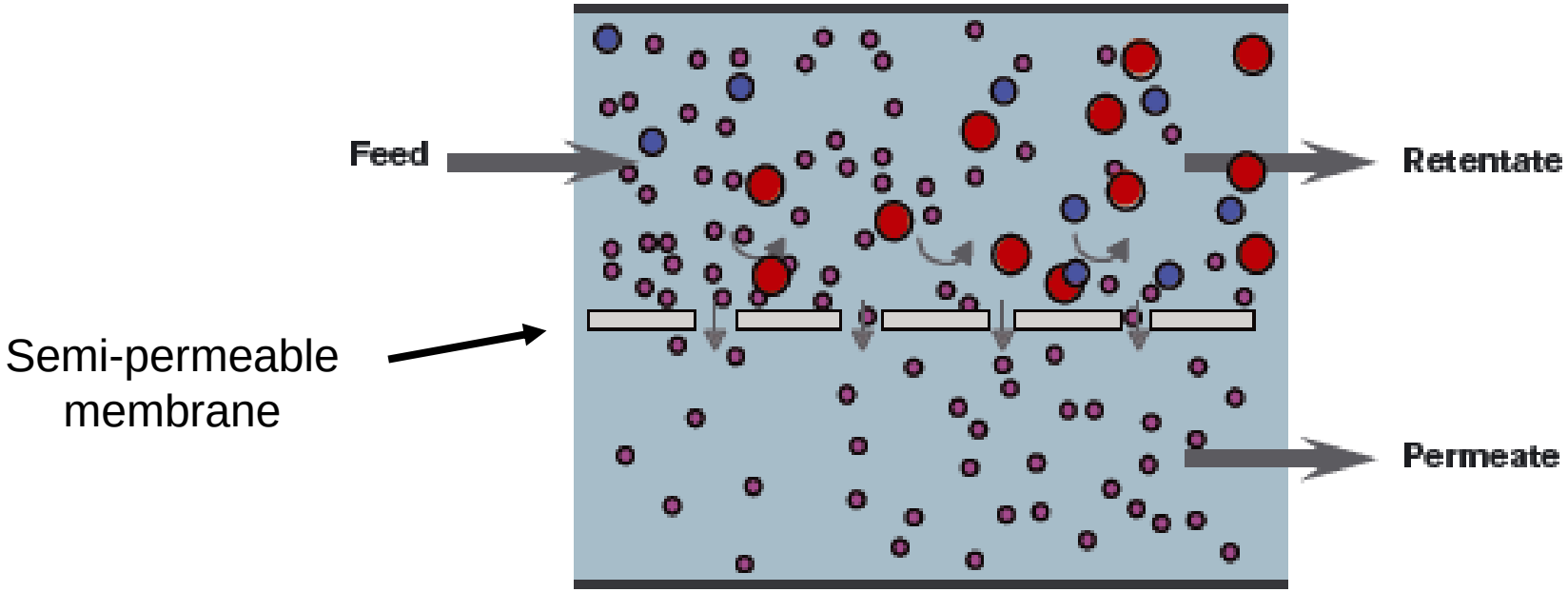
1. They use cross-flow filtration rather than dead-end filtration



Tetra Pak 2015

The membrane technologies 2

2. They use semi-permeable membranes



The membrane technologies 3

3. Different technologies use membranes with different pore sizes

Membrane technology	Pore size (µm)	Approx MW range of material filtered out (Da)
Microfiltration	0.1-10	>100,000 -3,000,000
Ultrafiltration	0.001- 0.1	10,000-150,000
Nanofiltration	0.0001-0.001	150-20,000
Reverse osmosis	< 0.0001	<300

The membrane technologies 4

4. Different membranes filter out different milk components

Membrane technology	Milk components retained by membrane	Milk components that permeate the membrane
Microfiltration (MF)	- “Loose” membrane: Bacteria, somatic cells, fat globules	All proteins, lactose, salts, water
	- “Tight” membrane: casein micelles	All proteins except casein micelles, lactose, salts, water
Ultrafiltration (UF)	As above **plus** all proteins, large peptides	Small peptides, lactose, salts, vitamins, amino acids, water
Nanofiltration (NF)	As above **plus** lactose, most mineral salts, vitamins, small peptides and amino acids	Some monovalent ions (potassium & sodium), water
Reverse osmosis (RO)	All particulate matter and solutes	Water only

Bacteria removal by microfiltration – ESL milk production

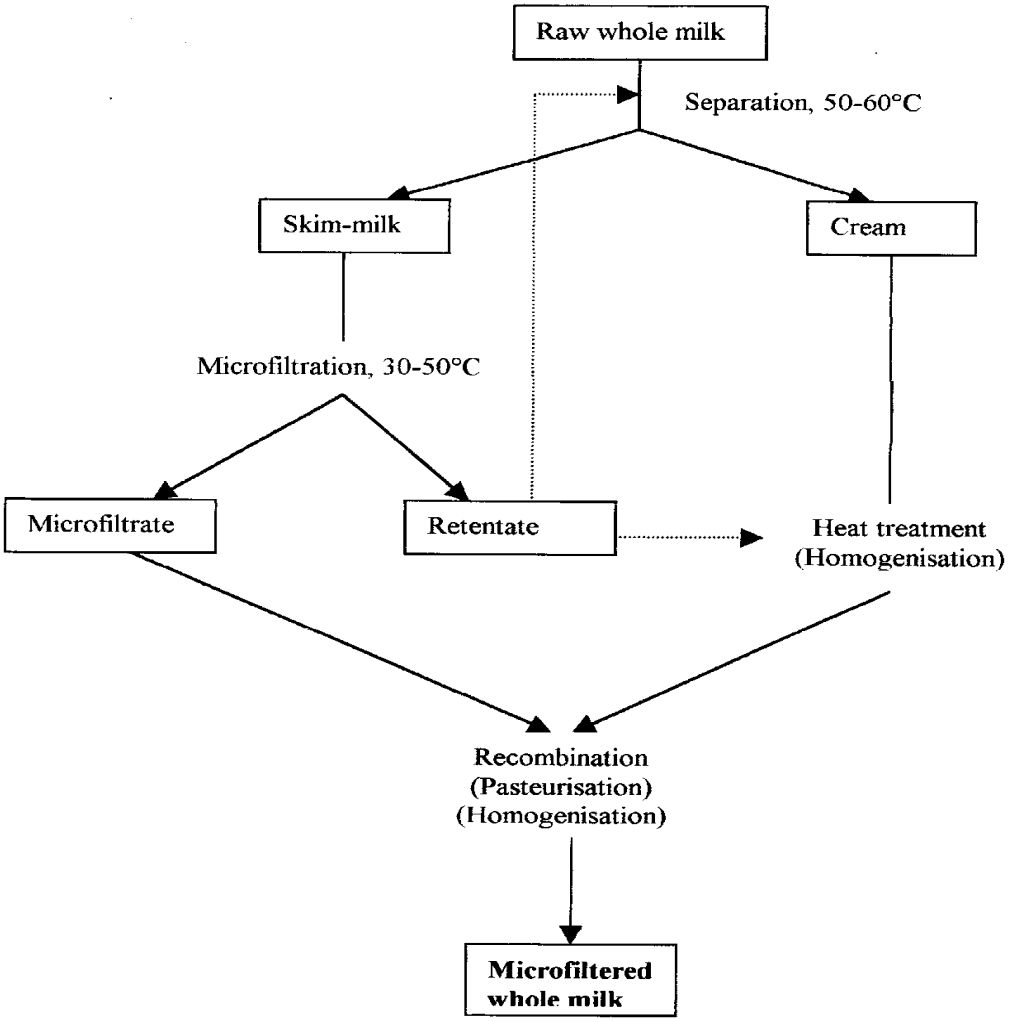
- Used now in several countries including Australia

ESL milk production by microfiltration

Steps involved:

1. Separation of whole milk to give cream and skim milk
2. Microfiltration of skim milk using 0.8-1.4 µm membrane to give permeate (wanted) and retentate (unwanted)
3. Homogenisation & heat treatment (typically 125°C for 4-5 s) of cream
4. Heated cream and skim milk permeate recombined
5. Recombined mixture pasteurised (≥ 72°C for 15 s)
6. Resulting ESL milk cooled & packaged under very clean conditions
7. ESL milk stored refrigerated

ESL milk by microfiltration (the Bactocatch® process)



Shelf-life of microfiltered ESL milk packaged under ultra-clean conditions

- ≥ 20 days
- can be contaminated after the membrane treatment
- ESL milk spoils due to:
- growth of post-processing contaminants (PPC) and/or
- growth of psychrotrophic bacteria which pass through membrane
  - Microfiltration reduces bacterial count by 4-5 logs – similar reduction to pasteurisation but it reduces spores while pasteurisation does not.
- PPC can enter the milk from the filler equipment, air and packaging material
  - steps have to be taken to eliminate contamination sources to achieve long shelf-life

ESL milk by bactofugation

Bactofugation

- Removes bacteria (and somatic cells) by centrifugation
- Referred to as 'bactofugation' because the commercial equipment manufactured by Tetra Pak is marketed under the tradename of *Bactofuge*®
- Uses a centrifugal force of ~9,000 g
- Separation of the bacteria is based on specific gravity (SG)
  - Bacterial spores have SGs of 1.30-1.32 g/mL
  - Vegetative bacterial cells have SGs of 1.07-1.12 g/mL
- milk has an SG of 1.028-1.038 g/ml; therefore difficult to remove vegetative bacterial cells from milk

Bactofugation 2

- Reduces total bacterial count in milk by 1.3 logs or ~95% (less than MF) – more with two centrifuges in series
- Removes >97% of spores; around 2-log reduction
- Without additional heat treatment, bactofugation extends shelf-life of drinking milk by 4-5 days

ESL milk by bactofugation

- ESL milk processing by bactofugation is similar to that by microfiltration
- Cream is first separated from whole milk
  - Cream removal also reduces the viscosity and increases rate of removal of bacteria
  - ~ 30% of the sporeforming bacteria move with the cream phase, hence need to first separate the cream
  - Cream is heat treated as with microfiltration
- Skim milk is centrifuged and centrifugate (unwanted) continuously removed
- Centrifuged skim milk is recombined with the heated cream
- Recombined milk is heat-treated (at pasteurisation temperatures of higher)
- Packaged and stored refrigerated as per microfiltered ESL milk
- Shelf-life ≥ 20 days, depending on final heat treatment and packaging used

ESL process using bactofugation

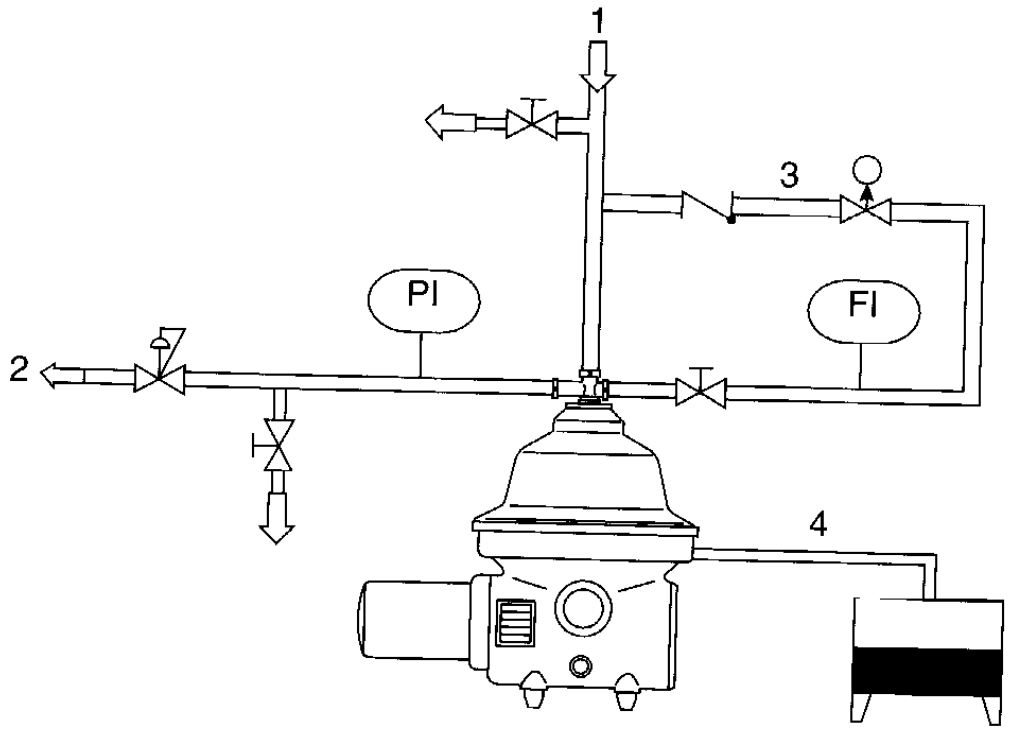


Figure 1 Schematic representation of bacterial clarification of milk by centrifugation with concentrate recyling. 1, Milk feed; 2, bacterially clarified milk, discharge; 3, recycled centrifugate; 4, discontinuously discharged bacterial concentrate. (Courtesy of Westfalia Separators Australia Pty Ltd.)

ESL milk by heat treatment only

ESL milk produced by heat treatment

- Produced in several countries including Australia
- Occupies substantial percentage of milk market in some European countries
- Considerable volumes of ESL milk are exported from Australia

Common heat treatments used for milk

Increasing severity

- **Thermisation**
  - 60-65ºC for 5-15 s
- **Pasteurisation**
  - 72ºC for 15 s (minimal conditions)
- **ESL (Extended Shelf Life) processing**
  - 120-135ºC for 1-10 s
- **UHT (Ultra High Temperature) processing**
  - 138-145ºC for 2-10 s
- **In-container sterilisation**
  - 110-120ºC for 10-30 min

	Pasteurisation	ESL	UHT
Heating conditions	72-82°C for 15-30 s (continuous, HTST)	Commonly 120-130°C for 2-8 s	Commonly 138-142°C for 2-5 s
Bacteria destroyed	All non-spore-forming pathogens; Most non-spore-forming spoilage bacteria	All non-spore-forming bacteria including thermodurics; Most spores	Almost all bacteria
Bacteria not destroyed	Non-spore-forming thermodurics and spores	Spores with high heat-resistance	Very highly-heat-resistant spores
Shelf life	10-20 days (refrigerated)	30-60 days with ultra-clean packaging (refrigerated)	6-12 months (at room temperature)
Cause of spoilage	Post-processing contaminants (PPC),	PPC and psychrotrophic sporeformers	Rarely bacterial; bitterness, gelation, sedimentation, fat separation

Shelf-life of ESL milk packaged under ultra-clean conditions

- 30-60 days
- can be contaminated after the heat treatment
- ESL milk spoils due to:
- growth of post-processing contaminants and/or
- growth of psychrotrophic spore-forming bacteria
- Post-processing contaminants can enter the milk from the filler equipment, air and packaging material
  - steps have to be taken to eliminate contamination sources, e.g.:
    - sterilisation of filler (e.g., steam, hydrogen peroxide [H_2O_2])
    - sterilisation of packaging material (e.g., $H_2O_{2)}$
    - use of sterile (HEPA-filtered) air in filler

Shelf-life of ESL milk if packaged aseptically

- Shelf-life of up to 90+ days
- Should not be contaminated after the heat treatment
- Spoilage should be due only to growth of psychrotrophic spore-forming bacteria whose spores are not killed by the heat treatment

How important are the heating conditions for the shelf-life of ESL milk

- It doesn't matter much what heating conditions are used if post-processing contamination occurs
  - If PPC is prevented, even milk pasteurised at 72°C for 15 s will last for 40+ days
- So let's now assume no PPC!
- Then bacterial spoilage can only occur by sporeformers whose spores survive the heat treatment **AND** can grow at refrigeration temperature, i.e., psychrotrophic sporeformers

ESL aim 1 : To kill all non-spore-formers & spores of psychrotrophic spore-formers

- Heating at ≥ 120°C kills all vegetative bacteria and most spores; main concern are spores of psychrotophic sporeformers
- Several types of sporeformers can be psychrotrophic, i.e, grow at refrigeration temperatures (≤ 7°C)
  - They occur in raw milk in low numbers (< 100/mL)
  - *Bacillus cereus, B. circulans, Paenibacillus* are the most common
  - *B. cereus* is the main problem
    - some strains are psychrotrophic
    - some strains are pathogenic
    - spores of some strains are quite heat-resistant
- Hence a major aim for ESL processing is to kill spores of psychrotrophic sporeformers
  - Known to be killed at ~134°C for ~4 s (or equivalent temp-time combos)

Taste of ESL milk

- Taste depends almost entirely on the heat treatment applied
- If produced by **heat treatment only**, ESL milk has a slight cooked taste but most consumers cannot distinguish it from pasteurised milk
  - Extent of chemical changes (like production of cooked flavour compounds) in milk depends on the heating conditions
  - Cooked flavour compounds are formed from the whey protein β-lactoglobulin and also the milk fat globule membrane
  - Extent of denaturation of β-lactoglobulin is a good indicator of cooked flavour production
  - Common ESL processes denature the β-lactoglobulin by 30 - 80%; this should be minimised for good flavoured ESL milk
- If produced by a **non-thermal process + a heat treatment**
  - Taste will be less cooked and denaturation of β-lactoglobulin will be less than in thermally produced ESL milk
  - Only the cream is treated at high temperature – cream represents only ~6% of the milk protein

ESL aim 2: To have flavour similar to pasteurised milk

Fact 1: For the same bacterial kill, the higher the temperature the better the flavour (less chemical change)

- For ESL milk (also UHT milk), heating at high temperatures for short time produces a better flavour than heating at lower temperature for a longer time

Fact 2: Heated milk in which the whey protein, β-lactoglobulin is denatured more than ~50% has a noticeable cooked flavour

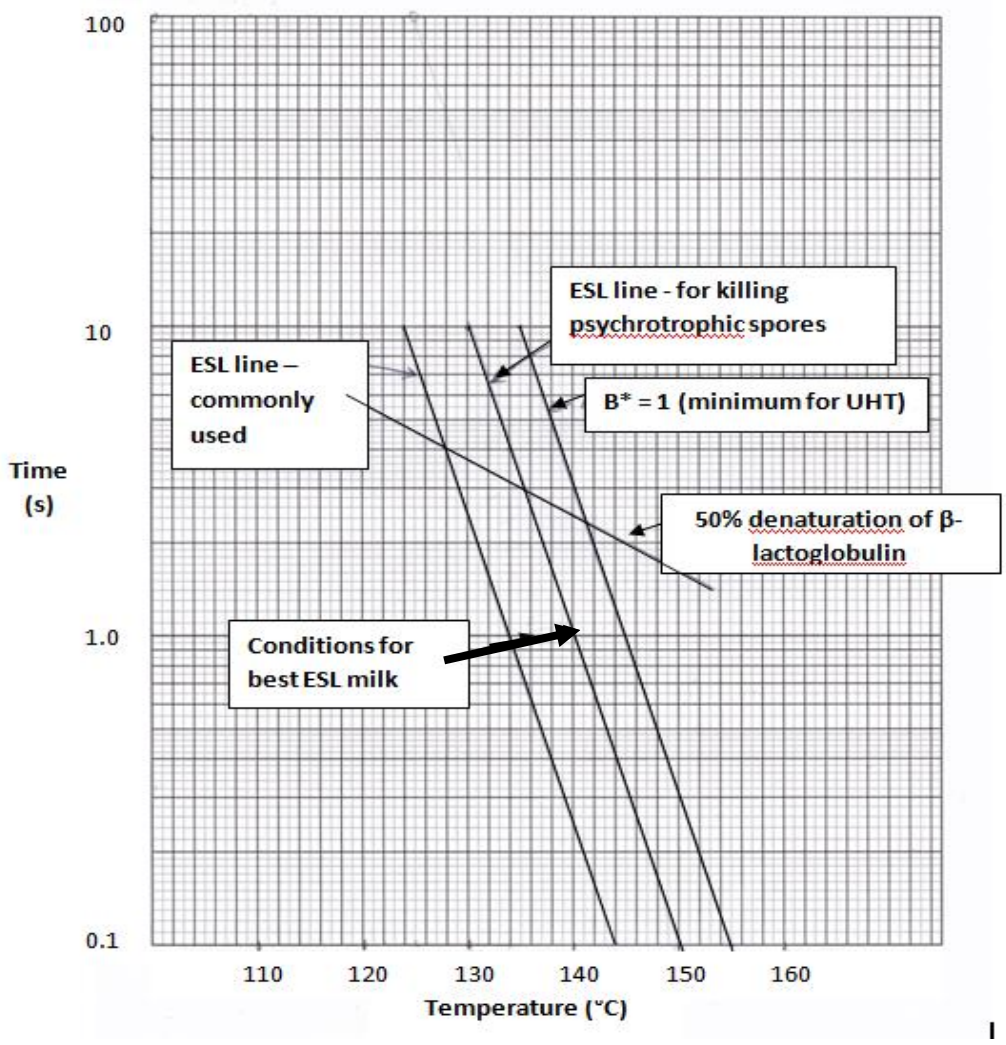
- Therefore the best flavoured ESL milk will be produced at high temperature for a short time to denature the β-lactoglobulin by ≤ 50%

Optimum heating conditions for ESL milk

Requirements:

1. To kill spores of psychrotrophic bacteria
   - equivalent conditions to ~134°C for 4 s
2. Heating conditions to denature ≤ 50% β-lactoglobulin
3. Heating conditions to be sub-UHT conditions
   - the minimum UHT heating conditions kills highly-heat-resistant spores by 9 logs (i.e., to 1/1000,000,000 of the initial count)
     - Known as B* of 1 (or F_0 of 3)
   - For ESL, recommend B* of ≥ 0.3 (F_0 of ≥ 1)

Temperature – time combinations for optimum ESL heating



Some ESL temperature-time combinations: Chemical and bacterial effects

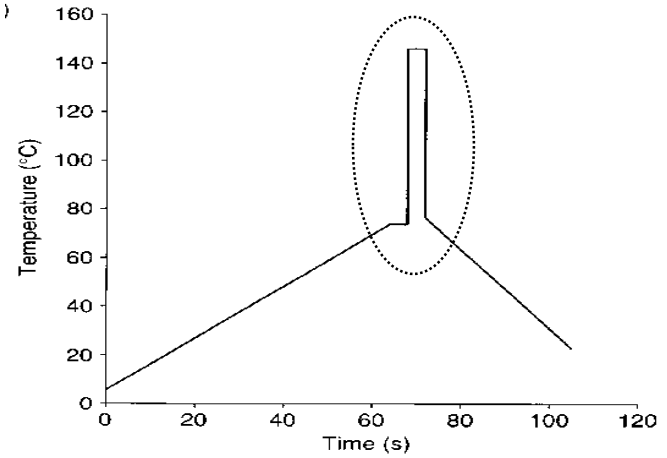
Heating conditions (°C/ s)	B*	β-Lactoglobulin denaturation (%)	
120/9	0.03	61	B* too low, β-Lg denat'n too high
127/5	**0.09**	**55**	Commonly used conditions for ESL
134/4	**0.32**	**56**	Conditions for killing psychrotrophic spores
136/2	0.26	44	Reasonable for ESL
138/2	**0.40**	**45**	Minimum conditions for ESL in USA
140/1	**0.32**	**34**	Recommended for ESL by some companies
145/0.3	0.32	24	Excellent for ESL if can be achieved

Preferred for ESL milk:

- B* ≥ ~0.3
- β-Lactoglobulin denaturation (%) ≤ 50%
  - **Un**denatured β-lactoglobulin (measured) of ≥ ~1600-1800 mg/L

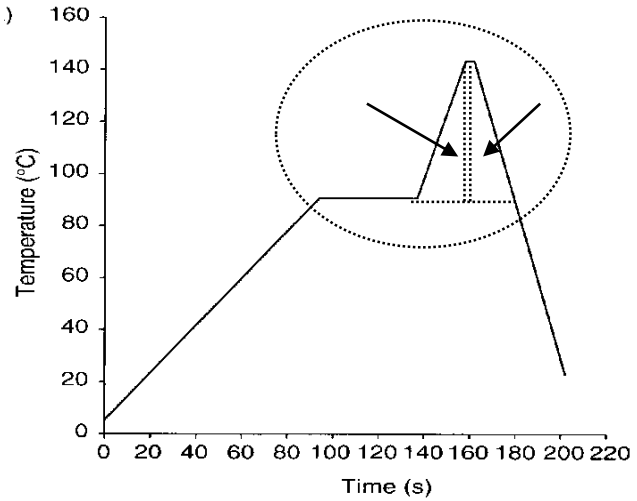
What do we mean by "temperature–time combinations"

- Refers to the highest temperature reached and the time the milk spends in the holding tube.
- If the heat input in the holding tube accounts for almost all of the heat input, then the temperature–time conditions of the holding tube can be used to estimate it
- This is the case for **direct** heating plants (steam injection or infusion)

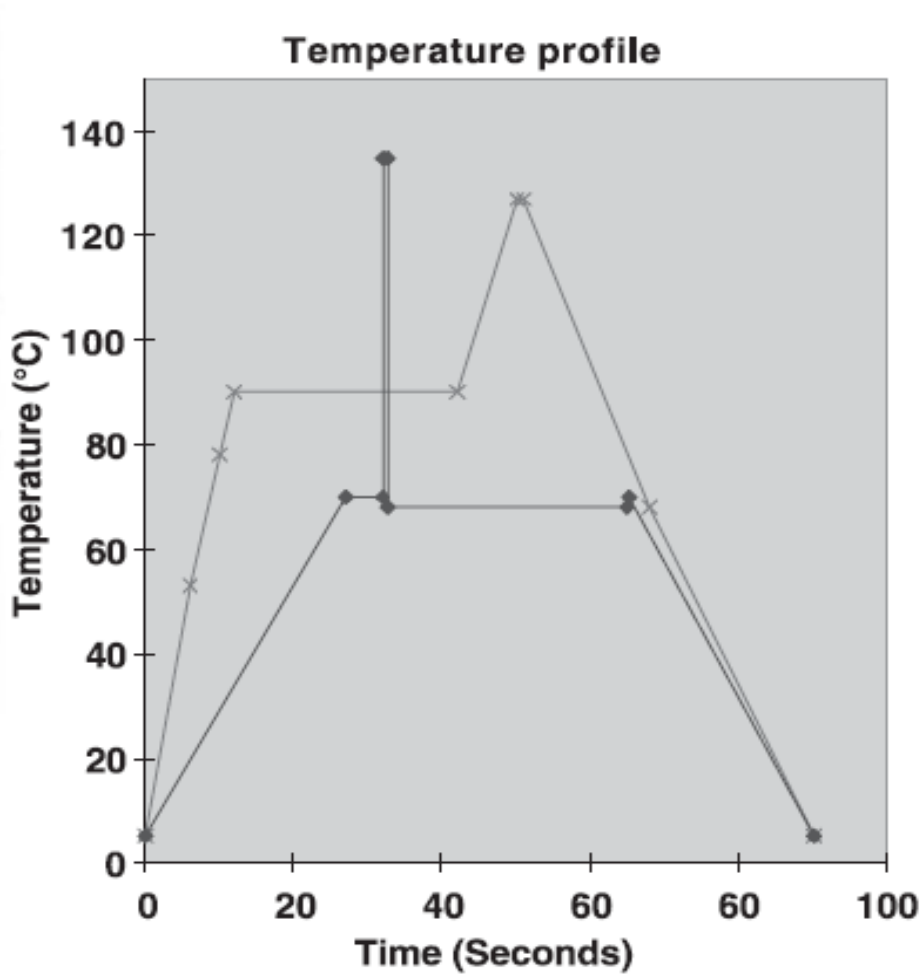


What do we mean by "temperature–time combinations" (cont)

- In many plants, the milk obtains heat before, during and after the holding tube
- This affects both the bacterial kill and the amount of denaturation of β-lactoglobulin
- The case with **indirect** heating plants (plate or tubular)



Comparison of direct and indirect ESL systems with the same F_0 (0.22)



Direct: 135°C for 0.5 s
Indirect: 127°C for 1 s

Rysstad & Kolstad 2006

Summing up – ESL milk produced by heating alone

Optimum conditions to produce ESL milk with a long shelf-life and with good flavour

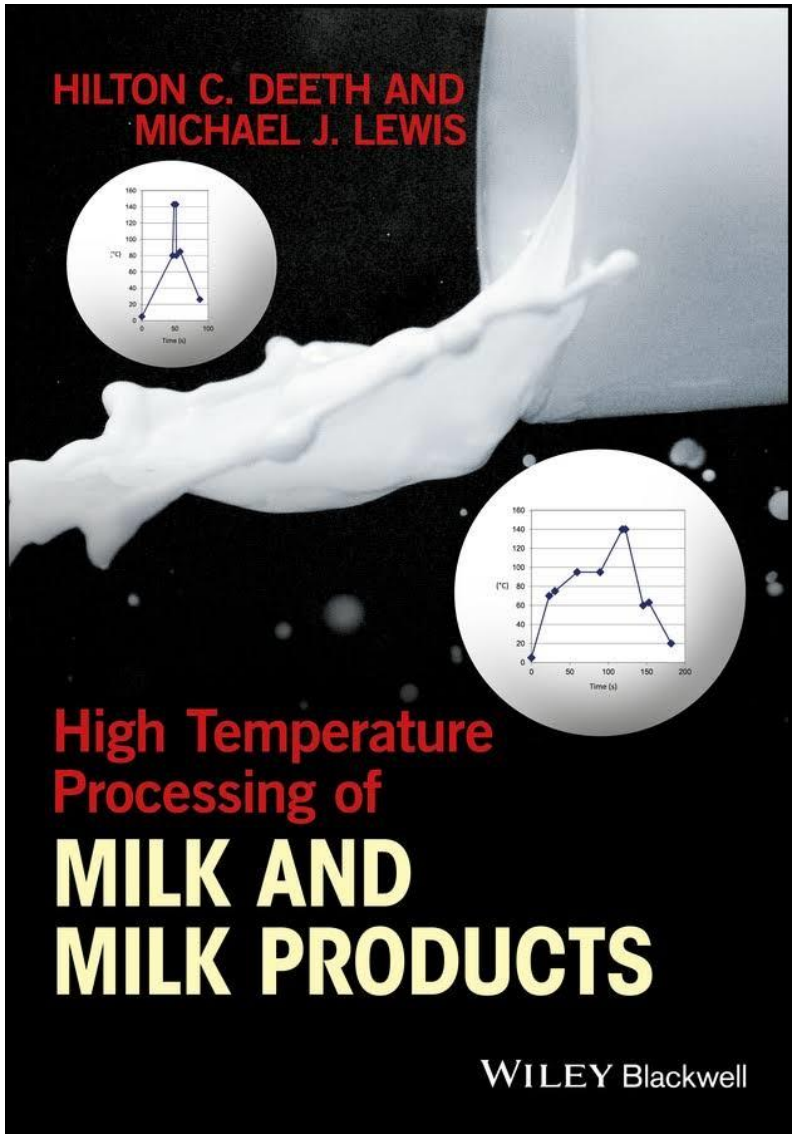
- Use direct heating at ~134-145°C for 4-0.3 s
- And package aseptically

Historical and practical considerations

- Less severe heating conditions, e.g., 125-130°C for 8-2 s with ultra-clean packaging has been, and is being, used successfully by many companies throughout the world, but occasional failures due to PPC do occur
- In some countries, heating at ≥ 135°C is defined as UHT heating and may not be accepted for ESL processing. Hence very high temperatures for a short time may not be an option

A commercial

All this and much more can be found in this recently released book



Thank you for your attention ☺