Life Cycle Assessment of Dairy Derivatives – Towards an eco-design of the pasteurization process

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Milk is a complete food comprising all essential nutrients for human.

It is vulnerable commodity product that needs processing to convert it into several products or to increase its shelf life.

Processing often require thermal treatment.

<table>
<thead>
<tr>
<th>Heat Treatment</th>
<th>Temp [°C]</th>
<th>Time scale [Sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermalization</td>
<td>63-65</td>
<td>15-20</td>
</tr>
<tr>
<td>Pasteurization</td>
<td>72 or 85</td>
<td>15 or 1</td>
</tr>
<tr>
<td>Ultra-Pasteurization</td>
<td>125-138</td>
<td>2-4</td>
</tr>
<tr>
<td>Preheat treatment</td>
<td>70-110</td>
<td>15-120</td>
</tr>
<tr>
<td>UHT</td>
<td>130-145</td>
<td>1-30</td>
</tr>
</tbody>
</table>

91% of consumed milk pass through pasteurization (Tamine, 2008).

Pasteurisation is relatively mild heat treatment, sufficient to eradicate microorganisms and extend shelf life.
Introduction

Average composition of milk (Bansal and Chen, 2006)

Food safety

Product transformation

Heat treatments in dairy industries

Fouling

Proteins + calcium + minerals

Al-Ogaili, 2014
### Dairy Fouling – A complex Phenomenon

<table>
<thead>
<tr>
<th>Beta-lactoglobulin (β-lg)</th>
<th>Unfolding</th>
<th>Aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Principal protein in deposits</td>
<td>- Starts at 65-70°C</td>
<td>- Unfolded molecules react with each other</td>
</tr>
<tr>
<td>- Tertiary structure due to internal S-S bridges</td>
<td>- Loss of the tertiary structure</td>
<td>- Formation of protein particles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unfolding</th>
<th>k(_{\text{unf}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregation</td>
<td>k(_{\text{agg}})</td>
</tr>
<tr>
<td>FOULING</td>
<td>Bulk</td>
</tr>
</tbody>
</table>

\[ M_{\text{fouling}} \text{ correlates with } \frac{k_{\text{unf}}}{k_{\text{agg}}} \] (depending on milk compositions)

### Dairy deposit build-up:

1- Induction
Unfolded protein only

2- Adhesion of protein-covered Ca particles

3- Arborescent Build-up

Introduction

Average composition of milk (Bansal and Chen, 2006)

Heat treatments in dairy industries

Fouling
Proteins + calcium + minerals

Cleaning costs
- Interruption of production
- Environmental footprint

Oversizing
- Additional heat resistance

Microbiological risks
- Favorization of settlement

Food safety

Product transformation

Cleaning costs - Interruption of production - Environmental footprint

Oversizing - Additional heat resistance

Microbiological risks - Favorization of settlement


Al-Ogaili, 2014

Food safety

Product transformation

Heat treatments in dairy industries

Fouling
Proteins + calcium + minerals

Cleaning costs - Interruption of production - Environmental footprint

Oversizing - Additional heat resistance

Microbiological risks - Favorization of settlement

Categories for fouling mitigation strategies?
General Context

**Acting on Process Parameters**
- Hydrodynamics
- Temperature profile
- Milk composition
- Heat exchanger arrangement
- Cleaning sequences

**Acting on Surface Properties**
- Chemical modification
- Hydrophilic coatings (antifouling)
- Hydrophobic coatings (fouling-release)
- Physical modification

Environmental Evaluation of Pasteurisation to propose recommendation for achieving Ecodesign
Fertilizer Manure Seed
Raw material (Feed production)

Emission to Soil and Water
(Heavy metals, Phosphate, waste water, solid waste)

Emissions to Air
$N_2O, CH_4, CO_2, NO_x, NH_3$

Pesticides Energy Machinery

Wheat straw Maize silage Barley etc etc..

Chemicals Energy Water Machinery

Dairy Production

Detergents Disinfectant S Water Electricity Natural gas Fuel

Milk

Dairy industry (pasteurization)

Meat production
Bibliography

Review of literature and state of the art for dairy sector

- LCA studies in literature deals only with raw material (crop production) or Dairy production
- Use of products from production system
- Various FU used according to milk function
- Most of them are quantitative
- Other used quality of milk as FU i.e ECM and FPCM
- System boundaries also varied from farm to gate and gate to gate
- Majority of them considered Global Warming.
Review of literature and state of the art for pasteurization

- Currently there is a lack of literature studies.
- No research paper/study found dealing Environmental approach for pasteurization currently.
- Lack of FU consideration for dairy processes.
- The FU previously defined are all according to the production system.
- Most of the research studies (LCA) dealing classic dairy sector and production chain.

Other studies found in the literature deals with:
- Kinetic model of deposits
- Denaturation
- Operating and Physicochemical conditions
Life Cycle Assessment of Pasteurization

Subsystem 1 (Raw material)
- Water
- Use of Energy Sources
- Raw Material

Subsystem 2 (Milk Production)
- Cleaning and sanitizing agents
- Electricity
- Fuel/Natural gas

Subsystem 3 (The Dairy Processing)
- Pasteurized Milk
- UHT Milk
- Yoghurt
- Cream
- Butter
- Cheese
- Milk powder

Environmental Impacts

Other subsystems
Subsystem Dairy processing

1st step
Pasteurization process

2nd step
Cleaning in place (CIP) procedure

Typical CIP station (source: Bratland and Rosenberg, 1992)
Life Cycle Assessment of Pasteurization

- Inventory data from INRA Pasteurizer to be applied in current setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total value</th>
<th>characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pasteurisation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft Water</td>
<td>600 L</td>
<td>For model fluid preparation</td>
</tr>
<tr>
<td>WPC</td>
<td>6 kg for total of 600L</td>
<td>1% w/w</td>
</tr>
<tr>
<td>Electricity for storage of model fluid</td>
<td>kw unknown</td>
<td>At 4 °C for 15h</td>
</tr>
<tr>
<td>Electricity for 3 pumps</td>
<td>43kw</td>
<td>$\sum$3pumps X total experiment time</td>
</tr>
<tr>
<td>Natural gas</td>
<td>45kw</td>
<td>15kw for preheating and 30 kw for heating (60°C to</td>
</tr>
<tr>
<td><strong>Cleaning In Place (CIP)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft Water</td>
<td>300L</td>
<td>150 L for 2% NaOH and 2% HNO3 solution</td>
</tr>
<tr>
<td>Electricity for 3 pumps</td>
<td>11kw</td>
<td>$\sum$3pumps X total cleaning time</td>
</tr>
<tr>
<td>Castic souda (NaOH)</td>
<td>3kg</td>
<td>In 150 L water at 85 °C</td>
</tr>
<tr>
<td>Nitric acid (HNO3)</td>
<td>3kg</td>
<td>In 150 L water at 85 °C</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Data unknown</td>
<td>For heating detergent at 85 °C</td>
</tr>
</tbody>
</table>
## Life Cycle Assessment of Pasteurization

### Database used for project

<table>
<thead>
<tr>
<th>Input/output</th>
<th>Type</th>
<th>Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Electricity, Fuel, Natural gas</td>
<td>IEA, Ecoinvent 3</td>
</tr>
<tr>
<td>Milk production</td>
<td>Raw Milk</td>
<td>IDF</td>
</tr>
<tr>
<td>Cleaning agents</td>
<td>Nitric acid (HNO3), Sodium hydroxide (NaOH)</td>
<td>Ecoinvent 3</td>
</tr>
<tr>
<td>Water</td>
<td>Surface water, Ground water etc. etc.</td>
<td>Ecoinvent 3</td>
</tr>
</tbody>
</table>

### Impact methodology used

- Impact 2002+
- ReCIPe
- CML 2 Baseline
Process contributors for GW potential for 10 year’s cycle

- Heat, natural gas: 53%
- Water, softwater: 20%
- Nitric acid: 13%
- Electricity: 13%
- Tap water: 1%
## Scenario – Variation of cleaning sequences

<table>
<thead>
<tr>
<th>Parameters</th>
<th>1. Base Scenario</th>
<th>1. Scenario amount of detergents increased with decrease in energy and water</th>
<th>1. Scenario amount of detergents decreased with increase in energy and water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity CIP</td>
<td>1</td>
<td>0.66 (↓ by 1/3)</td>
<td>2 (↑ doubled)</td>
</tr>
<tr>
<td>Tap water CIP</td>
<td>1</td>
<td>0.66 (↓ by 1/3)</td>
<td>2 (↑ doubled)</td>
</tr>
<tr>
<td>Tap water Rinsing</td>
<td>1</td>
<td>0.66 (↓ by 1/3)</td>
<td>1</td>
</tr>
<tr>
<td>Soft water CIP</td>
<td>1</td>
<td>0.66 (↓ by 1/3)</td>
<td>1</td>
</tr>
<tr>
<td>HNO₃</td>
<td>1</td>
<td>4 (↑ by 2/3)</td>
<td>0.5 (↓ by half)</td>
</tr>
<tr>
<td>NaOH</td>
<td>1</td>
<td>4 (↑ by 2/3)</td>
<td>0.5 (↓ by half)</td>
</tr>
<tr>
<td>Temperature CIP</td>
<td>1</td>
<td>0.66 (↓ by 1/3)</td>
<td>1</td>
</tr>
</tbody>
</table>
Results

Biomimetic Liquid-Infused Slippery Surfaces

- Lubricant-impregnated nanotextured surfaces
- Excellent anti-adhesive effect
- A simple water rinse removes all the dairy deposit as opposed to heavy standard clean-in-place procedures

Silane-based Thin Coatings by plasma Spraying

- Quick and versatile process
- Tunable surface properties
- Good fouling-release properties (-90 wt.%)
Conclusion

- Analysis of the reference case shows that Cleaning in place and thermal treatment have almost the same magnitude of impacts
- Influence of cleaning sequences is low on the gain regarding the environmental performance of pasteurization
- In order to improve the environmental consequences, further studies will concern to assess whether change in the composition and surface can decrease the environmental impact.
  - Influence of Ca+/Beta-lactoglobulin and phosphate
  - Influence of surface properties

LCA appears as a driver for further development in eco-friendly pasteurization process