Recombination theory and technology and Recombined UHT milk

Ranjan Sharma
Outlines

• Background
• Recombining – theory
• Recombined UHT milk
Descriptions

• Natural milk - white fluid produced by animals and human
  • Oil-in-water emulsion produced by natural emulsification

• Recombined milk - white fluid produced by mechanical means
  • Simulation of the natural milk by recombining individual constituents of the natural milk
  • Requires emulsification
Recombined milk - definition

- **FAO/WHO 1973 Codex milk committee**
  - Milk product resulting from the combining of milk fat and milk solids-not-fat in one or more of their various forms with or without water. The combination must be made so as to re-establish the product’s specified fat to solids-not-fat ratio and solids to water ratio.
Why recombining milk?

• Unavailability of sufficient local milk
  • Poor infrastructure for procurement and distribution
  • Poor cattle breeds
• Disproportional production of milk around the world - need for export
• Desire to provide adequate human nutrition, especially for infants and young people
• Balancing seasonal demand for milk & milk products
• Desire to develop tailor-made, novel formulations
Per capita milk consumption

• Milk producing countries (i.e. New Zealand, Australia, Western Europe, North America)
  • 1000 mL/day

• Developing countries
  • 100 mL/day
Recombining - emulsion formation

- Oil-soluble/dispersible ingredient
- Water-soluble/dispersible ingredients

Blend tank

- Homogenisation
- Packaging

Further heating

Additives
Recombining - emulsion formation

Oil-soluble/dispersible ingredient

Oil

Water

Water-soluble/dispersible ingredients

Blend tank

Homogenisation

Further Processing (e.g. UHT)

Additives

Packaging

Important variables
Reconstitution of milk powder

- Proper hydration and dispersion of milk powder essential
- Optimum conditions determined by the type of milk powder used
Simple setup for reconstitution of milk powder

- **Agitator**
- **Reconstitution tank**
- **Recirculation line**
- **Water**
- **Powder**
- **Powder-water Blending unit**
Recombination plat with in-line fat mixing

Dairy Processing Handbook, Tetrapak
Homogenisation

• Heart of the recombining process
• Leads to the formation of fat globules and migration of proteins to the fat globule surface layers
• High pressure valve homogenisers are most common
Homogenising devices

- High-speed blender
- Colloid mills
- High-pressure valve homogeniser
- Ultrasonic homogeniser
- Microfluidiser
- Membrane-based homogeniser
Homogeniser
Homogenising valve

Valve pressure

Impact ring

Homogenised product

Seat

Unhomogenised product
Two-stage homogeniser

Stage 1

Stage 2

Unhomogenised product

Homogenised product
Homogenisation efficiency

\[ \frac{\Delta E_{\text{min}}}{\Delta E_{\text{total}}} \times 100 \]

\( E_H \) - homogenisation efficiency

\( \Delta E_{\text{min}} \) - Minimum amount of energy theoretically required to form emulsion = \( \Delta A \gamma \) (interfacial area and interfacial tension)

\( \Delta E_{\text{total}} \) - Actual amount of energy expended during homogenisation
Types of powder-water blending systems

- Venturi blender
- Tri-blender
- Centrifugal blender
Venturi blender

Powder

Hopper

Isolating valve

Water

Reconstituted milk
Tri-blender
Centrifugal blender

- Powder
- Hopper
- Isolating valve
- Water from recirculating line
- Water
- Impeller
- Belt drive
- Reconstituted milk
High-speed blender for reconstitution of milk powder

Dairy Processing Handbook, Tetra Pak
Ingredients in recombined milk

Basic ingredients

- Skim milk powder
- Anhydrous milk fat
- Water

Other ingredients

- Whole milk powder
- Butter milk powder
- Milk protein concentrate/isolate
- Caseinate
- Whey protein concentrate/isolate
- Lactose
- Emulsifiers & stabilisers
Manufacture of SMP, AMF & BMP

Raw milk → Preheating (35-40°C) → Cream separation

Cream separation:
- Cream (40% fat)
- Skim milk (0.05% fat, 9% snf)

Cream:
- Preheating

Butter (80% fat) → Buttermilk powder
- Pasteurisation (71.7°C/15 s)
- Preheating (85°C, 1 min)

Buttermilk powder:
- Evaporation (3-4 effect, 70-40°C, 48-52% TS)
- Spray drying
- Air inlet: 180°C
- Air outlet: 80°C
- Final moist: 4%

SMP

Anhydrous milk fat (99.9% fat)
Manufacture of milk protein concentrates

- Skim milk
  - Membrane concentration
  - Milk protein Concentrate/isolate
- Rennet/Acid precipitation
- Casein curd
  - Resolubilisation
  - Spray drying
  - Caseinates
- Whey
  - Membrane concentration
  - Evaporation
  - Spray drying
  - Whey protein Concentrate/isolate
## Selective Chemical Composition of Milk Powders

<table>
<thead>
<tr>
<th>Attribute</th>
<th>SMP</th>
<th>WMP</th>
<th>BMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Fat, (%)</td>
<td>max 1.0</td>
<td>min 26</td>
<td>5.0</td>
</tr>
<tr>
<td>Total protein (N*6.38, %)</td>
<td>35</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>Lactose (%)</td>
<td>50</td>
<td>38</td>
<td>48</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Potassium (%)</td>
<td>1.6</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
## Selective Chemical Composition and Physico-Chemical Attributes of Milk Protein Products

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Milk protein concentrate</th>
<th>Sodium caseinate concentrate</th>
<th>Whey protein concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Total protein (N*6.38, %)</td>
<td>82.5</td>
<td>92</td>
<td>83.5</td>
</tr>
<tr>
<td>Casein (%)</td>
<td>66.0</td>
<td>92.0</td>
<td>0</td>
</tr>
<tr>
<td>Whey protein (%)</td>
<td>16.5</td>
<td>0</td>
<td>83.5</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>2.20</td>
<td>0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>Potassium (%)</td>
<td>0.01</td>
<td>0.005</td>
<td>0.05</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>1.40</td>
<td>0.80</td>
<td>0.18</td>
</tr>
<tr>
<td>Protein state</td>
<td>Casein micelles, Soluble aggregates</td>
<td>Soluble whey proteins of casein</td>
<td>Soluble whey proteins</td>
</tr>
<tr>
<td></td>
<td>soluble whey protein</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Classification of skim milk powder

<table>
<thead>
<tr>
<th>SMP type</th>
<th>Extra low-heat</th>
<th>Low-heat</th>
<th>Medium-heat</th>
<th>Medium-high-heat</th>
<th>High-heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPNI</td>
<td>-</td>
<td>&gt;6</td>
<td>5.9-4.5</td>
<td>4.4-1.5</td>
<td>&lt;1.4</td>
</tr>
</tbody>
</table>

**Caution**: Such classifications can be misleading
Emulsion formation, structure and stability

• During homogenisation, fat globules with sub-micron size are formed
• Milk proteins migrate to the newly formed fat globule surfaces
• Capability to form a stable emulsion is determined by the ability of the protein to unfold at the fat-water interface
• Protein load affects the stability of emulsion towards heating and storage
Milk protein – the functional ingredient in milk powder and protein concentrate

- Proteins are surface active due to their amphiphilic nature
- Aggregation state of protein affects the stable emulsion formation
- Two major proteins: casein and whey proteins
Physico-chemical properties of milk proteins

**CASEIN**
- Strong hydrophobic regions
- Low cysteine
- High ester phosphates
- Little or no secondary structure
- Unstable in acidic conditions
- Micelles in native form
- Random coil in dissociated form

**WHEY PROTEIN**
- Balance in hydrophobic and hydrophilic residues
- Contains cysteine and cystine
- Globular, much helical
- No ester phosphate
- Easily heat denatured
- Stable in mild acidic conditions
- Present as soluble aggregates (<10 nm)
Protein adsorption

Spherical interface (emulsion or foam)

Flat interface (solid surface, e.g. Stainless steel tank)

Homogenisation or Quiescent conditions
Protein load

\[ \Gamma = \frac{\text{Protein at the oil droplet surface (mg)}}{\text{Total droplet surface area (m}^2)} \]
Protein load at recombined milk oil-water interface

<table>
<thead>
<tr>
<th>Protein</th>
<th>Protein load (mg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_s$-Casein</td>
<td>3-4.2</td>
</tr>
<tr>
<td>$\beta$-Casein</td>
<td>1-1.75</td>
</tr>
<tr>
<td>$\kappa$-Casein</td>
<td>4.2</td>
</tr>
<tr>
<td>Casein micelle</td>
<td>20</td>
</tr>
<tr>
<td>Sodium caseinate</td>
<td>2.2-2.6</td>
</tr>
<tr>
<td>Skim milk powder</td>
<td>10-23</td>
</tr>
<tr>
<td>$\beta$-Lactoglobulin</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Factors affecting protein load

- Volume of oil
- Protein concentration
- Homogenisation temperature
- Homogenisation pressure
- Aggregation state of protein
- Pre-treatment of protein, i.e. Hydrolysis or cross-linking
Types of protein adsorption

• Reversible and irreversible adsorption
• Competitive adsorption
Fat globules in recombined milk

Natural milk

Recombined (homogenized milk)
Recombined milk - casein micelles and whey proteins at oil-water interface

Sharma (1993)

200 nm
TEM of recombined milk

Sharma (1993)
Emulsion destabilisation in recombined milk

• Thermodynamically unstable
• Mechanisms of destabilisation: aggregation, flocculation, coalescence and creaming
Colloidal forces important for emulsion stability

<table>
<thead>
<tr>
<th>Type of force</th>
<th>Character</th>
<th>Origin</th>
<th>Influenced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>van der Waals</td>
<td>Attraction</td>
<td>Permanent &amp; fluctuating dipoles</td>
<td>Refractive index, Dielectric constant</td>
</tr>
<tr>
<td>Electrostatic</td>
<td>Repulsion</td>
<td>Surface charge</td>
<td>Ionic strength, pH</td>
</tr>
<tr>
<td>Steric</td>
<td>Repulsion</td>
<td>Adsorbed polymers</td>
<td>Polymer coverage &amp; solubility</td>
</tr>
<tr>
<td>Bridging</td>
<td>Attraction</td>
<td>Adsorbed polymers</td>
<td>Polymer coverage</td>
</tr>
<tr>
<td>Depletion</td>
<td>Attraction</td>
<td>Non-adsorbed polymers</td>
<td>Molecular weight, Polymer polydispersity, Ionic strength, poly electrolyte coverage</td>
</tr>
<tr>
<td>Polyelectrolytes</td>
<td>Repulsion or attraction</td>
<td>Adsorbed polyelectrolytes</td>
<td></td>
</tr>
</tbody>
</table>
## Colloidal forces important for emulsion stability

<table>
<thead>
<tr>
<th>Type of force</th>
<th>Character</th>
<th>Origin</th>
<th>Influenced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrophobic</td>
<td>Attraction</td>
<td>Water-water affinity</td>
<td>Solvent properties, surface hydrophobicity</td>
</tr>
<tr>
<td>Hydration</td>
<td>Repulsion</td>
<td>Dehydration of polar group</td>
<td>Emulsifier head group, crystallinity</td>
</tr>
<tr>
<td>Protrusion</td>
<td>Repulsion</td>
<td>Reduction in movement of emulsifiers normal to the interface</td>
<td>Fluidity of the layer, head-group size, Oil/water interfacial tension</td>
</tr>
</tbody>
</table>

DLVO Theory for colloidal stability

Electrostatic repulsion

van der Waals’ attraction

Total interaction

Interaction energy vs. Distance of separation (nm)
Emulsion instability

Recombined Milk Emulsion

Creaming

Flocculation

Coalescence

Oil separation

Inversion
Characterisation of emulsions

- Emulsifying properties of proteins
  - Emulsifying activity
  - Emulsion capacity
  - Surface hydrophobicity

- Emulsion stability
  - Emulsion droplet size
  - Protein load
  - Creaming and oil separation
  - Heat stability

- Emulsion rheology
- Emulsion microstructure
Particle size distribution - A stable emulsion
Particle size distribution - unstable emulsion
Recombined milk products

- Pasteurised milk
- UHT milk
- Evaporated milk
- Sweetened condensed milk
- Cheese
- Yoghurt
- Ice cream
- Many formulated emulsion products
Guide to powder selection

<table>
<thead>
<tr>
<th>Recombined Dairy Product</th>
<th>Heat Treatment of Powder</th>
<th>Desirable Functional Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (Pasteurised)</td>
<td>Low</td>
<td>Lack of cooked flavour</td>
</tr>
<tr>
<td>UHT Milk</td>
<td>Low - medium</td>
<td>Heat stability</td>
</tr>
<tr>
<td>Evaporated Milk</td>
<td>High</td>
<td>Heat stability</td>
</tr>
<tr>
<td>Sweetened Condensed Milk</td>
<td>Medium</td>
<td>Viscosity</td>
</tr>
<tr>
<td>Cheese</td>
<td>Low</td>
<td>Rennetability</td>
</tr>
</tbody>
</table>
# Guide to powder selection

<table>
<thead>
<tr>
<th>Product</th>
<th>Heat Treatment of Powder</th>
<th>Desirable Functional Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoghurt</td>
<td>Low*</td>
<td>Water binding, viscosity, gelation</td>
</tr>
<tr>
<td>Ice-cream</td>
<td>Low-medium</td>
<td>Foaming, whipping, emulsifying</td>
</tr>
<tr>
<td>Confectionery</td>
<td>High</td>
<td>Water binding, emulsifying, foaming, whipping, heat stability</td>
</tr>
<tr>
<td>Bakery</td>
<td>High</td>
<td>Water binding, emulsifying, foaming, whipping, gelling</td>
</tr>
<tr>
<td>Chocolate</td>
<td>High</td>
<td>High “free-fat”,</td>
</tr>
</tbody>
</table>

* High heat powder can be used if the yoghurt milk is not given a high heat treatment at the recombination plant.
Recombined UHT Milk

Typical Formulation:
8.5% MSNF, 3.5% fat

Ingredients:
Whole milk powder
Skim milk powder, fat, emulsifier, stabiliser

Processing:
UHT
UHT recombined sweetened milk

- Anhydrous milk fat: 3.6
- SNF: 8.5
- Sugar: 3.5
- Vanilla: 0.1
- Stabilizer: 0.2
- Water: 84.1
UHT recombined concentrated milk

- Also known as UHT recombined evaporated milk
  - Can be manufactured using standard UHT equipment
  - Alternative to canned evaporated milk
  - Less expensive to manufacture than canned evaporated milk
UHT milk: important requirements

Powder usable

- Skim milk powder, whole milk powder, buttermilk powder

Requirements

- Heat classification: low, medium
- Reconstitutability
- Microbial standard
- Emulsifying capacity
- Emulsion stability
- Flavour quality
- Level of heat stable enzymes
Recombined UHT milk

• **Issues**
  
  • Flavour
  
  • **Age gelation**
    
    • Caused by the action of enzymes from Psychrotrophic bacteria
    
    • Most rapid at 26°C
  
  • **Sedimentation**
    
    • Protein denaturation and aggregation (heat instability) - pH affects the sedimentation
Effect of pH on stability of recombined milks to UHT processing

Sediment Depth
Recombined UHT Milk Powders

[Graph showing the effect of pH on sediment depth for High Heat, Medium Heat, and Low Heat processed milks]

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