Food Emulsions and Foams
Dr. Simeon Stoyanov

Unilever Food and Health Research Institute
Outline of the talk:

• Main Building blocks of food emulsions
• Aren’t these blocks too few?
• Food emulsions clock
• Examples of food emulsions
  Ice Cream
  Dressings (Mayo)
  Spreads (Margarine)
Foods Building blocks

Oils/Fats (8 kcal/g): TAGS, Saturated/ (Poly) unsaturated
Proteins (4 kcal/g): dairy, egg, meat, (vegetables, cereals)
Carbohydrates (4 kcal/g): sugars, starch
Foods Building blocks

Multiple functions of macro-nutrients:
- To provide structure during processing
- To keep this structure during storage
- To give pleasant mouth feel (taste/flavour) during eating
- To deliver energy to human body in bioaccessible ways
Where there is more “technology” and what are its applications?
Most foods are emulsions. Both water and oil phases are usually structured.
What is Ice Cream made of?

Ice

Cream

Flavours

Suga

Fat
Milk Protein

Air
What is Ice Cream?

We think of ice cream as a 4 phase system:

- partially frozen ice crystals
- an oil-in-water emulsion: fat droplets
- a foam: air bubbles
- in a dispersed phase: sugar solution (matrix)
<table>
<thead>
<tr>
<th>Ice Cream</th>
<th>Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 30% of volume</td>
<td>• No energy contribution</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume</th>
<th>Energy</th>
<th>Total Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>407 kJoule/100ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td>745 kJoule/100g</td>
</tr>
</tbody>
</table>
Ice Cream

- 50% of volume
- No energy contribution
- Softens the ice cream
- Provides smooth texture

Volume

Energy

Total Energy: 407 kJoule/100 ml, 745 kJoule/100 g
Ice Cream

Fat

- 4.5% of volume
- 45% energy contribution

Provides structure
Carries and delivers flavour
Boosts creaminess
Stabilises the air bubbles

Volume

Energy

Total Energy

407 kJoule/100ml
745 kJoule/100g
Ice Cream

Matrix

- 15% of volume

Protein
- 8% of energy
- Stabilises fat droplets
- Stabilises air bubbles
- Contributes to flavour

Sugars
- 50% of energy
- Controls ice content
- Provides sweetness
- Gives thickness

Stabilisers
- <1% of energy
- Heat shock stability
- Gives thickness

Volume

Energy

Total Energy
- 407kJoule/100ml
- 745kJoule/100g
FAT DROPLETS

40µm
Ingredients

Water
Milk / Cream
Fat / Oil
Air
Sugar

Flavours
Emulsifiers
Stabilisers
Colours
Ingredients: Stabilisers / Thickeners

Sea Weed (Carrageenan)

Seeds (Guar)

Fruit (Pectin)
Ingredients: emulsifiers

- **Monoglycerides**

- **Sodium stearyl lactylate**

- **Citrem**

**Ingredients:** emulsifiers
What is Ice Cream Made of?

Ingredients

- Water
- Milk / Cream
- Fat / Oil
- Air
- Sugar
- Flavours
- Emulsifiers
- Stabilisers
- Colours

Structural Components

- Ice Crystals
- Air Bubbles
- Fat Droplets
- Matrix
What is Ice Cream Made of?

Water
Milk / Cream
Fat / Oil
Air
Sugar
Flavours
Emulsifiers
Stabilisers
Colours

Ice Crystals
Air Bubbles
Fat Droplets
Matrix
What is Ice Cream Made of?

- Water
- Milk / Cream
- Fat / Oil
- Air
- Sugar
- Flavours
- Emulsifiers
- Stabilisers
- Colours

Ice Crystals
Air Bubbles
Fat Droplets
Matrix
What is Ice Cream Made of?

- Water
- Milk / Cream
- Fat / Oil
- Air
- Sugar
- Flavours
- Emulsifiers
- Stabilisers
- Colours

Ice Crystals
Air Bubbles
Fat Droplets
Matrix
What is Ice Cream Made of?

- Water
- Milk / Cream
- Fat / Oil
- Air
- Sugar
- Flavours
- Emulsifiers
- Stabilisers
- Colours

Ice Crystals
Air Bubbles
Fat Droplets
Matrix
Manufacturing of Ice Cream

- Fat, Milk powder, Emulsifiers, Sugar, Thickeners
- Homogenisation (Homog.)
- Pasteurisation (Pasteuris)
- Ageing (crystallising?)
- Freezing/Aeration
- Filling
- Hardening

- 100 bar, 60°C, D[3,2] < 1μm
- 15 Sec, 85°C
- Min. 2 hrs, 5°C
- Typical overrun ~ 100%
- Scraped Surface Heat Exchanger
- -5°C
- -20°C
Mixing ...

Raw materials tanks

Premix Tank
Ice Cream Manufacture

Ice cream emulsion comprises droplets of ca. 1 μm
Ice Cream Freezer

Cylinder

Dasher
Ice Cream Freezer

- Ice cream out (-5°C)
- Air in
- Mix in (+5°C)

* Refrigerant
Eating creamy smooth soft cold icy

Physics & Materials Science
viscosity density hardness heat capacity

Microstructure
ice crystals air bubbles fat droplets sugar solution

The Real World ...

The Engineering World ...

The Microstructure World ...
Colloid Science and Ice Cream

Foam stability (50% air)

Emulsion (fat particle) stability

Ice crystal stability

Colloids are stabilised by surface active agents: Milk Protein
Close up of an air bubble ...

FAT DROPLETS

0.04mm
Two approaching colloidal particles

Interaction between particles
van der Waals, electrostatic, steric, depletion

Attractive forces highly dominate

Repulsive forces dominate
Stable

Attractive forces dominate
Flocculation

Coagulation
Hard Spheres
Partial coalescence
Solid/Liquid
Coalescence
Emulsions
Role of the emulsifier

Saturated monoglycerides are often added to ice cream to improve quality

\[
\begin{align*}
\text{HO-} & \text{O} \\
\text{O} & \\
\text{OH} &
\end{align*}
\]
Role of the emulsifier

- Fat droplets containing emulsifiers contribute to gas phase stability through:
  
  Direct adsorption of fat at the air interface
  and/or
  Structuring of fat in the matrix (partial coalescence)

- Aeration assists directly in the mechanism of partial coalescence
Proposed mechanism for partial coalescence

Mechanism of surface roughening - applies to weak thin (monolayer) interfaces

- Touch and prick through membrane
- Fuse and wet, by capillary action fill up the gap, liquid bridge formation
- By sintering crystals grow together
Advantages of emulsifier fat destabilization in ice cream:

- improved air phase stability
- greater stability against meltdown
- perceived creamier texture
- dryness on extrusion

Disadvantages:

- loss of all-natural label
- excessive destabilization can cause buttering

Perceived quality of ice cream is highly dependent on the controlled destabilization of fat.
Application of emulsions in the food industry
Dressings

Real Mayonnaise

Unilever Food and Health Research Institute
Mayonnaise is oil in water emulsion, made from (healthy) oils stabilized by egg yolk and flavoured with salt, vinegar and mustard.
The real issue with low oil mayo

Aim:
structure a low-fat mayonnaise with a low-caloric and natural structuring agent while maintaining a fast oral breakdown

Low oil mayonnaise with starch

Full fat mayonnaise
And the solution is ...

Low oil Mayonnaise
Slow oral breakdown

Full fat Mayonnaise
Fast oral breakdown

Low oil mayonnaise with starch
Low oil mayonnaise with citrus fibre
Full fat mayonnaise
Two primary processing routes used for real mayonnaise processing

**Route 1: Continuous Premix + Continuous Single Pass Milling**

Vegetable Oil -> Egg Phase -> Water/Vinegar

**Route 2: Batch Premix and Multi-pass Milling**

Vegetable Oil -> Egg Phase -> Water/Vinegar
Continuous Processing - Premix

- The manufacturing process of mayonnaise typically requires formation of a pre-emulsion, or “premix”
- Premix is a coarse (~50 μm) densely packed dispersion of oil droplets stabilized by egg yolk protein - this provides a barrier to recoalescence; the other aqueous ingredients surround these droplets as the continuous phase
- The initial procedure used in batching the premix is critical to the kinetics of forming the correct (oil-in-water) emulsion
  - order of addition is critical: egg phase, oil and water vinegar
  - egg phase must have enough water to create the continuous phase.
The longer the premix residence time, the softer and smoother the finished mayonnaise.

Solubility of Yolk and yolk components in solution as a function of pH and salt levels:

- Egg yolk granule phase solubility is very sensitive to both salt level and pH.
- Long residence premix times result in low plummets - low pH causes granules to precipitate.

![Solubility Graph]
Continuous Processing

Single-Pass Milling

- Final emulsification is accomplished in a milling equipment via the application of a high concentration of energy into a small volume of premix within the annular space of the mill.
- The average oil droplet size is in the order of 2-8 μm depending on type of milling device.
  - Typical average residence times of product within the mill are in the order of 10 msec.
  - Typical average volumes of product within the mill are in the order of 10 cc.
## Continuous Processing

### Single-Pass Milling

- **Typical in-line milling equipment used for real mayonnaise**

<table>
<thead>
<tr>
<th>Charlotte® Colloid Mill Sanitary SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap = 0.007 - 0.010” (key control parameter)</td>
</tr>
<tr>
<td>3500 - 3600 rpm (usually fixed)</td>
</tr>
<tr>
<td>sizes: SD2, SD5, SD20, SD40</td>
</tr>
<tr>
<td>SD 40 has a 40 horse-power motor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ross in-line high shear mixer X-series</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap: 0.045 - 0.075” (usually fixed)</td>
</tr>
<tr>
<td>3400 - 6000 rpm (key control parameter)</td>
</tr>
<tr>
<td>sizes: 3”, 6”, 9”, 12” and 15” (rotor diameter)</td>
</tr>
<tr>
<td>e.g 15” has 250 horse-power motor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fryma Koruma Modular In-line Colloid Homogenizer (Romaco)</th>
</tr>
</thead>
</table>
Margarine
What is a margarine?

Margarine is a water-in-oil emulsion. It contains dairy powders, salt, flavours to get a good taste and other ingredients for functionality.

Fat levels: 80/70% - 60% - 40% - (20) - (0)

Packaging: tubs and wrappers

Application: spreading, cooking, baking
History of margarines

- 1869 Mege Mourier Patent
- 1902 Hydrogenation
- 1930 Cooling drum
- 1950 Surface scraped heat exchanger
- 1955 Tubmargarines
- 1963/4 Becel/halvarines
- 1969 Melanges
- 1980 Protein halvarines
- 1989 Very low fat spreads
- 1993 Zero fat spreads
- 1998 Margarines with sterols
QUALITY of Margarines depends on

- Ingredients
- Blend
- Processing
- Packing
- Temperature
  - storage
  - distribution
Formulation and processing of margarine

Ingredients
- oil
- hardstock
- water + salt
- (thickener/gelling agents)
- proteins
- emulsifier
- colour + flavours
- preservative + acid

Processing
- temperature profile
- shear applied

Microstructure

Product quality
- spreadability
- firmness
- stability
- appearance attributes: yellow and glossy
- mouthfeel attributes: dissolvable, melting, powdery, salt, sour, fatty.
Structure of Margarine

Liquid Oil
Fat Crystals
Water droplets
Manufacturing of margarines
Process tools

- Oil refining and modification
- Blending
- Ingredient preparation
- Emulsion preparation
- Margarine processing
- Packaging
- Storage/Distribution
Making Margarine
Structure of Margarine

What To Do?

Mix all Ingredients incl oils/fats
Create Crystals
Manipulate Crystals
Create Water Droplets
Making Margarine

Basic Flow Diagram

Refinery and/or Making Margarine

Supply

Oils & Fats

Warehouse

Ingredients Preparation

Emulsion Preparation

Margarine Processing

Packaging

Distribution
Spreads production: process line

Production process:
- Premix
- Pasteuriser 60 °C
- Pre cooler
- A-units (coolers) 18-11-8.5 °C
- C'-unit (inverter) ~14 °C
- Packaging machine ~16 °C
- Rework 58 °C

Usage at home:
- Mouth 37 °C
## Function of A, B, C-unit

<table>
<thead>
<tr>
<th>Function</th>
<th>A-unit</th>
<th>C-unit</th>
<th>B-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling</td>
<td>Crystallisation</td>
<td>Crystallisation in rest</td>
</tr>
<tr>
<td>Crystallisation</td>
<td></td>
<td>Working</td>
<td>Working by sieve plates</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>A-unit</th>
<th>C-unit</th>
<th>B-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Cooling area**
- **Rpm** / knives
- **Pins** (type/no)
- **Place**
Depends on
- amount of crystals
  temperature
  SFC of the fatblend
- type of triglycerides
- working

DIFFERENCE IN NETWORK
- at packing or filling on the line
- after storage or at use
Control of texture through crystal network

How to influence consumer requirements by the solid fat content

Temperature

Solids

Better spreadable

More ambient stable

Better oral melt and taste (inversion)
Fatty acid distribution of major oils

- CN
- PK
- PO
- CS
- SF
- RP

- C20 unsat
- C18:3
- C18:2
- C18:1
- C16:1
- C20
- C18
- C16
- C14
- C12
SFC t control hardness and oral properties

SFC Butter and margarines

Solids(%) vs Temperature

- soft tub
- hard tub
- soft wrapper
- hard wrapper
- Butter