Stability of Food Emulsions (1)

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Definition and Importance of Emulsion Stability

**Definition:** "Ability to resist changes in properties over time"

**Importance:** Determines the shelf-life and processing of food emulsions

*May be desirable or undesirable*
Emulsion Stability: Kinetic versus Thermodynamic Stability

Thermodynamically Stable

Kinetically Stable

Kinetically Unstable

Thermodynamically Stable

Separated Phases

ΔG

ΔG*

G^f

G^i
Physical stability:
Ability to resist changes in spatial distribution of ingredients over time
- *e.g.*, *creaming, flocculation, coalescence*..

Chemical stability:
Ability to resist changes in chemical structure of ingredients over time
- *e.g.*, *ω*-3 *oxidation, citral degradation*
Physical Stability Mechanisms

- Flocculation
- Stable Emulsion
- Coalescence or Ostwald Ripening
- Phase Separation
- Gravitational Separation

Flocculation → Stable Emulsion → Coalescence or Ostwald Ripening → Phase Separation
Gravitational Separation ↔ Stable Emulsion ↔ Coalescence or Ostwald Ripening
Flocculation ↔ Stable Emulsion
Importance of Identification of Major Instability Mechanisms

• Every food emulsion is unique!
• There is no single strategy that can be used to generally improve food emulsion stability
• It is therefore crucial to identify the major instability mechanism for the specific food emulsion of interest
• Knowledge of emulsion science and technology facilitates problem solving
Emulsion Stability Testing: Diagnostic Approach

Phase separation
Oiling off
Rancidity

Creaming
Flocculation
Coalescence
Ostwald Ripening

Process
Ingredient
Storage

Macroscopic Properties
Characterize product defect

Instability Mechanism
Determine instability mechanism(s)

Physicochemical Origin
Identify physicochemical origin

Solution

Ca^{2+}
Gravitational Separation Principles

Stokes Law:
\[ U = -2r^2(\rho_2 - \rho_1)g/9\eta_1 \]

Methods of Retarding Gravitational Separation:
• Reduce density difference \((\Delta \rho)\)
• Reduce droplet size \((r)\)
• Increase continuous phase viscosity \((\eta_1)\)
Gravitational Separation
Influence of Density Difference

Sunflower oil-in-water emulsions containing weighting agents:
Ester gum, Damar Gum, SAIB or BVO
Gravitational Separation

Influence of Droplet Size

Without thickening agent, O/W emulsions are unstable to creaming once $r > 0.5 \mu m$.

$U \propto r^2$

Sunflower oil-in-water emulsions
Gravitational Separation
Influence of Continuous Phase Viscosity

 Predictions: \( R_V = 1000; \) CFC = 0.004 wt%;
\( r = 0.5 \ \mu\text{m}, \ r_{floc} = 1.5 \ \mu\text{m} \)

Thickening agents may promote creaming instability if they cause flocculation!
Gravitational Separation

Influence of Droplet Concentration

Hexadecane oil-in-water emulsions (SDS)
## Strategies to Reduce Gravitational Separation

<table>
<thead>
<tr>
<th>Principle</th>
<th>Method</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce $\Delta \rho$</td>
<td>Add weighting agent</td>
<td>• Regulations, cost</td>
</tr>
<tr>
<td></td>
<td>Alter SFC</td>
<td>• Stability, quality, nutrition</td>
</tr>
<tr>
<td>Reduce $r$</td>
<td>Homogenize</td>
<td>• Cost, quality</td>
</tr>
<tr>
<td>Increase $\eta$</td>
<td>Add thickening or gelling agent</td>
<td>• Quality, sensory</td>
</tr>
</tbody>
</table>
Food Emulsions Susceptible to Gravitational Separation

High Susceptibility
- Beverages
- Infant formulae
- Salad Dressings
- Soups & Sauces

Low Susceptibility
- Margarine & Butter
- Mayonnaise

- Low droplet concentration
- Low continuous phase viscosity
- High droplet concentration
- Gelled continuous phase
Experimental Characterization of Gravitational Separation

Indirect Methods (Prediction)
- Stokes Law: \( U = -2gr^2\Delta\rho/9\eta \)
- Measure PSD, \( \eta \), \( \Delta\rho \)

Direct Methods (Measurement)
- Visual observation
- Physical sectioning
- Droplet profiling
Measuring Creaming Stability
Visual Observation

Upper “Creamed”

Middle “Emulsion”

Lower “Serum”

Creaming Index: \( CI = 100 \times \frac{H_L}{H_E} \)

Long-term storage tests or accelerated (centrifugation) tests
Measuring Creaming Stability

Visual Observation

One-layer System

Three-layer System

Two-layer System

CI (%)

Time (h)

CI

Clfinal

v = dCI / dt
Measuring Creaming Stability

Visual Observation

Container Requirements:
- Flat bottomed
- Graduated
- Material (Glass/Plastic)

Observation Problems:
- Where is the boundary?
- Which layer is which?
- Subjective analysis
Measuring Creaming Stability
Optical Imaging

(TurbiScan MA images from http://www.sci-tec-inc.com/)
Measuring Creaming Stability

Optical Imaging

- Cream Layer
- Emulsion Layer
- Serum Layer

- Back Scatter (%)
- Height (mm)

- 0.9 hr.
- 5.7 hr.
- 8.7 hr.
- 13.8 hr.
- 24 hr.
- 46.1 hr.
- 70.3 hr.
- 123.7 hr.
Measuring Creaming Stability: Accelerated Optical Imaging

Space and Time resolved Extinction Profiles

STEP™ - Technology
Measuring Creaming Stability
Ultrasonic Scanning / NMR Imaging

- Quantitative
- Concentrated Systems
Droplet Flocculation

“Aggregation of two or more droplets into a floc where the droplets retain their individual identities”