Fundamentals of Formulating Soft-serve "Ice Cream"/Frozen Dairy Dessert Mixes

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Introduction

– Soft-serve has been a popular foodservice serving format for many years

– Formulation and product challenges:
  - Emulsion stability during freezing
  - Mix stability during shelf-life

Formulation Considerations for soft-frozen products.

- **Fat:** 4% - 10%; lower fat = weak body; higher fat = churning issues, greasy texture.
- **Milk solids-not-fat:** higher than hard-frozen products; structure/texture enhanced by protein; no lactose crystallization issues.
- **Sugars:** typically slightly less sweet than hard-frozen products; freezing point depression is critical, balanced with lactose from SNF.

Formulation Considerations for soft-frozen products (cont'd).

- **Corn syrup (Glucose) solids:** typically lower than hard-frozen products; can easily lead to gummy texture.
- **Stabilizers:** viscosity enhancement and mouthfeel required, but their function in ice recrystallization is no longer needed. Carrageenan critical to inhibit serum separation.
- **Emulsifiers:** whippability/overrun, dryness and shape retention are big concerns.

Suggested mixes for soft-frozen products.

	Percent (%)		
Milk Fat	4.0	6.0	10.0
Milk SNF	14.0	12 - 13	11 - 12
Sucrose	11 - 14	12 - 15	12 - 15
Corn Syrup Solids	4 - 0	4 - 0	3 - 0
Stabilizer/Emulsifier *	______	______	______
Total Solids	32 - 33	33 - 35	36 - 38

*Highly variable depending on type; manufacturers recommendations are usually followed.

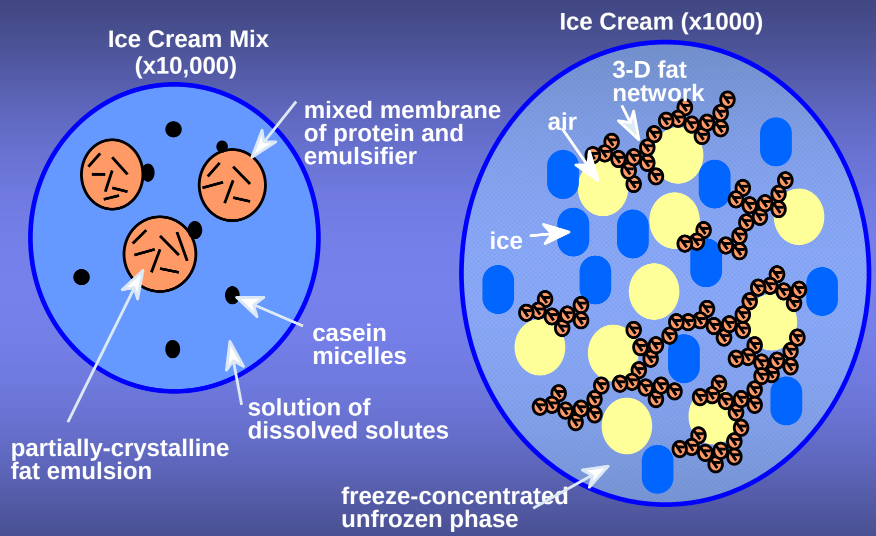
Formulation Considerations for soft-frozen products (cont'd).

- **Custards:** ~ 1.5% egg yolk solids
- **Draw temperatures:** -7 to -9°C (18-20°F).
- **Overrun:** 30 to 60%.

Soft-serve Freezers:

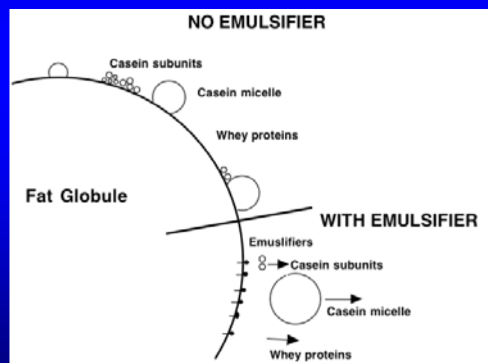
- Single or two-flavour models
- 8 – 40 litre mix reservoir
- 2-4 litre barrel capacity
- 110- 220 volts, air or water cooled
- Gravity-feed vs. pressurized barrels
- Dispense on demand: thermostated – issues with fat stability
- Cleaning: daily vs. heat-treatment freezers

Structure and Fat Destabilization



Fat Stability Issues in Soft-serve

- Whipping time
- Draw temperature
- Surfactant's



Manifestation: specking

Use of salts in soft-serve formulations

- **Citrate and Phosphate Ions**
  -- i.e., Na citrate, disodium phosphate
  -- decrease tendency for fat coalescence
  -- prevent churning in soft serve ice cream
  -- wetter ice cream
- **Calcium and Magnesium Ions**
  -- opposite effect
  -- promote partial coalescence
  -- drier ice cream

"Wheying-off" in Mix

- Formation of two-phases in unfrozen ice cream mix (especially destined for soft-serve applications).
- In soft ice cream, galactomannans and other stabilizers are added to enhance viscosity, structure and texture.
- Thermodynamic incompatibility/depletion flocculation between polysaccharides and dairy proteins leads to phase separation.
- Carrageenan added to inhibit "wheying off".

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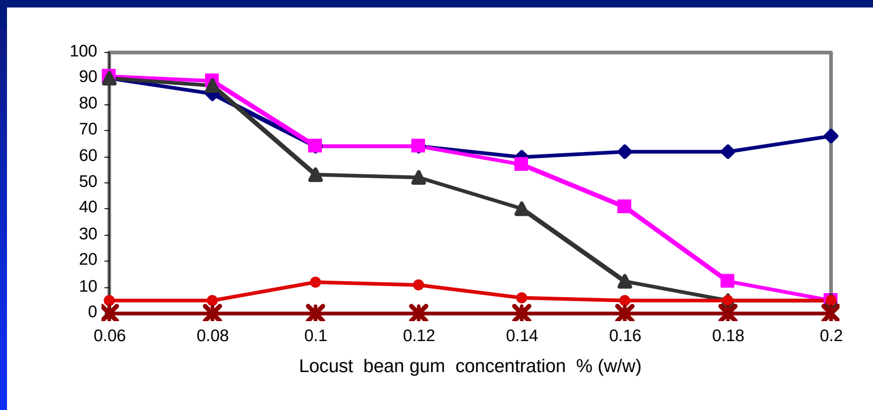
DANISCO
First you add knowledge...

Experimental soft serve mixes
- forms basis for all subsequent results

- 4% fat
- 9.75% skim milk powder
- 3.25% whey powder
- 13% sucrose
- 0-0.2% LBG or guar
- 0-0.015% κ-carrageenan
- 0.3% emulsifier

Mix instability profile with different κ-carrageenan and locust bean gum concentrations

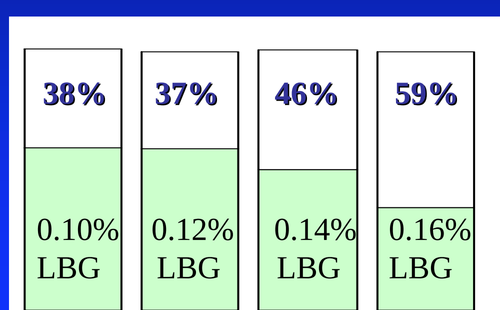


% Carrageenan: 0, 0.01, 0.0125, 0.015, 0.02

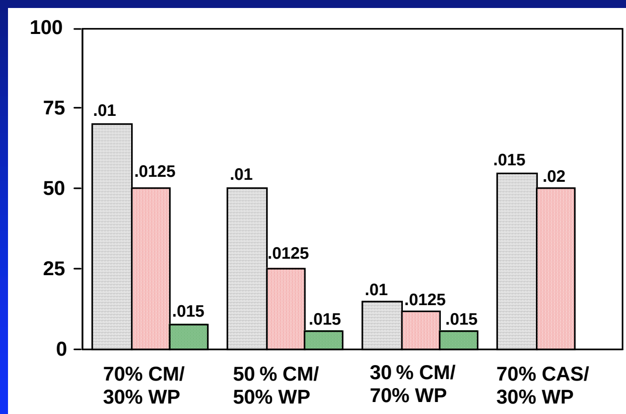
Casein and whey distribution in each phase

Top (Opaque) Phase Protein content (%):				
Casein	78.1	83.0	86.9	91.7
Whey	52.1	57.5	65.0	70.6

Phase volume:



Serum separation in soft-serve mixes (4% protein, 0.14% LBG) with different κ-carrageenan concentrations and varying protein sources



- **CM = casein micelles; WP = whey protein; CAS = sodium caseinate ***
- **CAS also incompatible with LBG but *not* inhibited by κ-carrageenan**

What are casein micelles?

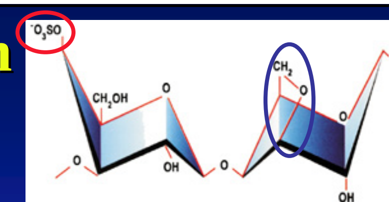
- Dispersed protein particles in milk containing high quantity of CaP
- 80% of milk protein
- ~100-300 nm diameter



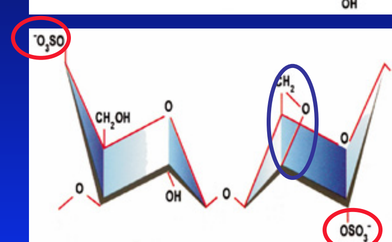

Carrageenan is obtained from various Rhodophyta, red seaweeds (marine algae), e.g., the cold water Irish Moss (*Chondrus crispus*) (Ireland, Canada, France, Spain, Denmark). The major sources of carrageenan are now the two tropical red seaweeds *Kappaphycus alverezii* and *Eucheuma denticulatum*, also known as Eucheuma cottonii (*κ*) and E. Spinosum (*ι*) in popular literature (Philippines). In addition, "κ-ι hybrid" or κ-II carrageenan can be extracted from alternative sources, e.g., *Gigartina skottsbergii, Sarcothalia crispata* or *Mazzaella laminarioides,* formerly *Gigartina radula* (Chile).

Carrageenan structures

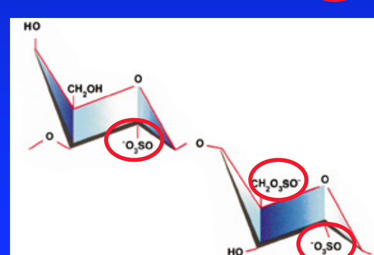
Linear sulfated polysaccharides (400-600 kD wt. av. mol. wt.); repeating disaccharide units of alternating 1,3 linked β-D-galacto-pyranose and 1,4 linked α- (3,6 anhydro) D-galacto-pyranose



Kappa (κ)
- 25% sulfate ester groups
- 34% anhydro-



Iota (ι)
- 32% sulfate ester groups
- 30% anhydro-



Lambda (λ)
- 35% sulfate ester groups
- 0% anhydro-

κ - carrageenan properties

- Coil to helix transition on cooling, ~50°C
- Ion sensitive, esp. K^+
- Firm, brittle, thermoreversible gels

Milk reactivity

- Protein synergy in terms of viscosity and gelation
- Prevention of wheying off

Milk reactivity

- *How?*
- Interaction with micelle surfaces

suggested at positive regions on κ-casein

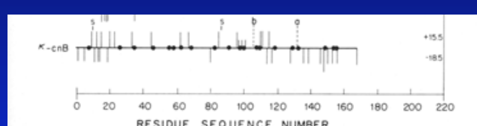


figure 6.3. Location of charged residues (pH 6–7), Pro (●) and Cys (S), in caseins. (a) Location of glucide residue. (b) Point of cleavage by chymosin.

Walstra & Jenness, 1984

–(but electrostatic and steric considerations?)

- Also weak, thixotropic gel formation in milk has been suggested

–(but κ-carrageenan is functional at concentrations < apparent gelling concentration)

How does κ-carrageenan prevent macroscopic phase separation?

κ-casein/κ-carrageenan interaction maintains droplet integrity

κ-carrageenan weak gel network prevents droplet coalescence

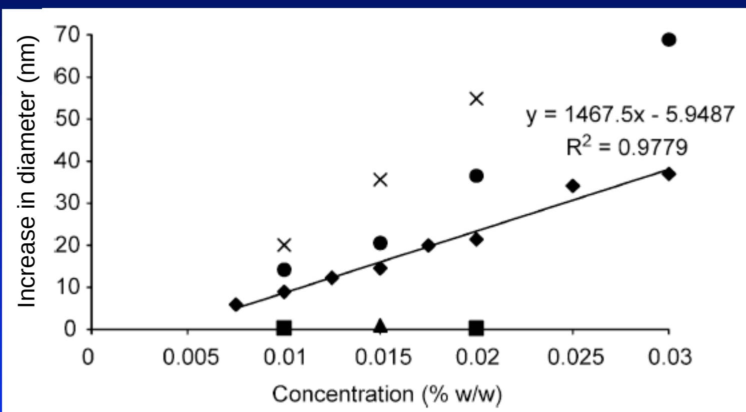


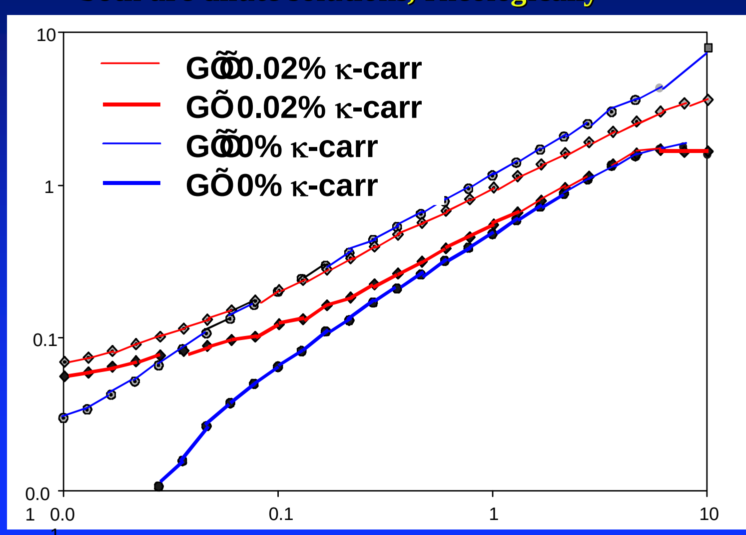
Fig. 5. The effect of polymer concentration on casein micelle diameter as measured by dynamic light scattering at 25 °C. (◆) κ-carrageenan (with trendline and corresponding regression equation), (●) κ-carrageenan with NaI, (■) guar gum, (▲) agarose, (×) λ-carrageeenan.

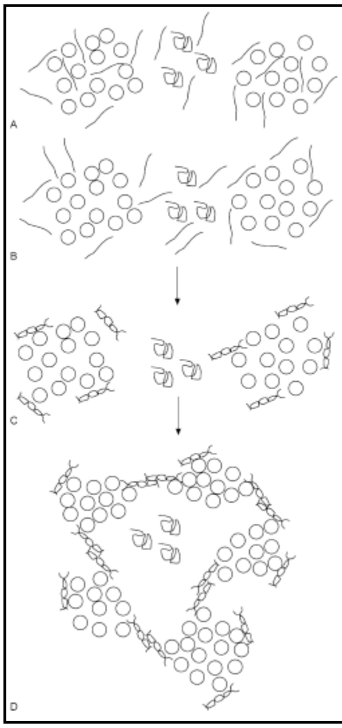
Phase separation experiments:

- 13.5% MSNF, 0.14% LBG, 0.015% κ-carrageenan, no phase separation at 4°C, but there was at 60°C
  - **κ-carrageenan helices are required**
- With NaI, to block κ-carrageenan helices from associating, there was phase separation
- Phase separation with λ-carrageenan
  - **interaction of helices is required to block phase separation**
- Phase separation with agarose
  - **helix aggregation in the absence of direct micelle interaction is insufficient to prevent macroscopic phase separation**

Mechanical spectra of soft-serve mixes with and without carrageenan

- both are dilute solutions, rheologically





Schematic diagram outlining the mechanism of stability of κ-carrageenan.

A: During pasteurization, κ-carrageenan is in the coil conformation and is found distributed within solution. Casein micelles have been concentrated via incompatibility with locust bean gum.

B: When the ratio of casein micelles:κ-carrageenan coils within the domains becomes unfavourable there is an exclusion of κ-carrageenan via depletion flocculation and/or segregative interactions.

C: Once the temperature is lowered κ-carrageenan, now at the periphery of the domains, changes conformation to the helical form.

D: Interaction between κ-carrageenan helices and casein micelles at the periphery of the micro-domains occurs and subsequent interaction between neighbouring helices on adjacent domains stabilizes the domains against flocculation and coalescence and eventual separation.

Conclusions

- In soft-serve, optimal shape retention without churning is the roe of the emulsifier, perhaps supplemented by salts addition.
- κ-carrageenan uniquely inhibits macroscopic protein: polysaccharide phase separation but not microscopic phase-separation, seems to “emulsify” protein-enriched phase
- Phase separated systems could be described as water-in-water emulsions
- Casein micelles are separating, but whey protein remains more evenly dispersed; sodium caseinate will also separate and this is not inhibited by κ-carrageenan
- κ-carrageenan appears to be associated with the casein-enriched phase
- Macroscopic phase separation prevented by direct casein micelle: κ-carrageenan interaction and by κ-carrageenan self-interaction in the continuous phase

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