A PHYSICIST'S DREAM OR NIGHTMARE?

THE MICROSTRUCTURE OF ICE-CREAM: ITS IMPORTANCE, AND HOW IT IS INFLUENCED BY PROCESSING AND STORAGE.

William J. Frith, Unilever R&D Colworth

bill.frith@unilever.com

INTRODUCTION TO UNILEVER

- What is a "Fast-Moving Consumer Goods" (FMCG) company?
- Pretty big
  - » >170,000 employees
  - » ~ €50bn turnover
  - » Truly global company present in >190 countries, >50% of turnover in D&E markets
  - » ~ 2bn people use our products each day.
- We make:
  - » Foods & "**Refreshments**"
  - » Home & Personal Care products (HPC)
- Research
  - » ~ €1bn spend worldwide
  - » ~ 6000 Staff
  - » Labs in Europe, US, India & China

PRODUCTS

Unilever

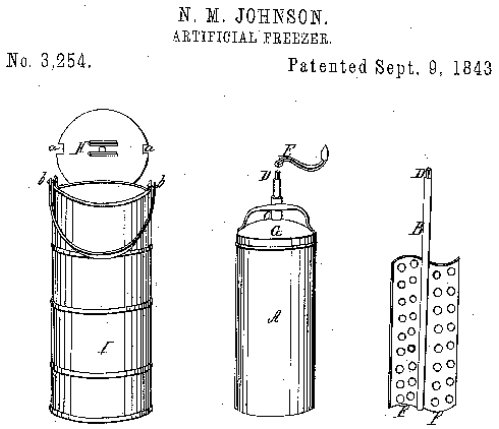
Share Happy

SOME HISTORY

ICE CREAM MANUFACTURING

Documented history goes back ~500 years

- 1843 – Nancy Johnson invents hand-cranked ice-cream maker.
- This, combined with Pasteurisation, enabled mass production.


N. M. JOHNSON.
ARTIFICIAL FREEZER.
No. 3,254. Patented Sept. 9, 1843


White Mountain Freezer
(TRIPLE MOTION)
The "World's Best" Ice-Cream Freezer

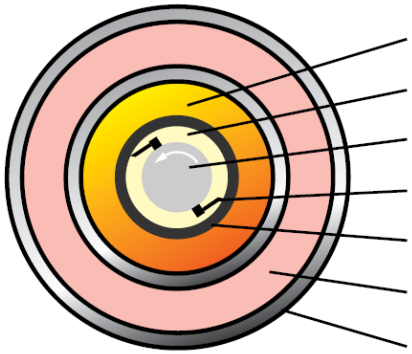
This World-Famous Freezer

Makes the most perfect ice-creams and sherbets in a very few minutes, as well as an unlimited variety of delicious frozen fruits, puddings, and chilled dainties at a very trifling cost. It will surprise you to learn the great extent of "White Mountain" usefulness. Send for our recipe book, "Frozen Dainties," which tells everything you need to know about the making of the most delicious desserts and gives about one hundred recipes.

THE WHITE MOUNTAIN FREEZER COMPANY
NASHUA, N. H.

- 1926 – Clarence Vogt invents continuous ice-cream freezer (later called the votator).


Photographic Archives, Ekstrom Library, University of Louisville



INGREDIENTS

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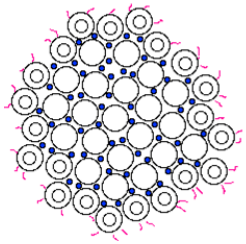
Sugars
- sucrose
- fructose
- dextrose
- corn syrups
- ...



Milk Protein
- caseins
- whey

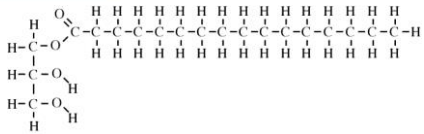
Flavours
- Vanilla
- Strawberry
- Chocolate
- Mint

Ingredients

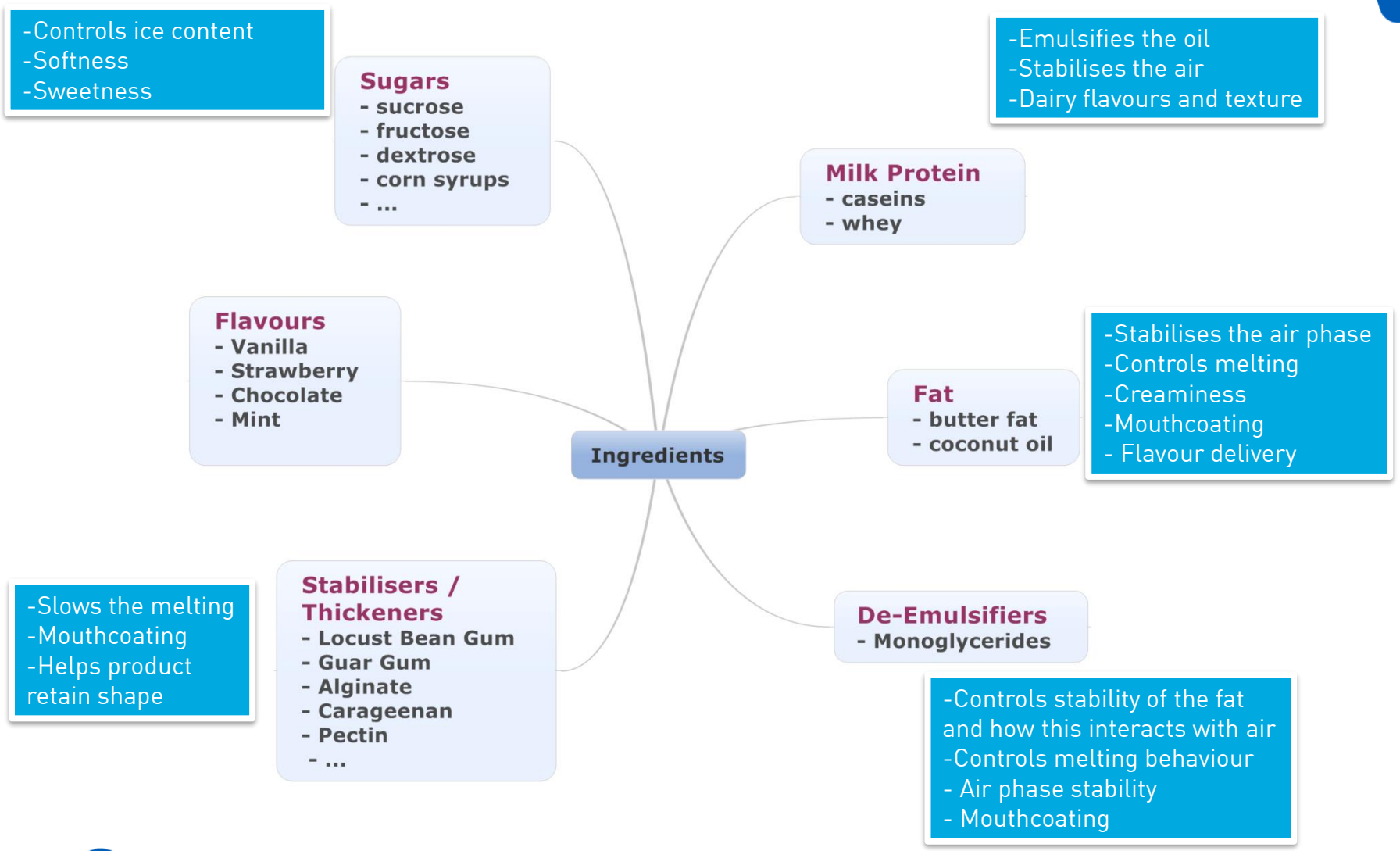
Fat
- butter fat
- coconut oil

Stabilisers / Thickeners
- Locust Bean Gum
- Guar Gum
- Alginate
- Carageenan
- Pectin
- ...

De-Emulsifiers
- Monoglycerides



INGREDIENTS … AND THEIR ROLE



MICROSTRUCTURE

IT'S AN AERATED SLURRY!?

What's in ice-cream?

- Ice (concentrated suspension)
- Matrix (viscous liquid)

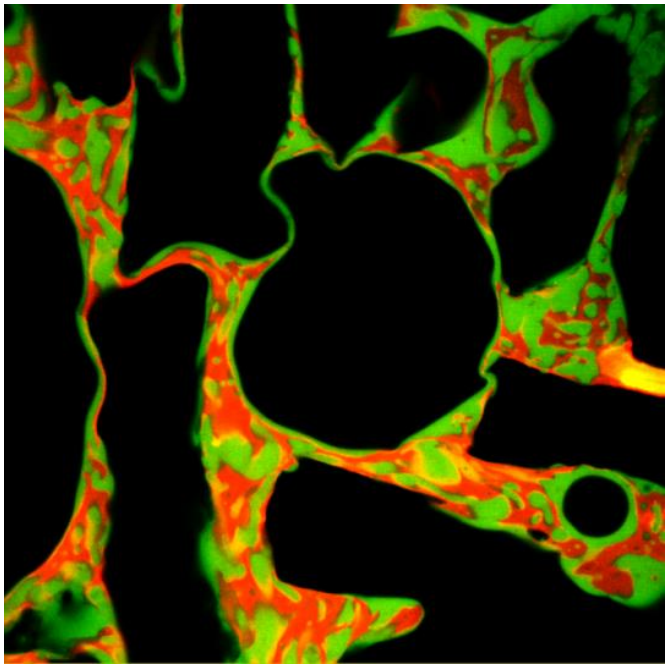


Image above is a microscopic view of ice-cream (without fat):

- Black is ice
- Coloured regions are unfrozen sugar solution:
  - Red indicates protein
  - Green indicates Gum (LBG)

Flow behaviour: Jammed suspension?

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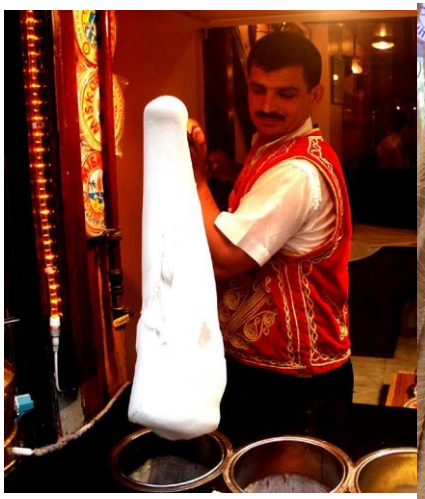
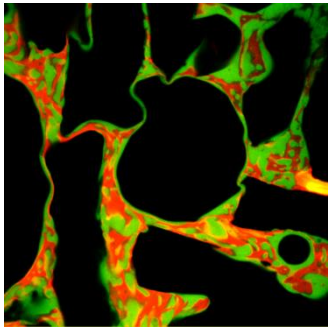
Maraş Dondurma – Turkish Ice-cream (one of the most ancient forms?)



Look familiar?!?

EUROPEAN AND AMERICAN ICE-CREAM IS DIFFERENT: WE PUT AIR IN

An air bubble in ice-cream (here the green represents fat)



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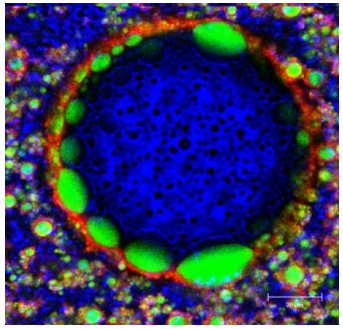
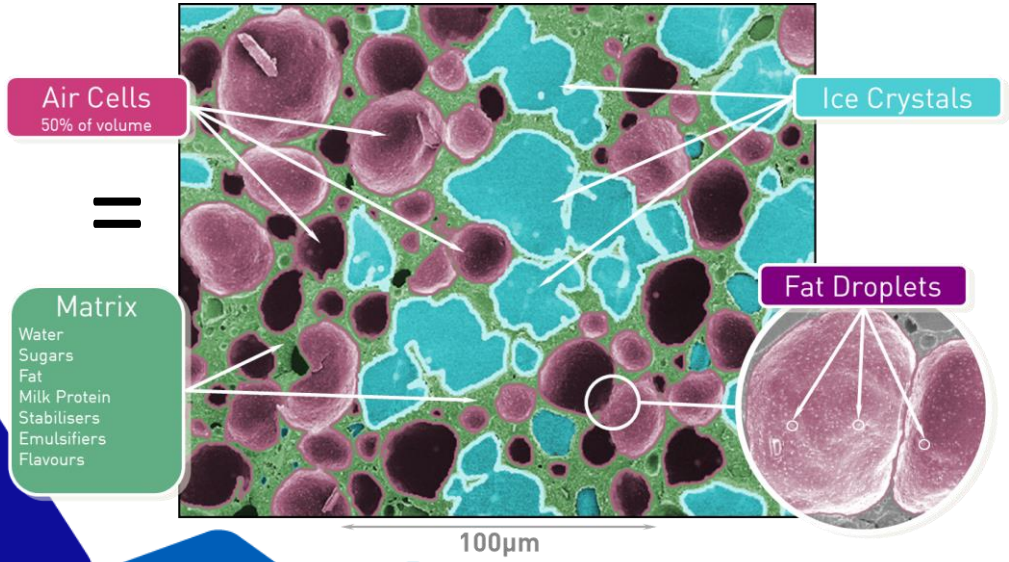




Incorporating air makes the ice-cream soft, "shear thinning"

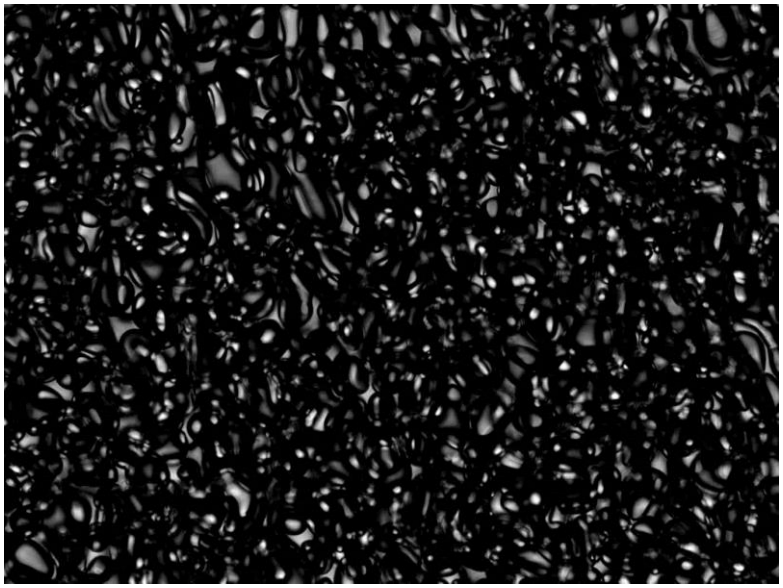
Fresh ice-cream (Mr Whippy) hardens on storage to become scooping ice-cream

- More ice forms at the colder storage temperature
- The ice crystals stick together to form a network

STRUCTURAL EVOLUTION

ICE-CREAM STABILITY MAINLY DETERMINED BY RIPENING OF PHASES

ICE-CRYSTAL SIZE EVOLVES ON STORAGE

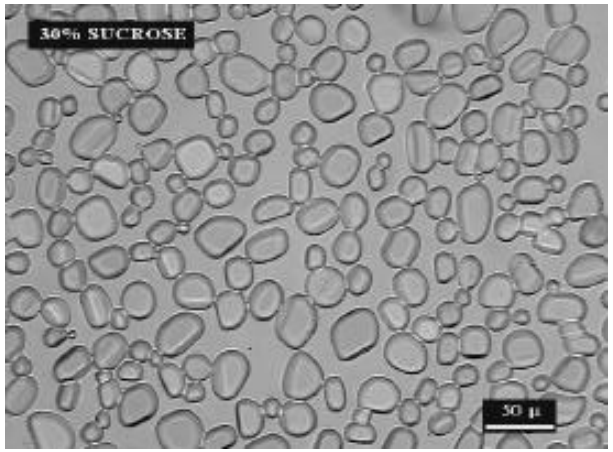


Movie: Courtesy R Farr, Unilever Colworth

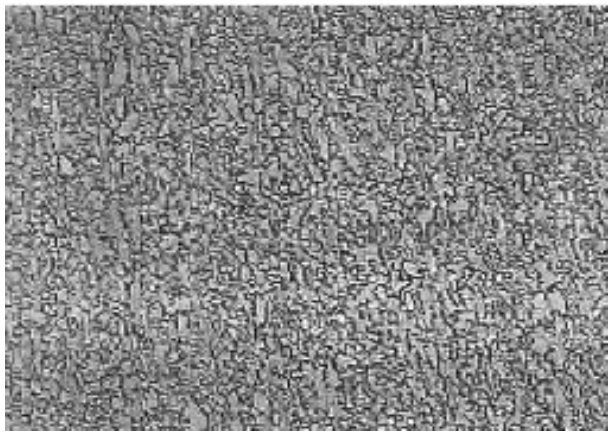
Proteins classed as anti-freeze (AFP) or ice-structuring (ISP) are active at ice crystal interfaces

- Inhibit recrystallization
- Habit modifiers

Control



With ISP



Clarke, Buckley & Lindner, CryoLetters **23**, 89-92 (2002)

FOAM STABILITY:
FAT AND DE-EMULSIFIERS

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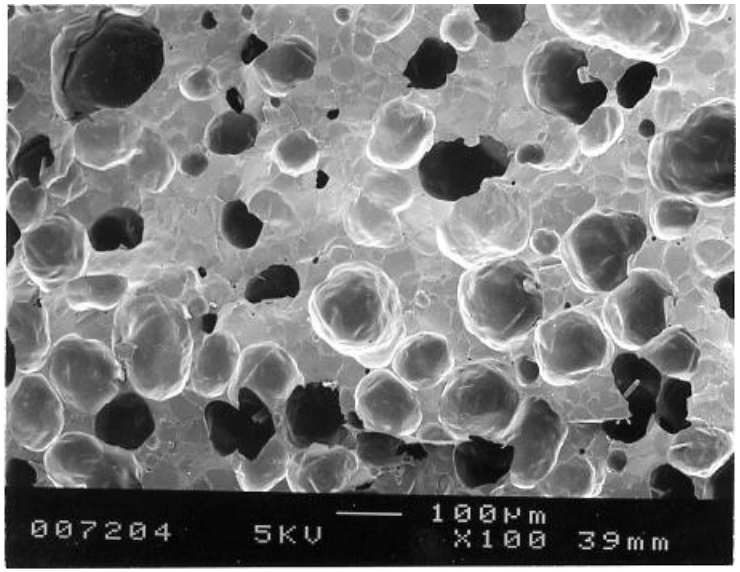
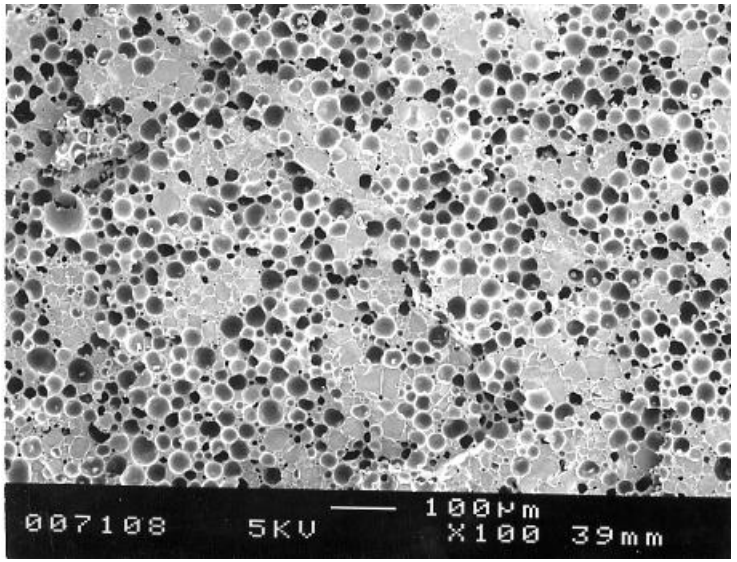
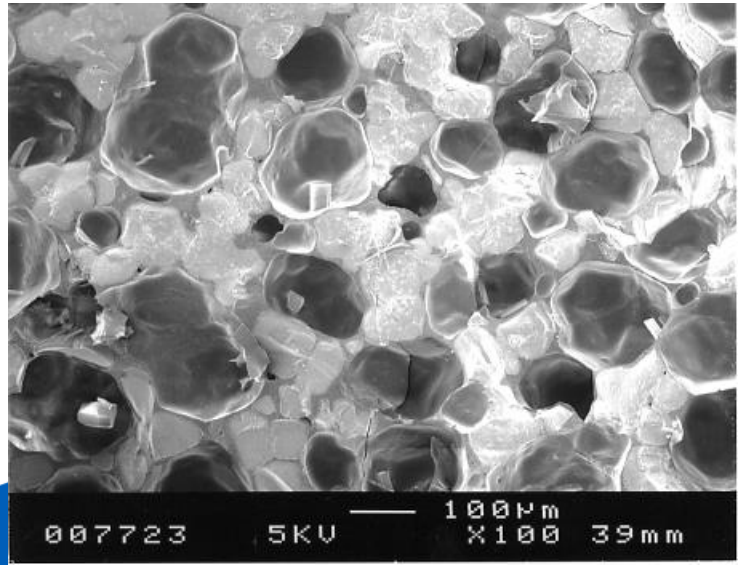
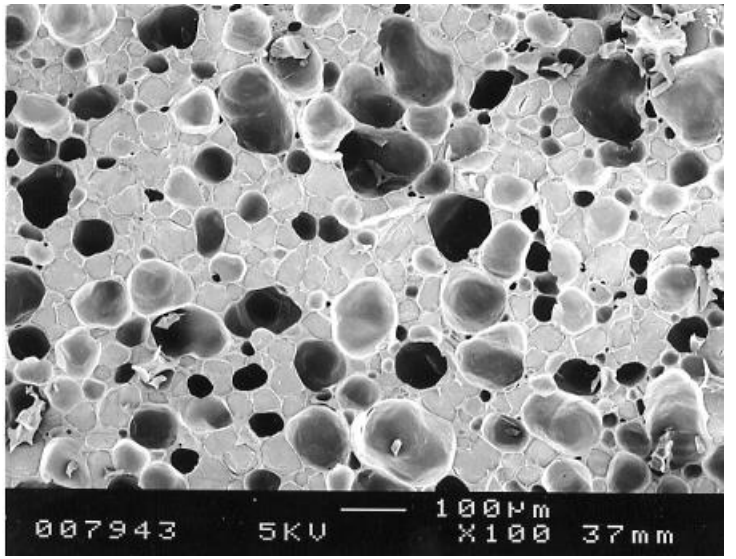
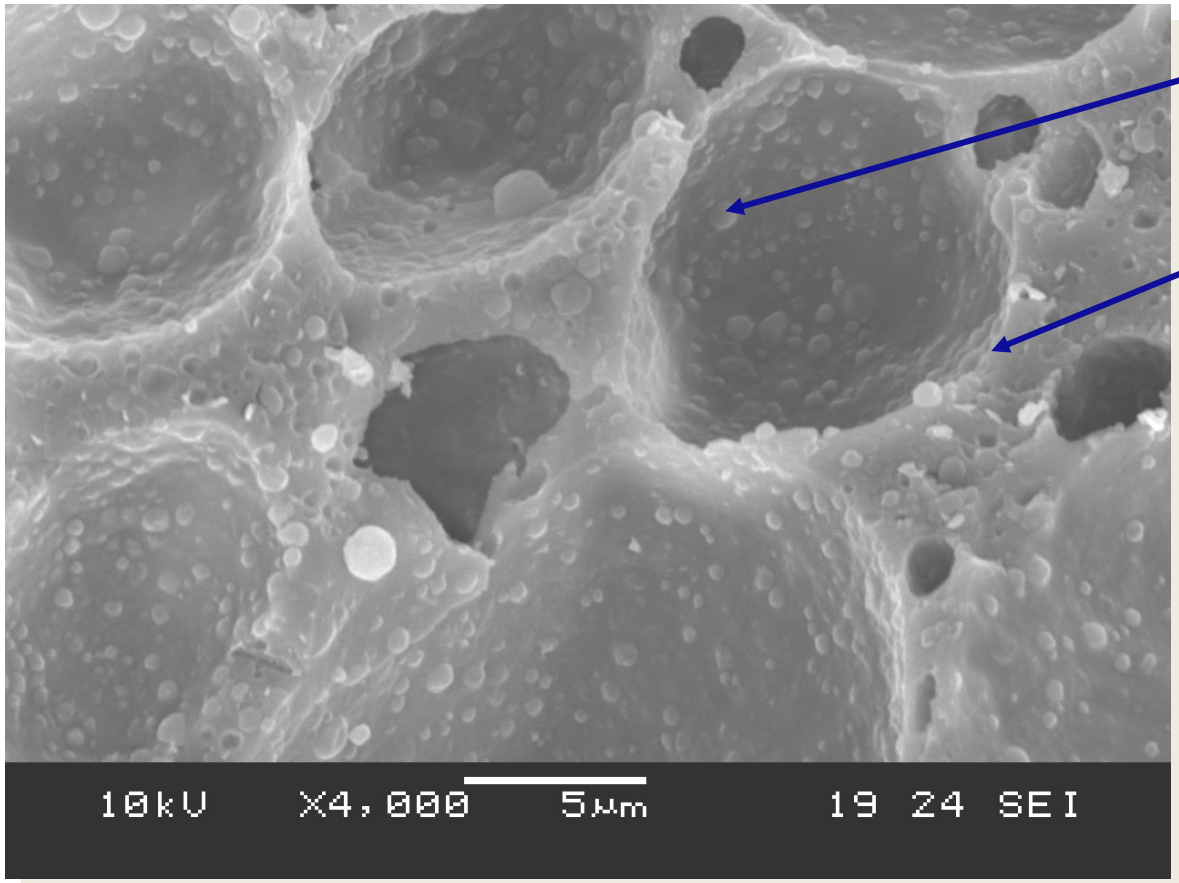
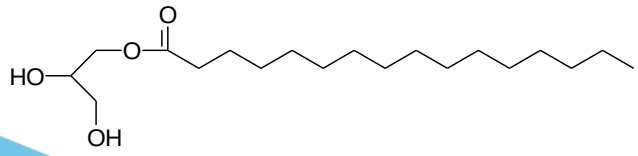
	No De-Emulsifier	0.3% De-Emulsifier
FRESH		
T CYCLED		

DE-EMULSIFIERS REDUCE THE STABILITY OF FAT PARTICLES TO SHEAR



Fat Droplets
(Pickering Stabilisation)

Protein



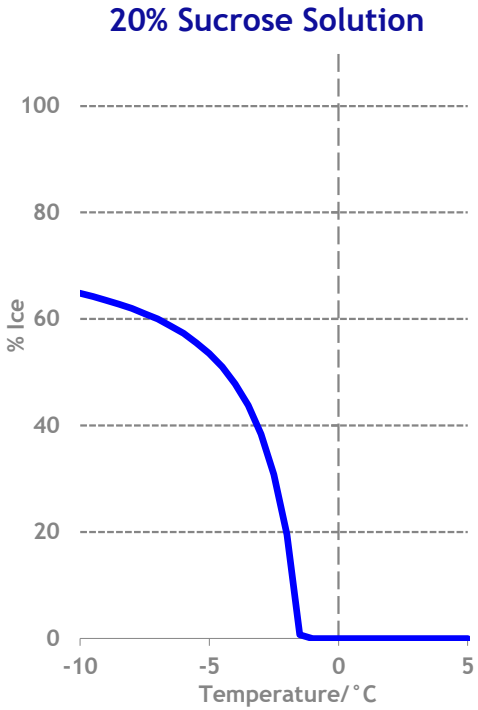
Mono-/di-glycerides of saturated fatty acids

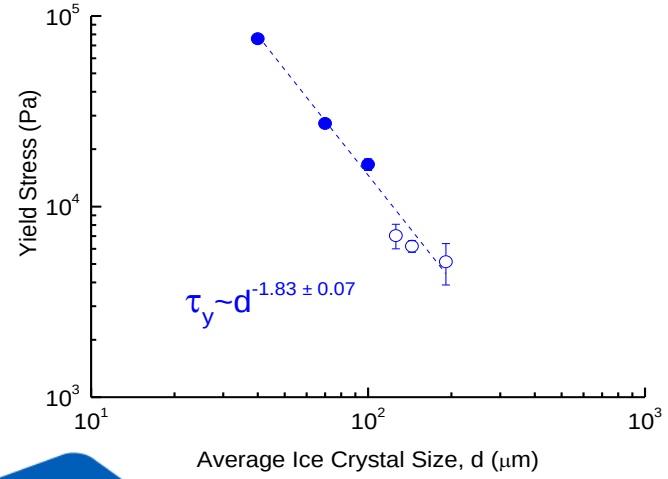
NETWORKS IN ICE-CREAM CONTROL PROPERTIES

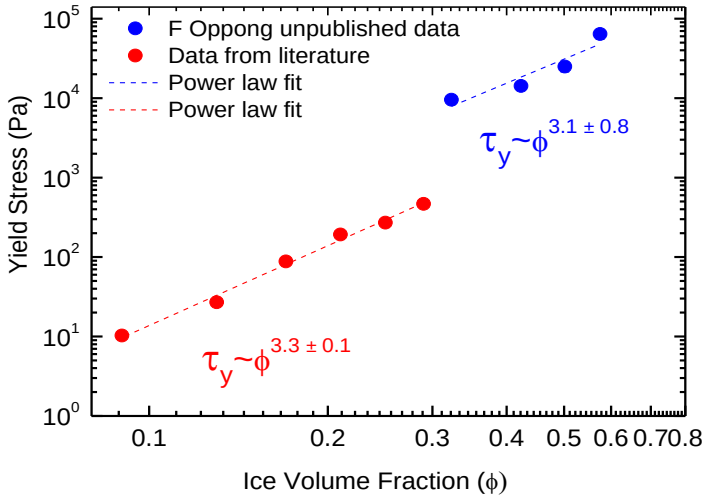
NETWORKS IN ICE-CREAM

Ice crystal network

- Generally the dominant factor determining hardness
- Strong power law dependence on concentration underlies temperature dependence of hardness
- Stronger dependence on ice crystal size means ice cream softens with storage time







Stokes, Telford, Williamson. Journal of Rheology 49.1 (2005): 139-148.
Oppong, Private communication

DESTABILISED FAT NETWORKS - MORE THAN JUST AGGREGATION

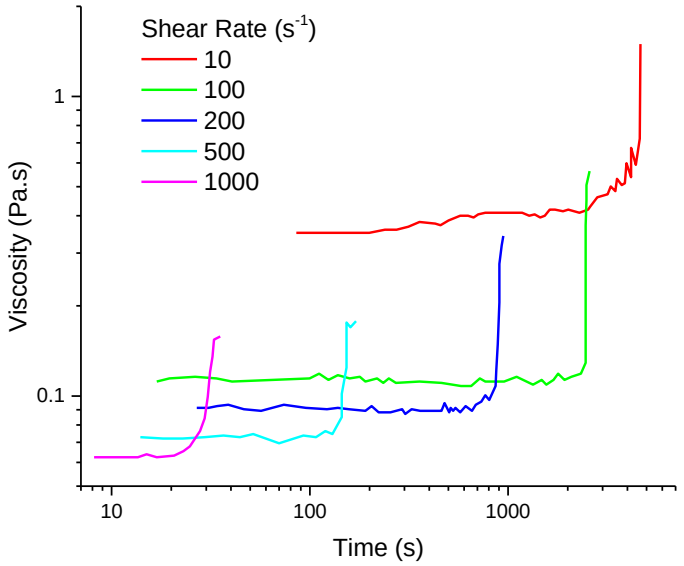
Fat globule network

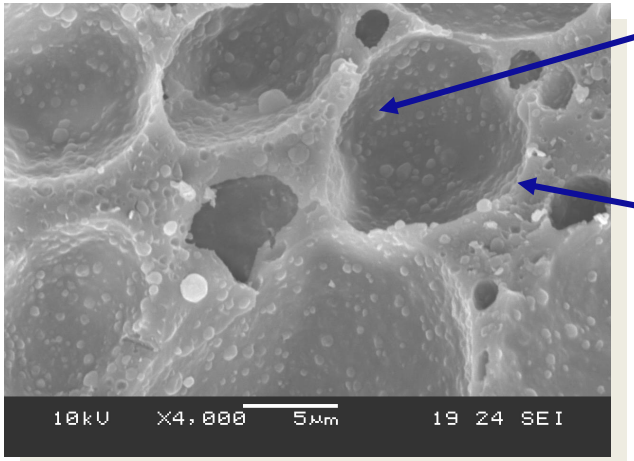
- Created during manufacturing/freezing (orthokinetic aggregation rather than static gelation)
- Requires presence of de-emulsifiers & solid fat.
- Mechanism thought to involve removal of protein from droplet surface, leading to hydrophobic interactions

Hydrophobic interactions

- Create a mixed fat and air network
- More significant than simple stabilisation of air cells

Lips,et al.
Sp Pub RSC.(1993) **113** p31.





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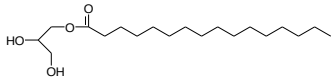

Mono-/di-glycerides of saturated fatty acids

SUMMARY – ICE-CREAM IS COMPLICATED!

- Out of equilibrium multiphase material whose quality is critically dependent on microstructure.
- Understanding process/physico-chemical/ microstructure relationships key to making a good quality product
- Slowing kinetic processes (mainly ripening) is key to preserving quality over time.

THANK YOU!

QUESTIONS?