The effects of ultrasound in dairy processing

Thomas Leong

Dairy Australia Webinar
Wednesday 2nd May, 2018

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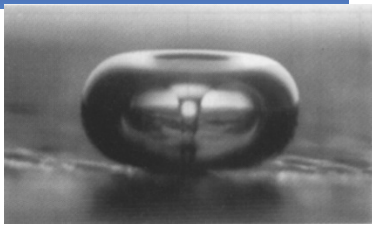
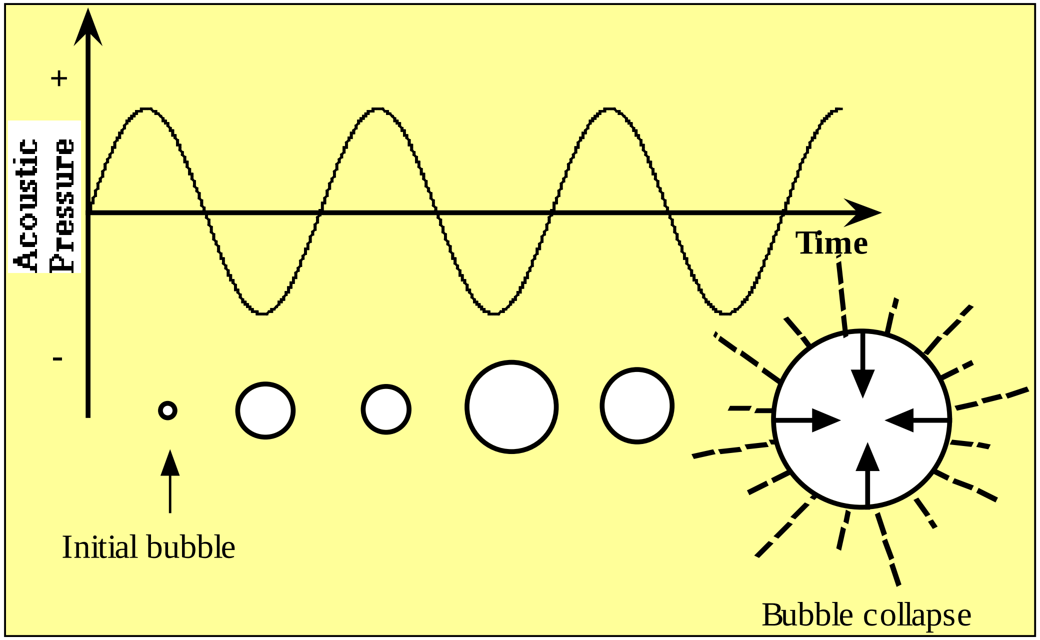
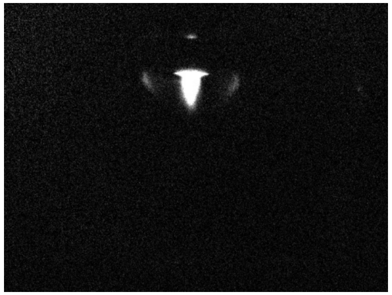
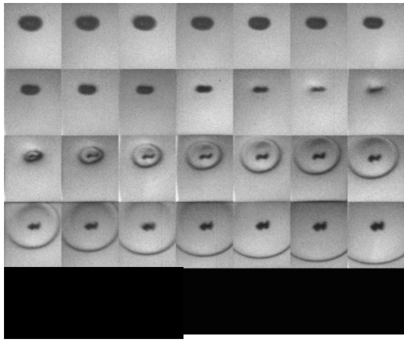
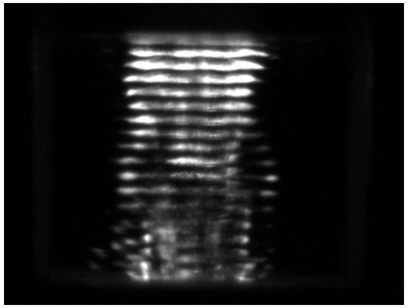
Ultrasonics & Sonochemistry

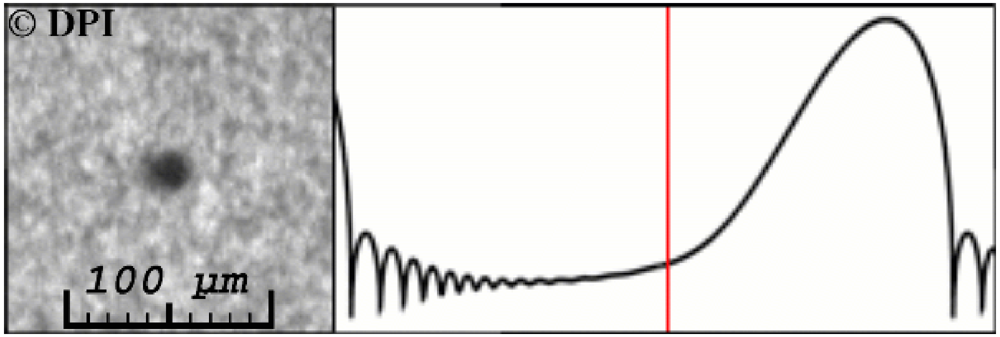












- ➢Bubble Implosion - “near adiabatic”
- ➢Tmax of the order of 5000 K
- ➢Radical generation – Sonochemistry
- ➢Shock waves, shear forces, etc.

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Sonochemistry Research Team

The Sonochemistry Research Team at University of Melbourne performs cutting edge research in the areas of ultrasonics and sonochemistry.

Key Research Areas

Synthesis of Nanomaterials, Microspheres, Photocatalysts and Polymers for Catalytic and Drug/Flavour Delivery Applications.

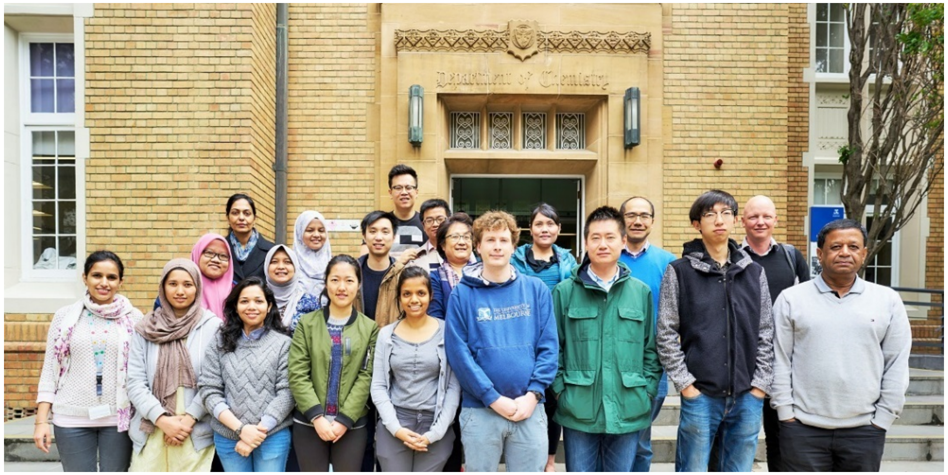
Ultrasonic Processing of Food and Dairy

Ingredients for Enhancing Their Functional Properties

Ultrasonics for biofuels

Degradation of Organic Pollutants in Aqueous Environment (Wastewater Treatment)

Single and Multibubble Sonoluminescence



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Webinar overview

1. Basic concepts of sonochemistry and ultrasonic processing
2. Effects of ultrasound on the deactivation of microbes
3. The use of ultrasound to homogenise and emulsify fats into milk
4. Effects of ultrasound on the functional properties of milk proteins
5. Ultrasound accelerated crystallisation of lactose, fats and ice-crystals
6. Ultrasound enhanced separation and fractionation of fat globules from milk

Ultrasound and sonochemistry

Overview of key concepts

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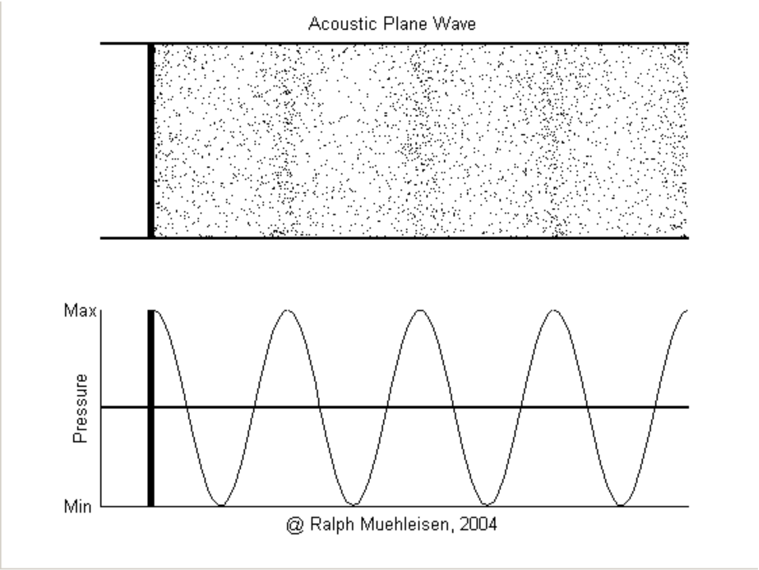
What is sound?

- Sound is an oscillating pressure wave that is transmitted through a medium such as a solid, liquid or gas.
- Audible sound for humans in the range of 20 - 20,000 Hz



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What is ultrasound?

- Ultrasound is sound beyond the limits of human hearing (above 20,000 Hz)

Spectrum of sound waves

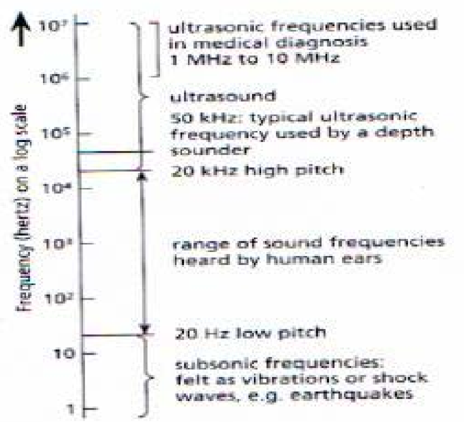
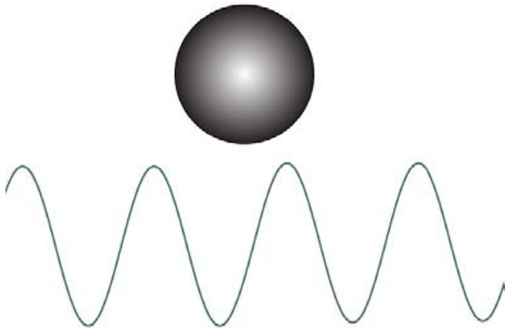
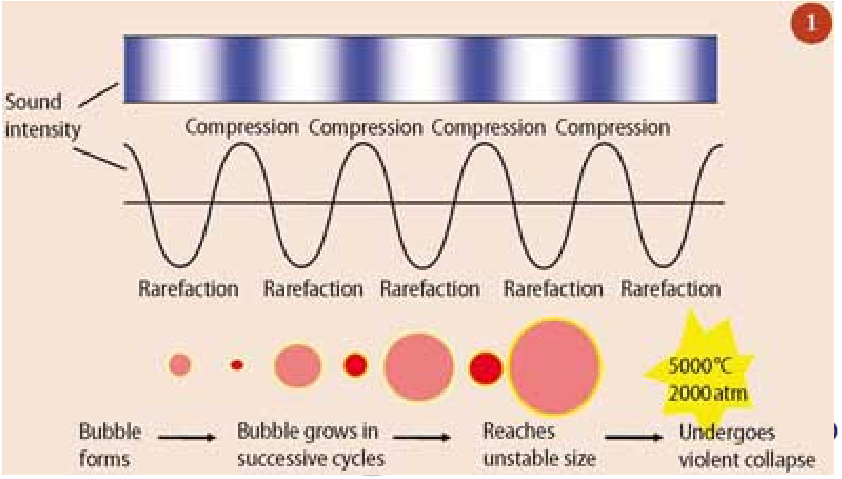


Figure 2.20
Spectrum of sound waves.

Acoustic cavitation

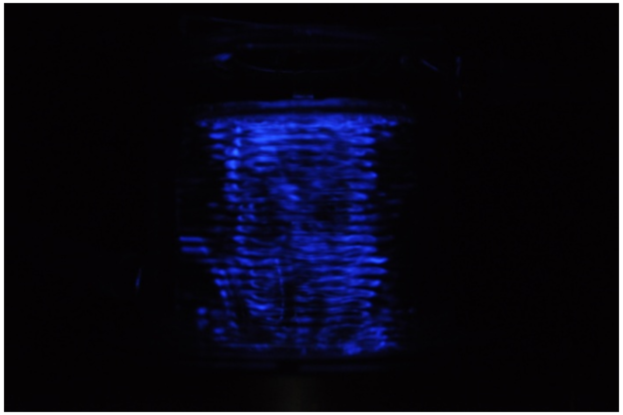
- Gas bubbles or liquid droplets in a food system will oscillate with an applied sound field
- Gas bubbles will grow over time until they reach an unstable size when they collapse



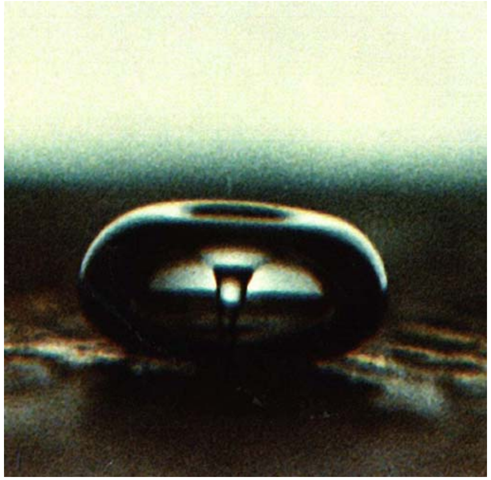


Effects of acoustic cavitation

- Collapse is accompanied by release of large amounts of energy – LOCALIZED HEATING – PRESSURE SCHOCKWAVE



Formation of radicals that react with light emitting chemicals



Bubble jet formation (L.A. Crum)

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Low frequency high power ultrasound vs high frequency low power ultrasound

- Low frequencies and high powers (~18-100 kHz, >50 W/cm^2):
  - Emulsification
  - Cell breakage (e.g., for microbe deactivation)
  - Cleaning

- Medium to high frequencies (100 kHz to 2 MHz) and moderate powers (~5 W/cm^2):
  - Biochemical stress responses (e.g., for texture modification)
  - Cleaning of small (fragile) structures (Megasonic cleaning)
  - Particle separation (standing waves)

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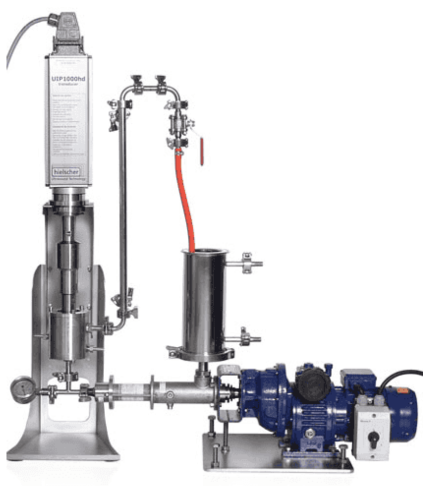
Ultrasonic equipment

- Low frequency ultrasound
  - Ultrasound horns (~$8000 lab scale unit, ~$25,000 pilot scale unit)
  - Ultrasound baths (~$5000 lab scale)
- High frequency ultrasound
  - Ultrasound baths
  - Ultrasound plates (range from ~$500 per plate at lab scale to ~$30,000 per plate at pilot scale)



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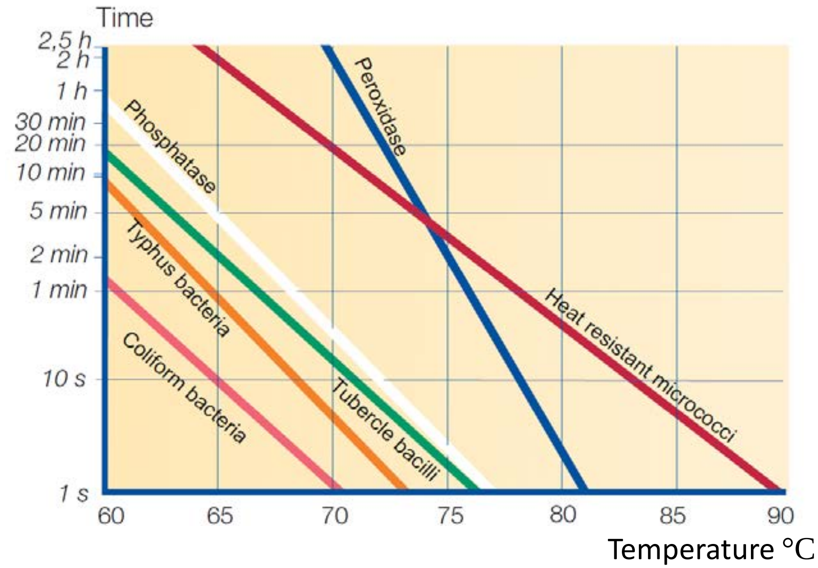
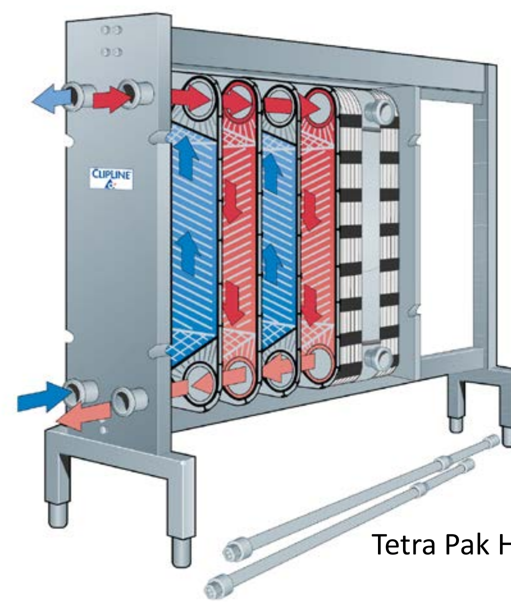
Ultrasonic deactivation of microbes

Thermal processing

- Heat is used to inactivate microorganisms and enzymes
- Thermal treatment can result in loss of nutritional and organoleptic properties
- Ultrasound is an example of a non-thermal preservation technology of high interest

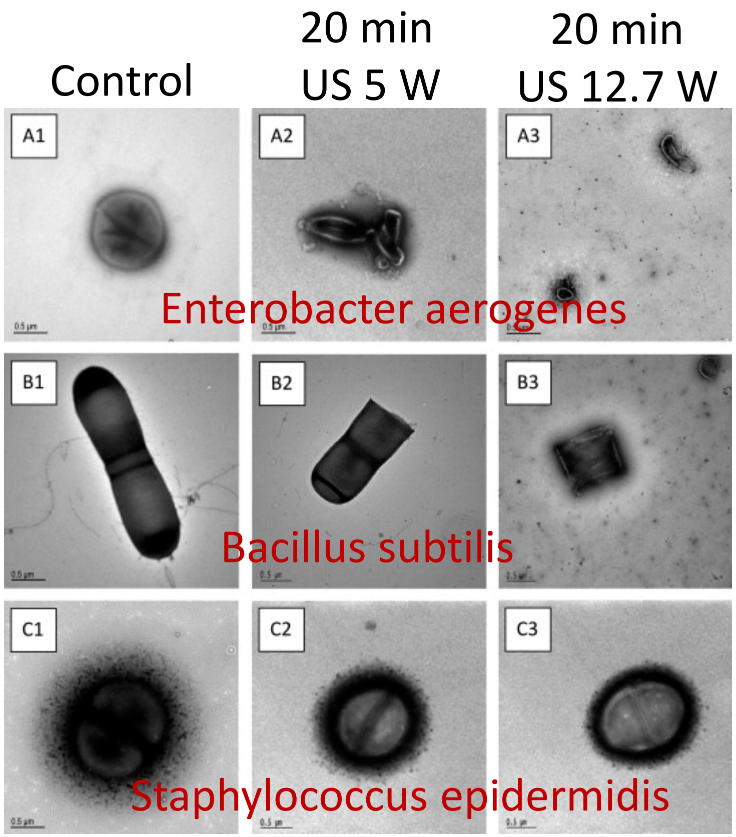




Tetra Pak Handbook

Ultrasonic mechanisms of cell deactivation

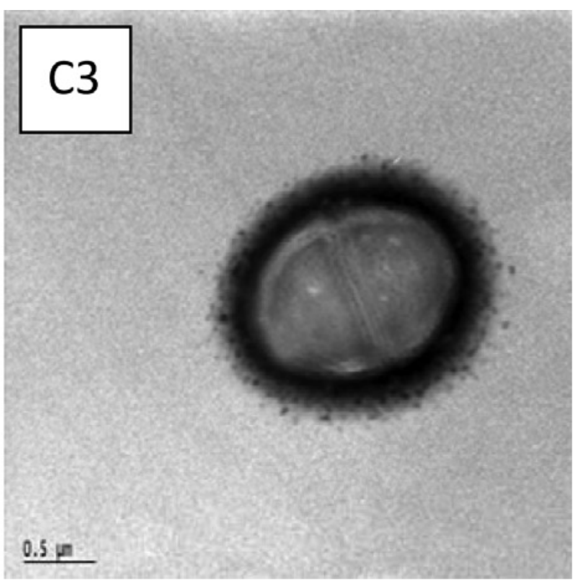
- Low frequency, high power ultrasound
- Mechanisms of deactivation attributed to:
  - Cavitation bubble collapse
  - Microjetting
  - Microstreaming
  - Intracellular cavitation
  - Localised heating
  - Free radical production

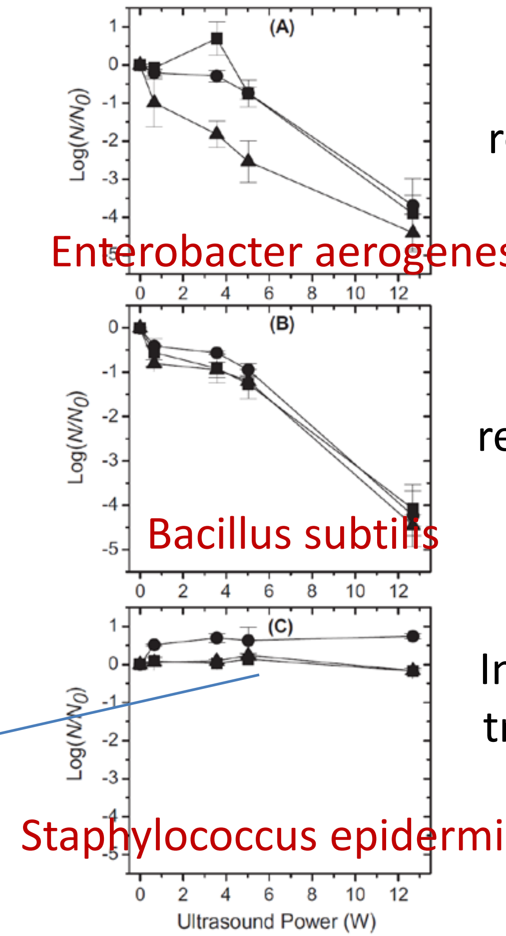


Gao, S., Lewis, G. D., Ashokkumar, M., & Hemar, Y. (2014). Inactivation of microorganisms by low-frequency high-power ultrasound: 1. Effect of growth phase and capsule properties of the bacteria. *Ultrasonics Sonochemistry*, *21*(1), 446-453.

Efficacy on microbes

- Ultrasound has selective effectiveness for different types of microbes
- Effectiveness is dependent on range of variables e.g. thickness of the cell wall
- Ineffective treatment for thick walled species such as S. epidermidis





4 log reduction

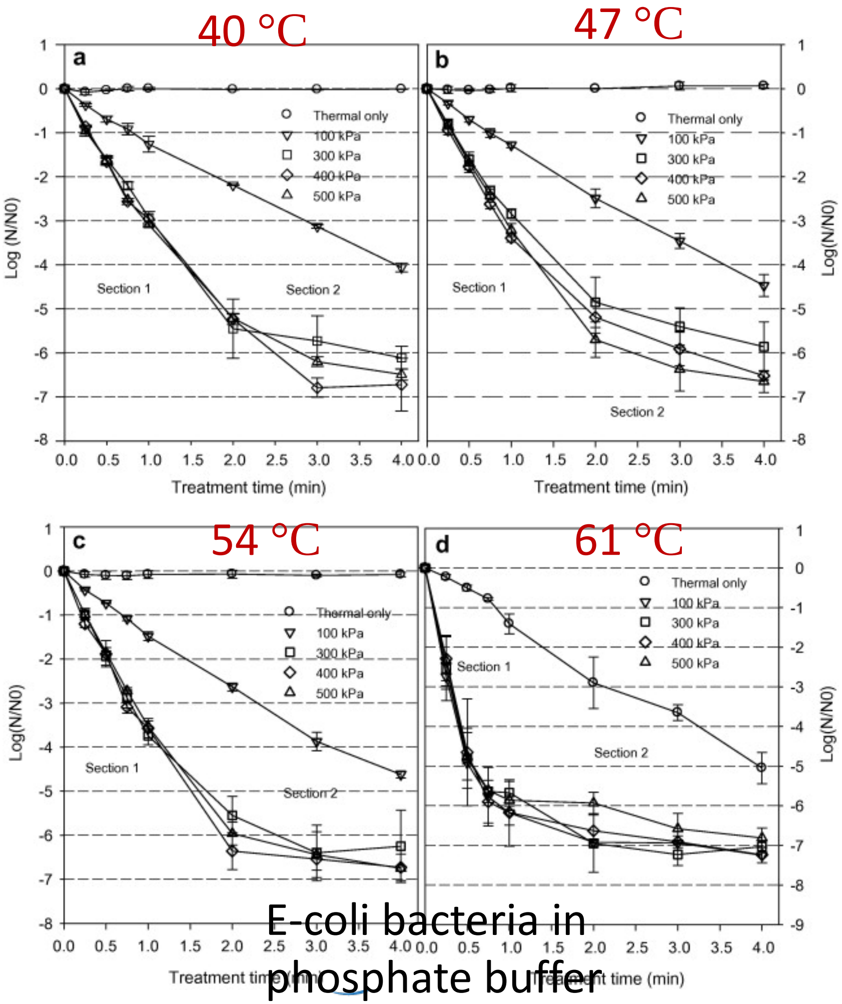
4 log reduction

Ineffective treatment

Gao, S., Lewis, G. D., Ashokkumar, M., & Hemar, Y. (2014). Inactivation of microorganisms by low-frequency high-power ultrasound: 1. Effect of growth phase and capsule properties of the bacteria. *Ultrasonics Sonochemistry*, *21*(1), 446-453.

Efficacy combined with pressure and/or temperature

- Thermo-sonication – ultrasound combined with heat
- Mano-sonication – ultrasound combined with pressure
- Mano-thermo-sonication – ultrasound combined with heat and pressure
- Synergistic effects compared with individual treatments alone



Lee, H., Zhou, B., Liang, W., Feng, H., & Martin, S. E. (2009). Inactivation of Escherichia coli cells with sonication, manosonication, thermosonication, and manothermosonication: microbial responses and kinetics modeling. *Journal of Food Engineering*, *93*(3), 354-364.

Commercial opportunities

- Opportunities to reduce the thermal history of pasteurised products e.g. reduced pasteurisation temperature, reduced duration of treatment
- Create longer shelf life products

Summary

- Ultrasound deactivation of microbes is most effective when used as a complementary method to other techniques
- Combined treatments show excellent efficacy that may be beneficial for development of reduced or non-thermal processing strategies in dairy processing

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Ultrasound homogenisation and emulsification of fat

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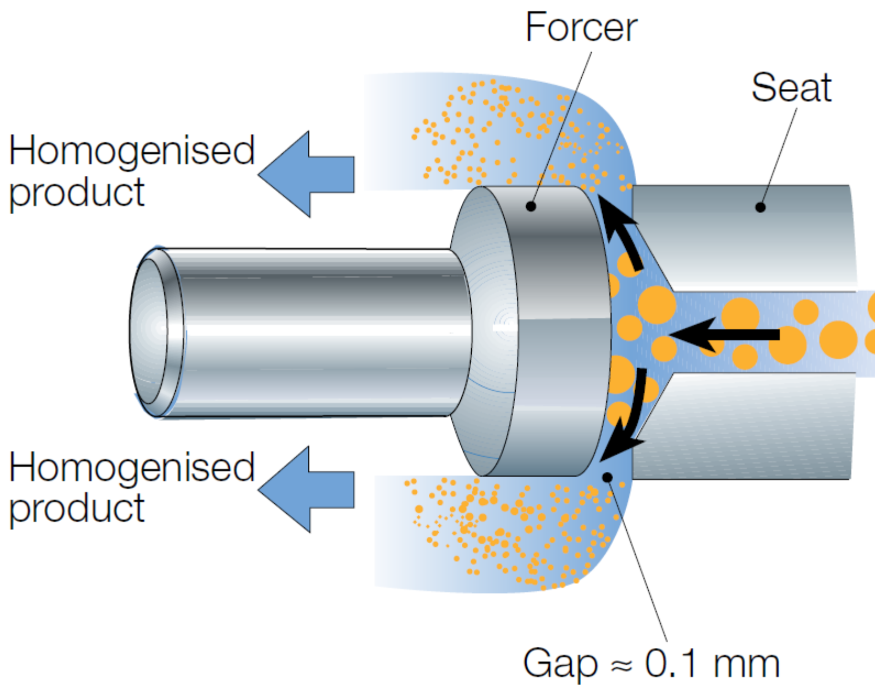
Homogenisation and emulsification

- High pressure homogenisation most frequent technique within dairy industry to homogenize milk
- Homogenisation is highly beneficial to product stability against storage, esp. milk, yoghurt and ice cream
- The strong shear forces generated by ultrasound can be used to homogenise and emulsify fats in milk systems



Tetra Pak Handbook

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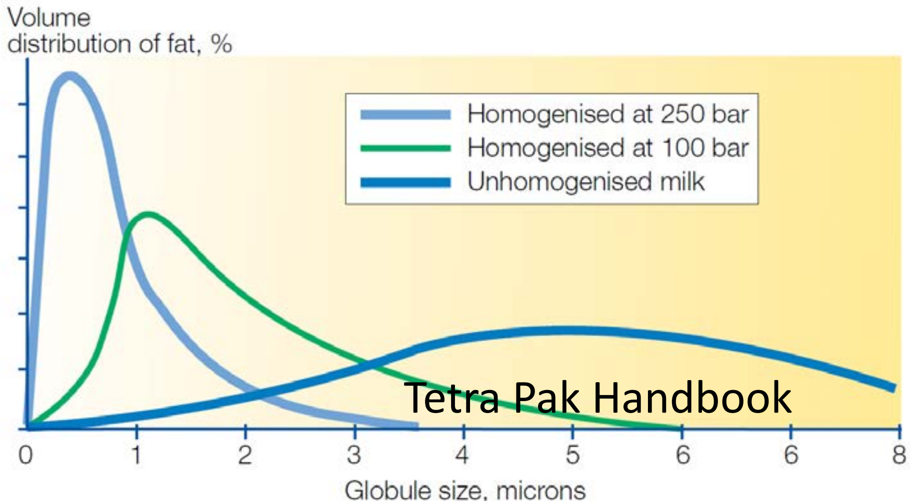
Efficacy of homogenization



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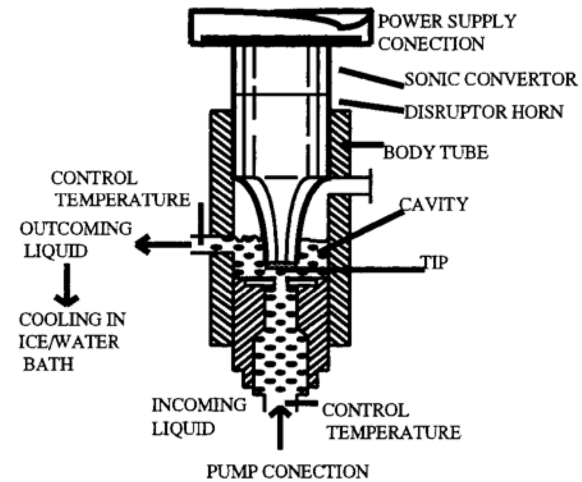

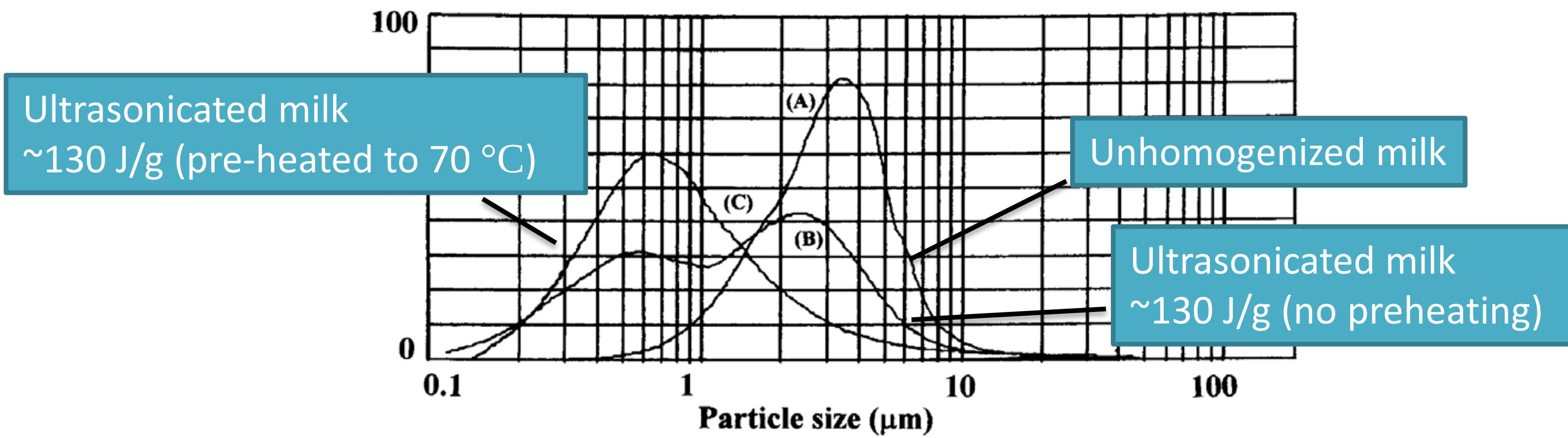

Villamiel, M., & de Jong, P. (2000). Influence of high-intensity ultrasound and heat treatment in continuous flow on fat, proteins, and native enzymes of milk. *Journal of Agricultural and Food Chemistry*, *48*(2), 472-478.

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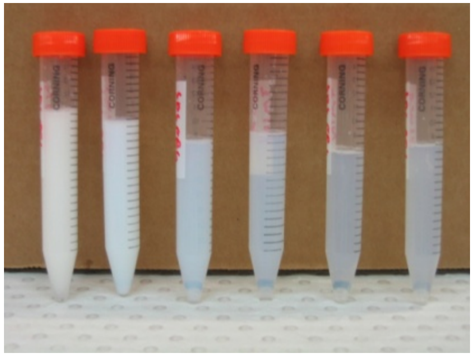
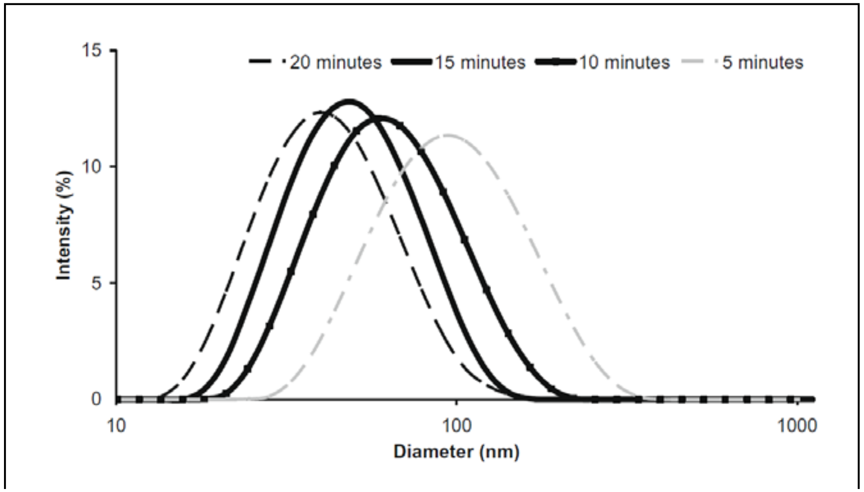
Creation of nano-sized emulsions

- Able to produce very small droplets in the order of <100 nm – this can create eye-clear emulsions
- Comparable effectiveness to microfluidization – one of the more effective emulsification techniques

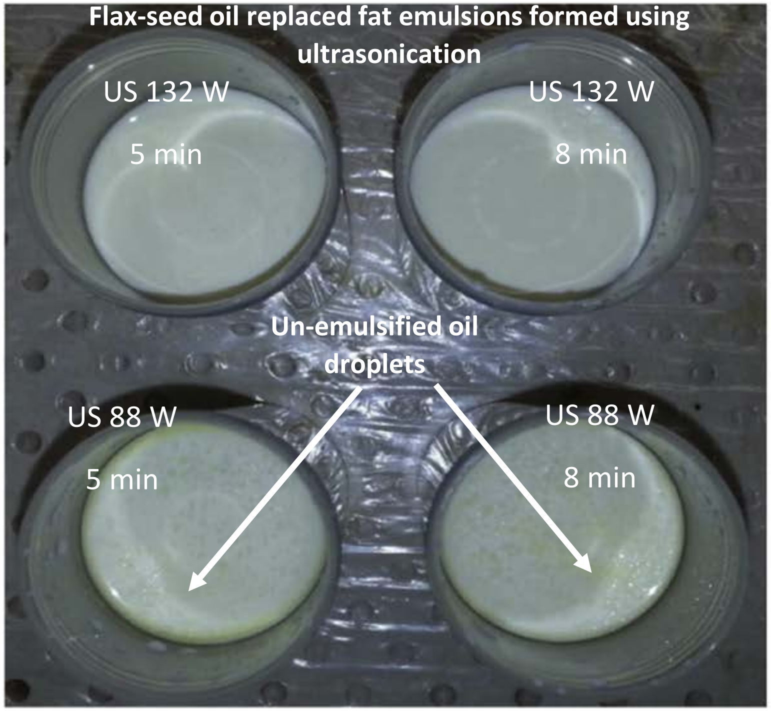




Leong, T. S. H., Wooster, T. J., Kentish, S. E., & Ashokkumar, M. (2009). Minimising oil droplet size using ultrasonic emulsification. *Ultrasonics Sonochemistry*, *16*(6), 721-727.

Development of novel emulsion systems

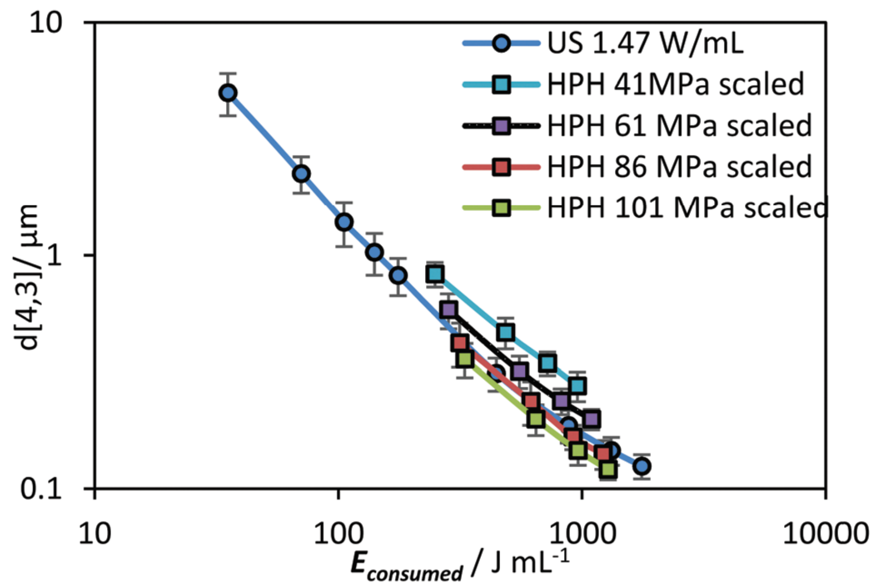
- Ability to emulsify fats into milk systems using ultrasound
- No emulsifiers necessary
- Opportunities to develop new emulsion-based products



Shanmugam, A., & Ashokkumar, M. (2014). Ultrasonic preparation of stable flax seed oil emulsions in dairy systems–physicochemical characterization. *Food Hydrocolloids*, *39*, 151-162.

Scale-up opportunities

- At lab-scale, ultrasound is highly efficient – excellent for lab-based proof of concept development
- There exist capabilities for large-throughput continuous flow ultrasound processing
- Ultrasound not yet competitive from an energy standpoint for bulk-scale homogenisation or emulsification



Li, W., Leong, T. S., Ashokkumar, M., & Martin, G. J. (2018). A study of the effectiveness and energy efficiency of ultrasonic emulsification. *Physical Chemistry Chemical Physics*, *20*(1), 86-96.

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Summary

- Ultrasound offers an effective and highly efficient (at lab-scale) tool for the emulsification and homogenisation of fats in milk
- These can be used to design new proof-of-concept emulsion systems

Ultrasound modification of protein functionality

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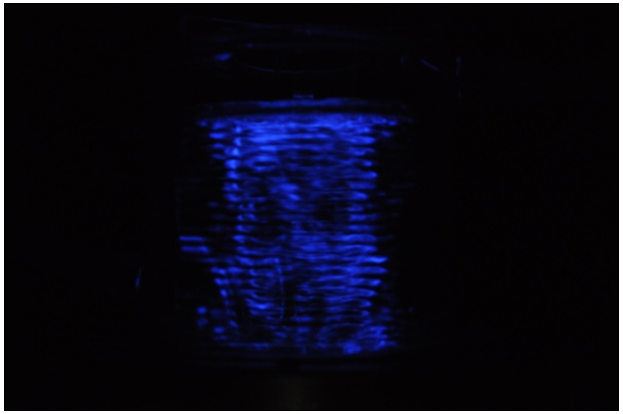
Ultrasonic mechanisms

- Proteins are susceptible to the effects of high power low frequency ultrasound
- Localised heating promotes partial denaturation, unfolding and modification of surface hydrophobicity
- Strong shear breaks up large aggregates of proteins



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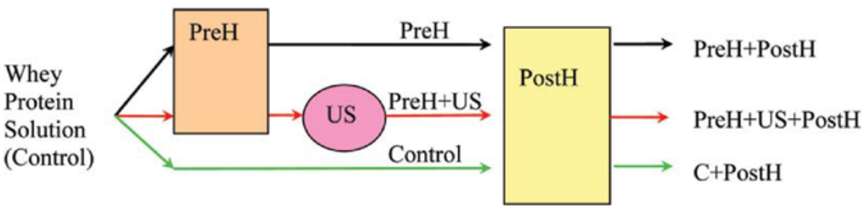
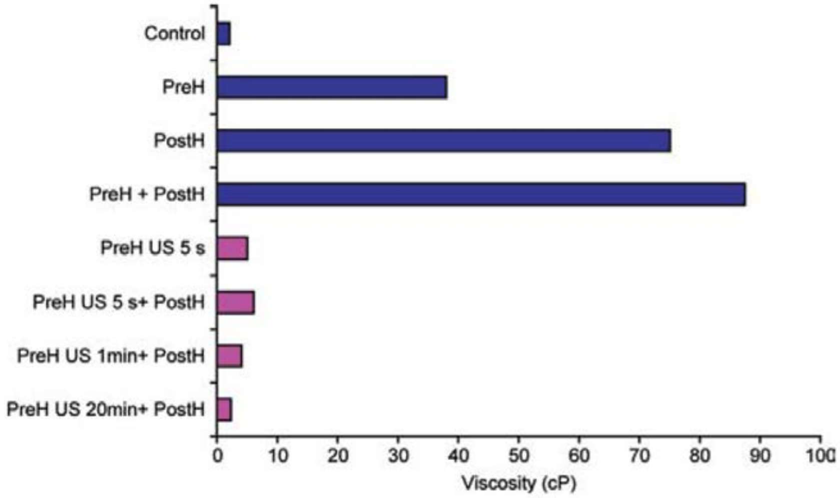
Viscosity control of protein streams

- High protein dairy streams e.g. whey concentrates, subject to undesirable viscosity increase
- Ultrasound pre-treatment of whey prior to heating reduces viscosity increase



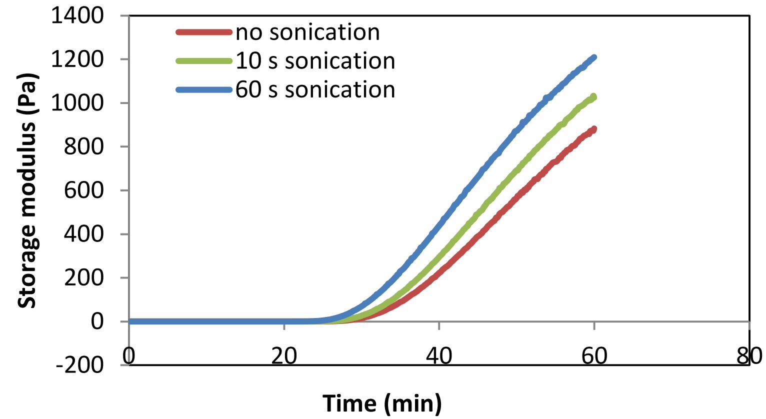


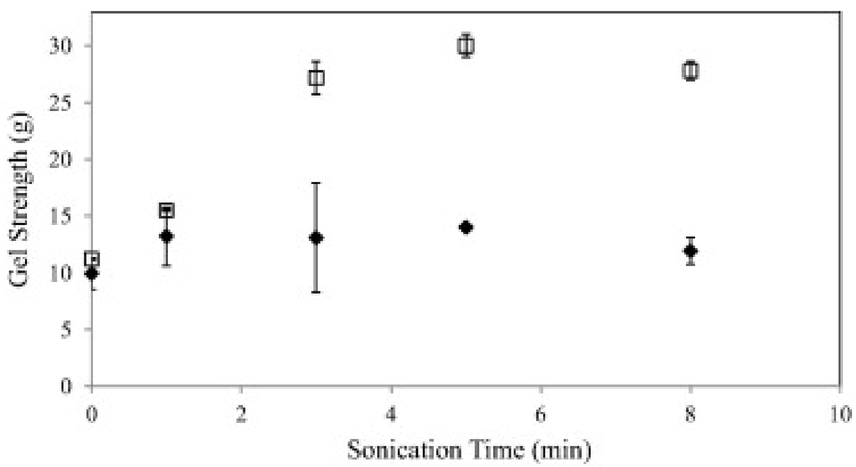
Ashokkumar, M., Lee, J., Zisu, B., Bhaskarcharya, R., Palmer, M., & Kentish, S. (2009). Hot topic: Sonication increases the heat stability of whey proteins. *Journal of Dairy Science*, *92*(11), 5353-5356.

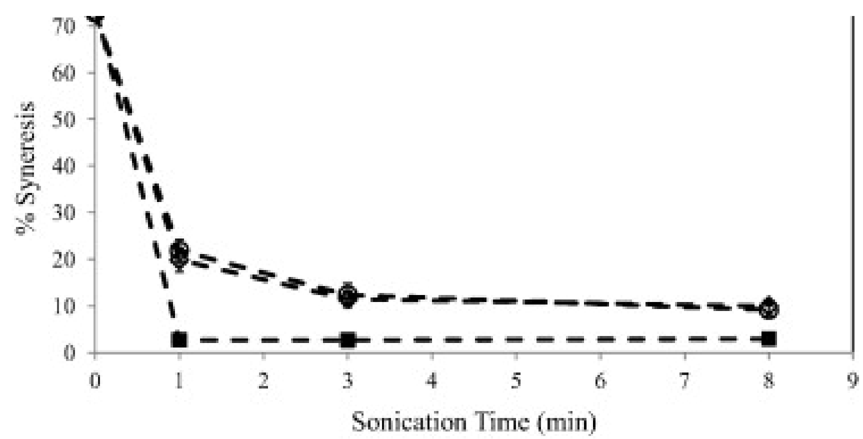
Modification of protein gelling performance

- Ultrasound can modify the rate of gelation processes

- Enhance the strength of formed gels and their water holding stability



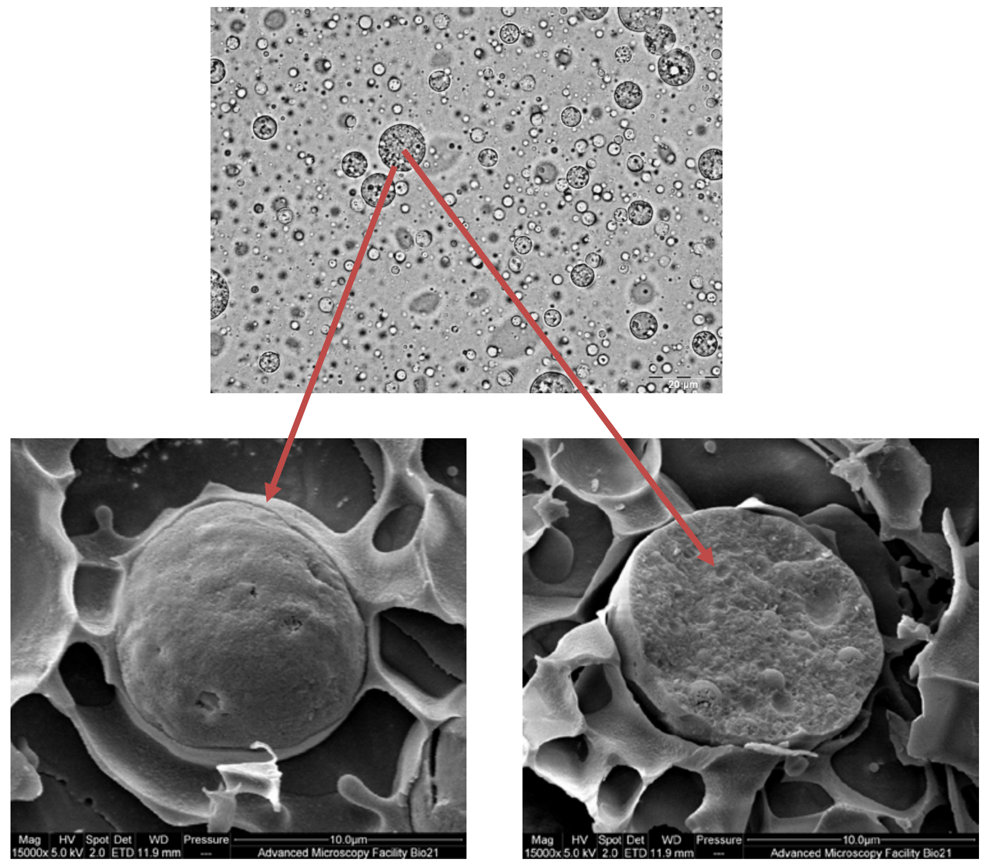




Shanmugam, A., & Ashokkumar, M. (2014). Functional properties of ultrasonically generated flaxseed oil-dairy emulsions. *Ultrasonics sonochemistry*, *21*(5), 1649-1657.

Enhancement of protein emulsification properties

- Ultrasound can improve the emulsifying ability of natural proteins
- This can be used to make emulsions with reduced requirements for synthetic emulsifiers
- E.g. double emulsions stabilized by milk proteins



Leong, T. S., Zhou, M., Zhou, D., Ashokkumar, M., & Martin, G. J. (2018). The formation of double emulsions in skim milk using minimal food-grade emulsifiers–A comparison between ultrasonic and high pressure homogenisation efficiencies. *Journal of Food Engineering*, *219*, 81-92.

Commercial opportunities

- Depending on the degree of modification desired, ultrasound has potential to be applied at commercial scale
- For example, viscosity control in whey protein concentrate streams is a commercially viable, ready-to-be implemented technology
- Excellent scope to modify functionality for proof-of-concept and/or new product development

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Enhanced crystallisation of lactose, fats and ice crystals

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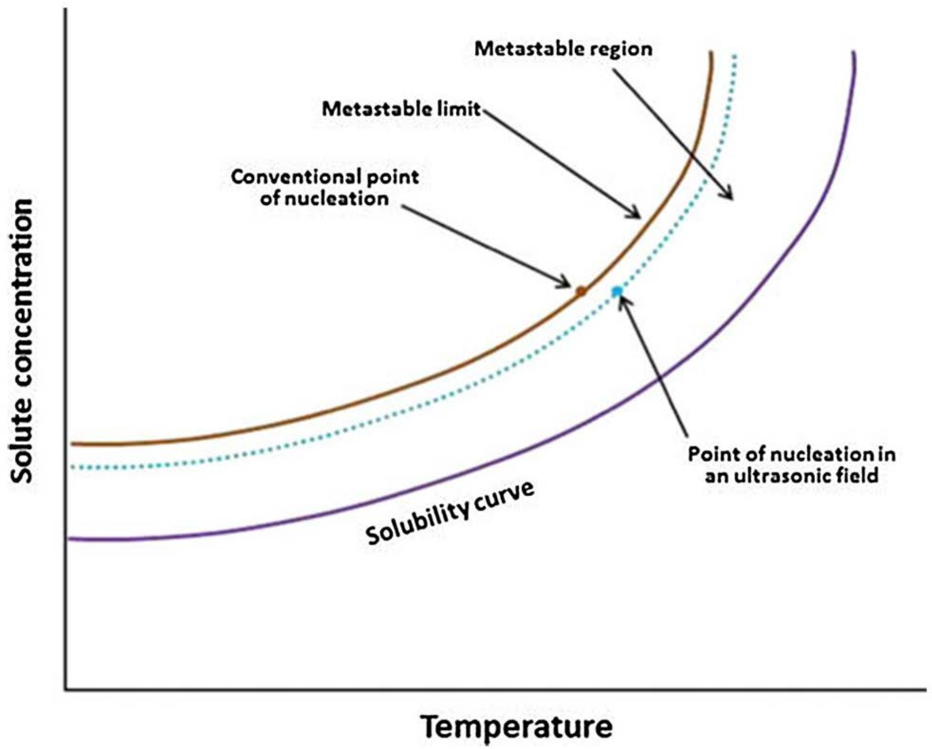
Conventional crystallisation processes

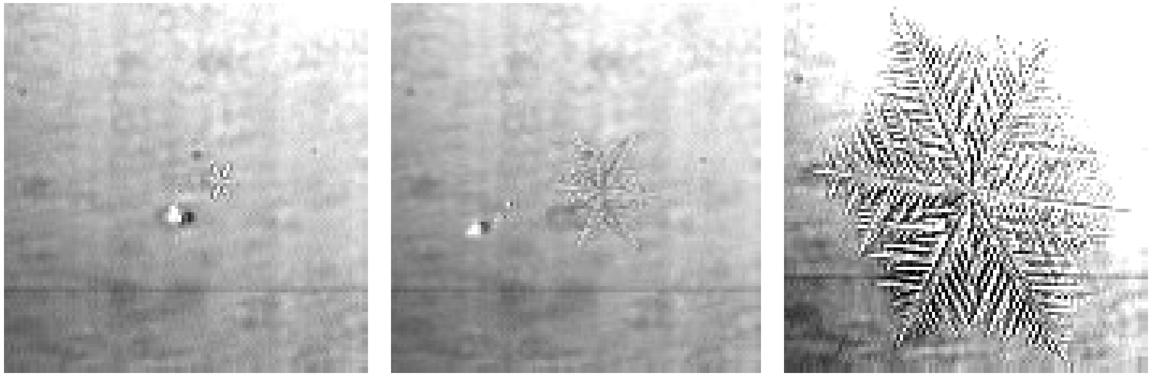
- Crystallisation is important in dairy and food processing for e.g. lactose removal, controlling quality of frozen products, controlling fat crystal morphology
- The process involves super-concentrating solute and/or then cooling to initiate crystal formation
- Long induction times, slow crystallisation rates e.g. in lactose recovery, recovery takes ~12-72 hours
- Ultrasound can be used to reduce the induction time, reduce the metastable region, enhance rate of crystallisation



Deora, N. S., Misra, N. N., Deswal, A., Mishra, H. N., Cullen, P. J., & Tiwari, B. K. (2013). Ultrasound for improved crystallisation in food processing. *Food Engineering Reviews*, *5*(1), 36-44.

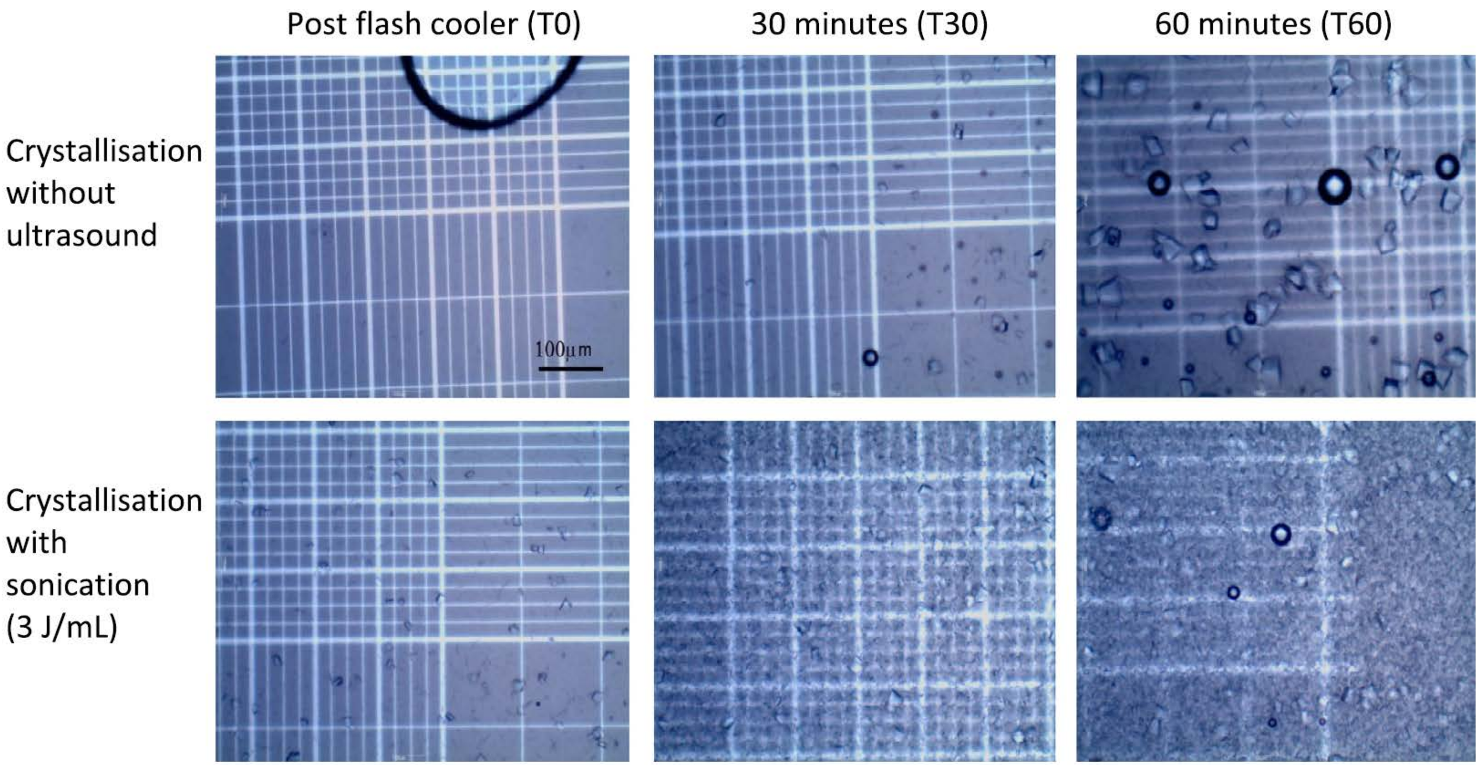
Ultrasonic mechanism

- The collapsing cavitation bubble acts as site of rapid heating and cooling
- Promotes nucleation to occur at higher temperatures than conventional
- Once nucleated, crystal formation proceeds rapidly



Chow, R., Mettin, R., Lindinger, B., Kurz, T., & Lauterborn, W. (2003, October). The importance of acoustic cavitation in the sonocrystallisation of ice-high speed observations of a single acoustic bubble. In *Ultrasonics, 2003 IEEE Symposium on*(Vol. 2, pp. 1447-1450). IEEE.

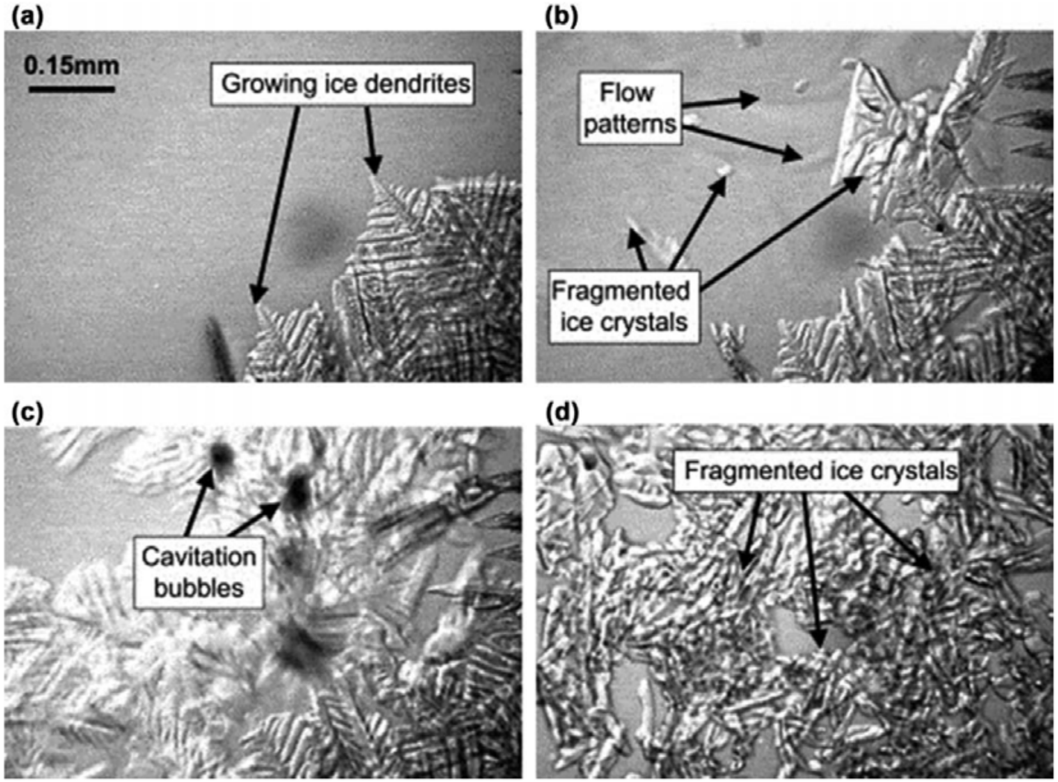
Lactose recovery using sonocrystallisation



Zisu, B., Sciberras, M., Jayasena, V., Weeks, M., Palmer, M., & Dincer, T. D. (2014). Sonocrystallisation of lactose in concentrated whey. *Ultrasonics sonochemistry*, *21*(6), 2117-2121.

Ice crystal formation

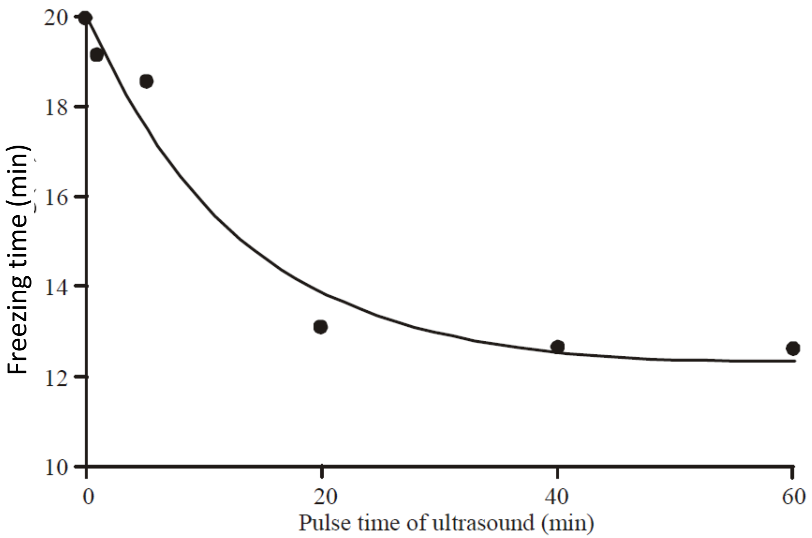
- The quality of frozen dairy products e.g. icecreams, frozen yogurts, depends on size of ice crystals formed during freezing
- Ultrasound can promote more rapid freezing to occur, which promotes formation of smaller ice crystals
- Cavitation bubbles act as nucleation sites



Chow, R., Blindt, R., Chivers, R., & Povey, M. (2003). The sonocrystallisation of ice in sucrose solutions: primary and secondary nucleation. *Ultrasonics*, *41*(8), 595-604.

Ultrasound effect on ice-cream

- Treatment for 20 minutes had the best sensory evaluation for flavour, texture and mouthfeel



Mortazavi, A., & Tabatabaie, F. (2008). Study of ice cream freezing process after treatment with ultrasound. *World Applied Sciences Journal*, *4*(2), 188-190.

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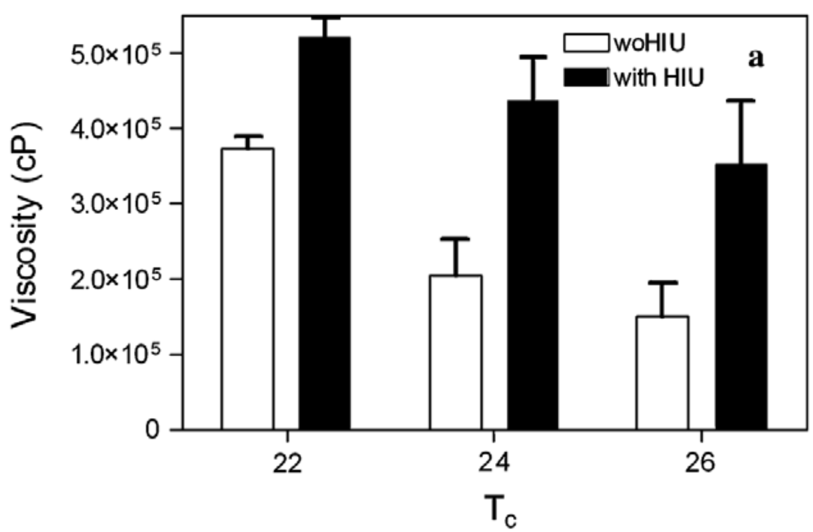
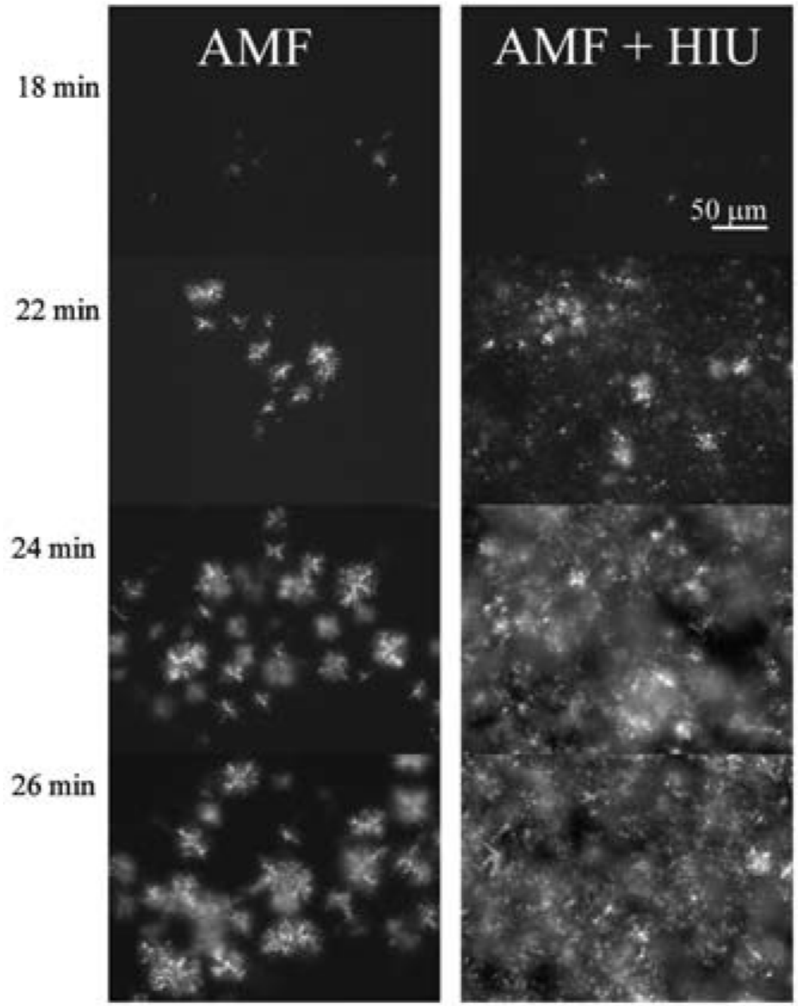
Fat crystallisation

- Promotion of crystal growth with HIU (high intensity ultrasound)
- Smaller crystal aggregates formed
- Can be used to control functional properties of the fat e.g. viscosity





Temperature = 24 °C

Martini, S., Suzuki, A. H., & Hartel, R. W. (2008). Effect of high intensity ultrasound on crystallization behavior of anhydrous milk fat. *Journal of the American Oil Chemists' Society*, *85*(7), 621-628.

Commercial opportunities

- Lactose crystallisation using ultrasound is demonstrated at pilot scale
- Opportunities to enhance freezing rate and form smaller ice crystals in frozen products
- Fat crystallisation can be used to modify textural properties of butter and other high fat products

Ultrasonic separation of cream

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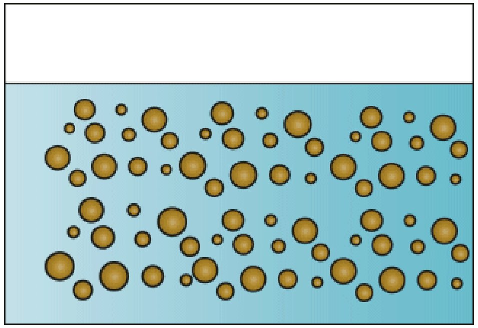
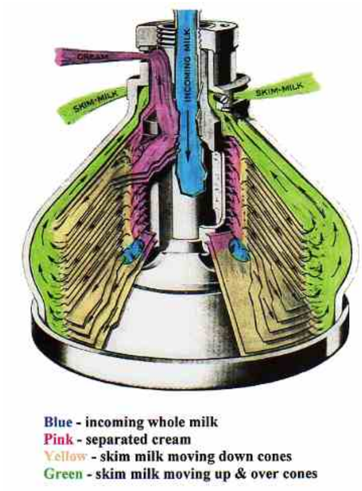
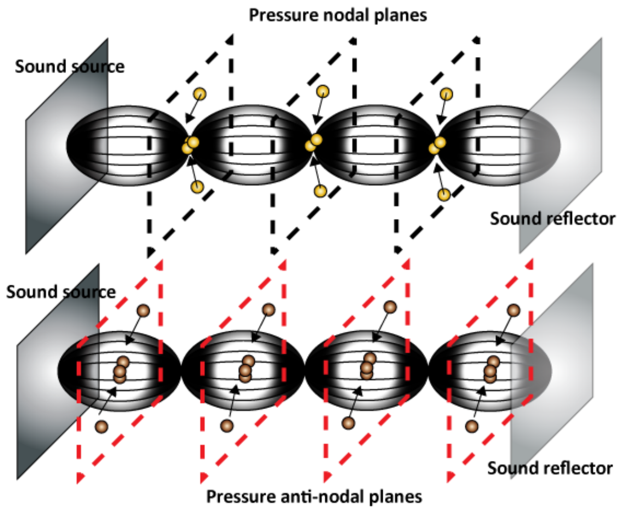
Cream separation

- Traditionally performed by natural creaming (slow process)
- Mass scale production on an industrial scale achieved using centrifugation (rapid process)

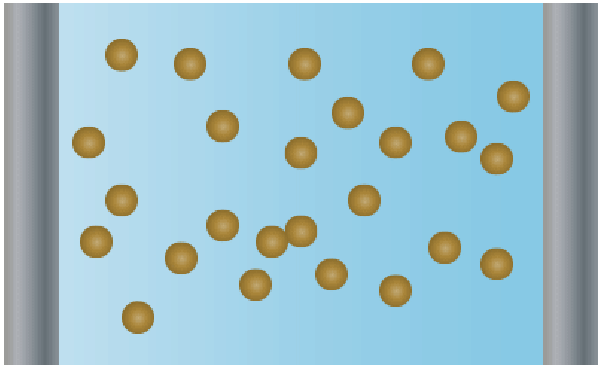




Ultrasonic separation of milk fat – operating principle



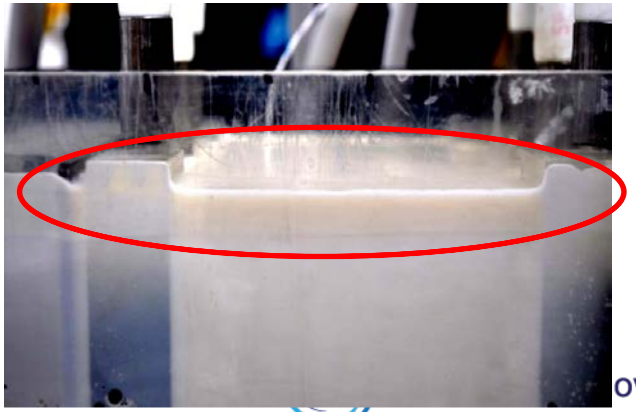
- Application of standing waves to a system causes fat globules to coagulate at regions of high pressure (anti-nodes)
- These coagulated fat droplets then rise much faster due to buoyancy than individual globules themselves



Ultrasonic creaming of fat

US on

US off



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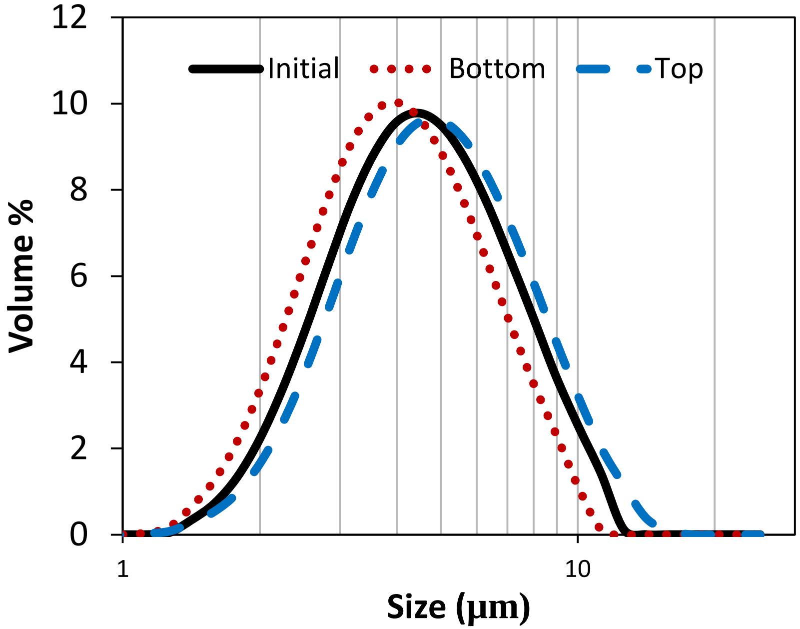
Potential Applications

- Dairy products with modified micro-structure
- Cheese making – fractions with enriched small fat globules makes cheese with improved 'textural' qualities and higher yield
- Butter making – fractions with enriched large fat globules easier to churn and improved flavour



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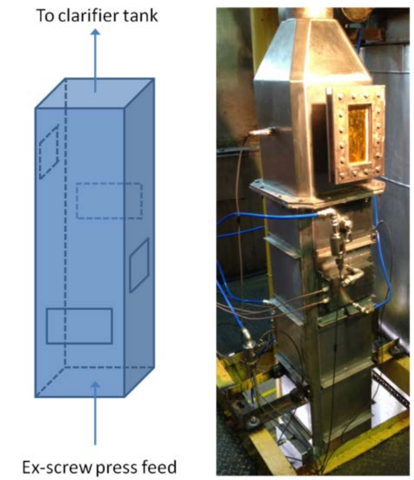
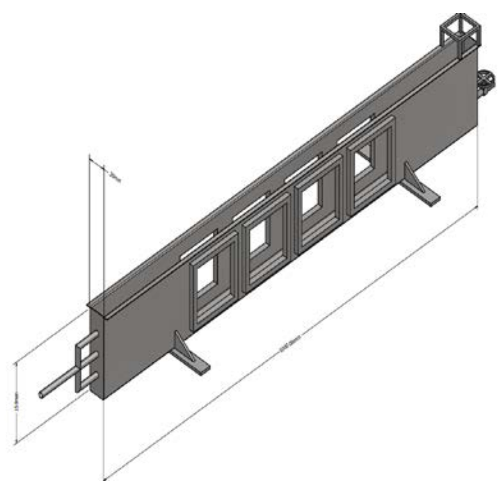
Scale-up opportunities

- Proven and successful commercial technology in palm oil milling
- Interesting applications for dairy processing that could be investigated further



(a) (b)



Concluding thoughts

- Ultrasound can be used for a variety of applications in the dairy industry
- Promising outcomes, but most of these examples are yet to be commercially developed
- Reduction in the cost of ultrasonic equipment and improvements in the technology, will make its implementation highly attractive

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Thank you!

Questions?

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