Design, realisation and characterisation of industrial-scale ultrasound cells for honey processing

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Roadmap

- Project and technical background
- Underpinning studies
- Laboratory scale cells
- Industrial scale cells
- Conclusions
BACKGROUND

http://www.usgreenchamber.com/blog/the-mysterious-case-of-the-disappearing-bees/
Project support

- Funded by EU R4SME initiative (SME’s, trade associations, supply chains)
- Eight European countries represented, spanning equipment manufacturers (ultrasound, engineering), academia, RTO’s, honey cooperatives and an independent beekeeper
- Scheme aims to provide beneficiaries (SME’s) with proven technology and IP to then exploit benefits
Project motivation

- Consortium assembled by CRIC (Catalonia), to solve industry-wide problem of crystal formation in honey over extended time periods
  - Desired retail shelf-life of 12 months
  - Consumer perception of ‘spoiled’ when granular
- Pasteurisation approaches can help solve the problem, but remove nutrients, and can mask the geographical origin
- Lab-scale studies in literature and academia suggested beneficial effects of ultrasound on extending longevity, but not tested industrially
Our challenge? Generate and exploit acoustic cavitation in honey, to modify crystal populations, and scale it up.

Cavitation research

Hodnett & Zeqiri, IEEE UFFC, 2008

Zeqiri et al, IEEE UFFC, 2003
Vessel modelling

UIA 38, Vancouver: Memoli et al, Ultrasonics Sonochemistry, 2012
What is honey?

- Supplementary food for bees
- 600,000 tonnes harvested worldwide p.a.
- Composed primarily of a solution of glucose and fructose, with some maltose, sucrose, enzymes, pollen, water, air and other organic matter
- Glucose-fructose content is determined by floral origin
Problem scoping

- Crystallisation occurs when glucose spontaneously precipitates out from the supersaturated solution, losing water, and forms a lattice.

- Technical challenges
  - Maintain honey quality, i.e. chemical measures, consumer perception of texture and taste.
  - Industrial viability – 250 kg/h throughput.
  - Accessible to all production scales.

- Temperatures >55 degrees C adversely affect quality
  - Standards exist for levels of HMF (Hydroxymethylfurfural).
  - Diastase and invertase levels also relevant.
EXPERIMENTAL
Underpinning studies
http://www.thisiscolossal.com/tags/honey/
Honey at room temperature
Liquid properties

- **Density (kg/m³)**
  - Tesco
  - Clover
  - Water

- **Surface Tension (mN/m)**
  - Honey
  - Pure water

Temperature / Celsius vs. Density (kg/m³)

Temperature (Celsius) vs. Surface Tension (mN/m)
Detailed density with temperature

- Temp to 15 °C from 20°C den. increase (crystallisation?)
- Temp to 10 °C den. increase continues
- Temp to 20°C den. decrease dissolution
- Crystals fully dissolved?
- Temp to 40 °C density stable
- Temp to 80 °C density decreases
- Return to 20°C rapid density increase

Dense residual from linear ft of density to temperature kg/m³
Honey characteristics

Measured attenuation of honeys under various temperatures

Clover honey:
Three measurements for 4 mm cell: 175, 150, 145 dB/MHz/cm
Four measurements for 10 mm cell: 44, 97, 64, 45 dB/MHz/cm
Honey characteristics

- Honey

- Water
Material summary

- Initially thought to be acoustically complex – but more workable at 30 – 40 degrees C
- Surface tension similar to water
- Relative densities around 1.4 - 1.5
- Viscosities around 2– 3 Pa.s
- Attenuation around 25 kHz of ~0.06 dB/cm
- Acoustic pressure threshold at 25 kHz of ~160 kPa
LAB-SCALE CELLS
Design, build and test
Design parameters

- Prime number of transducers
- Double-walled approach for active cooling
- Scaleable
- Achievable
Finite-Element modelling

- PAFEC used to simulate forced response of cell as a function of frequency
- Spatial maximum of RMS acoustic pressure then investigated in detail to optimise frequency of operation
Pentagonal cell
Pressure simulation
Manufactured cell
Cavitation tests – water
Cavitation tests – water

Cavitation as a function of applied power -
transducer centre

Cavitation as a function of applied power - transducer edge
Honey tests
Hydrophone characterisation

Sound pressure (RMS) in honey with cooling water
4.2 – 5.5 MHz cavitation results
Crystal coverage

- 20%, 16 min
- 50%, 8 min
- 80%, 8 min
- 100%, 4 min
Results – citrus, 100% power, 30 degrees pre-heat
Lab-scale findings

- Can generate significant cavitation in a range of honey samples
- Can produce significant changes in crystal populations
- With cooling, required operating envelopes can be achieved to maintain quality

➢ Scale up
Flow cell requirements

- Need to treat a minimum **250 kg** of honey per hour
- Each ‘unit’ of honey needs to be exposed to > 160 kPa for approximately 10 min, at a bulk power density of 150W/l to attain desired crystal morphology
- Temperature of honey should not exceed 55 °C
- Pentagonal cells have demonstrated proof-of-concept at lab scale but are likely to present practical challenges
- Original design study concluded with cells of circular cross-section ➔ pursue this approach
FLOW CELLS
Design, build and test
Cell concept (1/2)

- 70 transducers
- Frequency of operation ~22 kHz
Cell concept (1/2)

- More preferable vibration characteristic than the staggered option
- ANSYS modelling by partners suggested temperature rises >60 degrees C
- Need for cooling/mixing
• 35 transducers, two cells in series, intermediate mixing and cooling
• Frequency of operation ~21-24 kHz
• Central cooled region
• PAFEC modelling completed for range of configurations
Acoustic pressure at 22 kHz
3 mm wall thickness
Acoustic pressure at 25 kHz
3 mm wall thickness

Centre of transducers
Spatial / frequency variation (honey)
Honey tests – external

- In flow configuration, honey void is inaccessible and so cell performance must be monitored externally.
- Two piezo pick-ups fitted (epoxy bonded) to outer surface – these respond to wall vibrations - output voltage monitored.
- Polytec PSV400 laser vibrometer used to probe wall variations, including over piezos, for static and flow.
Vibrometer output
Thermal camera images
Conclusions

- NPL’s proven capability in acoustic cavitation research taken up in collaboration with EU partners
- Fundamental parameters of honey characterised, and acoustic properties derived
- Lab-scale cells manufactured and demonstrated to modify crystal populations
- New honey processing treatment method designed, realised and scaled-up to industrial pilot, beginning to overcome longstanding barriers
Thank you!

http://lambrian.deviantart.com/art/Happy-bee-family-284708546