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

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42nd Ultrasonic Industry Association Symposium
Orlando, FL
22nd April 2013

Roadmap

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

http://www.123rf.com/photo_3200832_golden-honey-dripping-from-a-spoon.html

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

SEVENTH FRAMEWORK PROGRAMME

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

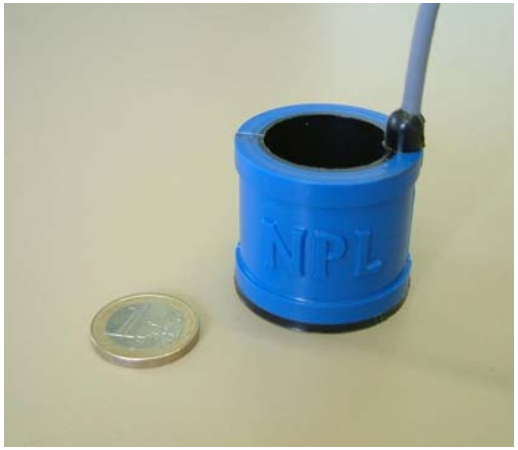
http://www.sciencedaily.com/releases/2008/12/081223091308.htm

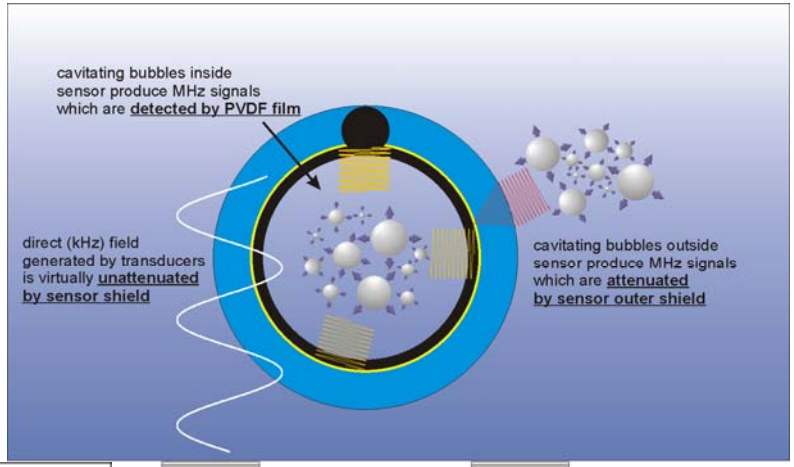
http://www.honey.com/newsroom/photo-gallery

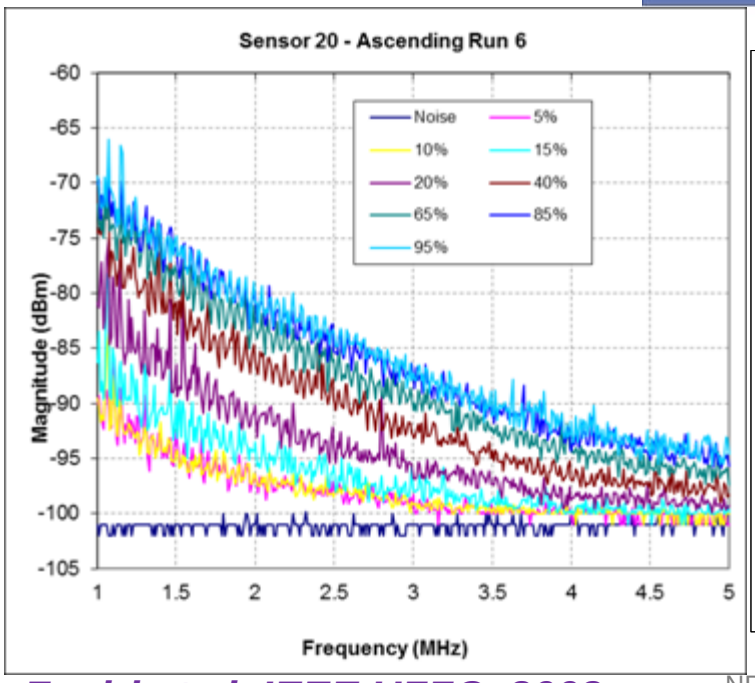
http://dietandi.com/get-healthier-with-honey/

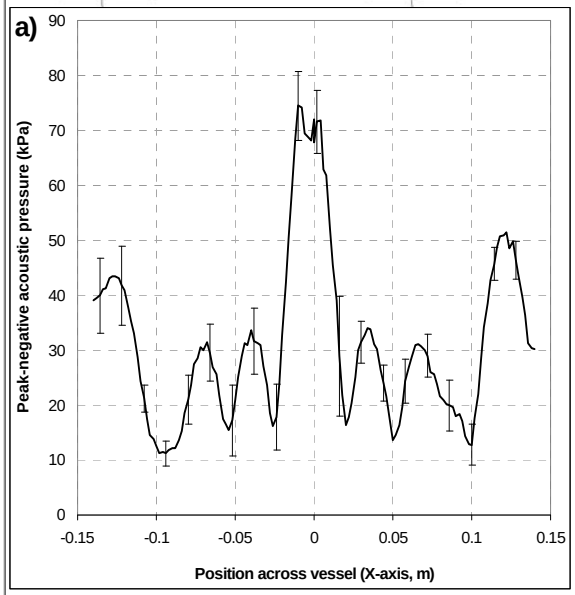
Cavitation research

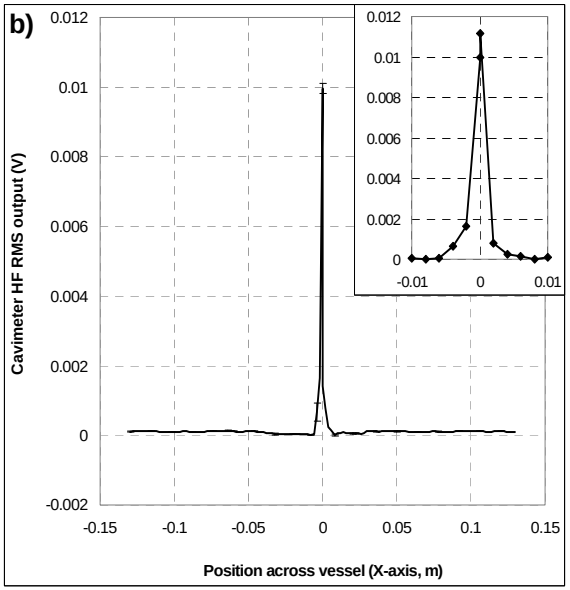
NPL National Physical Laboratory







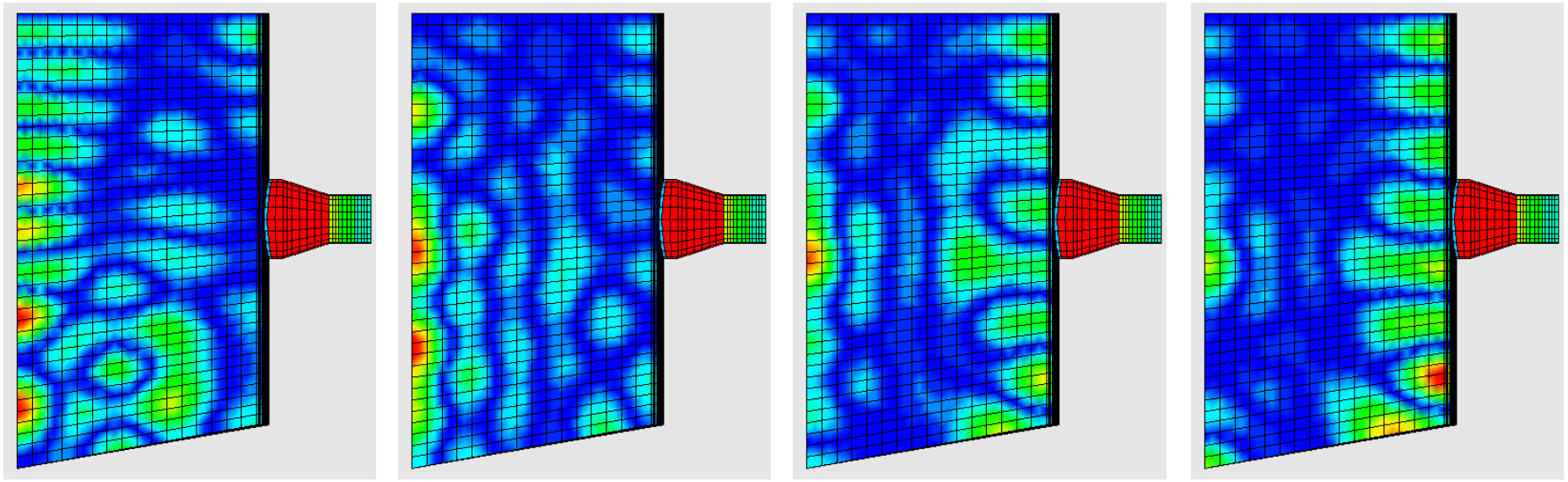




Zeqiri et al, IEEE UFFC, 2003

Hodnett & Zeqiri, IEEE UFFC, 2008

Vessel modelling

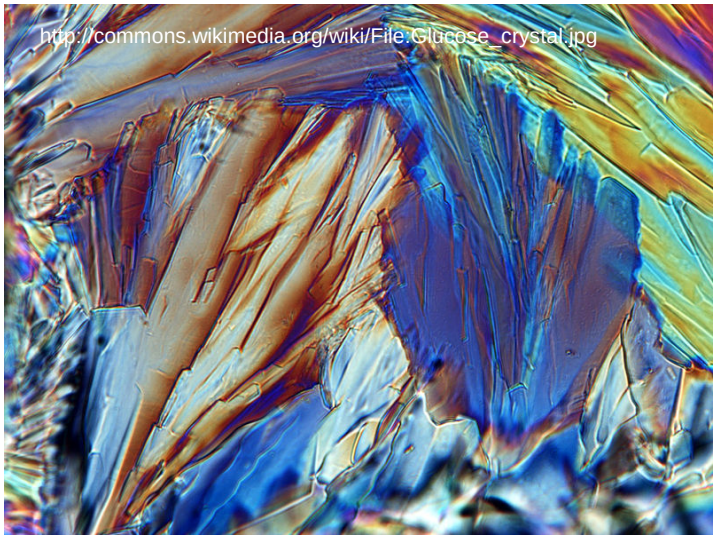


Temp 25 °C 27 °C 29 °C 31 °C

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

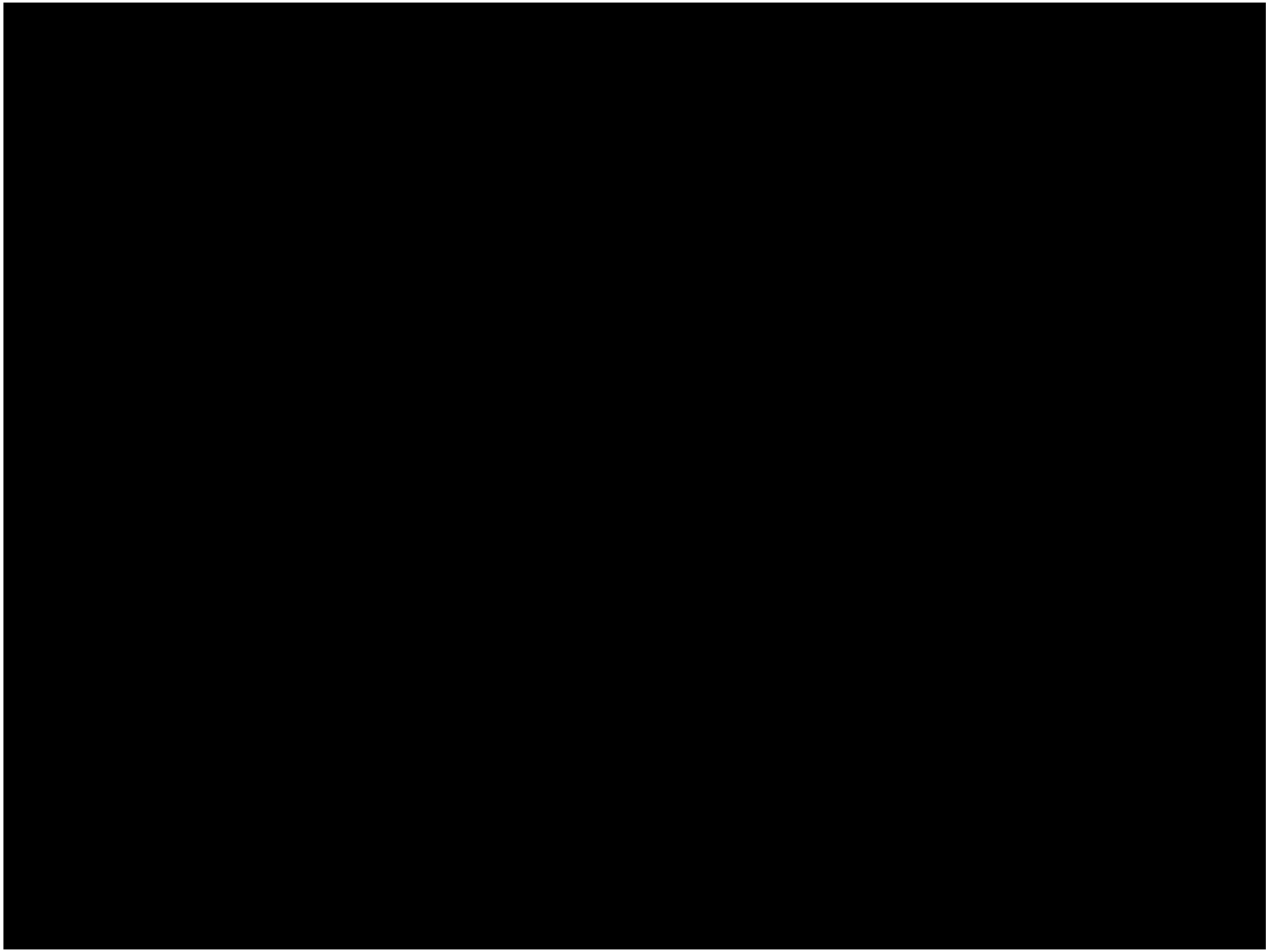
- Crystallisation occurs when glucose spontaneously precipitates out from the supersaturated solution, losing water, and forms a lattice
- Technical challenges
  - Maintain honey quality, i.e. chemical measures, consumer perception of texture and taste
  - Industrial viability – 250 kg/h throughput
  - 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

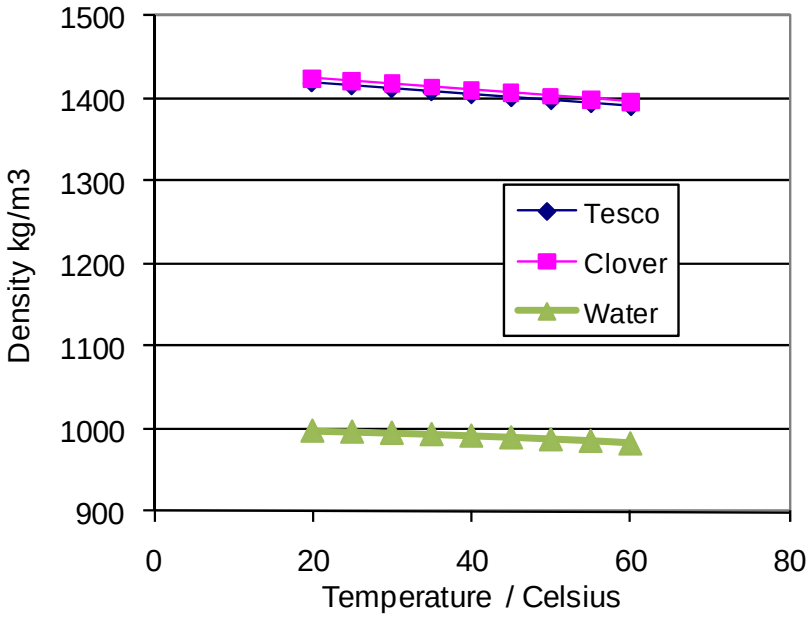
Underpinning studies

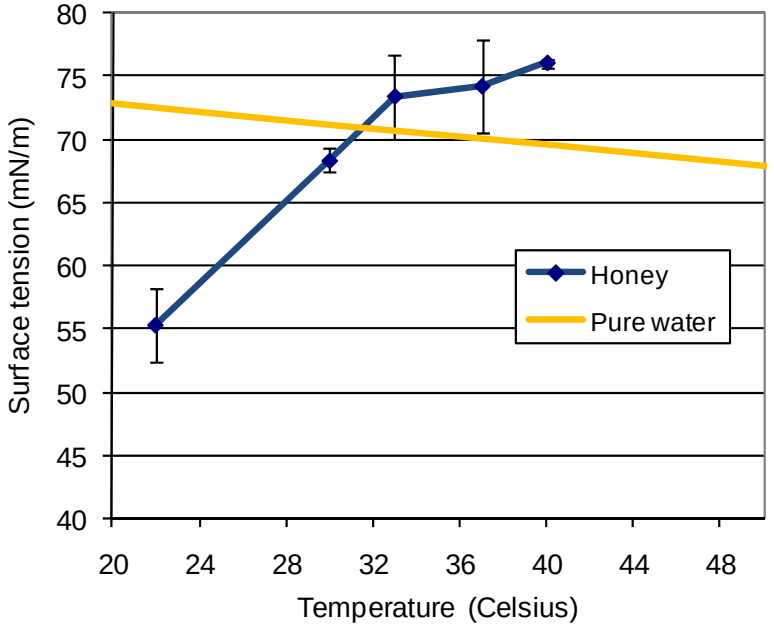
http://www.thisiscolossal.com/tags/honey/

Honey at room temperature

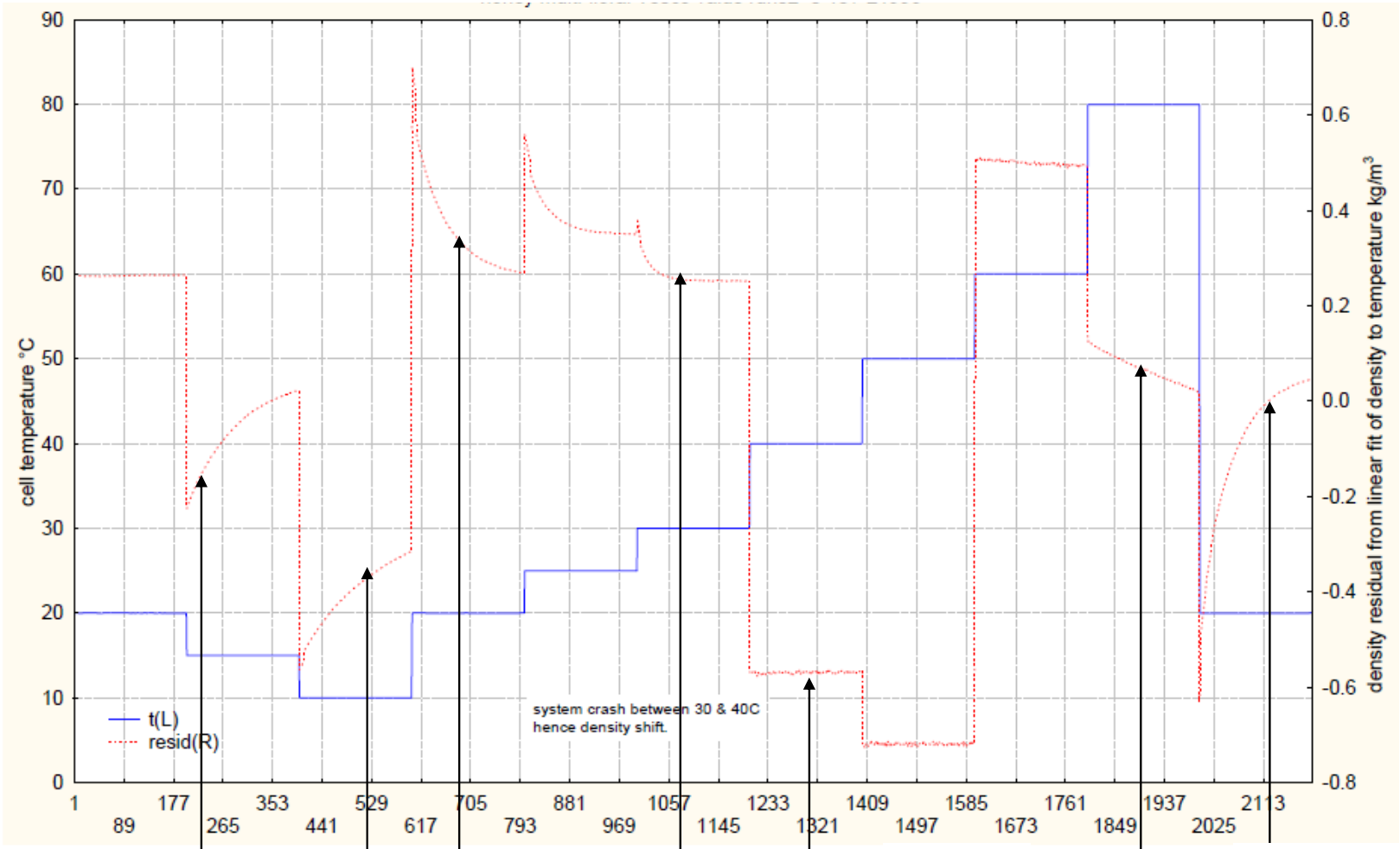


Liquid properties

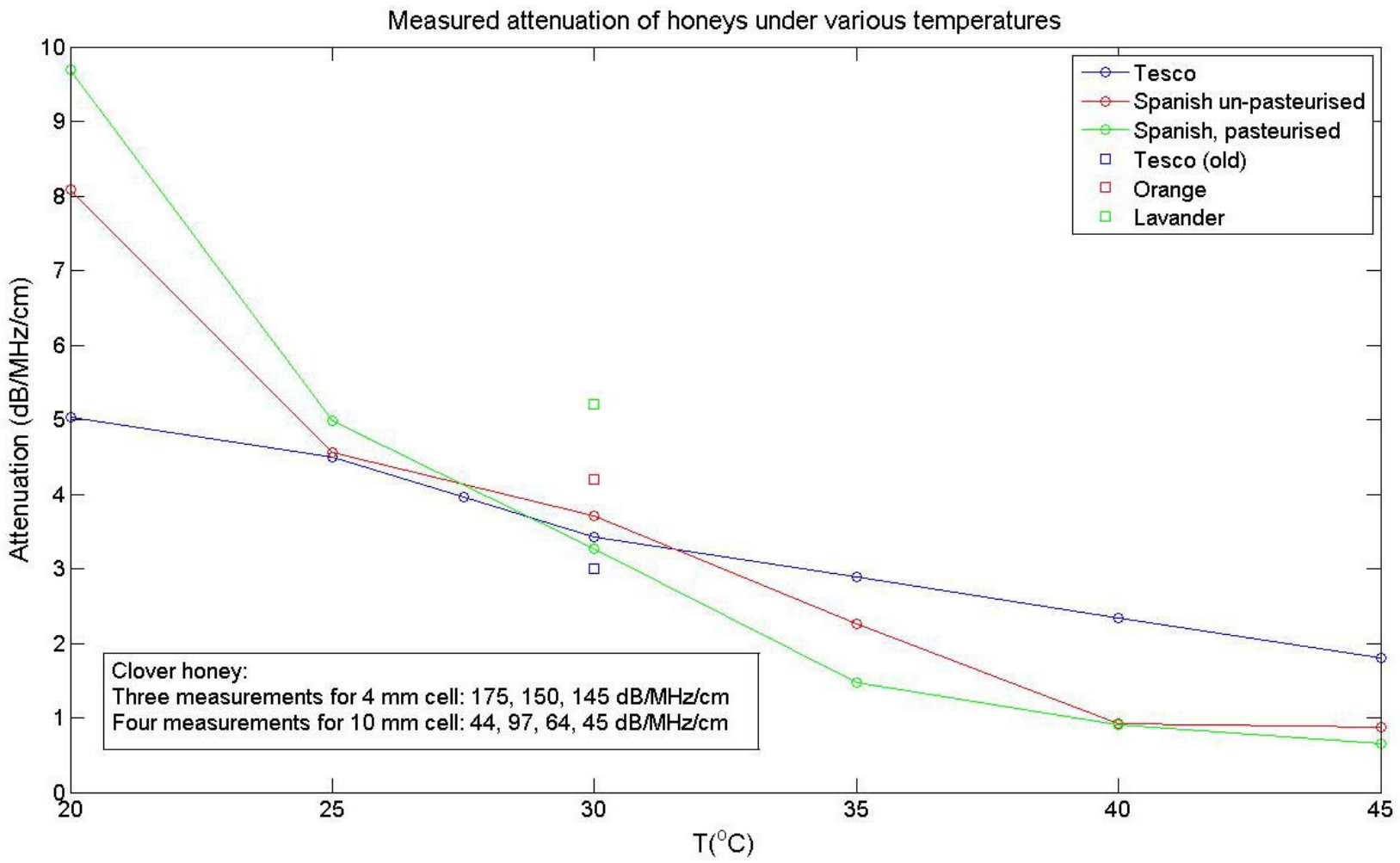




Detailed density with temperature

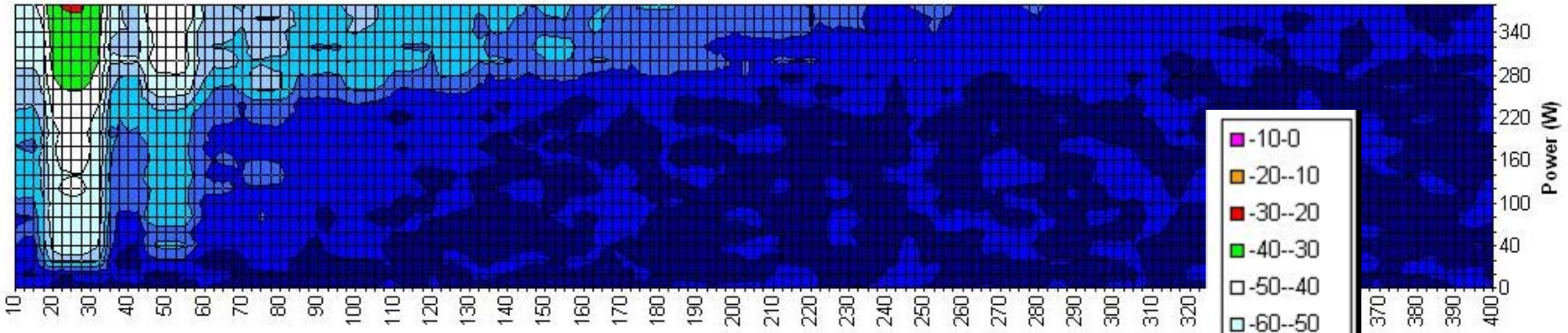


Honey characteristics

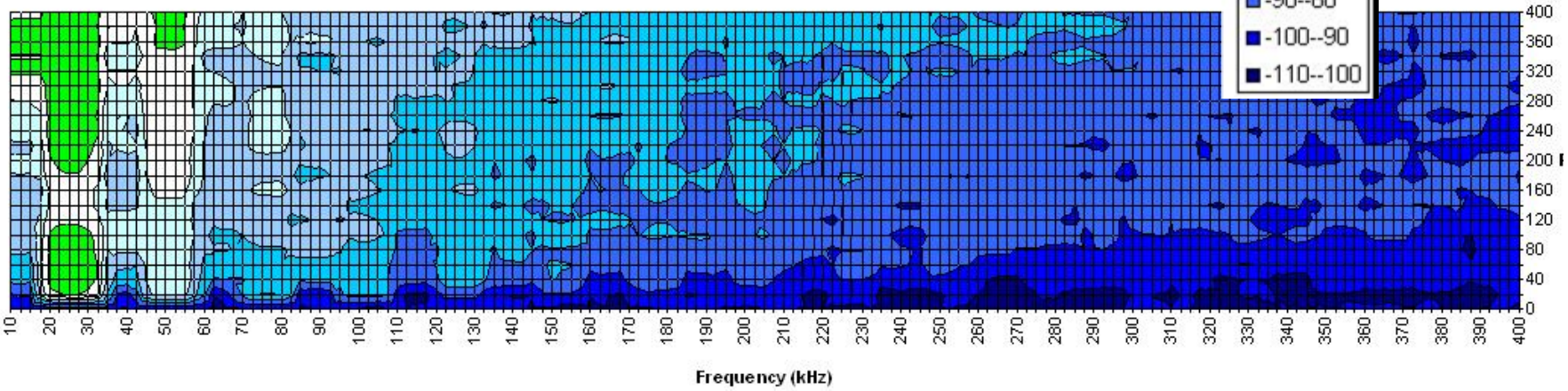


Honey characteristics

- Honey



- Water

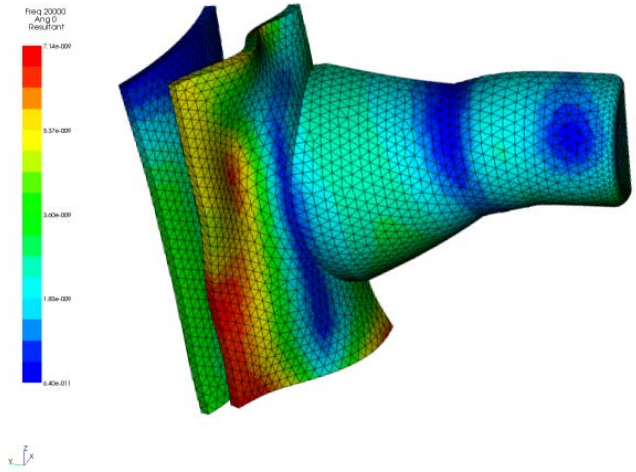


Material summary

- 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

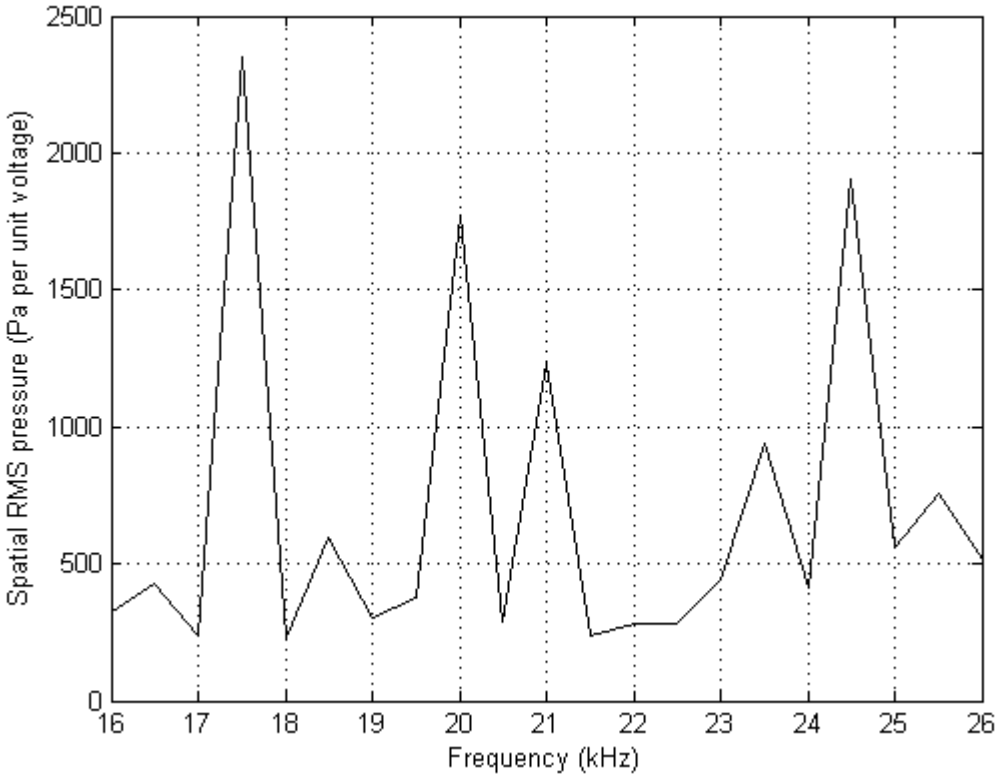


Design parameters

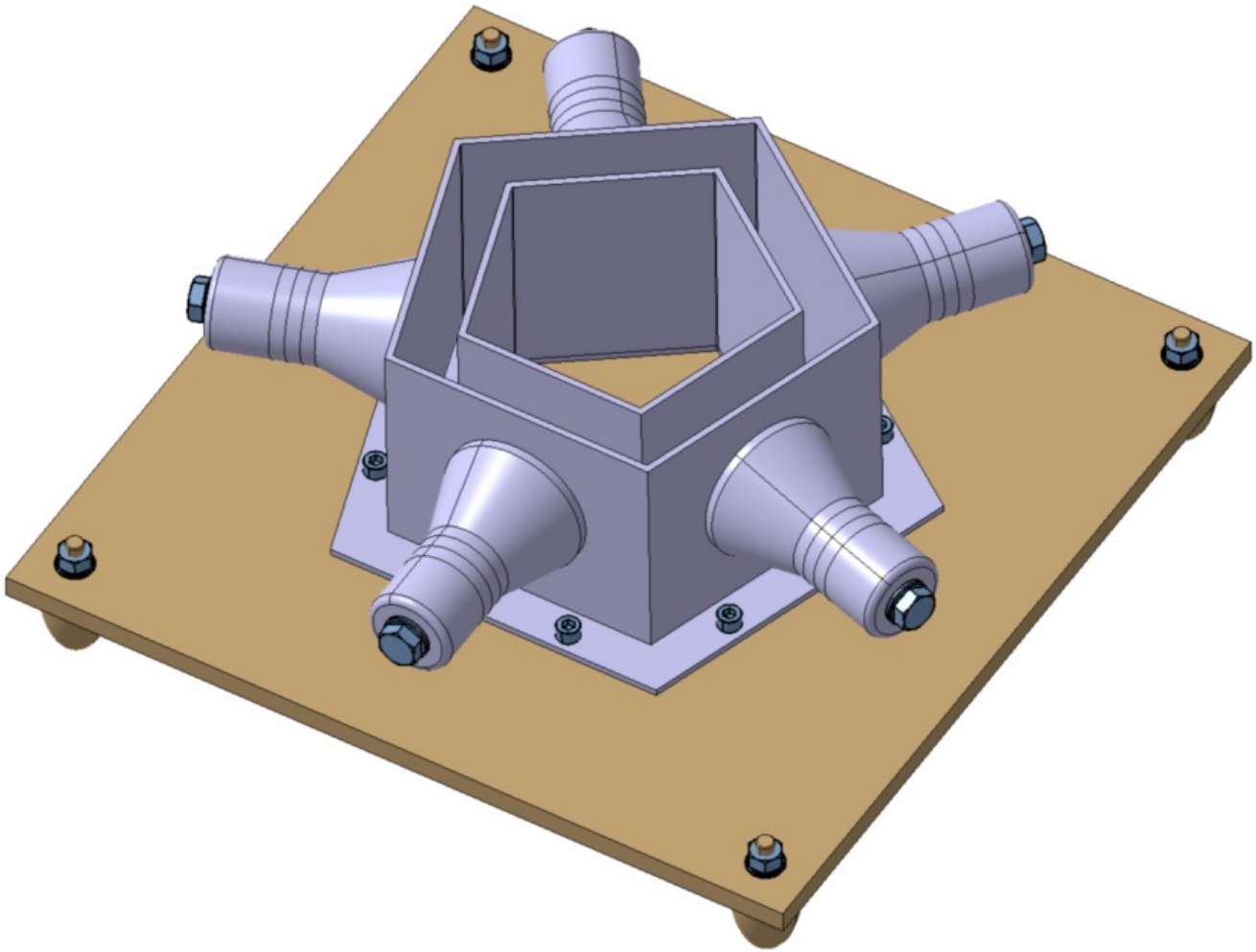
- Prime number of transducers
- Double-walled approach for active cooling
- Scaleable
- Achievable

Finite-Element modelling

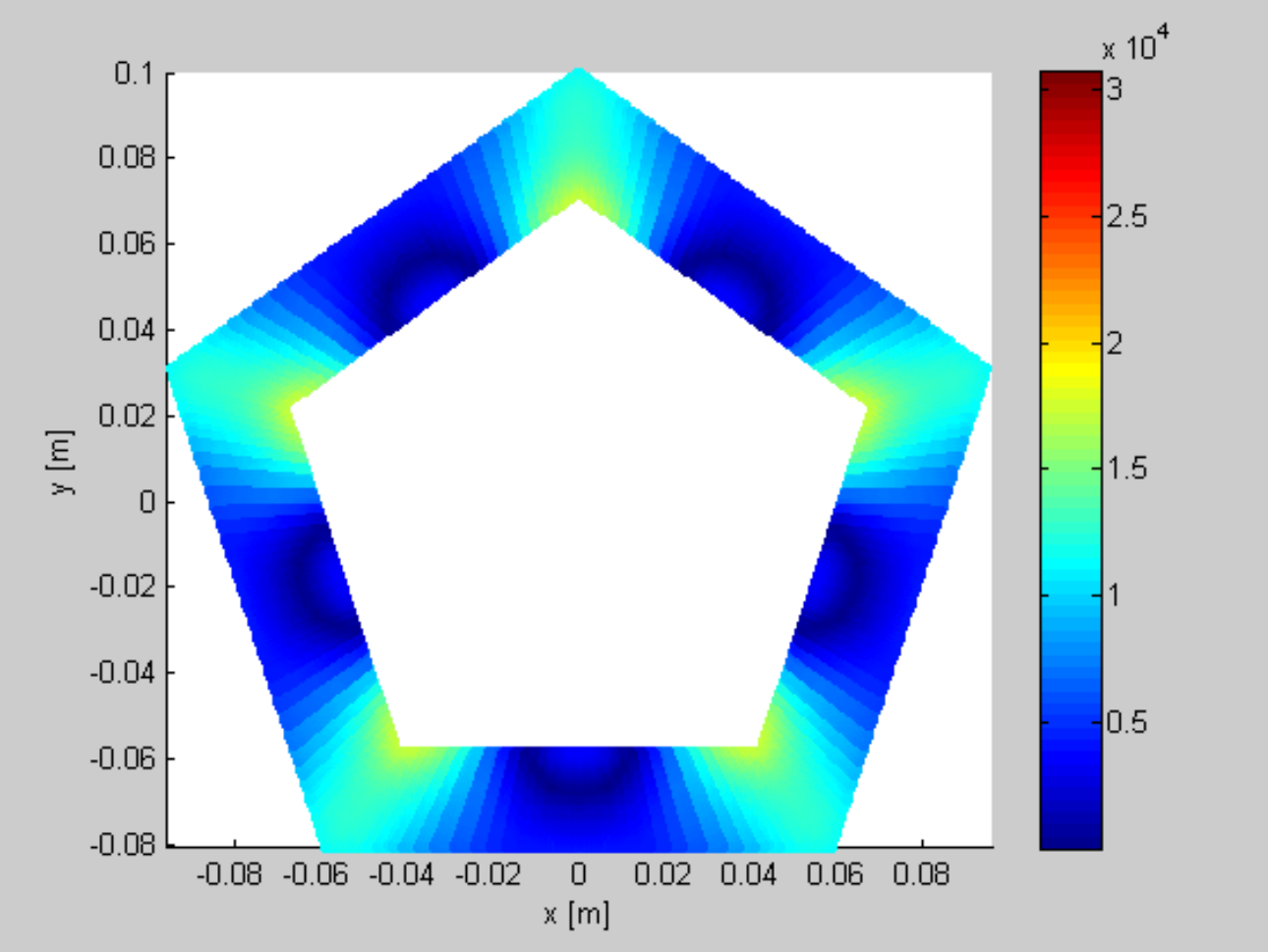
- PAFEC used to simulate forced response of cell as a function of frequency
- Spatial maximum of RMS acoustic pressure then investigated in detail to optimise frequency of operation



Pentagonal cell



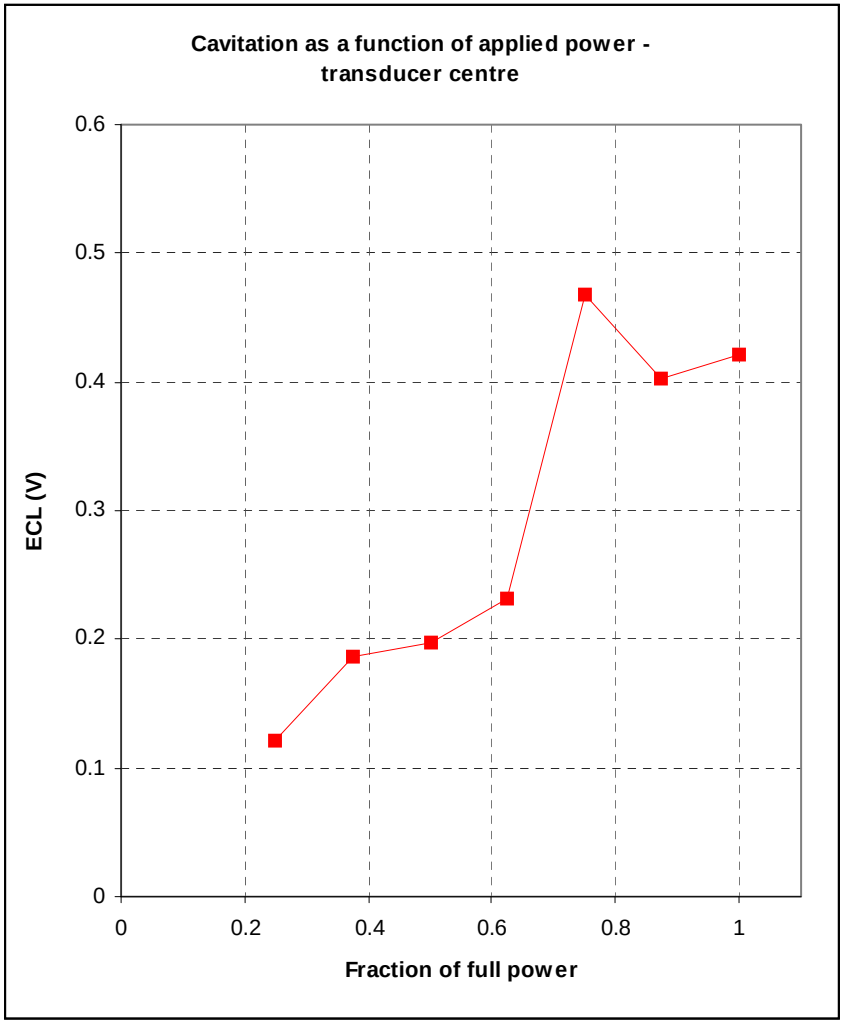
Pressure simulation

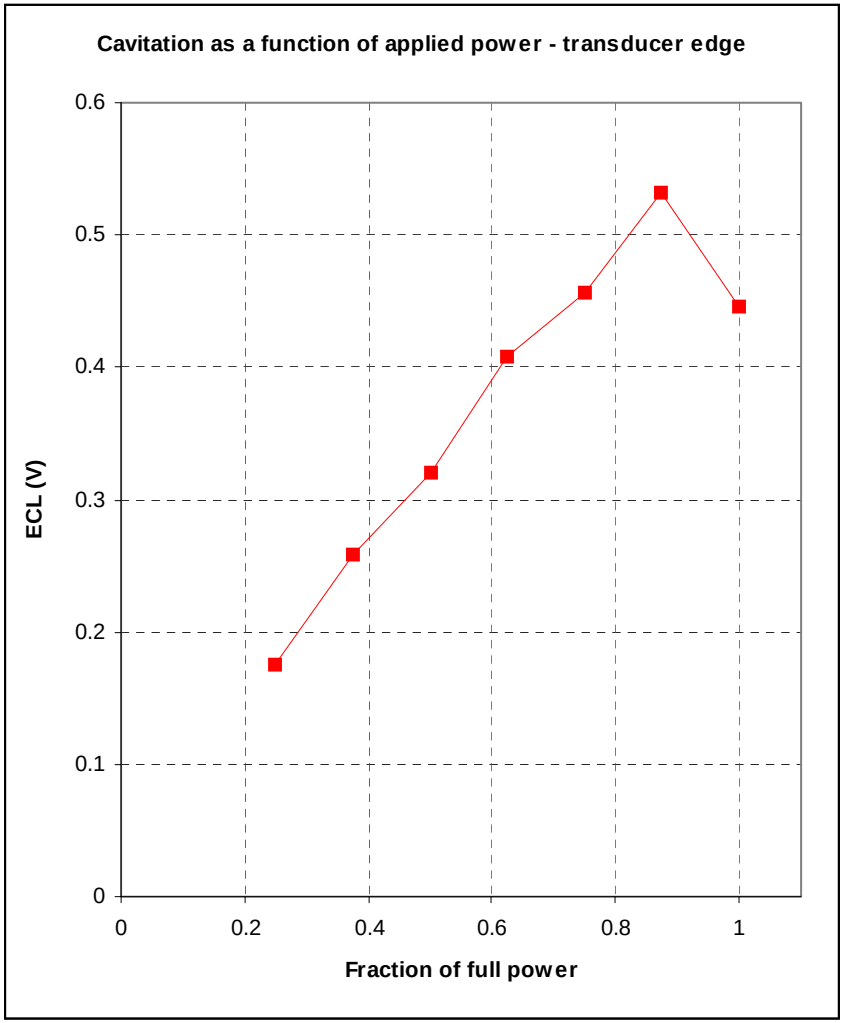


Manufactured cell

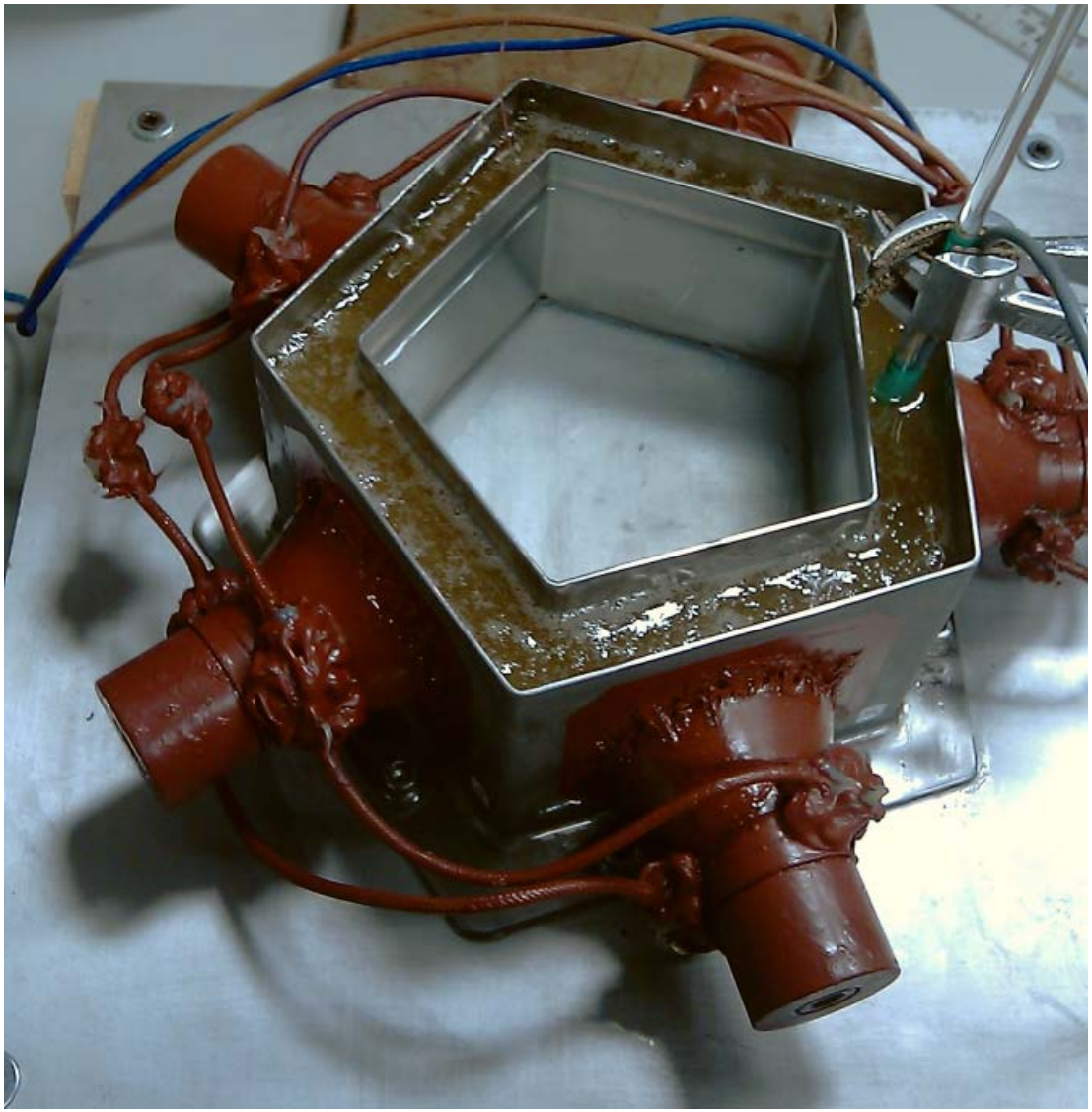
Cavitation tests – water

Cavitation tests – water

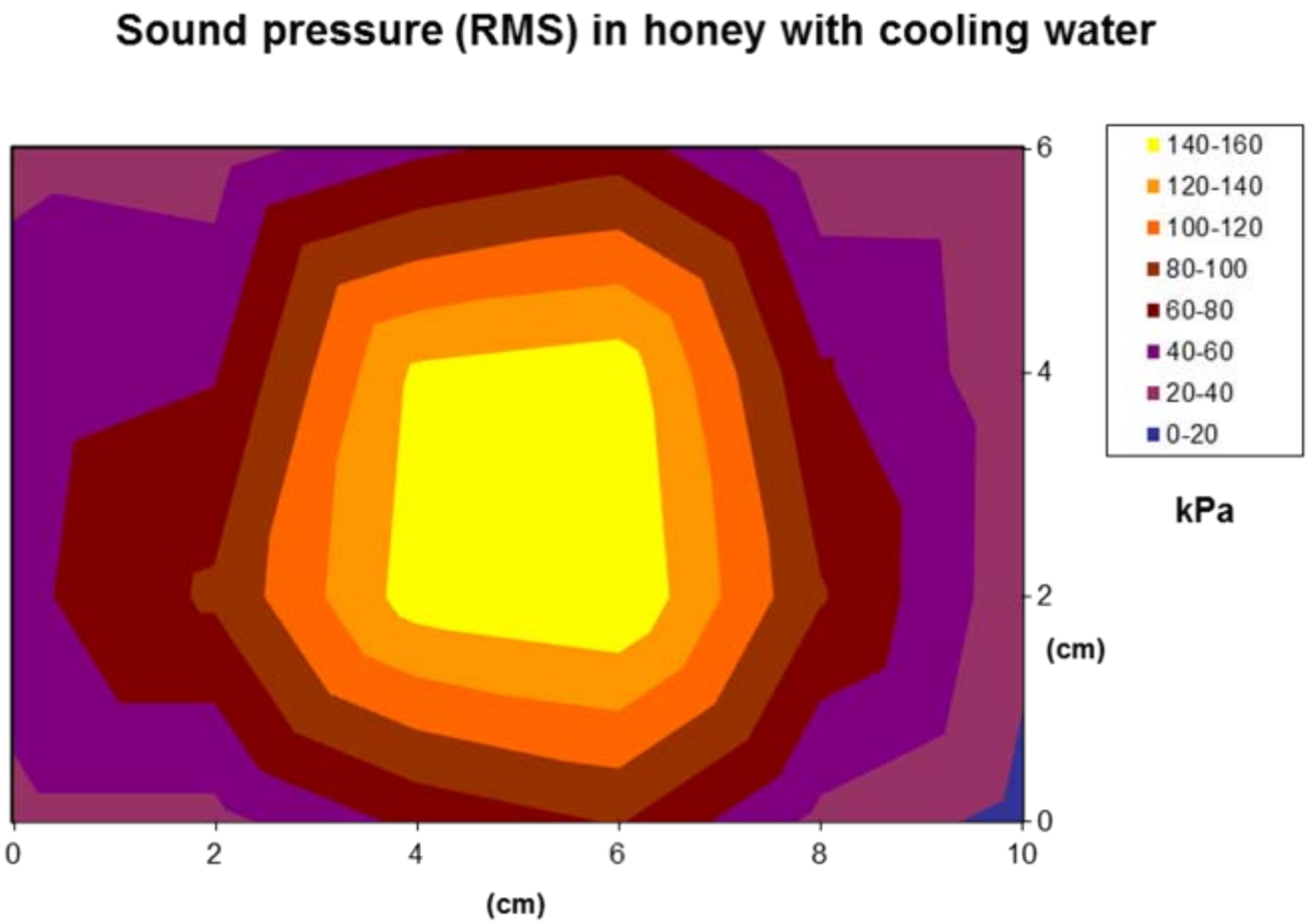




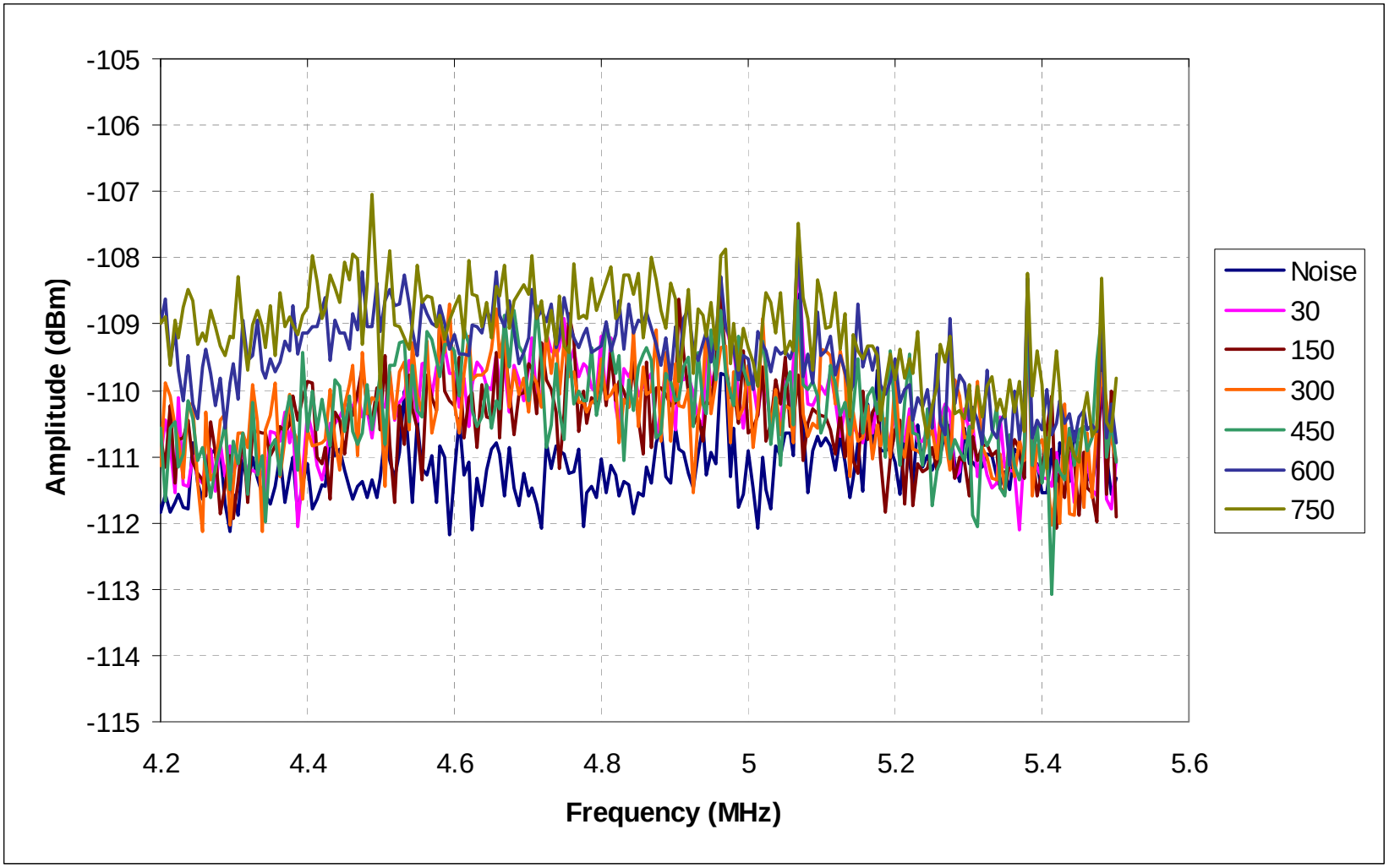
Honey tests



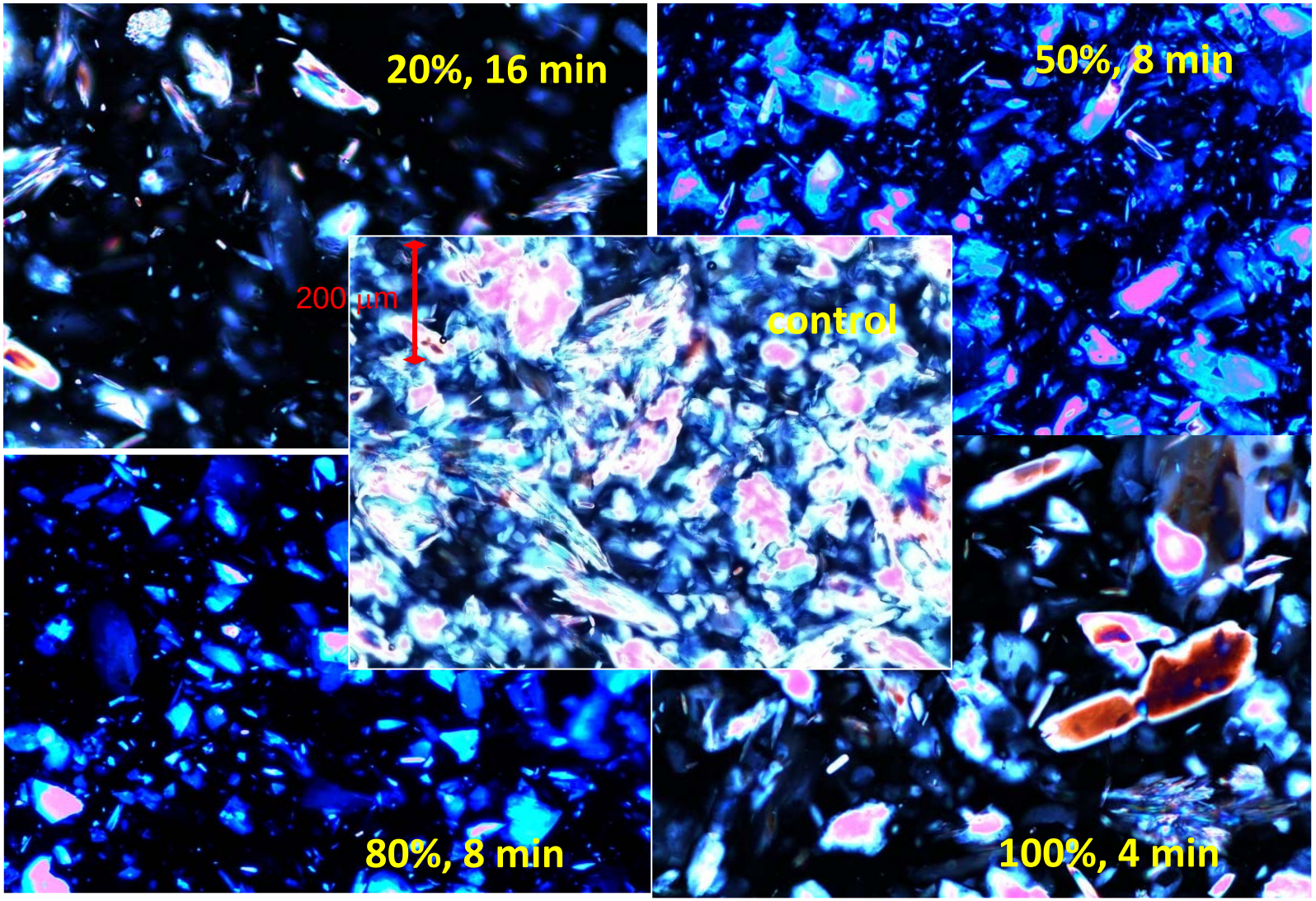
Hydrophone characterisation



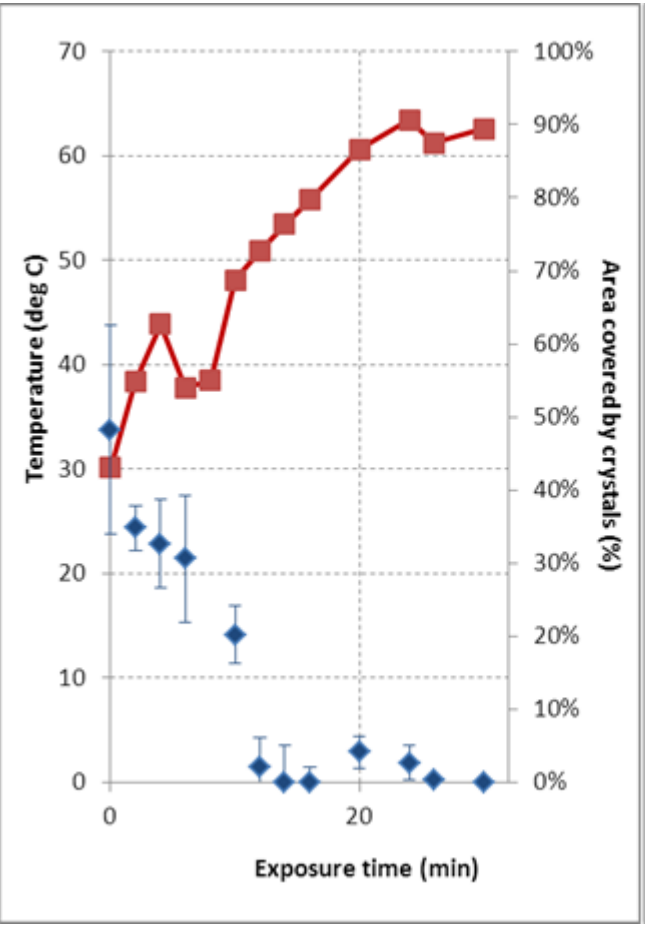
4.2 – 5.5 MHz cavitation results

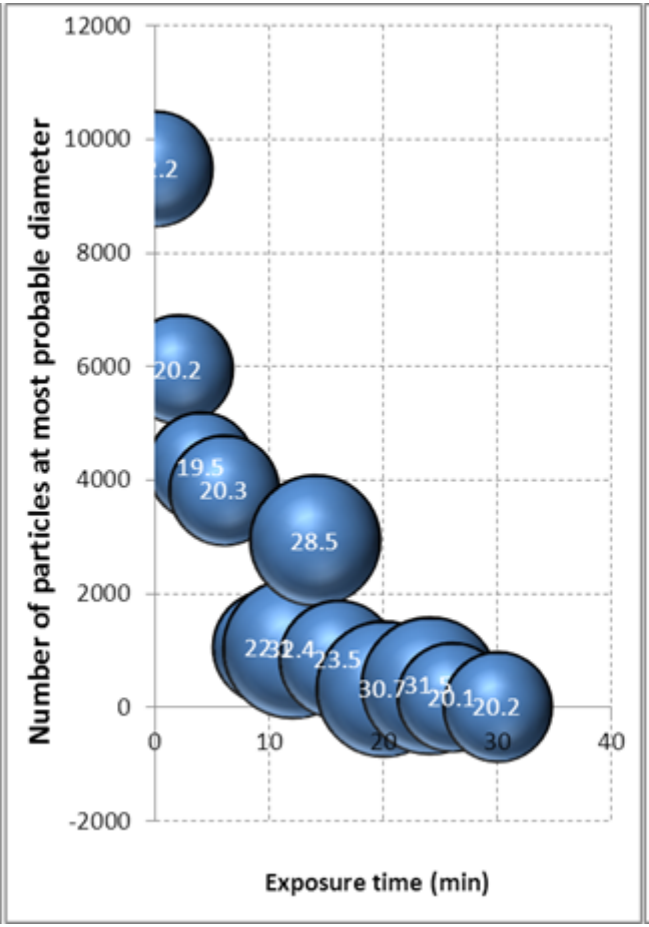


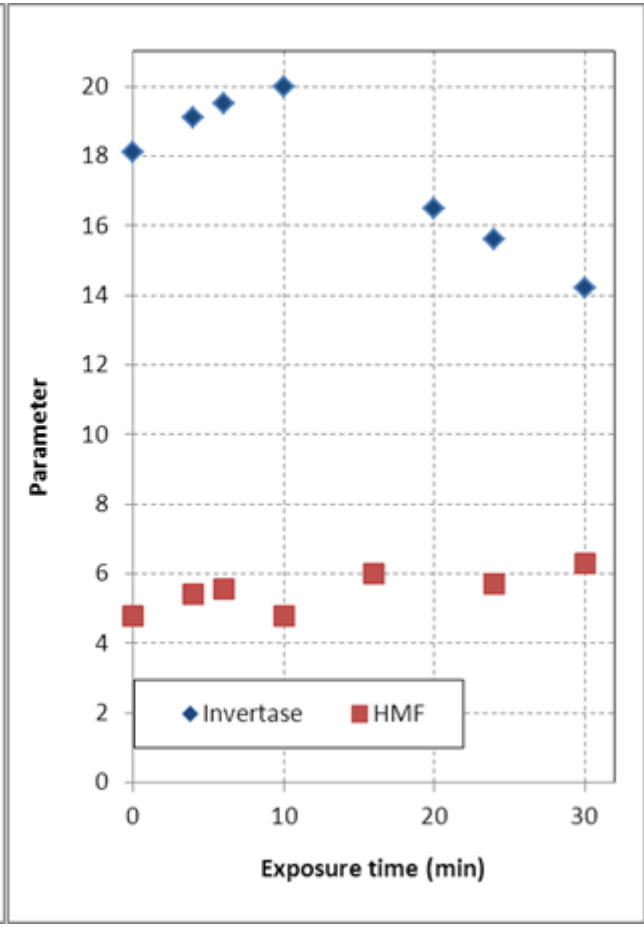
Crystal coverage



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*

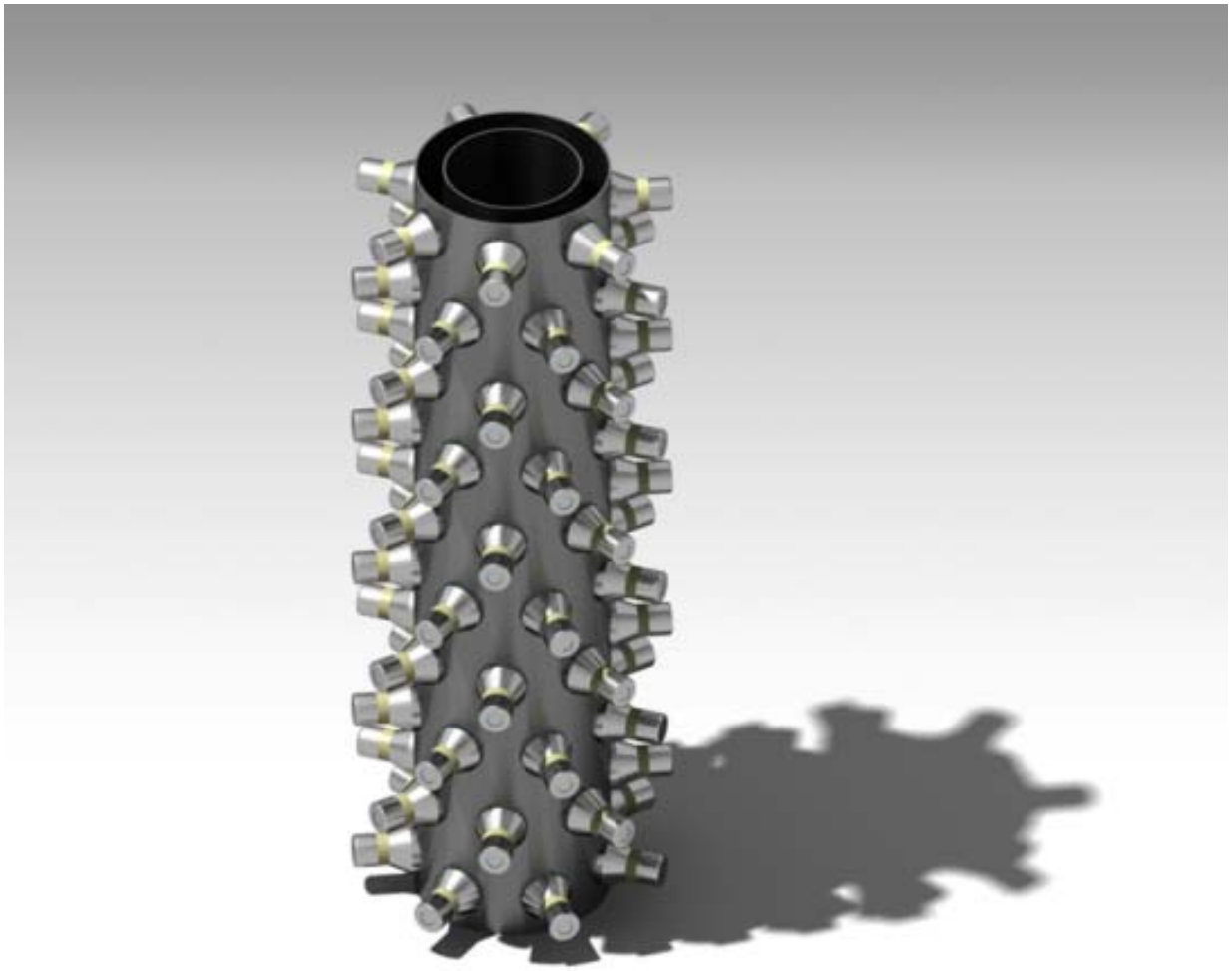
Flow cell requirements

- 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 ºC
- 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

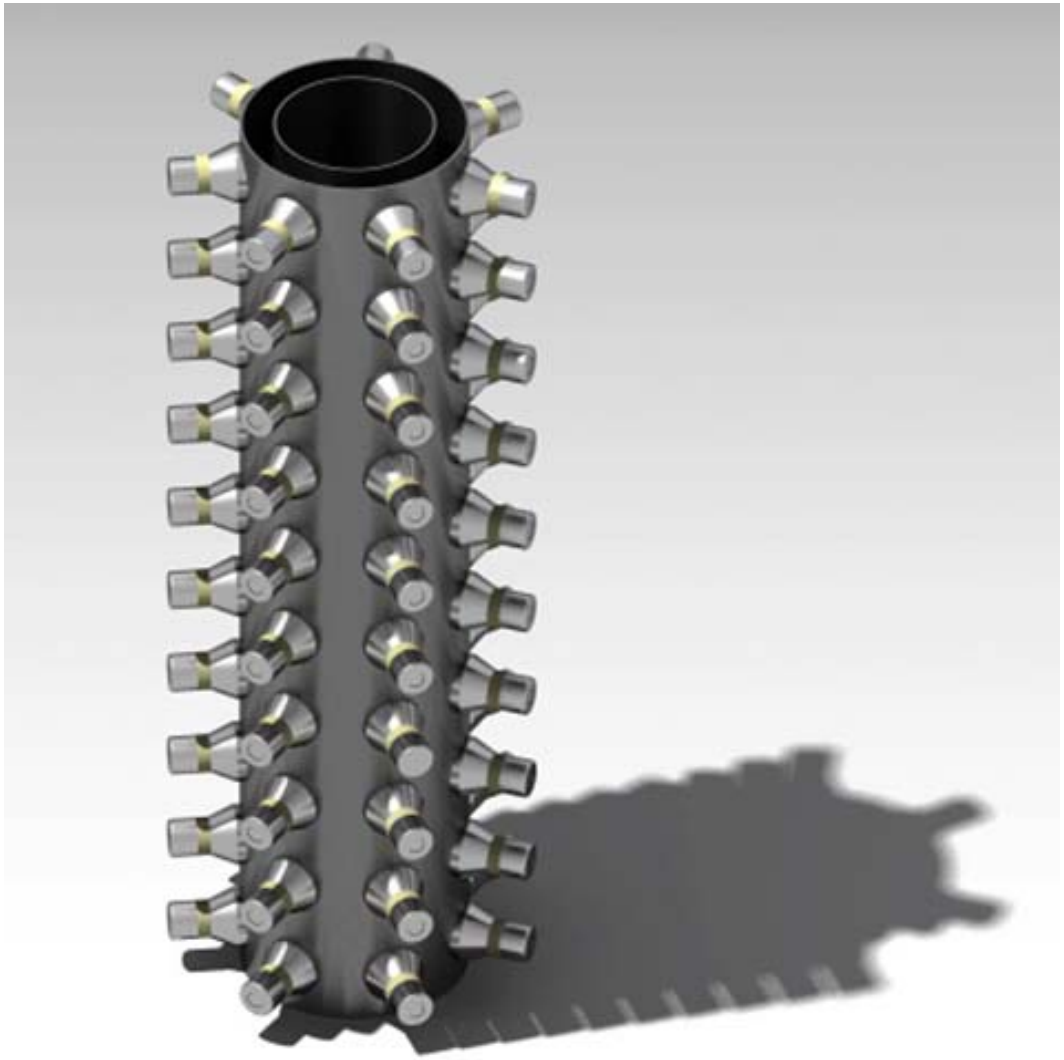
Design, build and test

Cell concept (1/2)



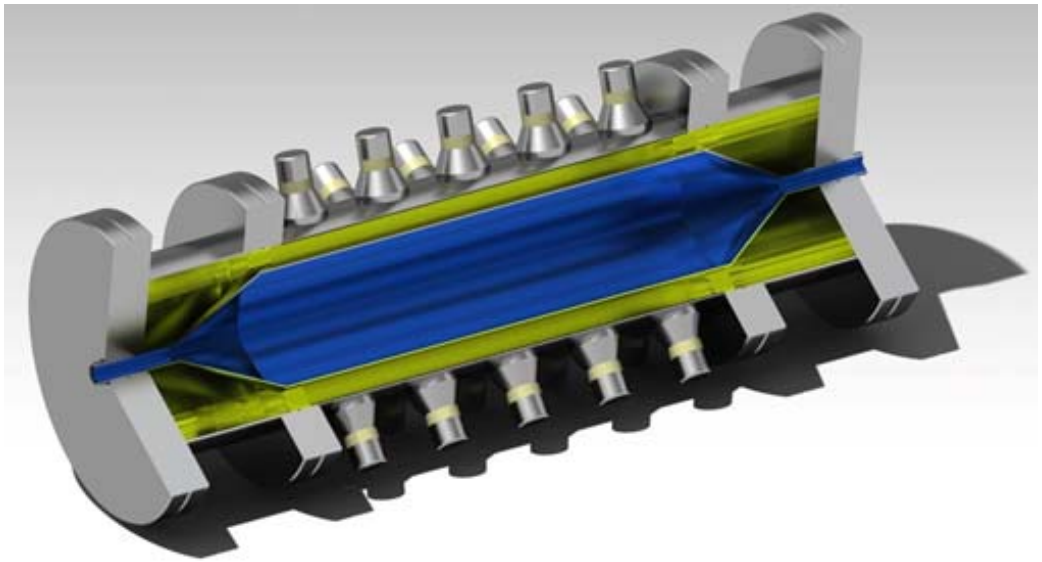
- 70 transducers
- Frequency of operation ~22 kHz

Cell concept (1/2)



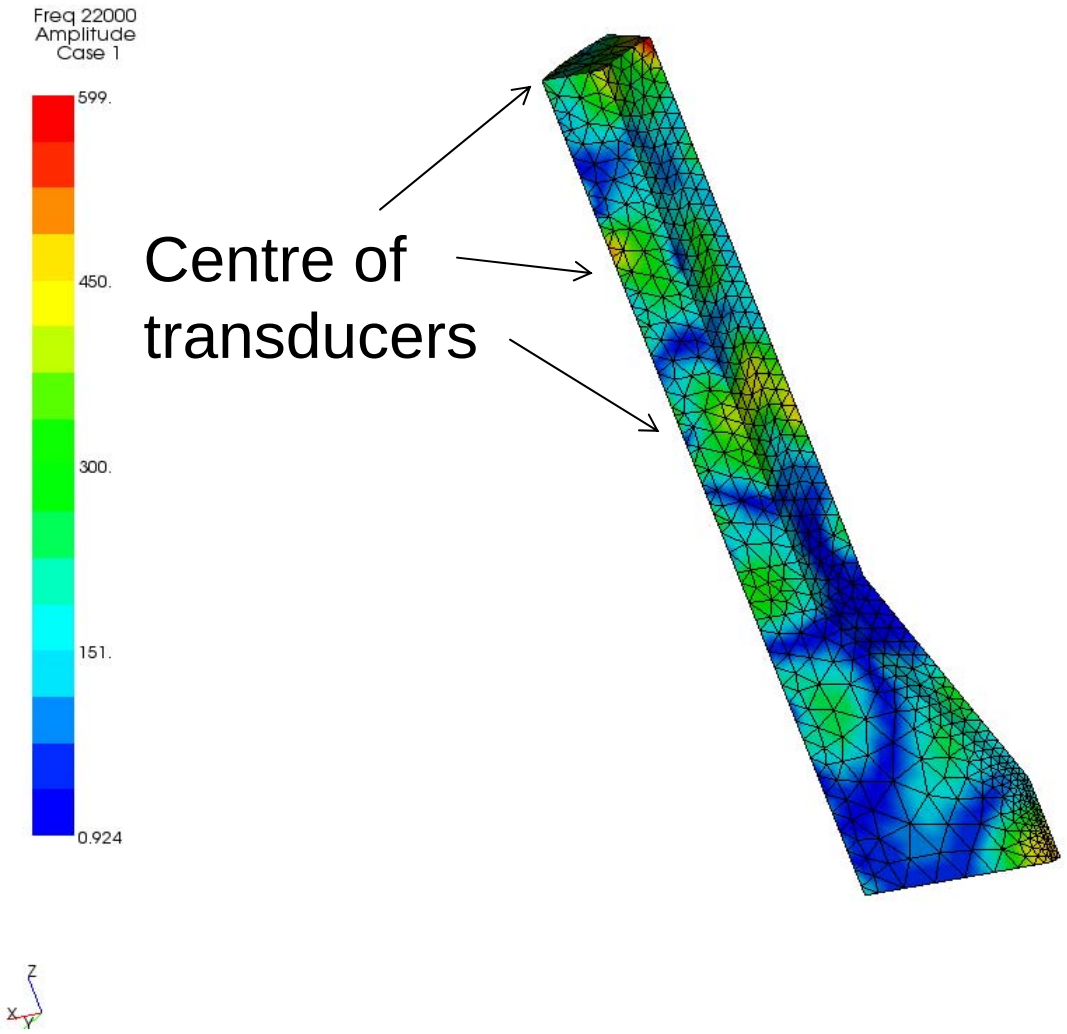
- More preferable vibration characteristic than the staggered option
- ANSYS modelling by partners suggested temperature rises >60 degrees C
- Need for cooling/mixing

Cell concept (2/2)

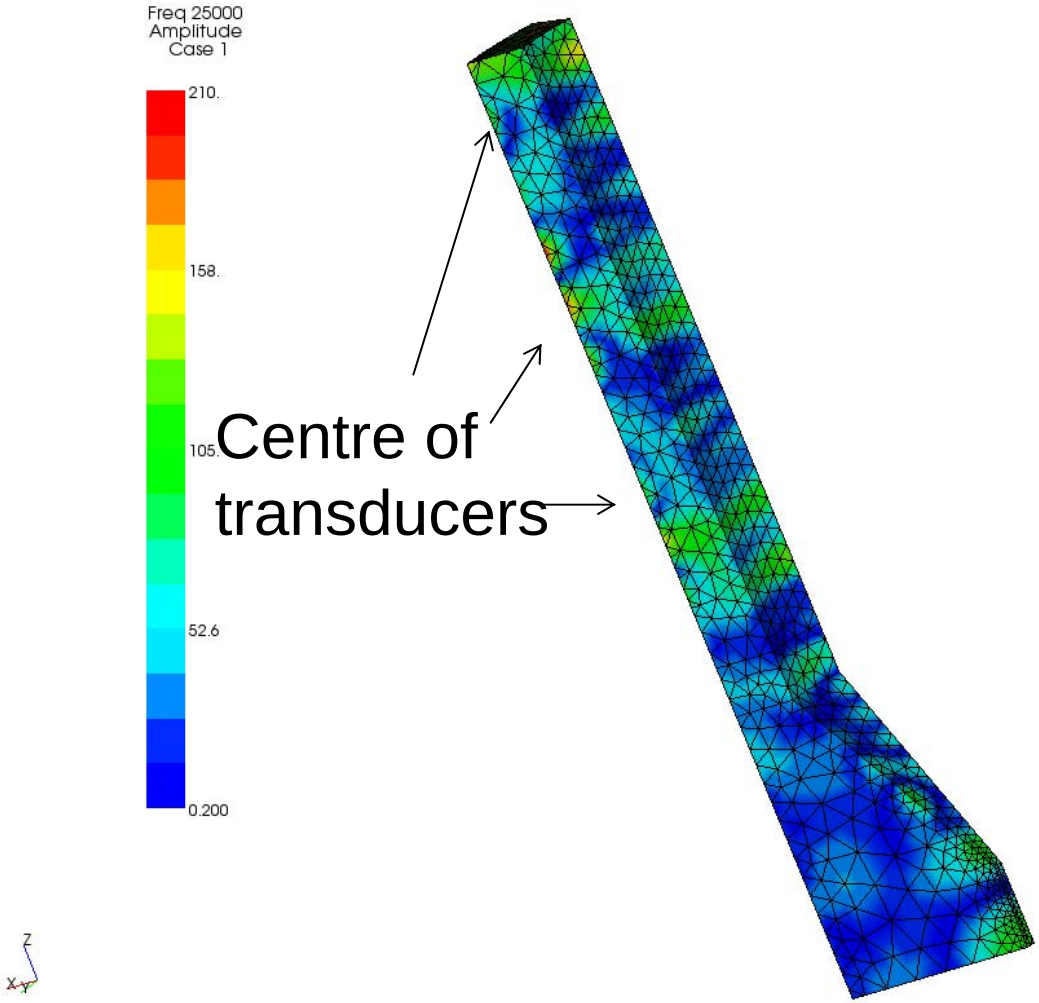


- 35 transducers, two cells in series, intermediate mixing and cooling
- Frequency of operation ~21-24 kHz
- Central cooled region
- PAFEC modelling completed for range of configurations

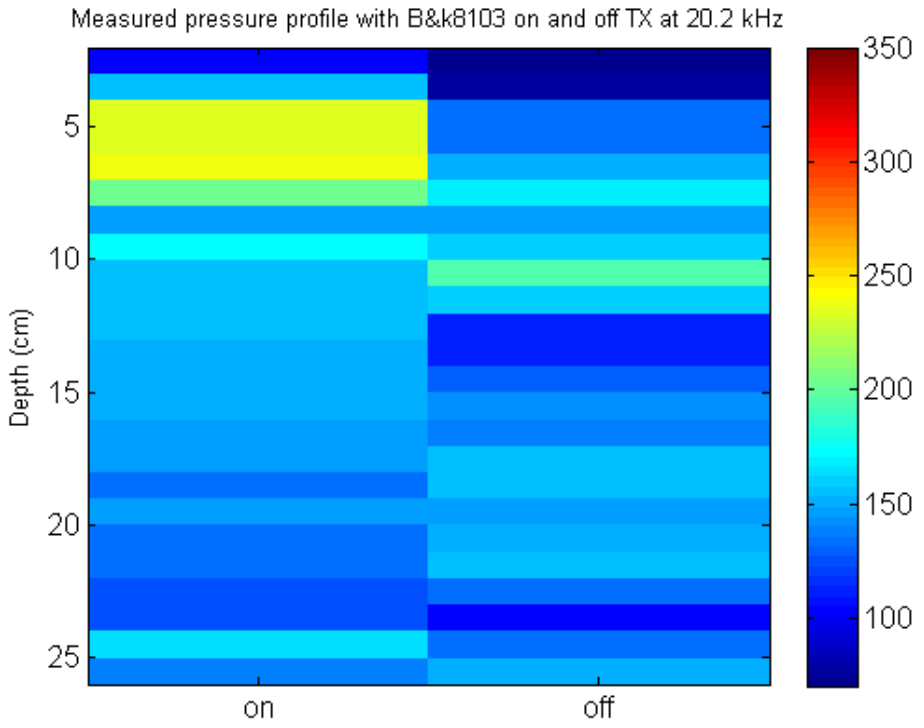
Acoustic pressure at 22 kHz
3 mm wall thickness

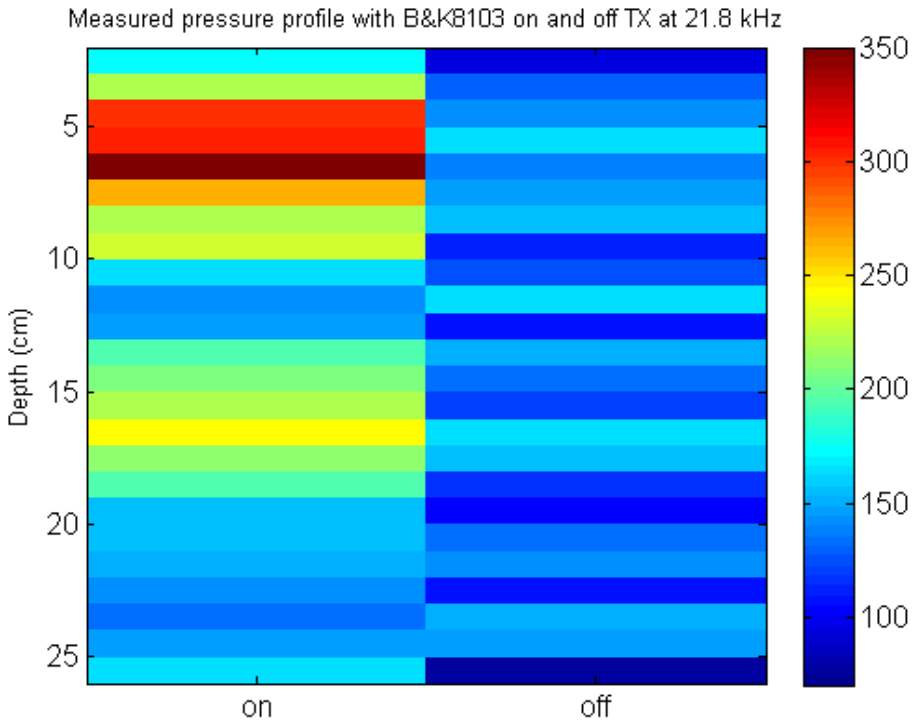


Acoustic pressure at 25 kHz
3 mm wall thickness



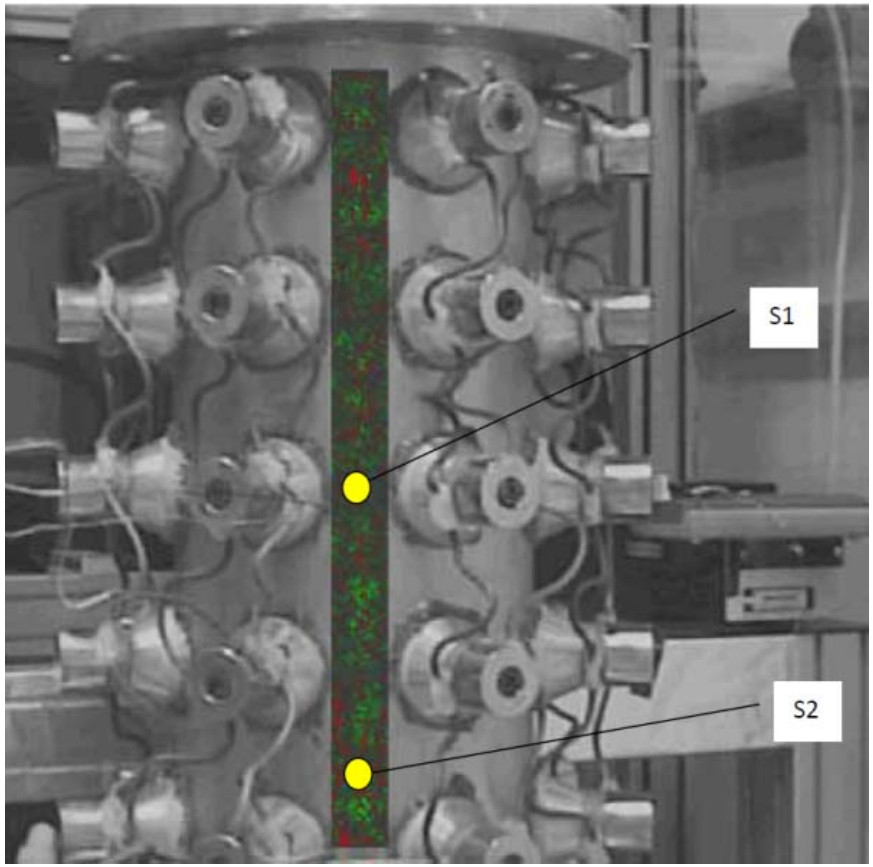
Spatial / frequency variation (honey)



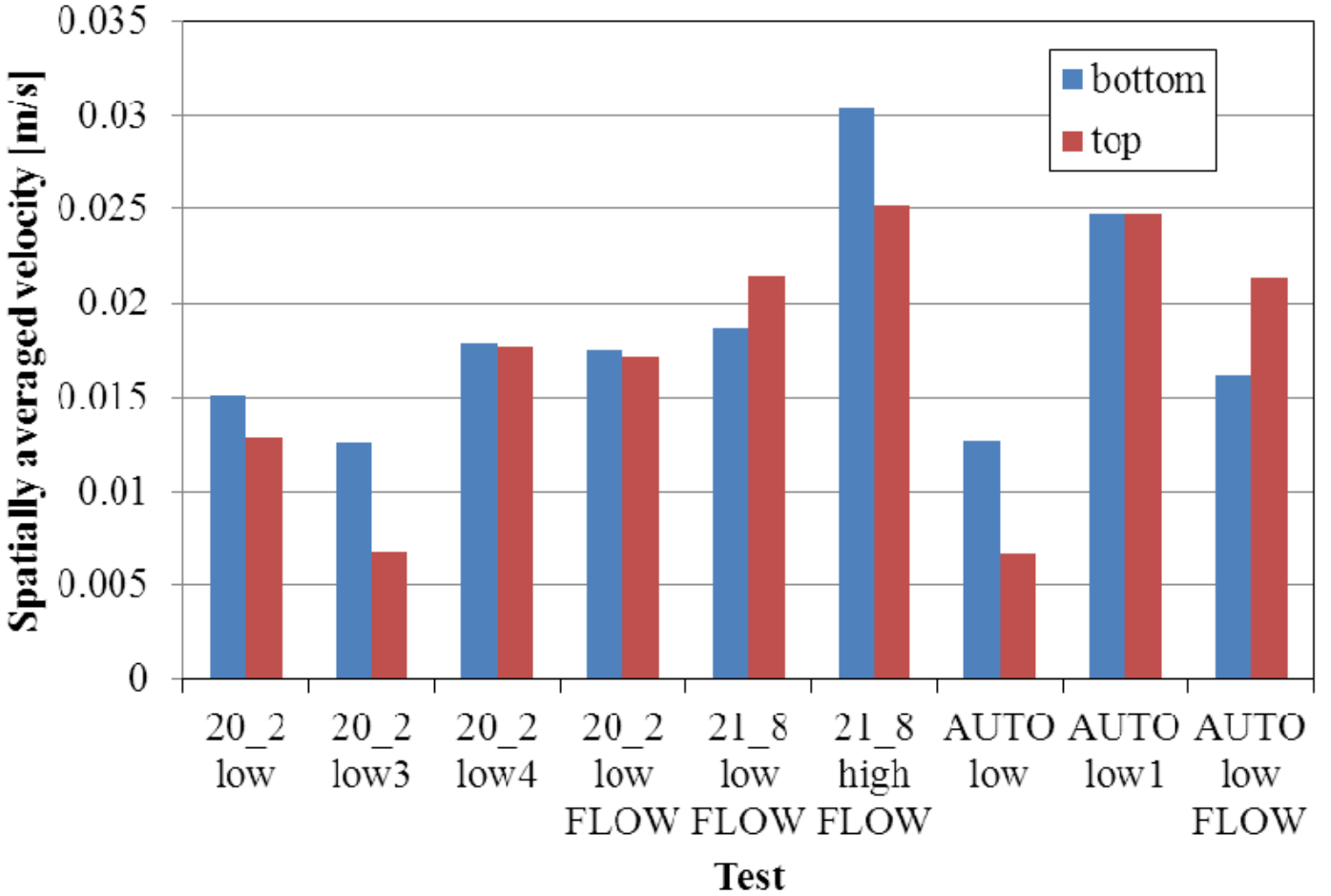


Honey tests – external

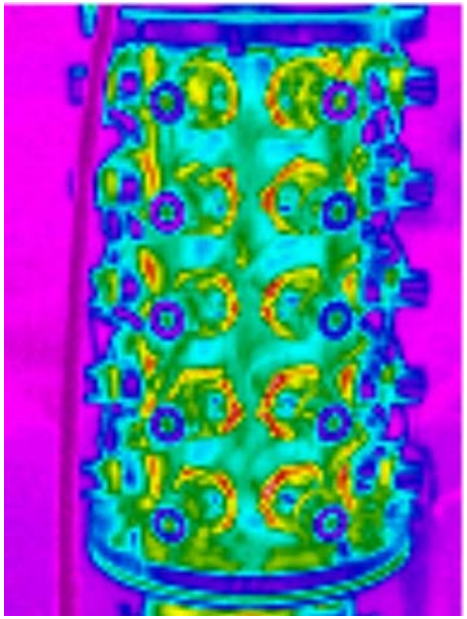
- In flow configuration, honey void is inaccessible and so cell performance must be monitored externally
- Two piezo pick-ups fitted (epoxy bonded) to outer surface – these respond to wall vibrations - output voltage monitored
- Polytec PSV400 laser vibrometer used to probe wall variations, including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

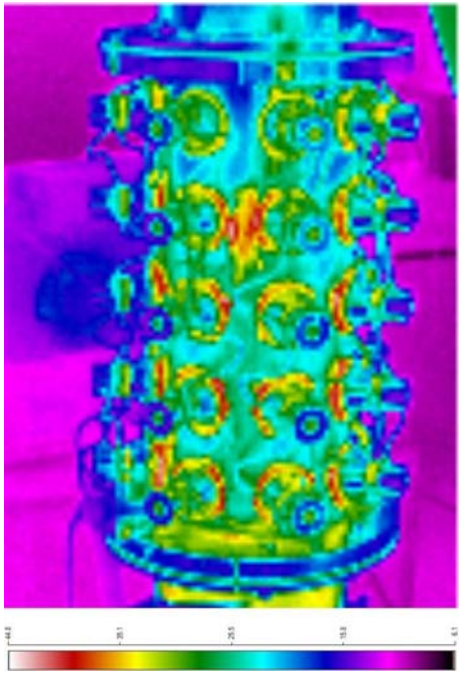


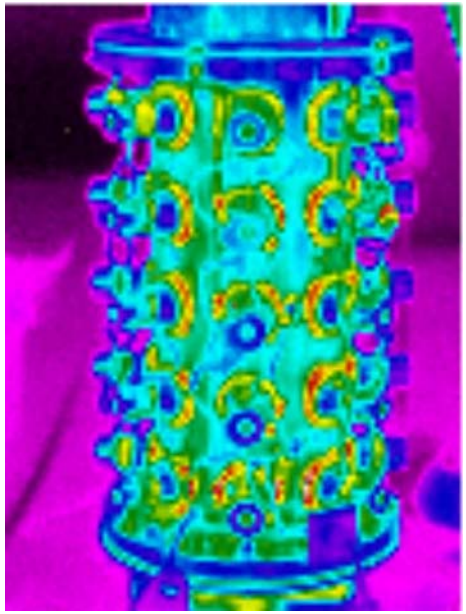
Vibrometer output

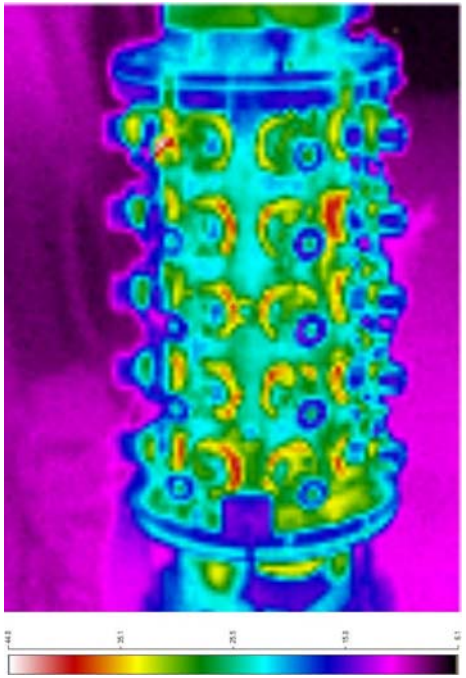


Thermal camera images

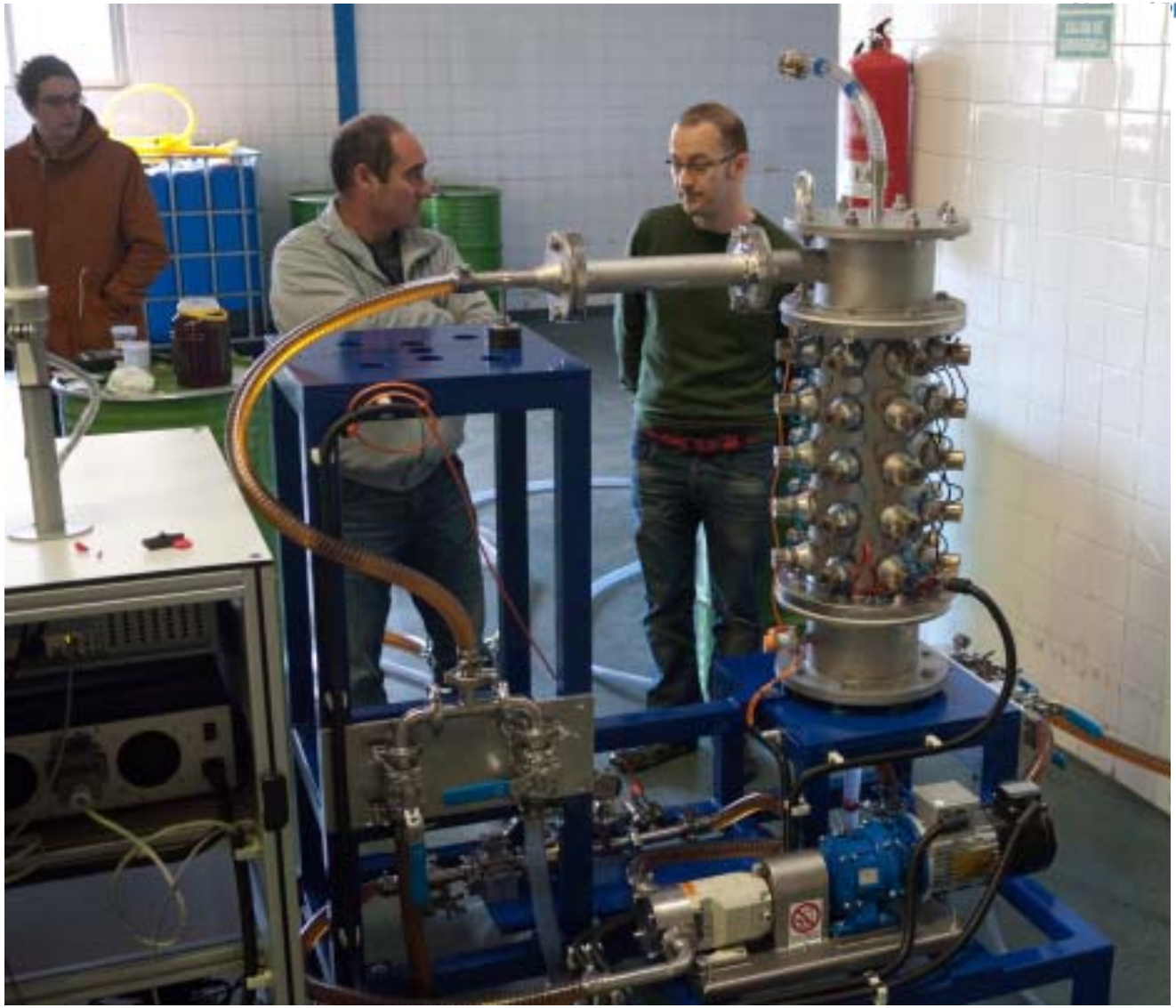








Installation



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-284708946