Ultrasound technology in food processing and preservation

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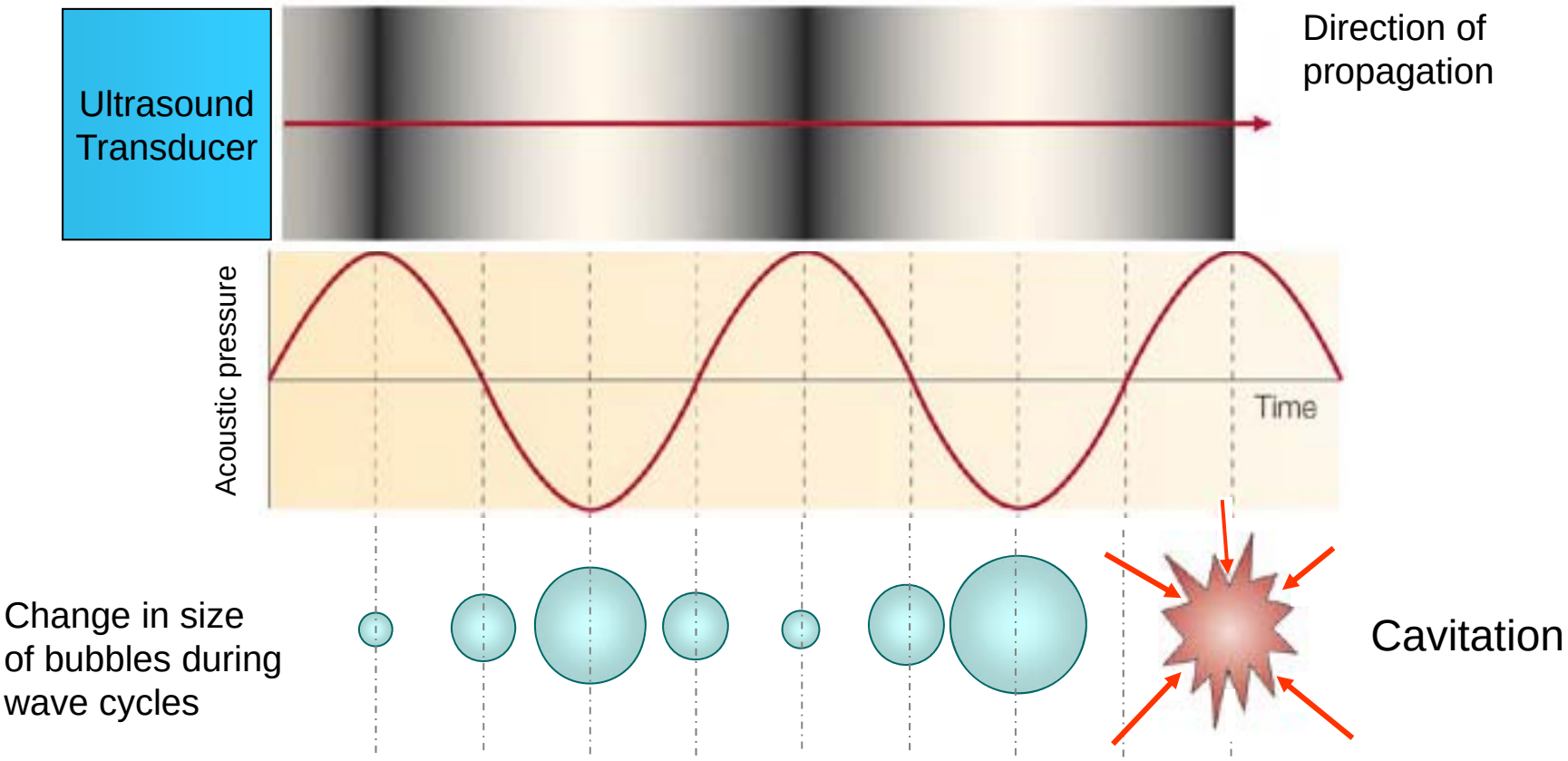
Power Ultrasound

Mechanical waves (20 – 100 kHz) traveling in a liquid

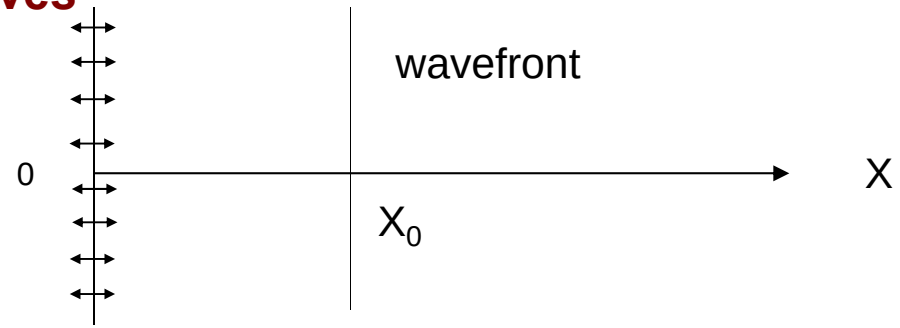


Ultrasonic Field

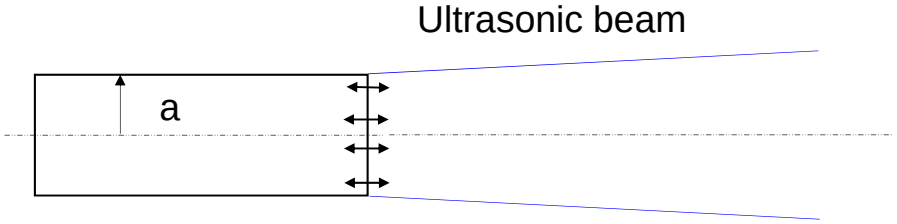
A. Non-focused ultrasonic plane waves

$$x(t) = A\cos(2\pi f\, t + \phi_0)$$

$$p(x,t) = p_0 e^{-\alpha x}\cos(kx - \omega t)$$



B. Piston source: can be treated as a plane wave in the "far-field" region



When a>> λ and **x > a^2/λ** (far-field), within the Beam, the acoustic pressure can be approximated by x(t) and p(x,t)

C. Spherical ultrasonic waves

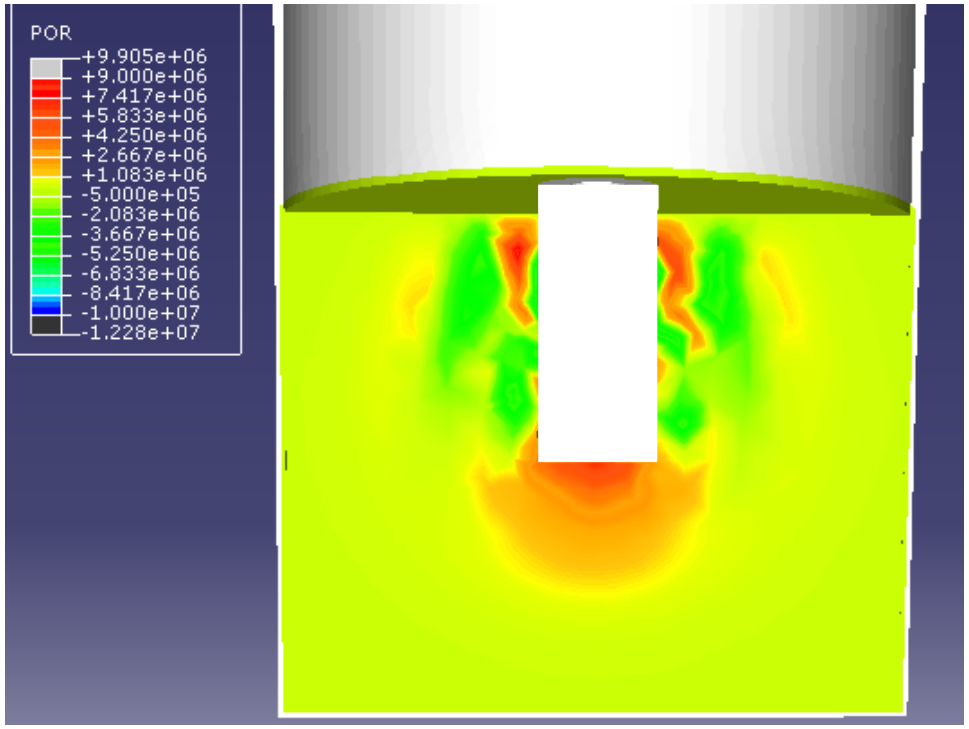
$$p(r,t) = \frac{C}{r} e^{i(k\,r - \omega t)}$$

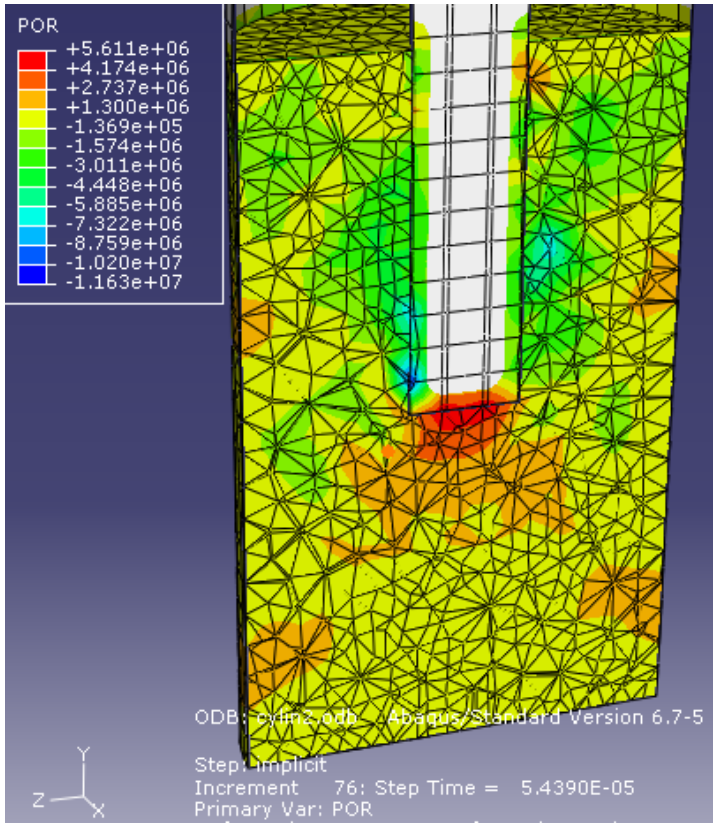
Non-uniformity

The *wavelength in water* at *20 kHz* is about 75 millimeters

Ultrasonic Field

Acoustic pressure distribution

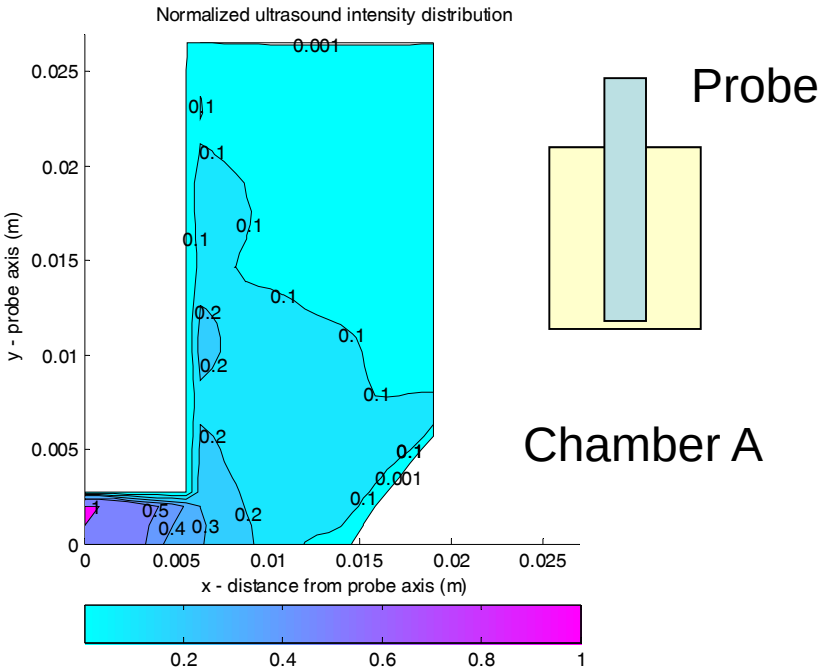


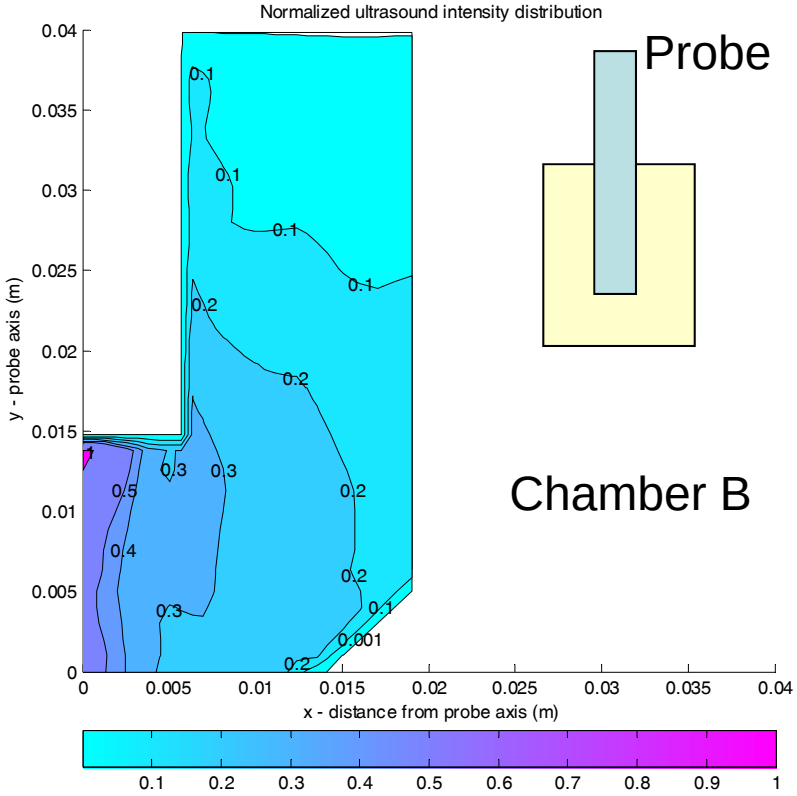


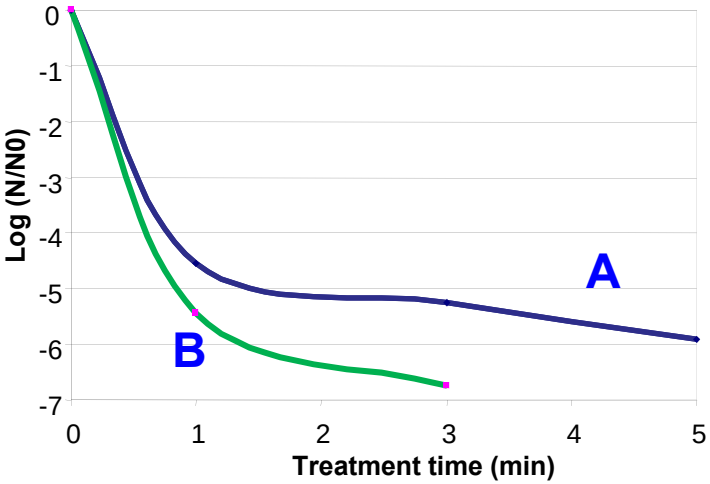
- Abaqus
- 4-node linear acoustic tetrahedron
- sinusoidal acoustic pressure boundary

Complicated standing wave pattern

Ultrasonic Field







Survival curve of *E. coli* K12

$$I = \frac{1}{2} p\dot{u} = \frac{1}{2} \frac{p^2}{\rho c}$$

Ultrasound: Way to Success

A. Increase cavitation activity: similar to the HTST (HIST)

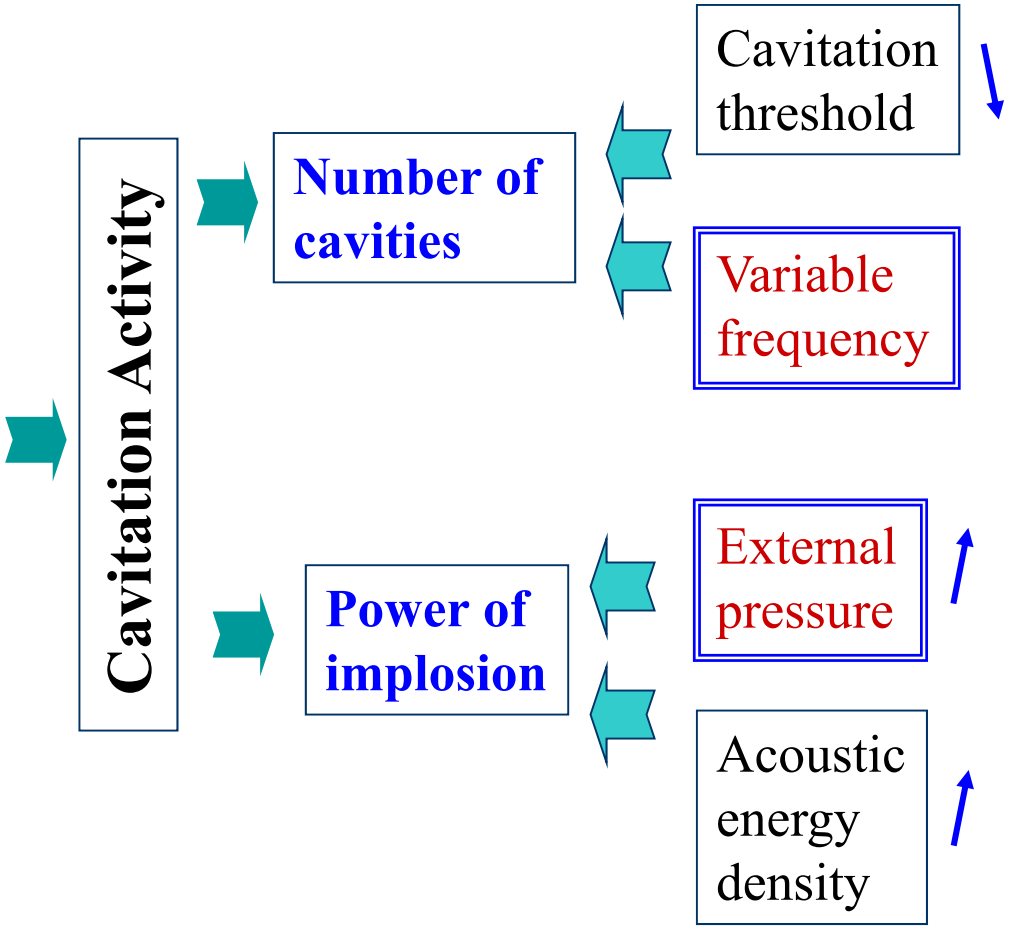
B. Improve uniformity

Ultrasound: Way to Success

A. Increase cavitation activity: similar to the HTST (HIST)

B. Improve uniformity

- Localized hot spots
  - 5,000^{o}C
  - 2,000 atm
  - Rate: 10^{10} ^{o}C/s
- Shock waves
- Chemical effects
  - Free radicals, H_2O_2
- Liquid jets
- Micro-streaming



Cavitation generated physical and chemical activities

Ultrasound: Way to Success

A **Mano-thermo-sonication: cavitation ↑**

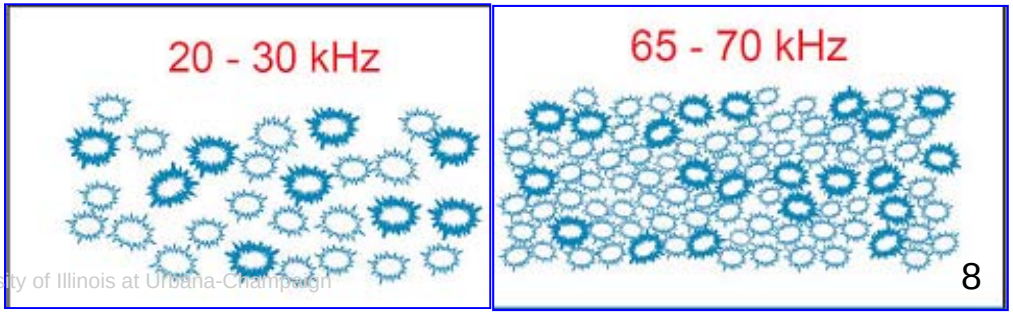
- **Low pressure: 100-500kPa**
- **Elevated temperature: 40-70C**
- **Ultrasound**

B **Variable frequency technology: cavitation ↑; uniformity**

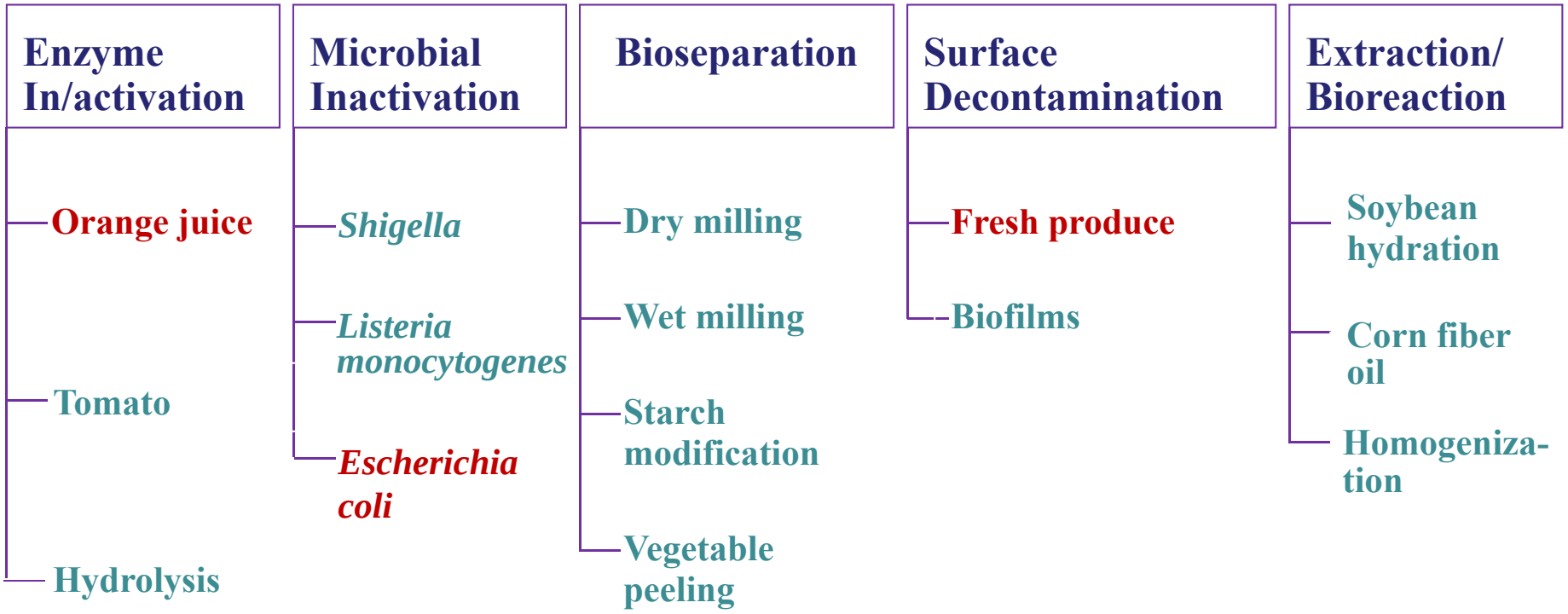
–**multi-frequency, multimode, modulated (MMM)**

$$f_r = \frac{1}{2\pi R_r}\left[\frac{3\gamma P_h}{\rho}\right]^{0.5}$$

Natural resonance frequency



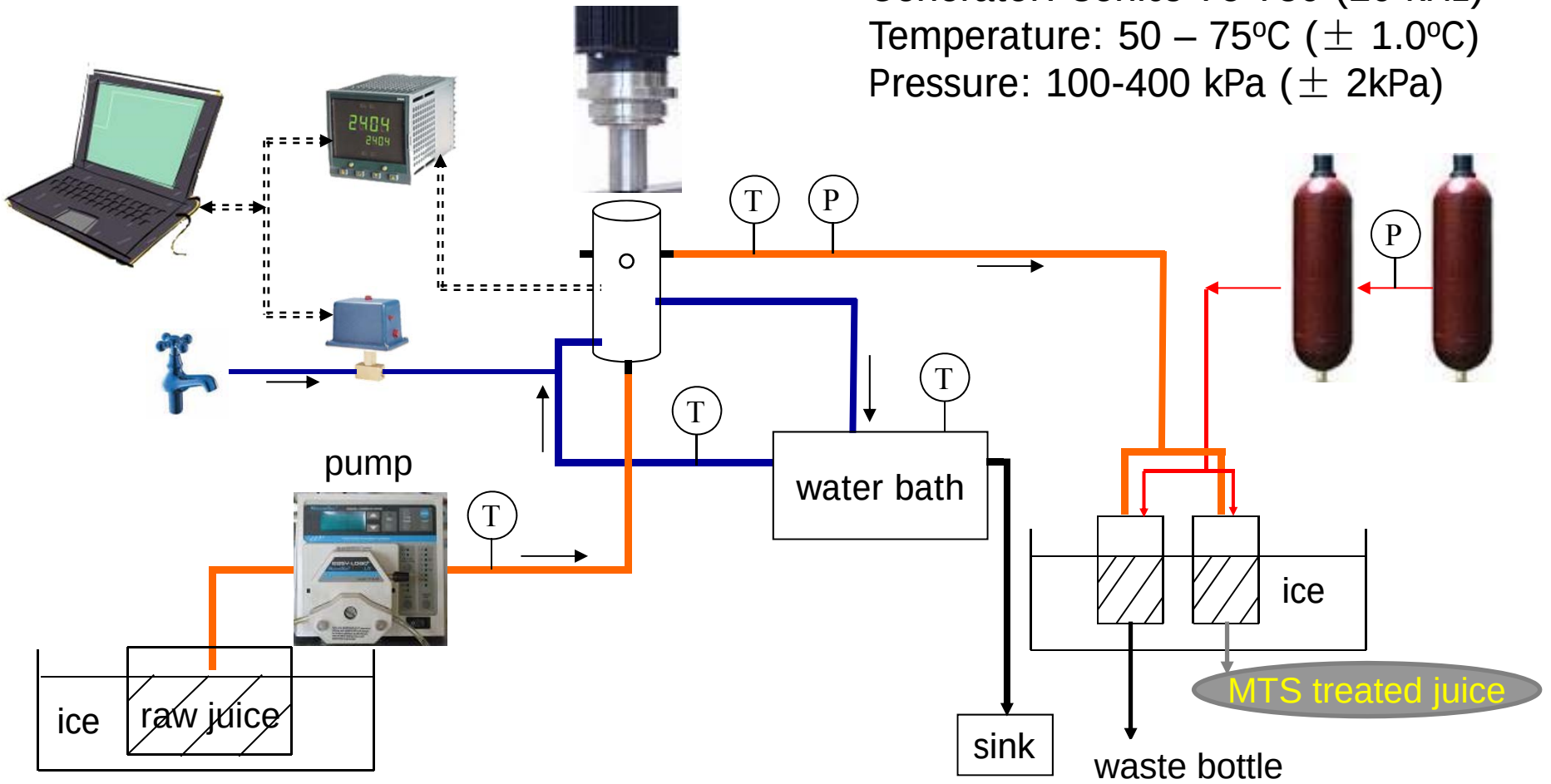
Power Ultrasound Research at Feng Lab



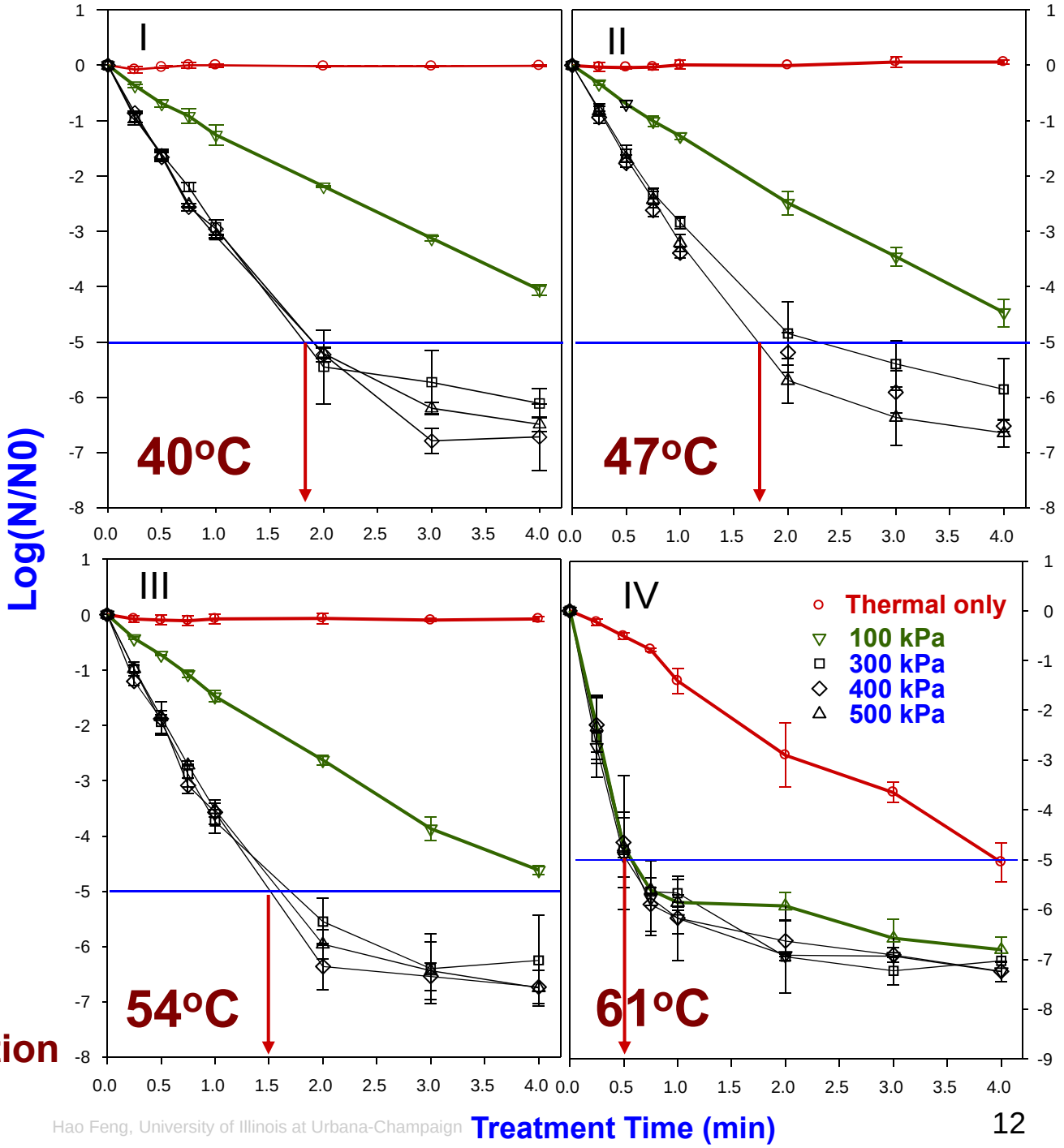
Liquid Food Processing

Mano-thermo-sonication (MTS) System

Generator: Sonics VC-750 (20 kHz)
Temperature: 50 – 75°C (± 1.0°C)
Pressure: 100-400 kPa (± 2kPa)



MTS Inactivation of *E. coli* K12

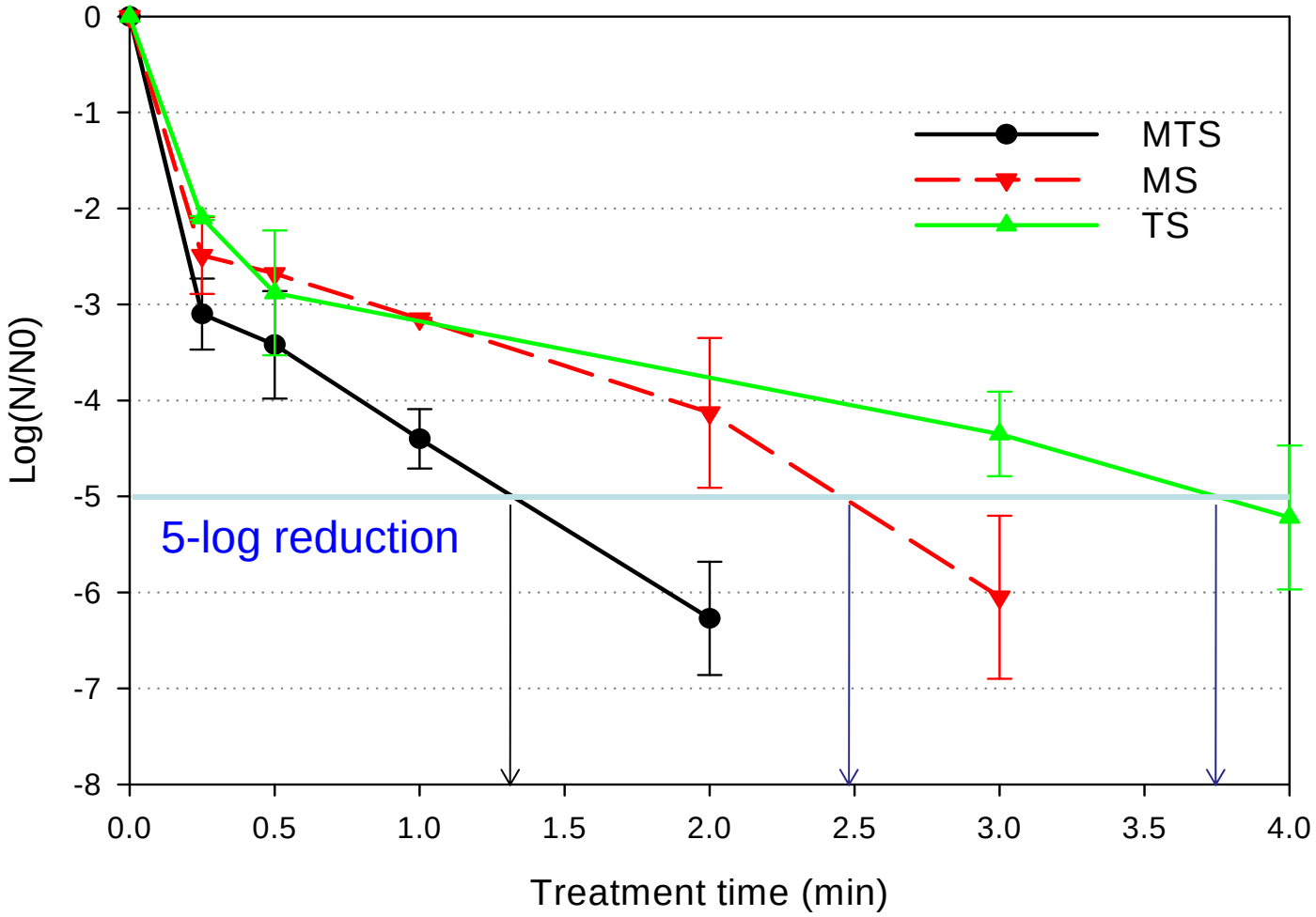


The very first complete date set:

a) Sonication
b) Mano-sonication
c) Thermo-sonication
d) Mano-thermosonication

Inactivation of *E. coli* in Apple Cider

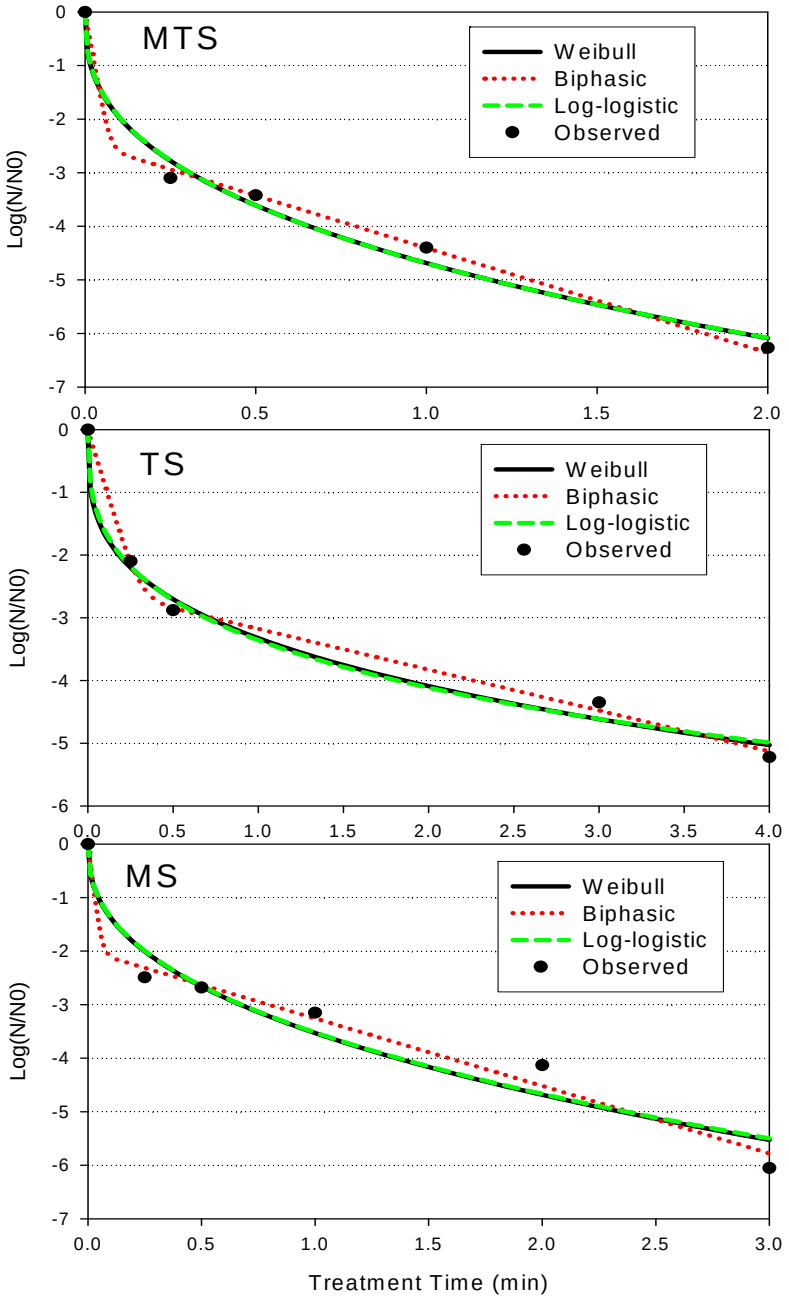
Mano-thermo-sonication (MTS):	59C and 400 kPa,
Thermo-sonication (TS):	59C and 100 kPa,
Mano-sonication (MS):	55C and 400 kPa.



Non-linear Inactivation Kinetics

Non-linear inactivation kinetic models

- Weibull
- Biphasic
- Log-logistic



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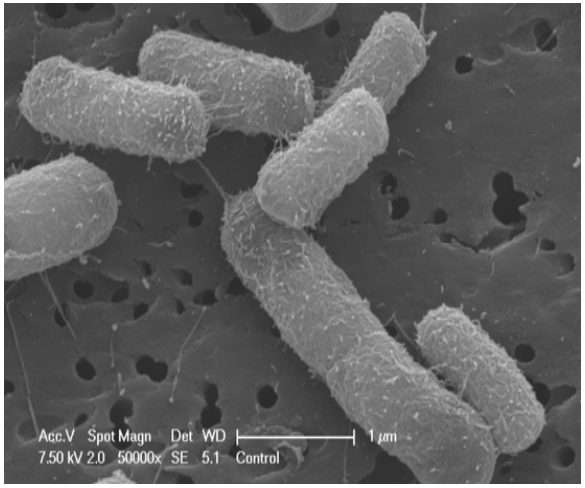
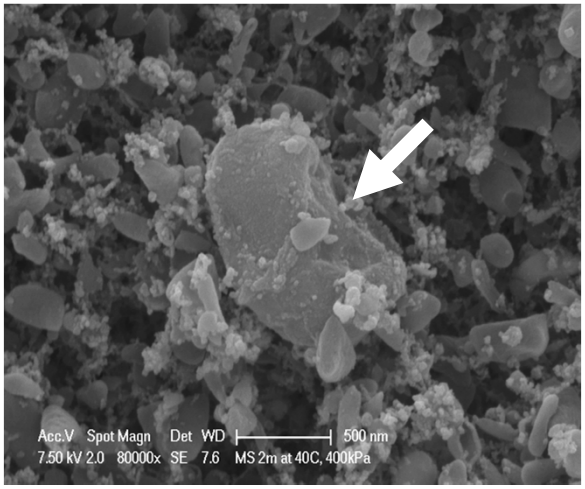
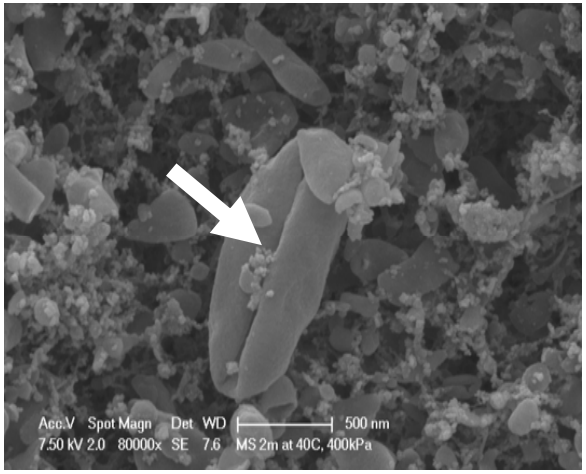


Control



Manosonication at 40C/500 kPa for 2 min



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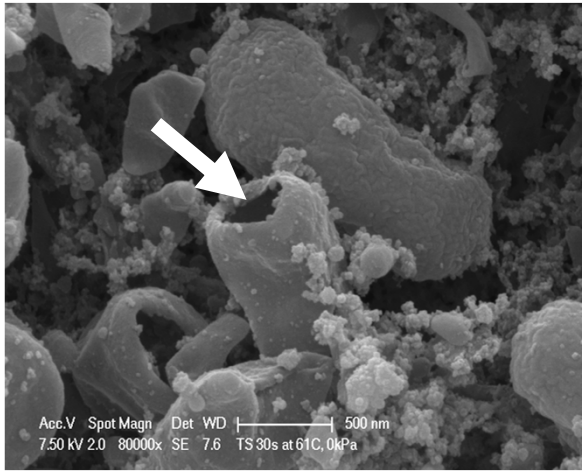
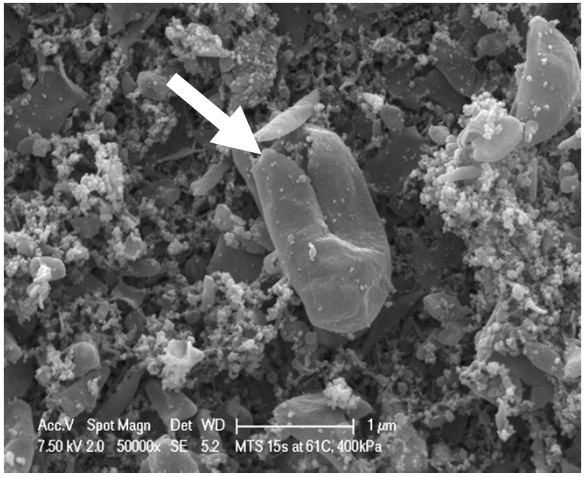
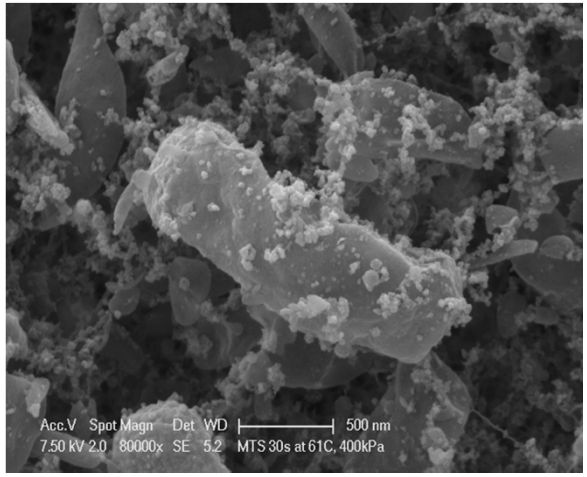


Thermosonication at 60C/100 kPa for 0.5 min



Manothermosonication at 61C/500 kPa for 0.25

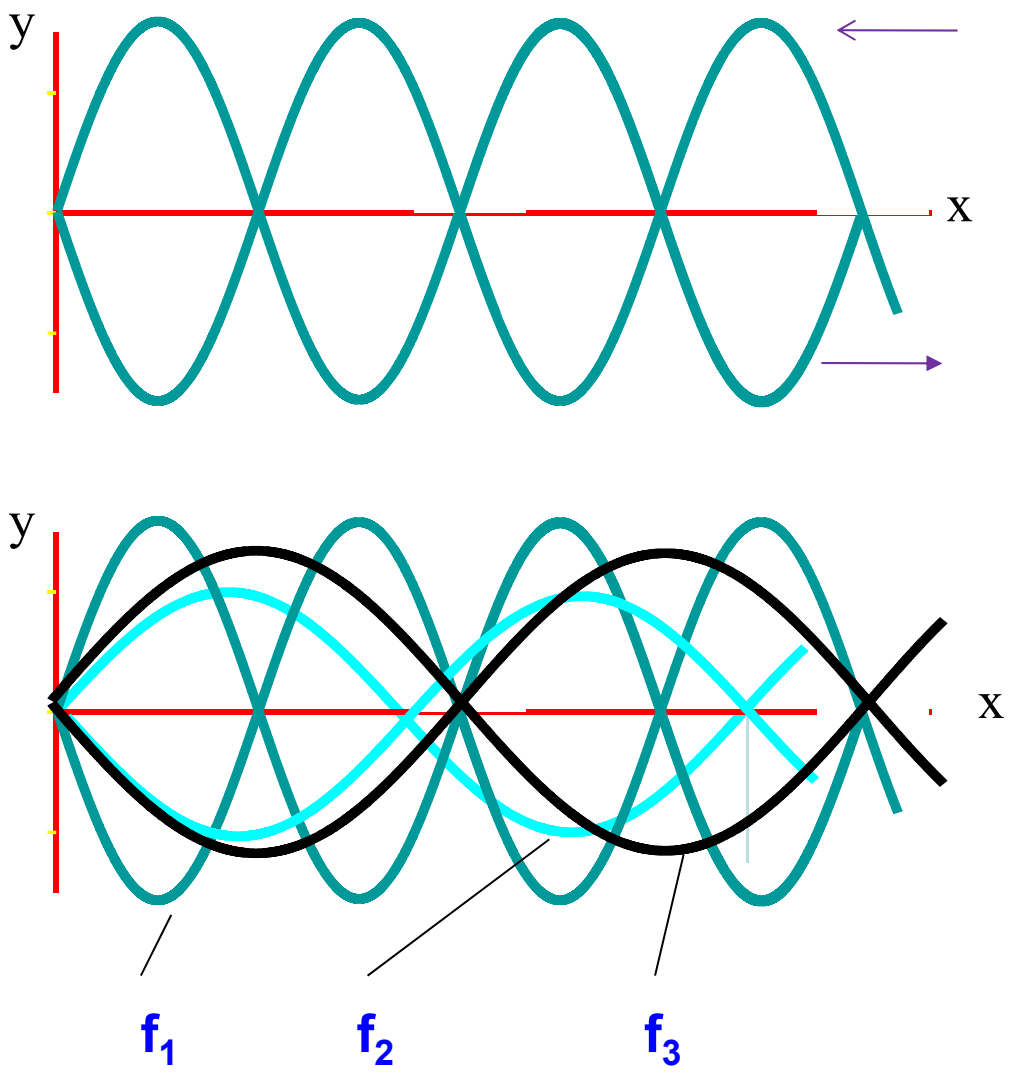


Manothermosonication at 61C/500 kPa for 0.5

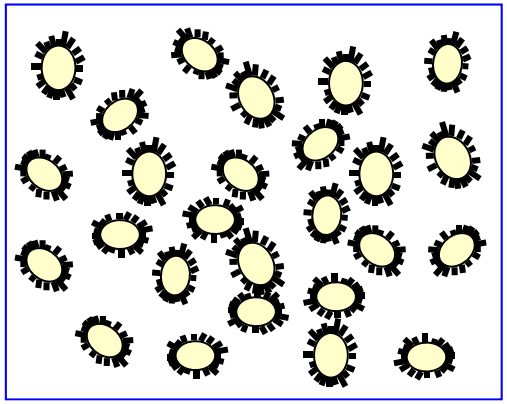
Variable Frequency Technique

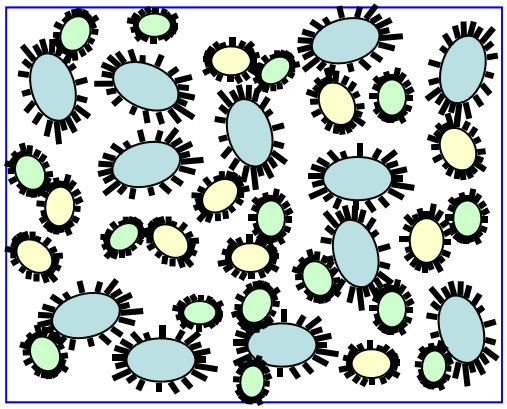
Variable Frequency Technique

Field Distribution



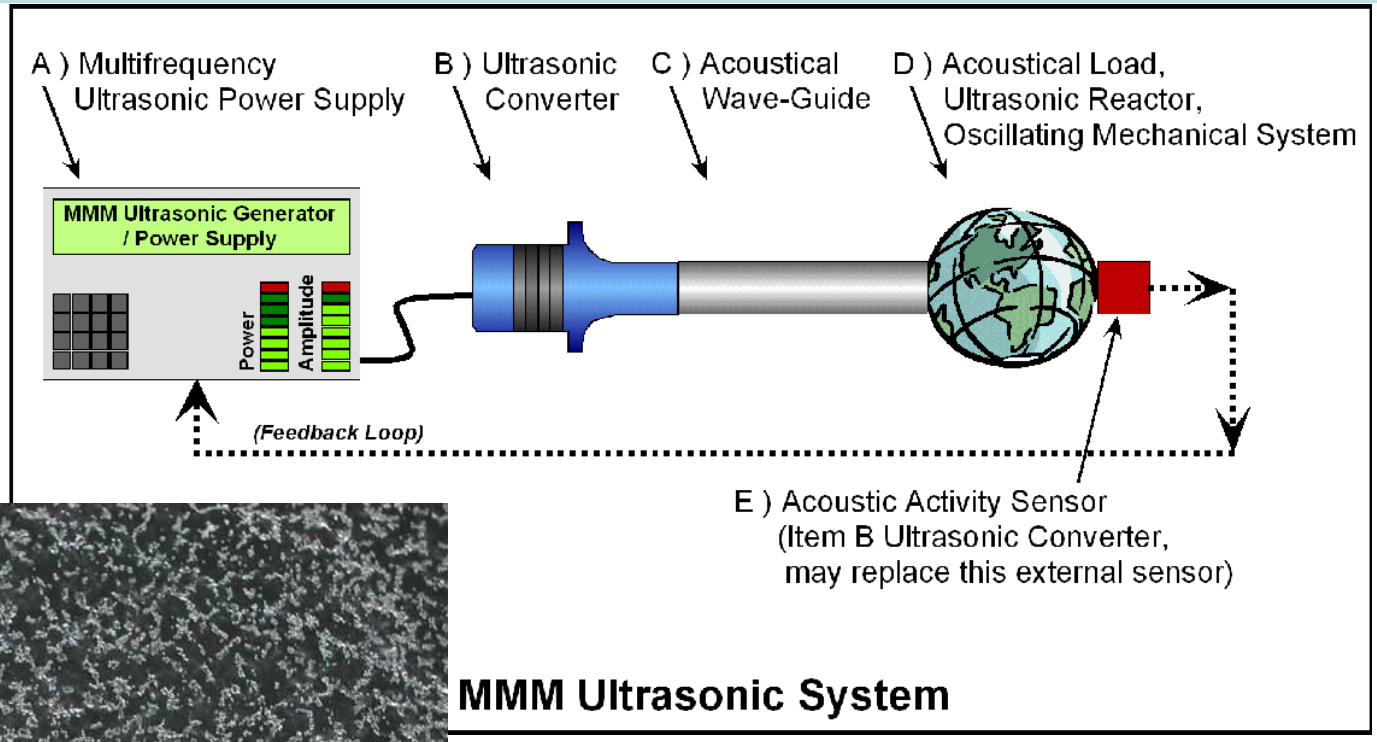
Cavitation Activity



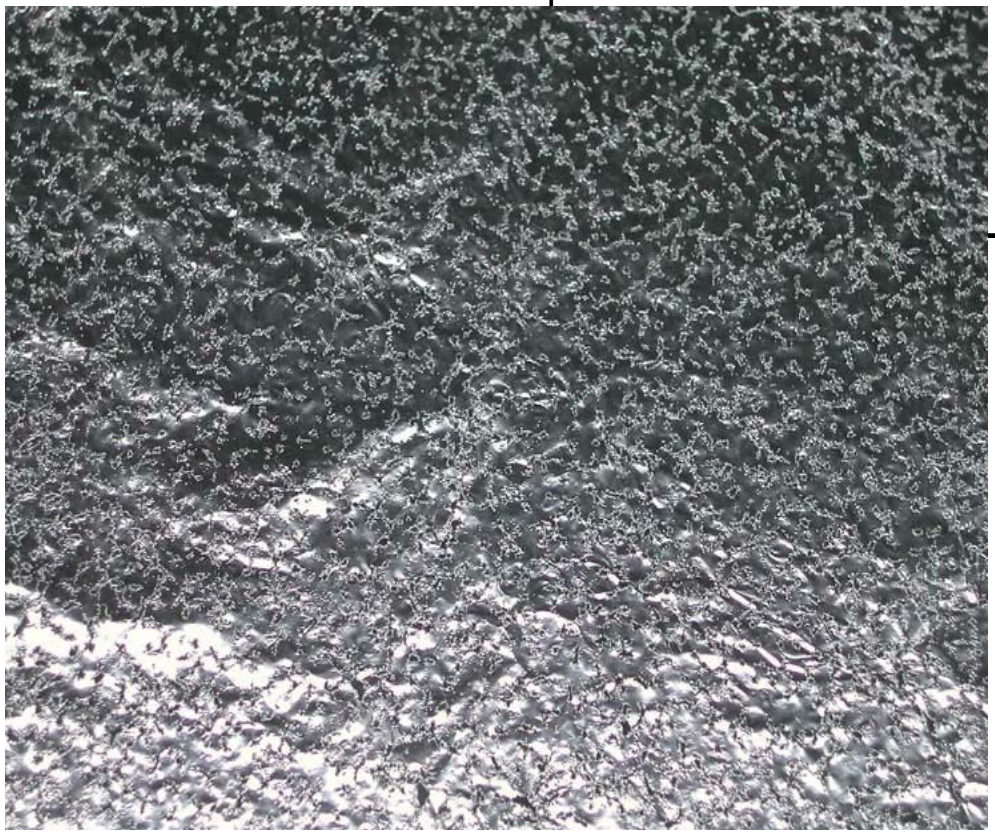


MMM Technique

Multi-frequency, multimode, modulated (MMM)



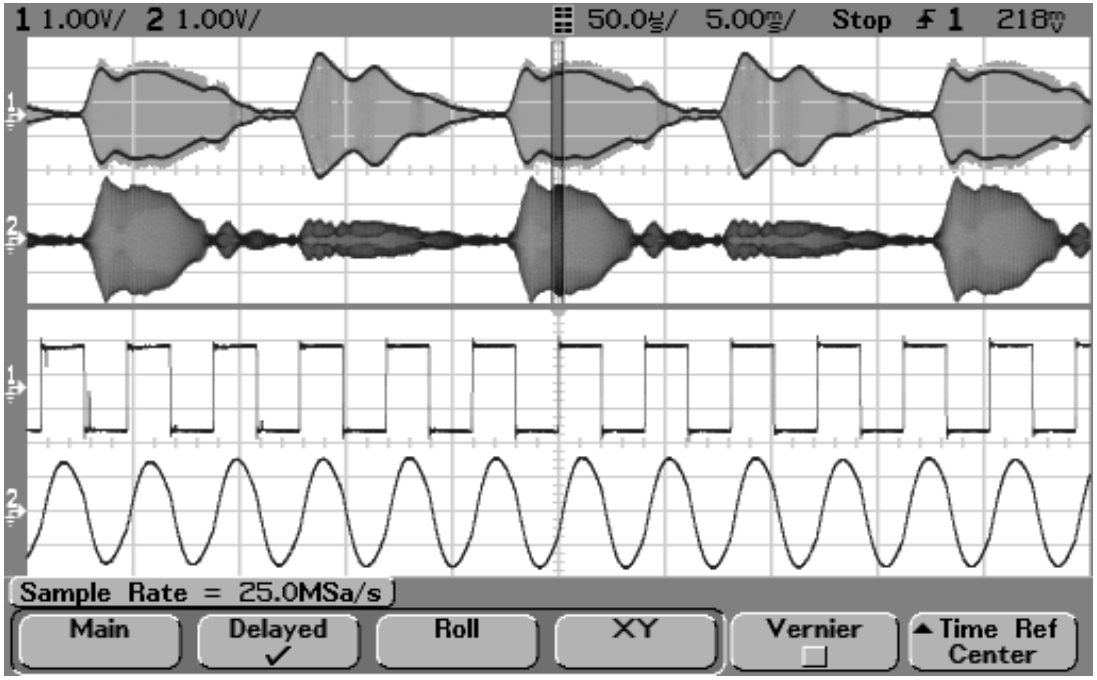
MMM Ultrasonic System

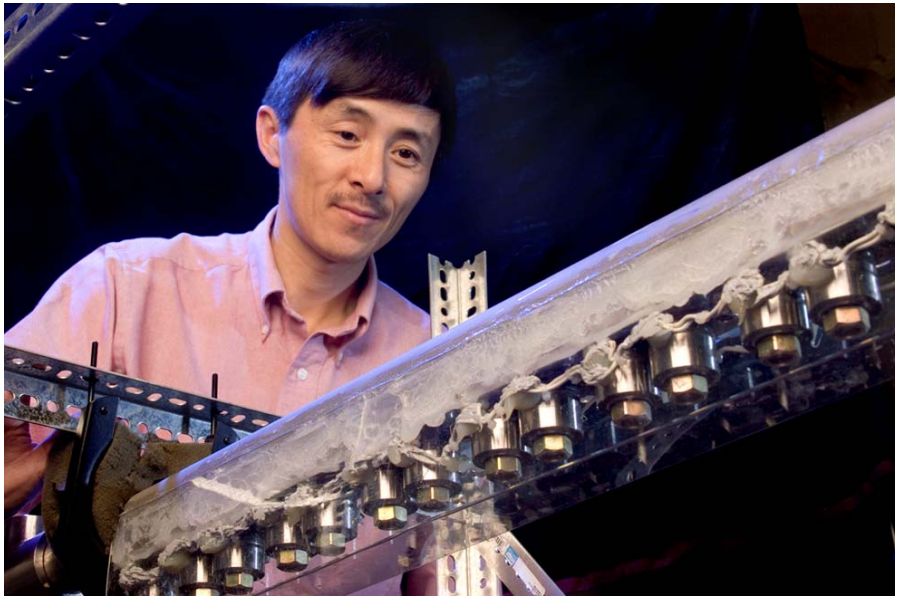


Uniformly perforated aluminum foil, after 10 sec of exposure to MMM ultrasonic vibrations in a ultrasonic cleaner

MMM Technique

Multi-frequency, multimode, modulated (MMM)





MMM Technique

Tomato enzyme inactivation with ultrasound

Extracted enzymes

Ultrasound Unit	Power density (W/cm^3)	PME Inactivation Rate Log(A/A0)/min/W	PG Inactivation Rate Log(A/A0)/min/W
Probe system	2.0	0.11	0.07
	2.7	0.06	0.06
	4.7	0.02	0.02
MMM reactor	0.1	0.32	0.11

Pectin-methylesterase (PME)

Polygalacturonase (PG)

MMM Technique

Tomato enzyme inactivation with ultrasound

Tomato slurry

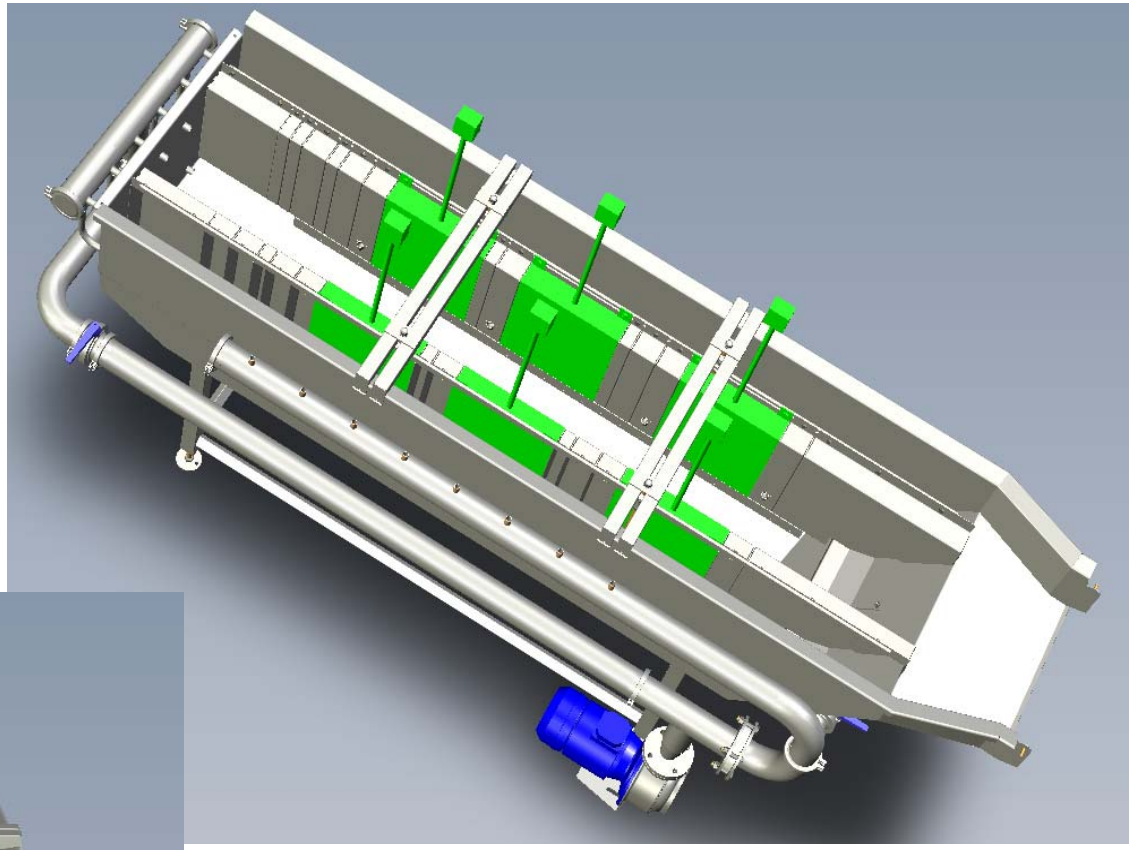
Ultrasound Unit	Power density (W/cm^3)	PME Inactivation Rate Log(A/A0)/min/W	PG Inactivation Rate Log(A/A0)/min/W
Probe system	2.0	0.02	0.02
	2.7	0.03	0.03
MMM reactor	0.1	0.17	0.10

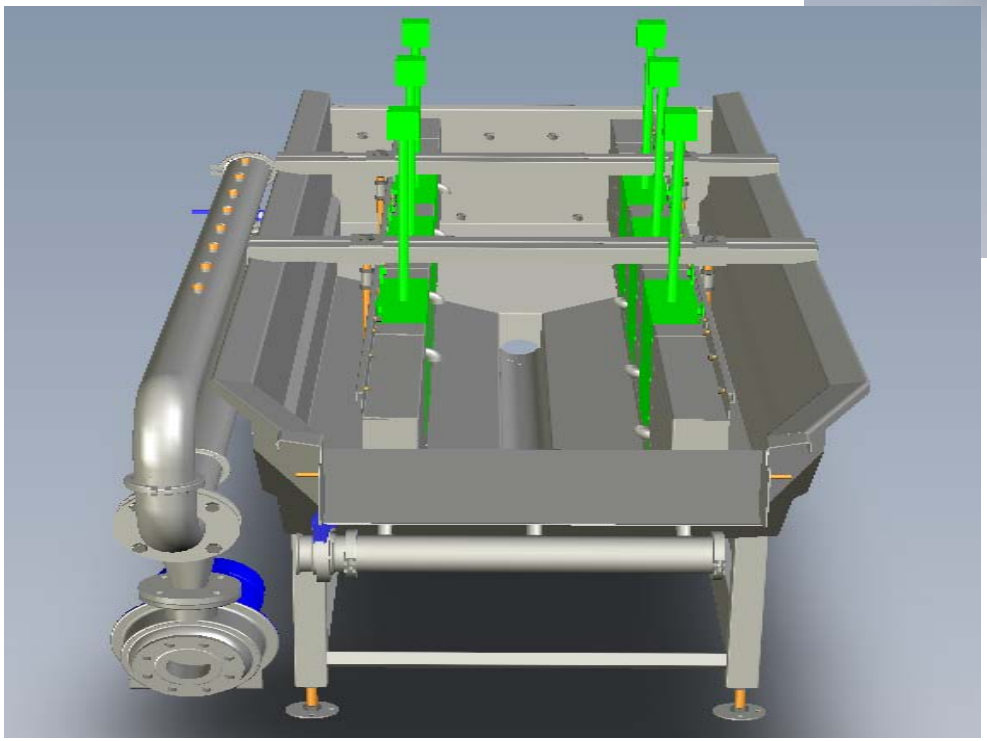
Pectin-methylesterase (PME)

Polygalacturonase (PG)

Surface Decontamination/ Treatment

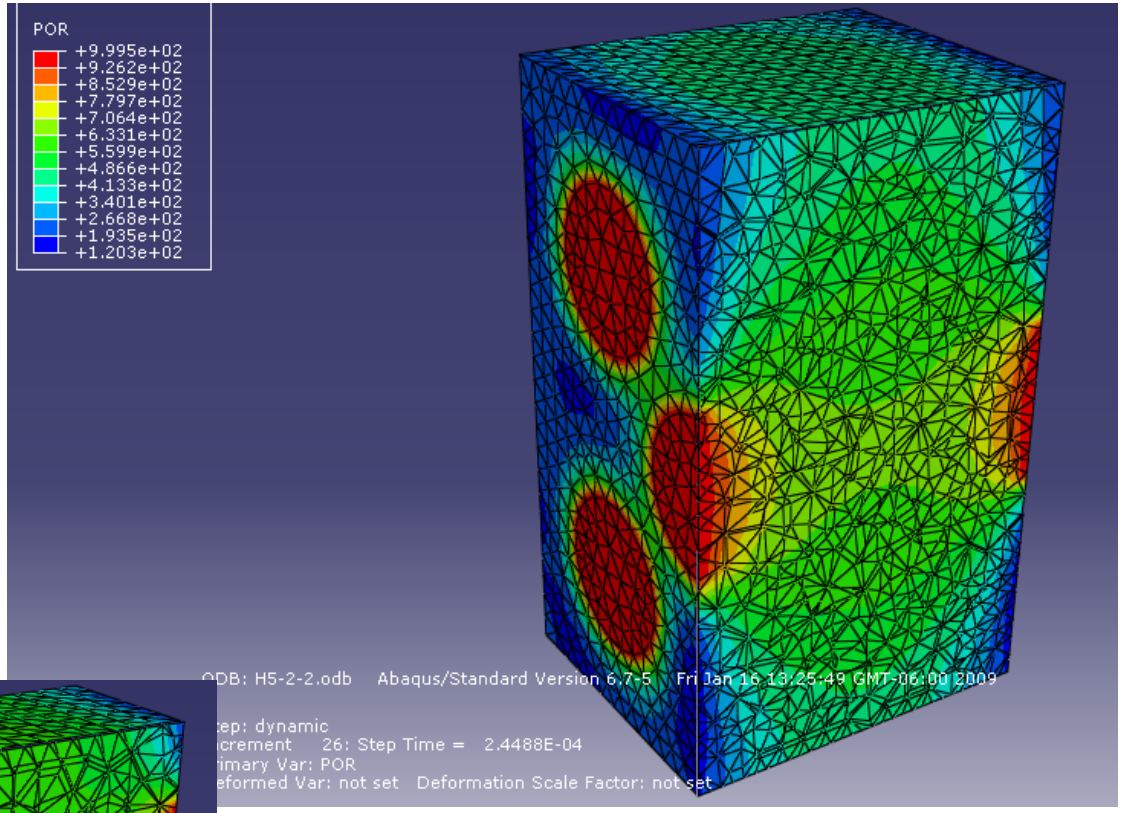
Pilot Scale Ultrasonic Washer

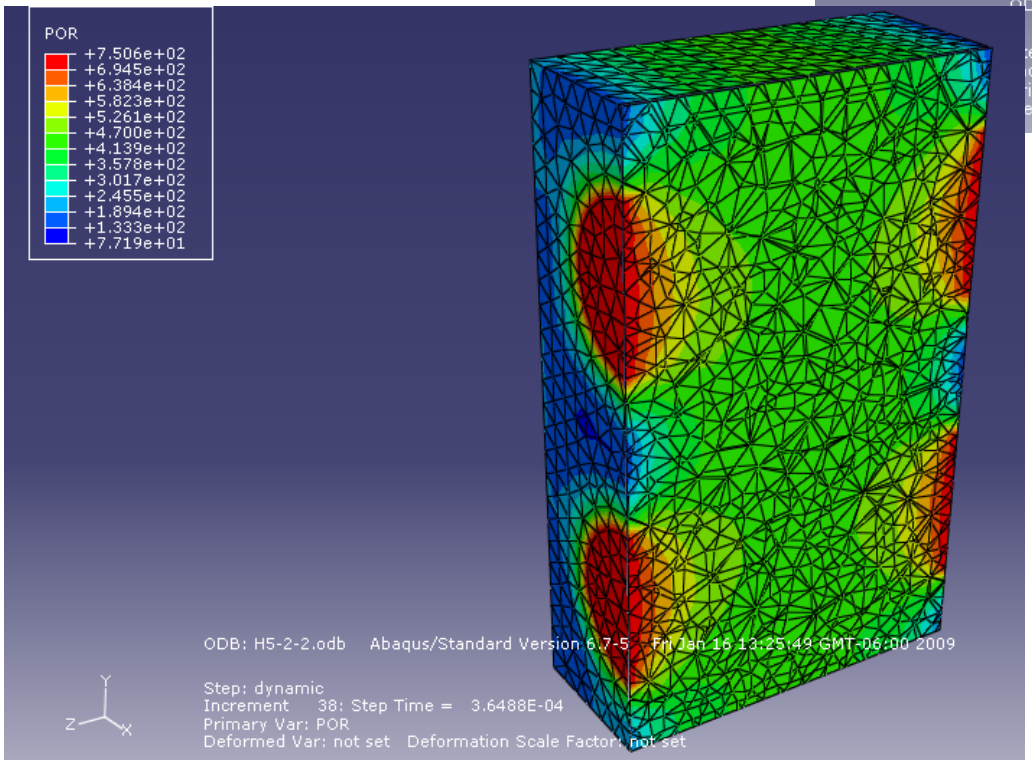


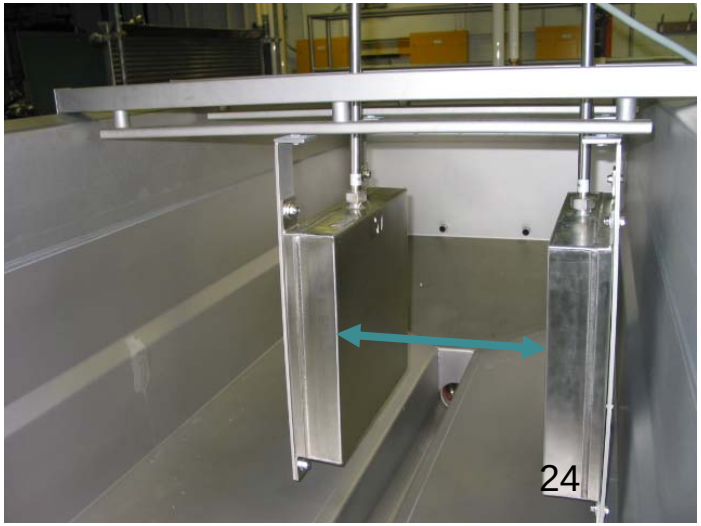


"Continuous-Flow Bacterial Disinfection of Fruits, Vegetables, Fresh-Cut Produce and Leafy Greens Using High-Intensity Ultrasound". #61/245,382.

Acoustic Pressure Distribution

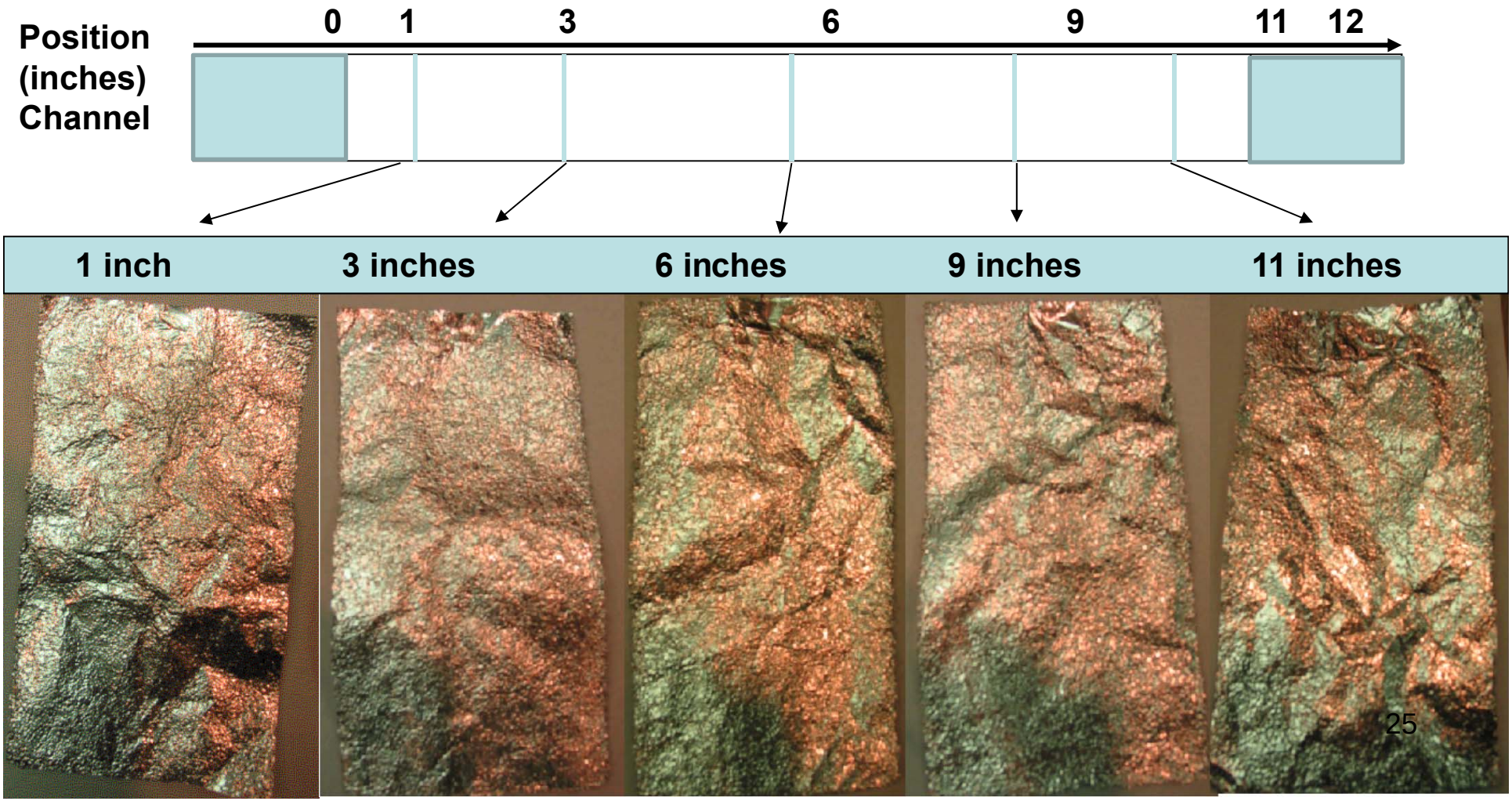






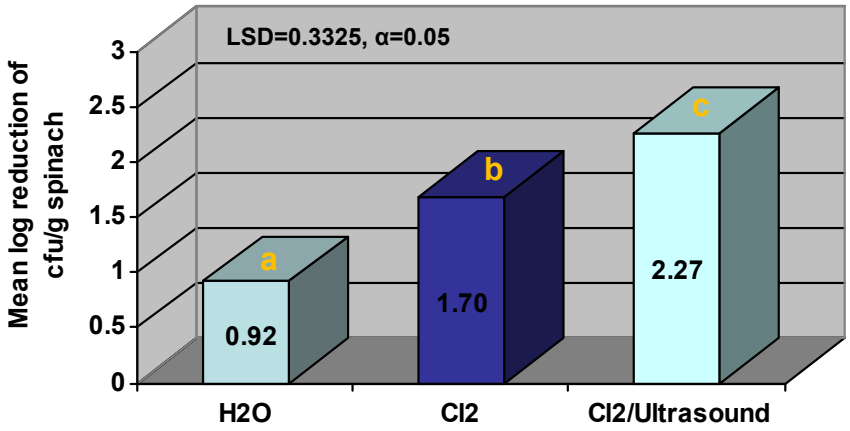
Cavitation Activity

The distribution and strength of ultrasound across ultrasonic washing channel

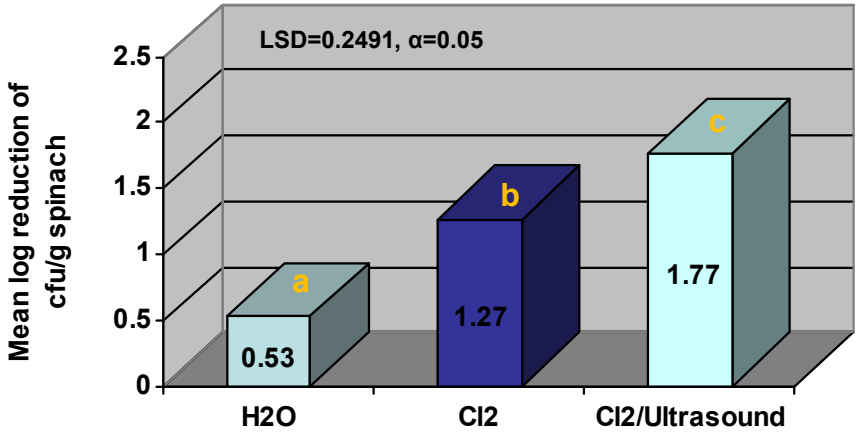


Ultrasound-Assisted Produce Wash in a Pilot Scale Washer

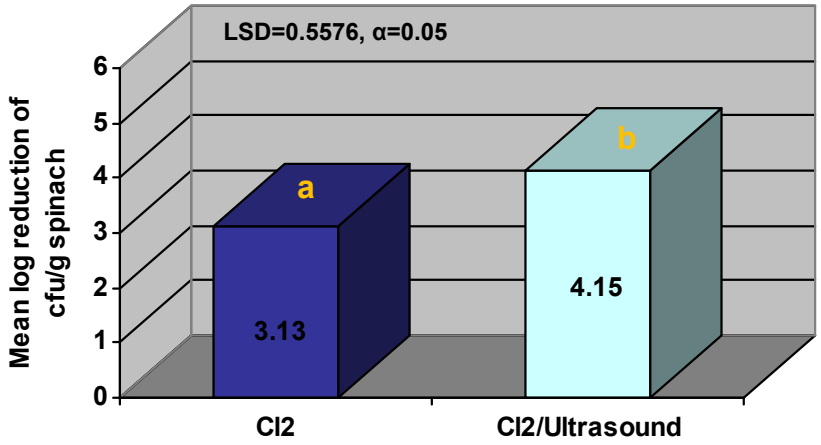
Single-leaf spinach wash



(A) Aerobic Plate Count



(B) Yeast and Mold

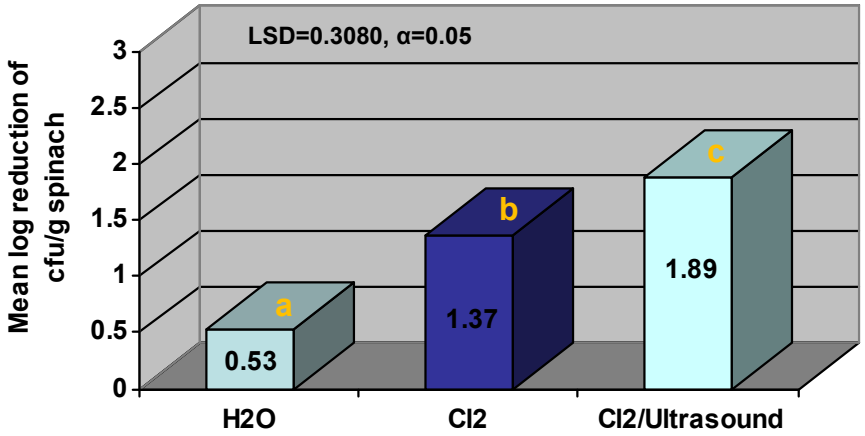


(C) *E. coli* 87-23 (inoculated)

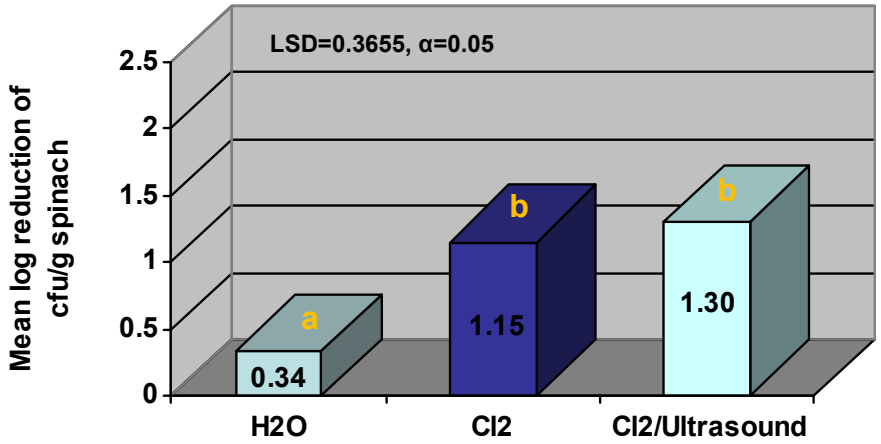
Microbial reduction after a single-leaf wash in the pilot scale washer with and without ultrasound treatment, with a residence time of 60±20 seconds

Ultrasound-Assisted Produce Wash in a Pilot Scale Washer

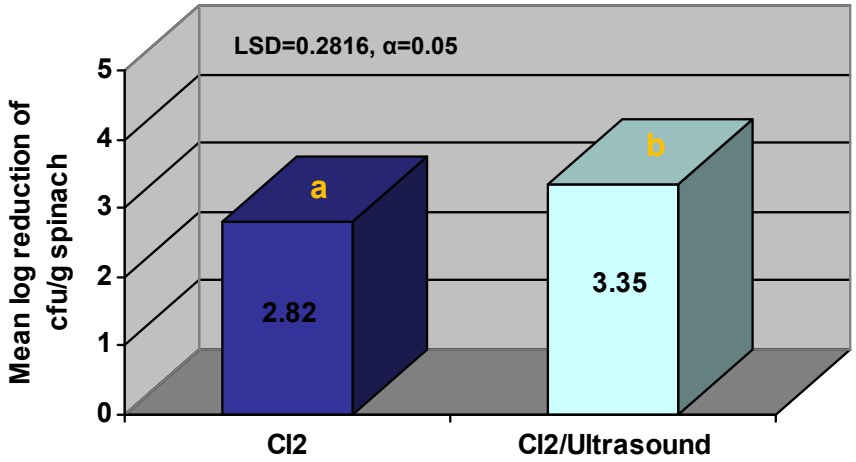
Batch-leaf spinach wash



(A) Aerobic Plate Count



(B) Yeast and Mold



(C) *E. coli* 87-23 (inoculated)

Microbial reduction after batch-leaf wash in the pilot scale washer with and without ultrasound treatment, with a residence time of 60±20 seconds

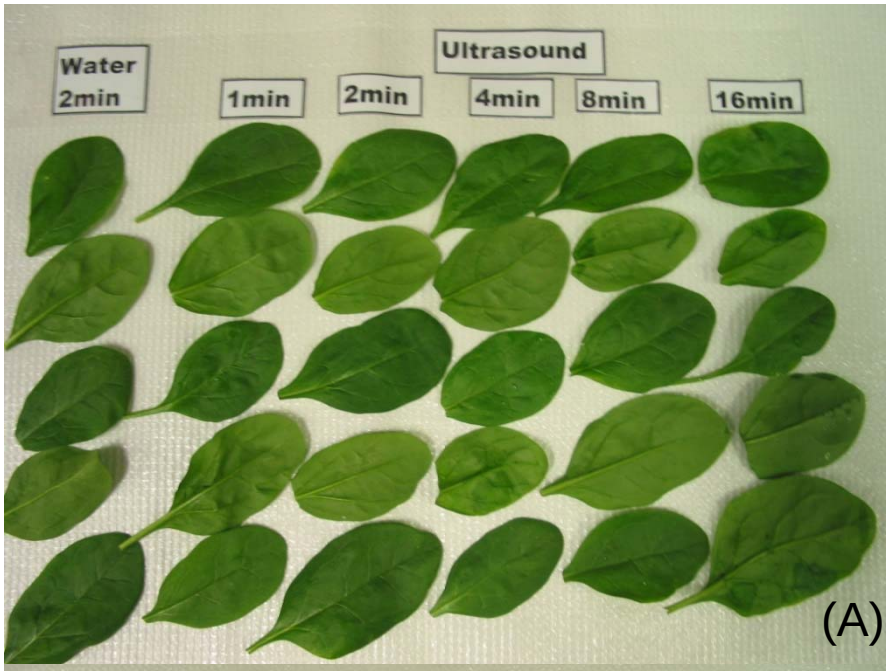
Ultrasound-Assisted Produce Wash in a Pilot Scale Washer

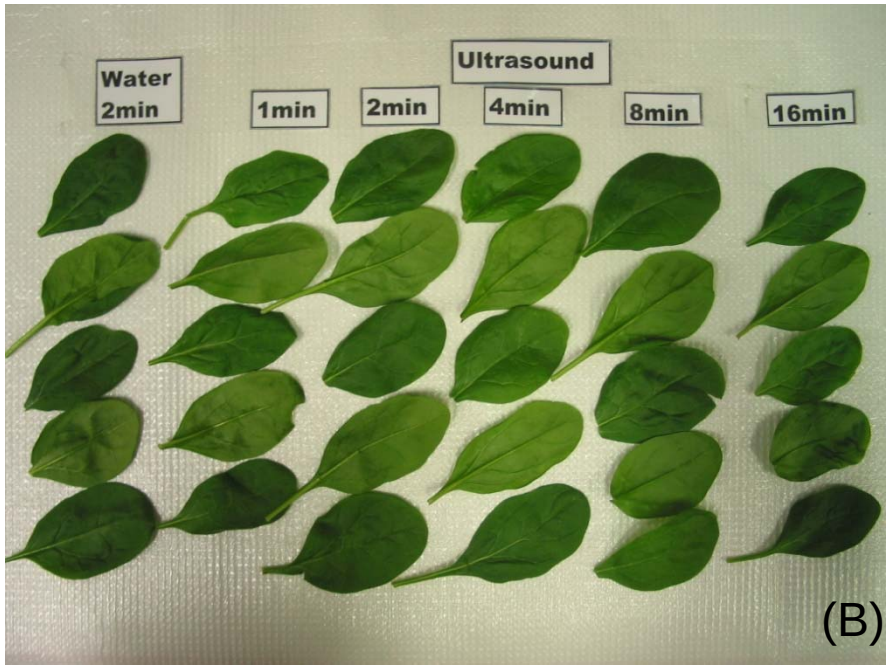
Summary of microbial count reduction on spinach

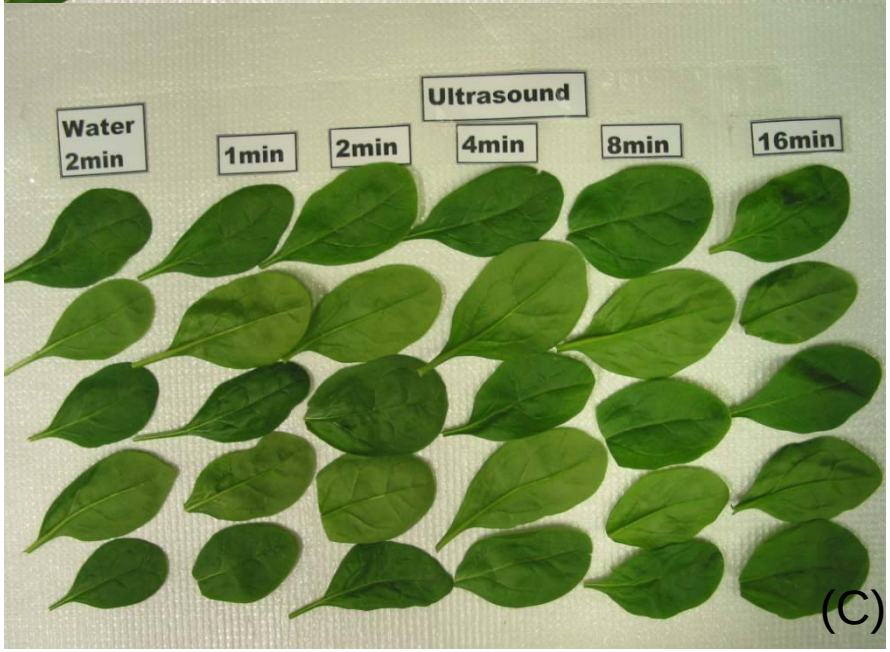
	Single-Leaf Washing			Batch-Leaf Washing		
	APC[1]	Yeast / mold	*E. coli*	APC	Yeast / mold	*E. coli*
Chlorine	1.70	1.27	3.13	1.37	1.15	2.82
Chlorine + Ultrasound	2.27	1.77	4.15	0.89	0.30	3.35
Additional reduction (log)	0.57	0.50	1.02	0.52	0.15	0.53
Additional reduction (%)	77.3	65.4	91.8	71.2	39.4	72.8

[1] APC: Aerobic Plate Count.

Ultrasound-Assisted Produce Wash: Quality







Images of spinach leaves treated by ultrasonication for different time during storage at 1C

(A) Day 0

(B) Day 7

(C) Day 14

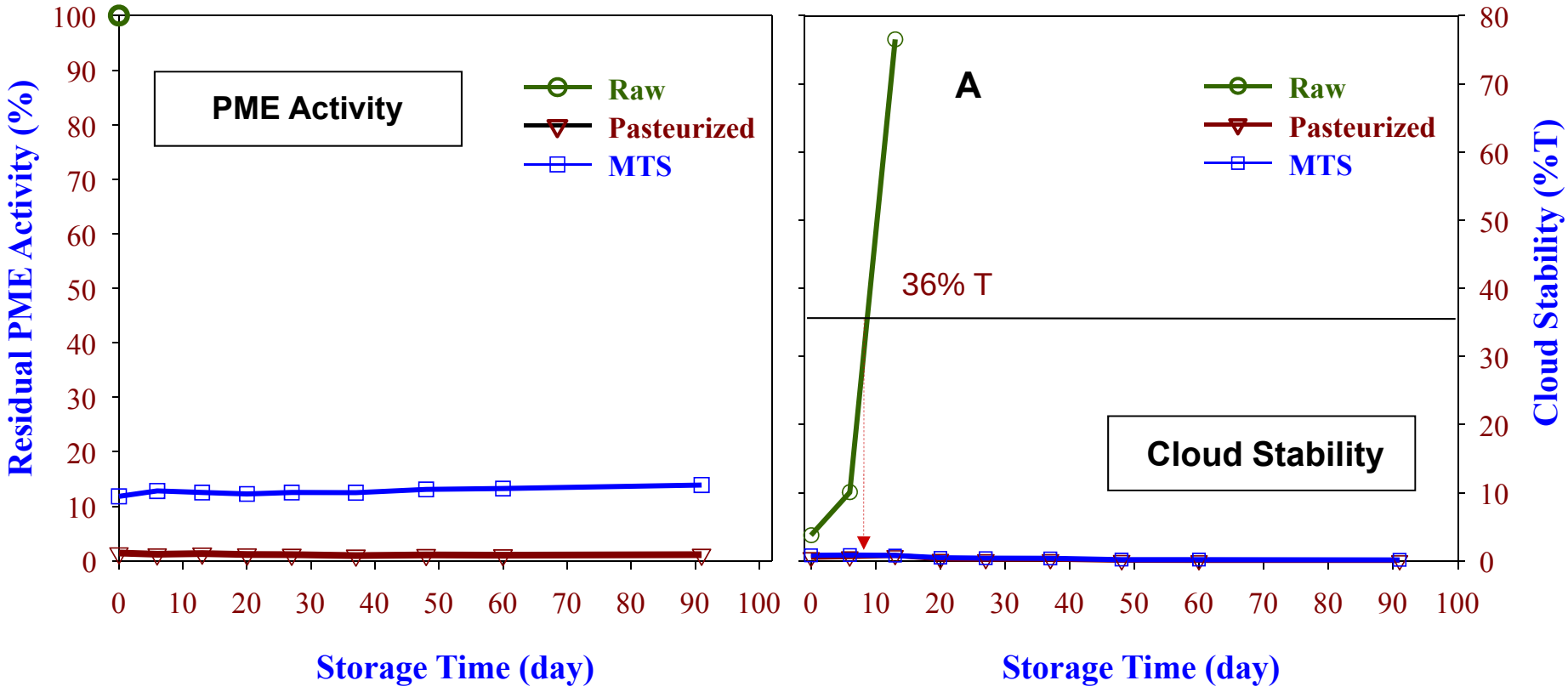
Experiments done in a MMM reactor

Effect on Product Quality

MTS Treated Orange Juice

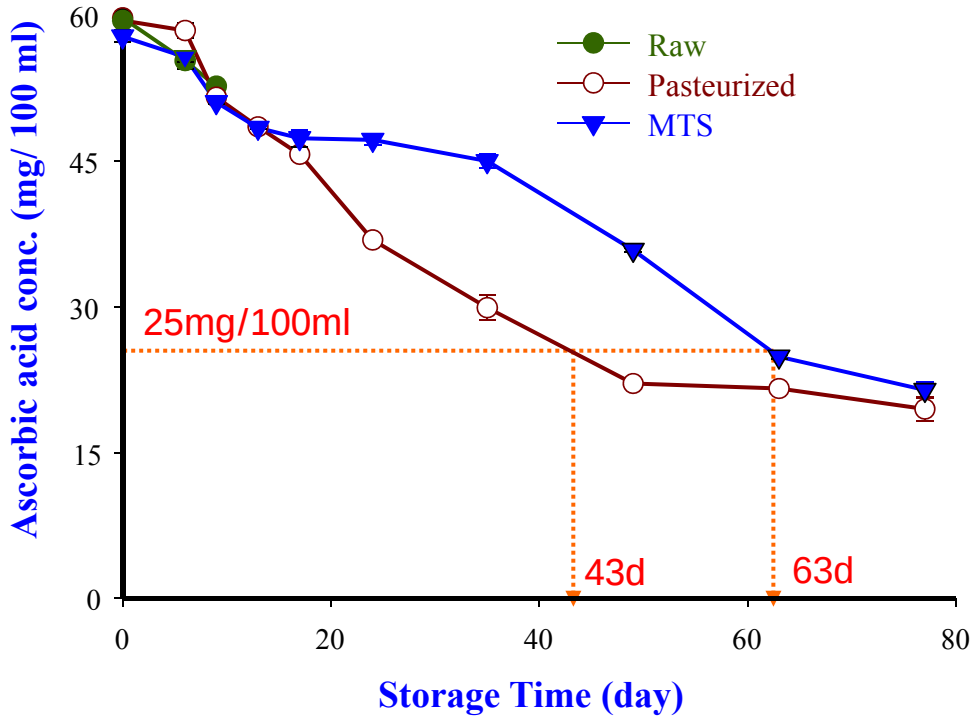
Pasteurization: 91°C for 13 sec

MTS: 200 kPa, 65/70°C for 30 sec

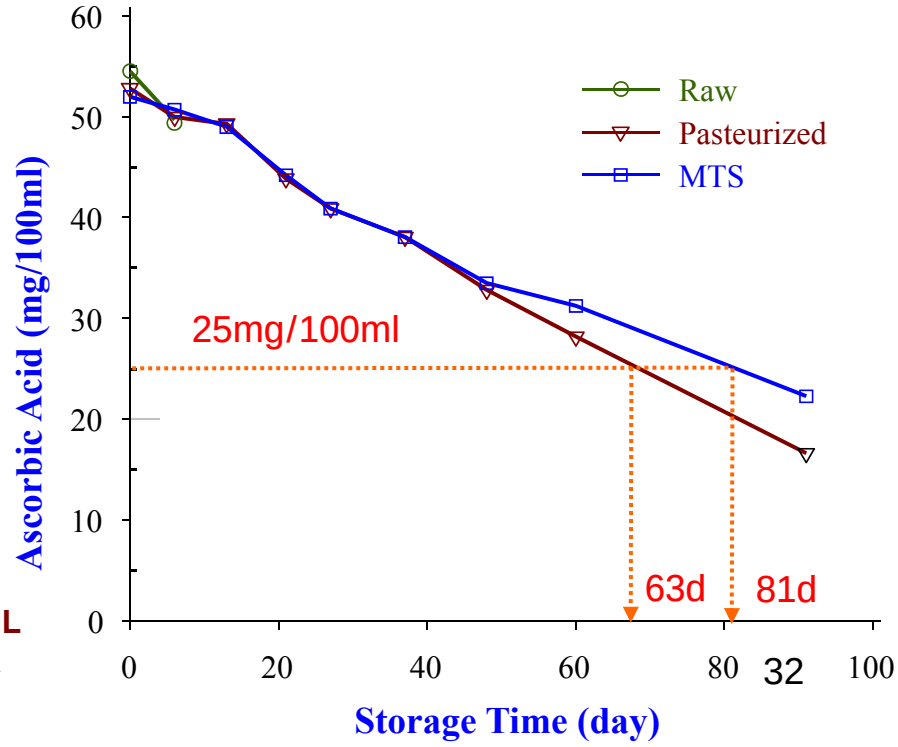


Pectin-methylesterase (PME)

MTS-Treated Orange Juice



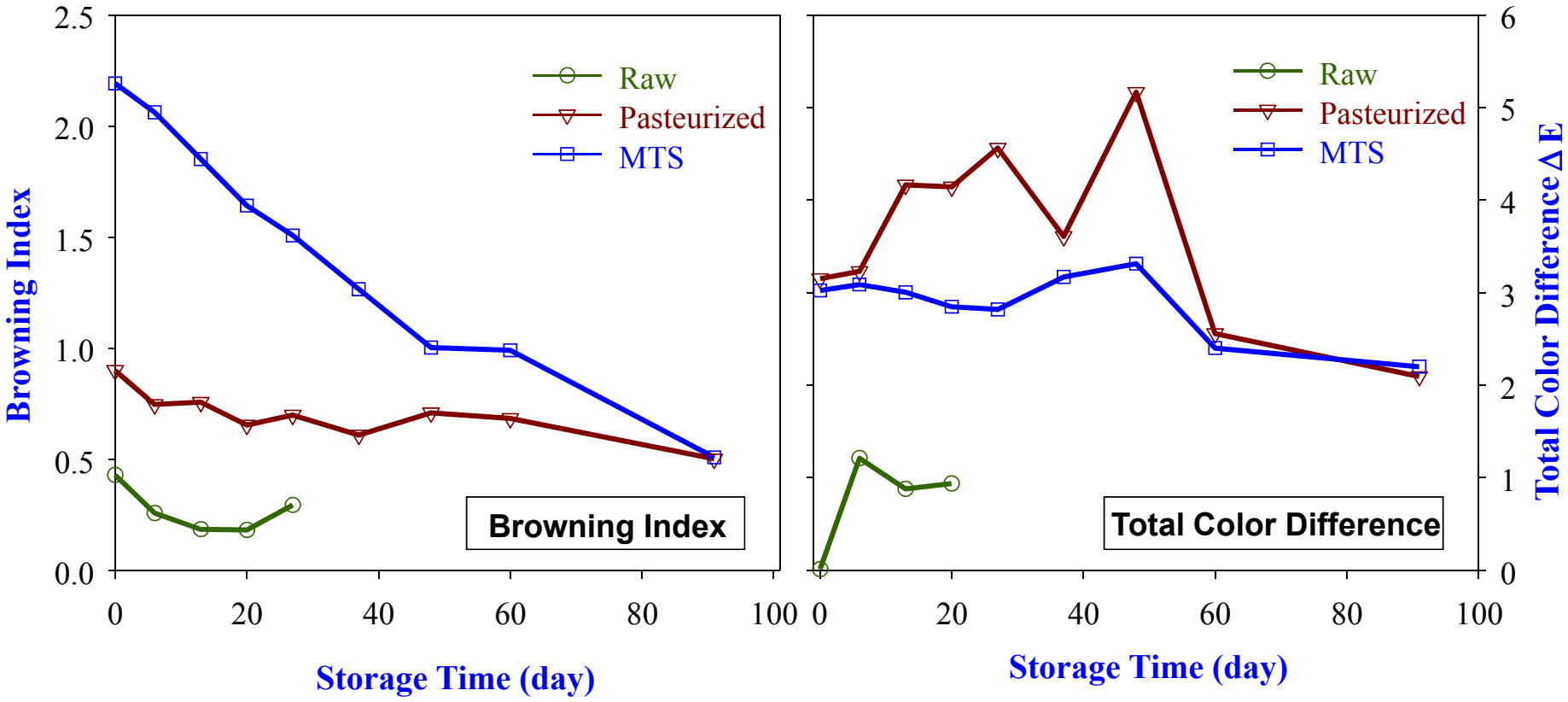
Ascorbic acid retention during storage at 4°C



AA concentration in orange juice should be at least 25mg/100mL at expiration day for 100% vitamin C supply according to USDA recommended daily allowances.

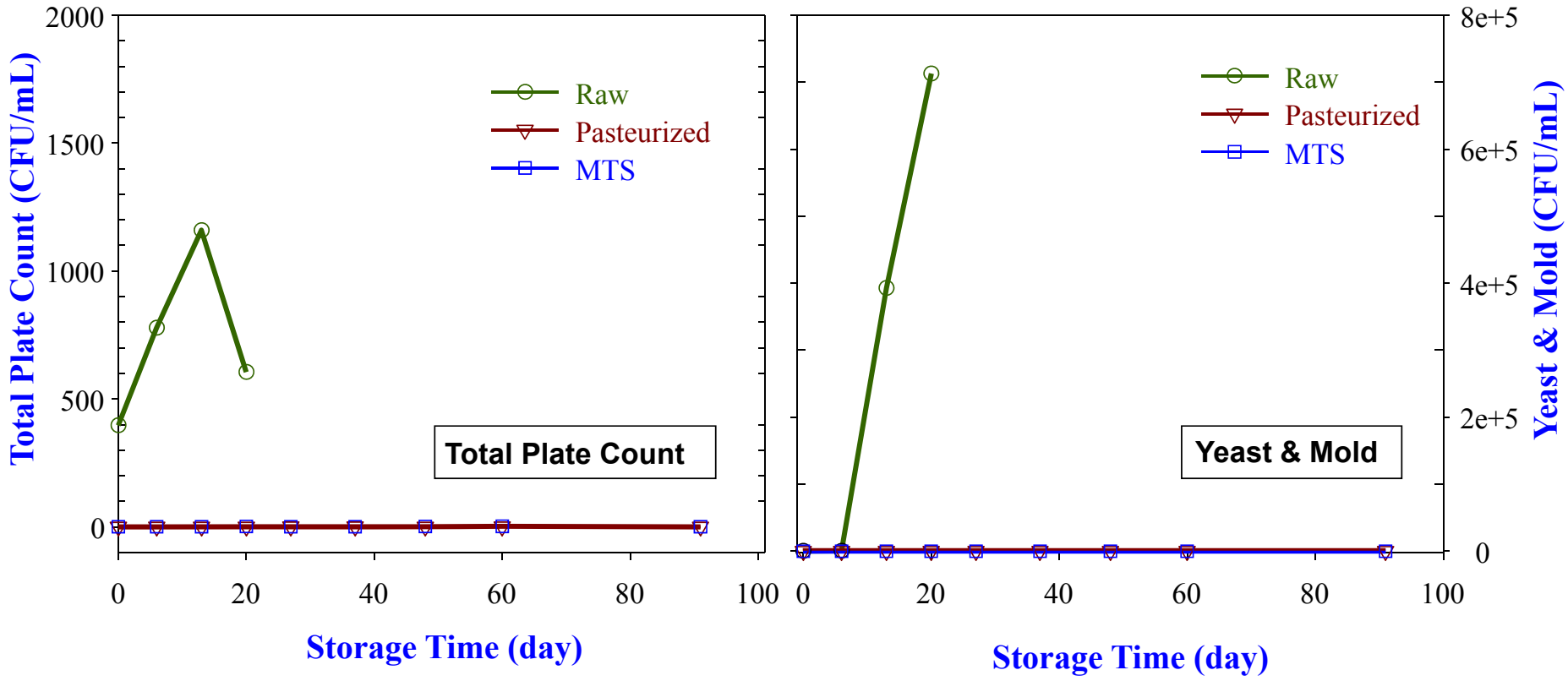
MTS-Treated Orange Juice

Pasteurization: 91°C for 13 sec
MTS: 200 kPa, 70°C for 30 sec



MTS-Treated Orange Juice

Pasteurization: 91°C for 13 sec
MTS: 200 kPa, 70°C for 30 sec



Summery

- Two key issues
  - Cavitation intensity enhancement
  - Improvement of acoustic field uniformity
- Mano-thermo-sonication (MTS)
  - Promising orange juice treatment method
  - Liquid food pasteurization: 5 log in seconds
- Variable frequency technique (MMM) is more effective

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Questions?