COMSOL Multiphysics Simulation of Ultrasonic Energy in Cleaning Tanks

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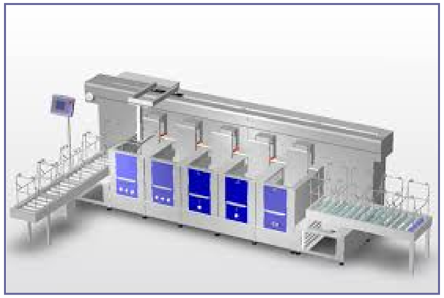
Outline

- Background of Ultrasonic Cleaning
- Motivation for the Study
- Model Descriptions
- Results and Discussion
- Conclusion

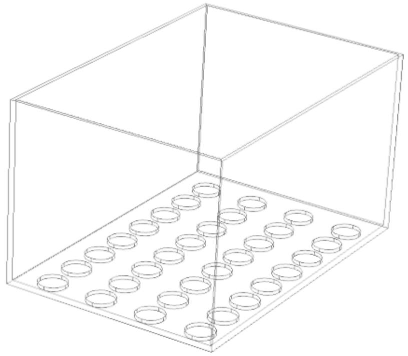
Background of Ultrasonic Cleaning

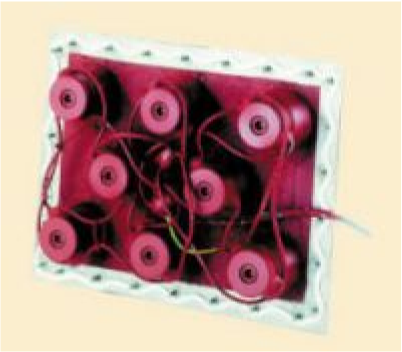
•Ultrasonic based cleaning technique, widely used in various industries

Small volume table top unit



Large scale, multi tank unit





*Schematic drawing of a typical ultrasonic cleaning tank with **plate type transducers**, showing array of transducers bonded to the bottom*

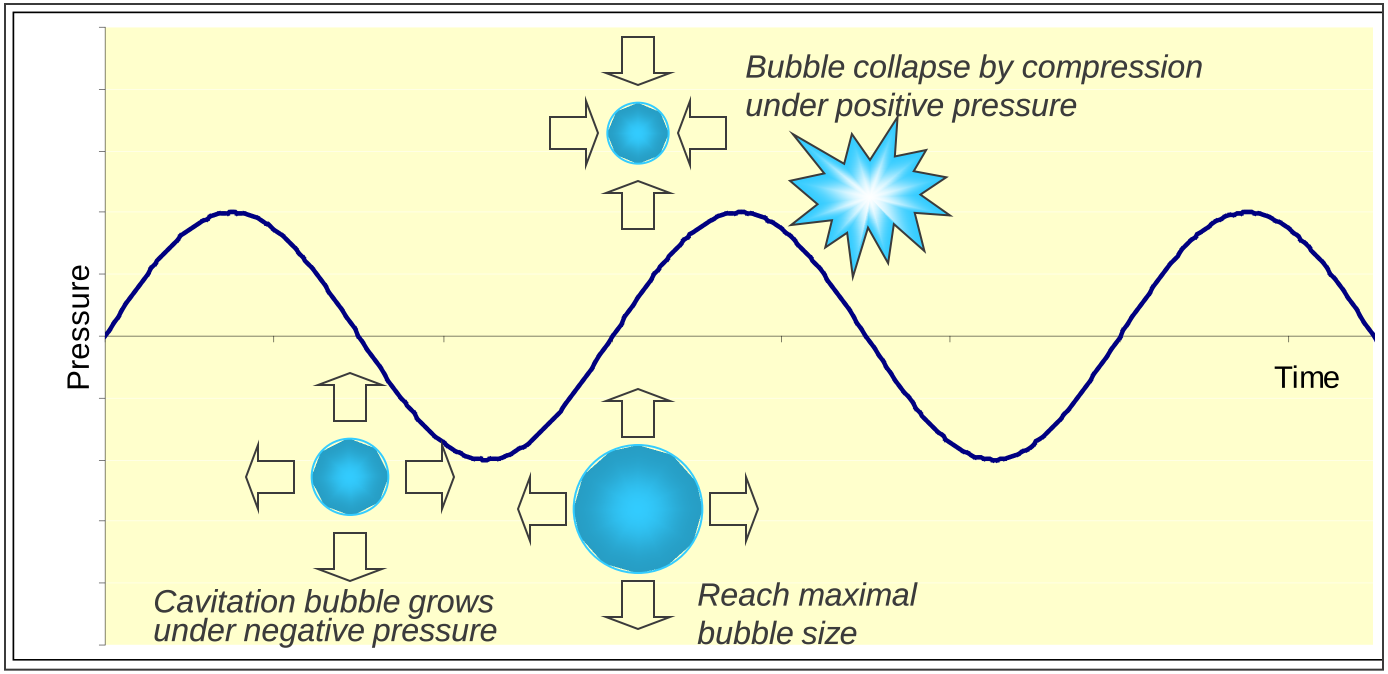
•Transducers convert the input high frequency electronic oscillation from the ultrasonic generator to mechanical vibrations with ultrasonic frequency (generally 15kHz to 400kHz)

•Once generated, the transducer vibrations propagate through the fluid medium in the cleaning tank and form time-varying pressure field

Background of Ultrasonic Cleaning-continue

Main effect to achieve contamination removal in ultrasonic cleaning: **ultrasonic energy driven cavitation**

Within the fluid medium , each point along the wave oscillates with pressure ranging between a maximum and a minimum, where cavitation bubbles grow.



•In almost all cleaning applications, it is important to control the cavitation energy.

•For a given set of ultrasonic tank parameters, the cavitation effect is largely impacted by the amount of ultrasonic energy.

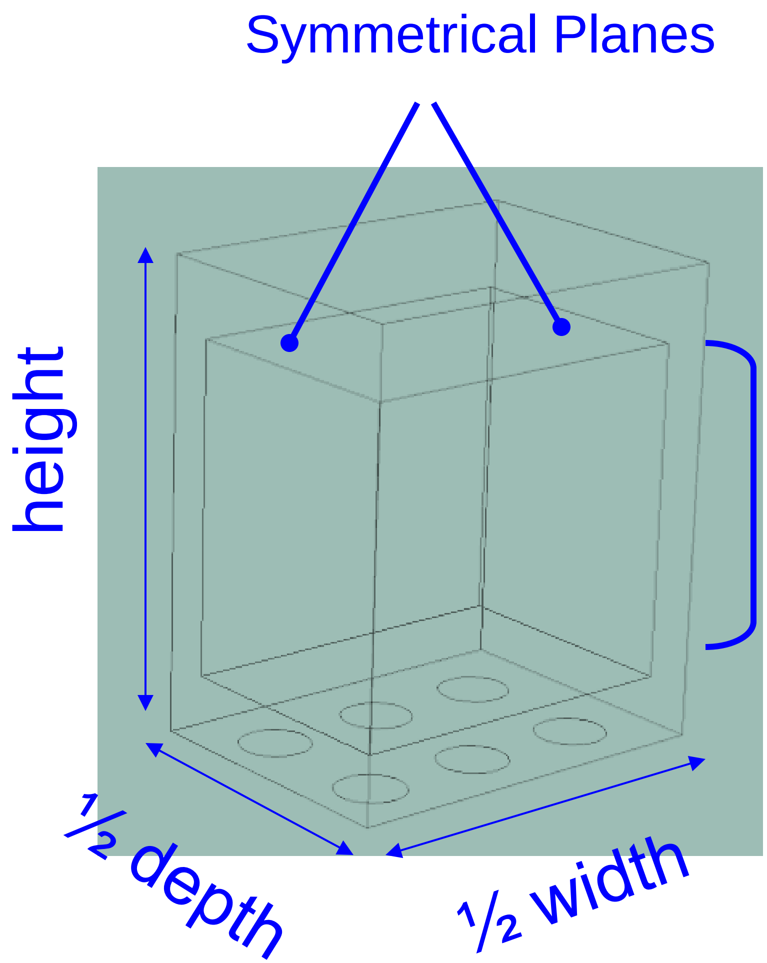
Motivation for the Study

To study the ultrasonic energy as impacted by tank volume and/or shape by evaluating the propagation of ultrasonic waves in cleaning tank containing cleaning fluid.

- Determining optimal ultrasonic energy level often becomes the key to the success of ultrasonic based cleaning.
- Ultrasonic energy requirement, usually represented by watts per gallon, developed in one ultrasonic cleaning tank often can not be used as a base to design another one with different volume and/or shape for the same process performance

Model Geometry

A quarter of ultrasonic cleaning tank with water as cleaning medium



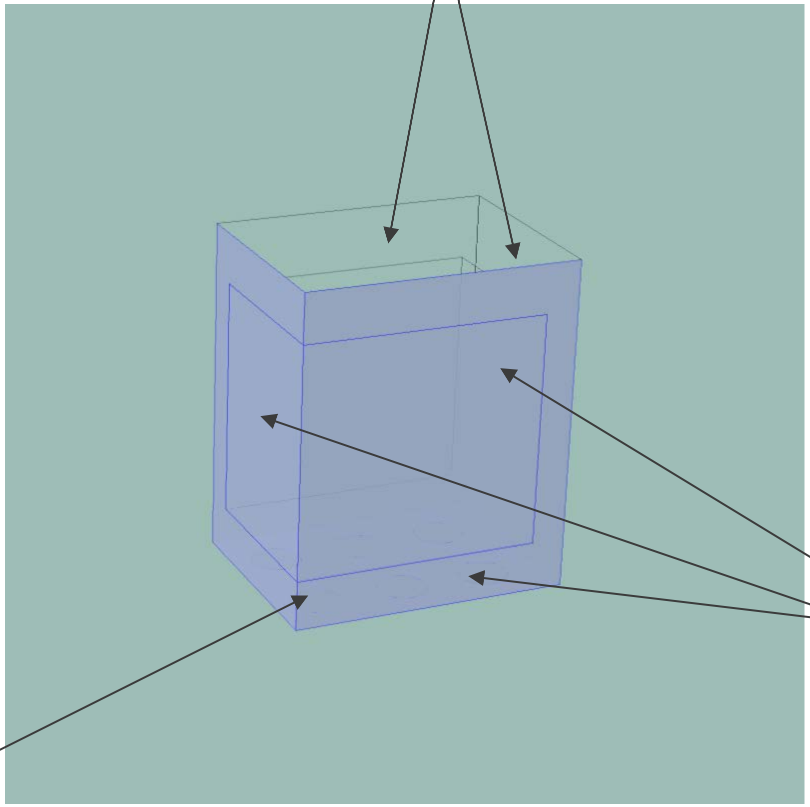
•Define a cleaning zone where parts to be cleaned typically located.

•1 inch from the tank wall and 2 inch from the top/bottom

Each circle representing the radiation area of one transducer

Boundary Conditions

Tank Wall: **External Shell**



- Symmetrical planes
- Bottom (non transducer area): **hard wall**

Transducer radiation area: **pressure**

Governing Equations

Pressure acoustic model for water domain

$$\nabla \cdot -\frac{1}{\rho_c}(\nabla p_t - q_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$$

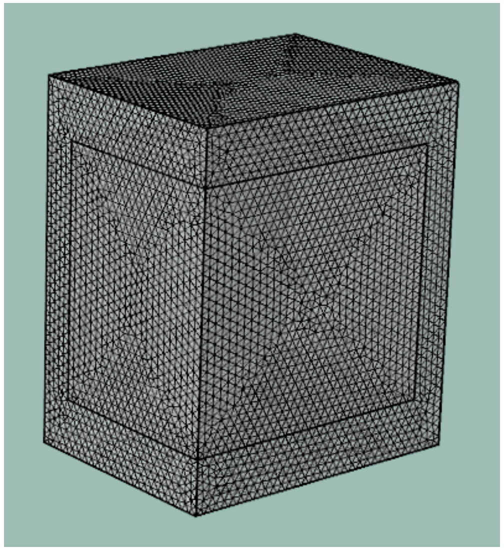
$$p_t = p + p_b$$

$$k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2$$

Linear elastic shell for stainless steel tank wall

$$-n \cdot \left(-\frac{1}{\rho_c}(\nabla p_t - q_d)\right) = a_n$$

$$-\rho\omega^2 u - \nabla \cdot \sigma = -\frac{p_t n}{d}$$

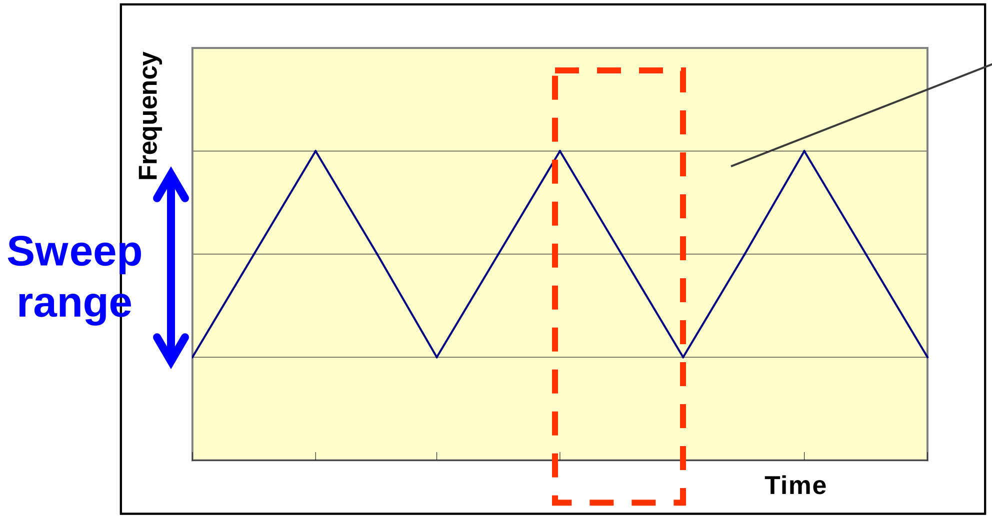


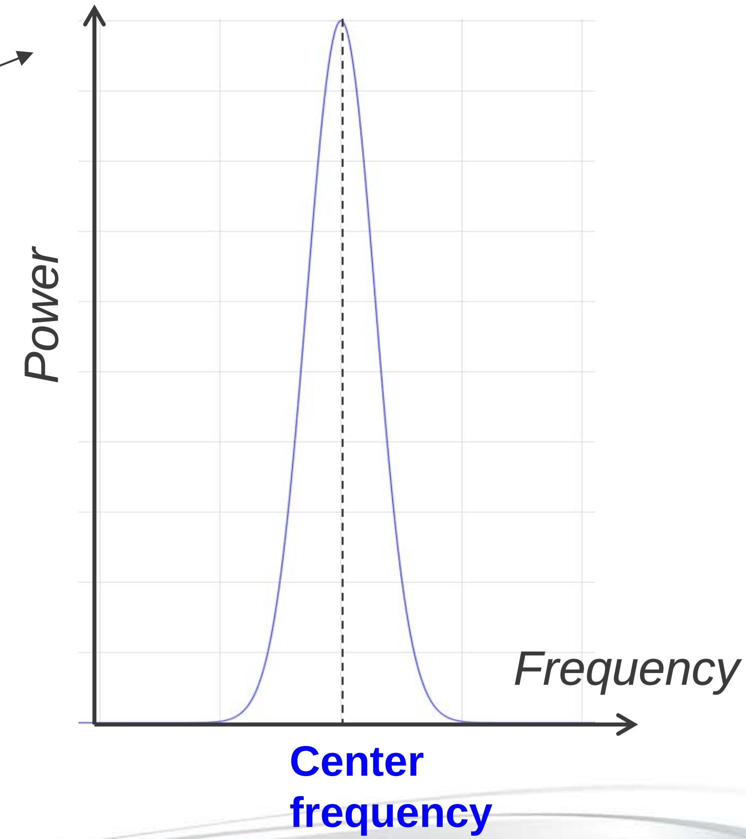
Maximal mesh elements size : 1/5 of wavelength

Describing Ultrasonic Transducer Operation

During ultrasonic cleaning, it is common practice to sweep around a frequency range near the center frequencies of ultrasonic transducers.

- Compensate variation of transducer center frequency
- Avoid acoustic wave transmission dead spot (nodes) in the tank





During each sweep cycle, the transducer output power peaks at the center frequency and reduces away from center frequency

Describing Ultrasonic Transducer Operation -continue

Boundary pressure for transducer area $$p_0 = \left(\frac{2 \cdot \rho_c \cdot C_c \cdot P_e}{A}\right)^{1/2}$$

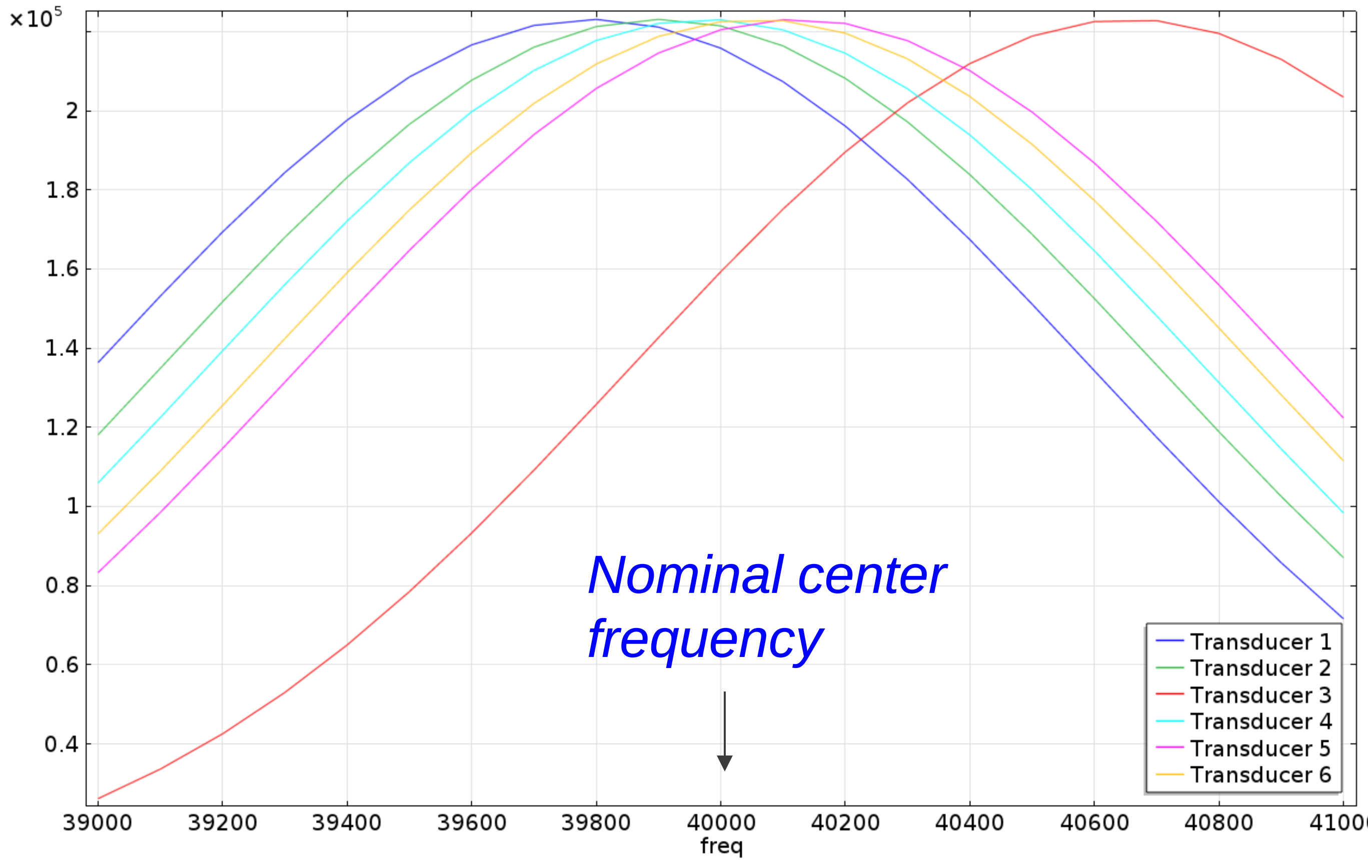
ρ_c: density of water, $1000 kg/m^3$

C_c: speed of sound, 1418m/s

Pe: transducer operation power

A: radiation area of transducer

While sweeping transducer arrays around a center frequency, peak power for each transducer occurs randomly around the nominal center due to manufacturing variation.



Results and Discussion

Frequency domain simulation scanned from 39kHz to 41 kHz at a step of 0.01 kHz and solved for

- Pressure,
- Displacement field
- Displacement of shell normals

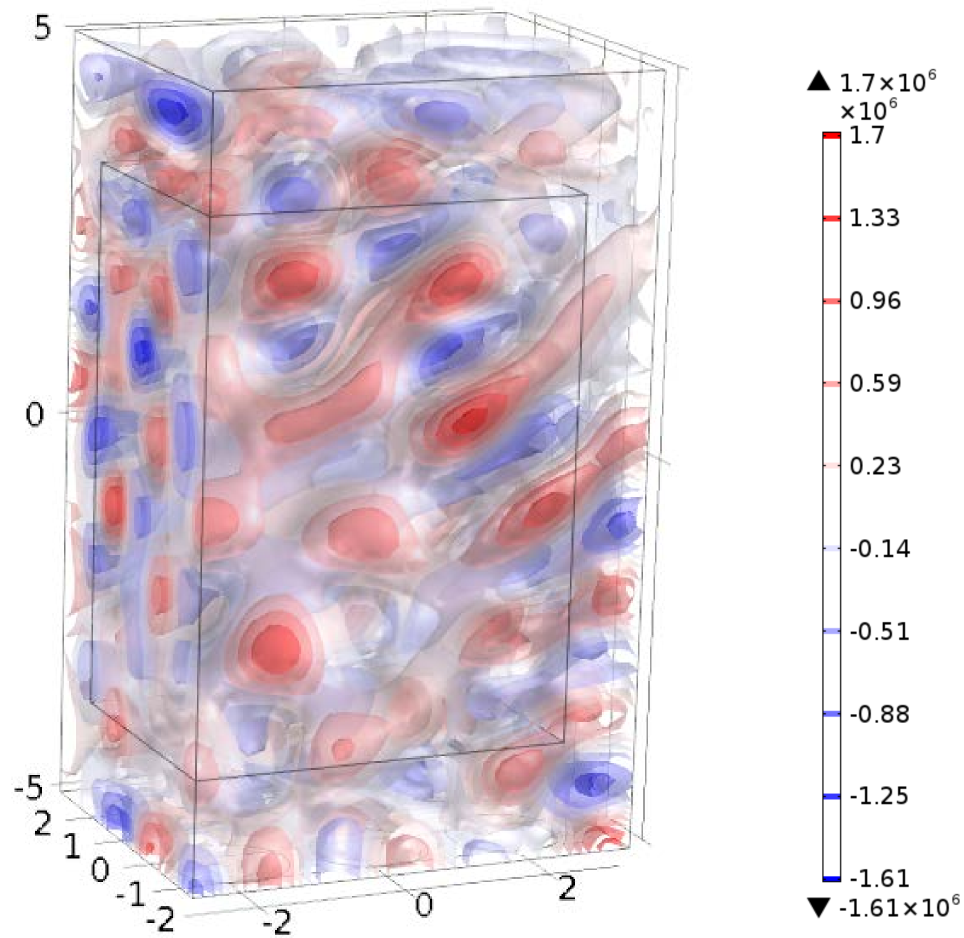
From the pressure field distribution, ultrasonic intensity(W/in^2) distribution is calculated based on following equation

$$P_{ac} = \frac{p^2}{2 \cdot \rho_c \cdot C_c}$$

ρ_c: density of water, 1000kg/m^3

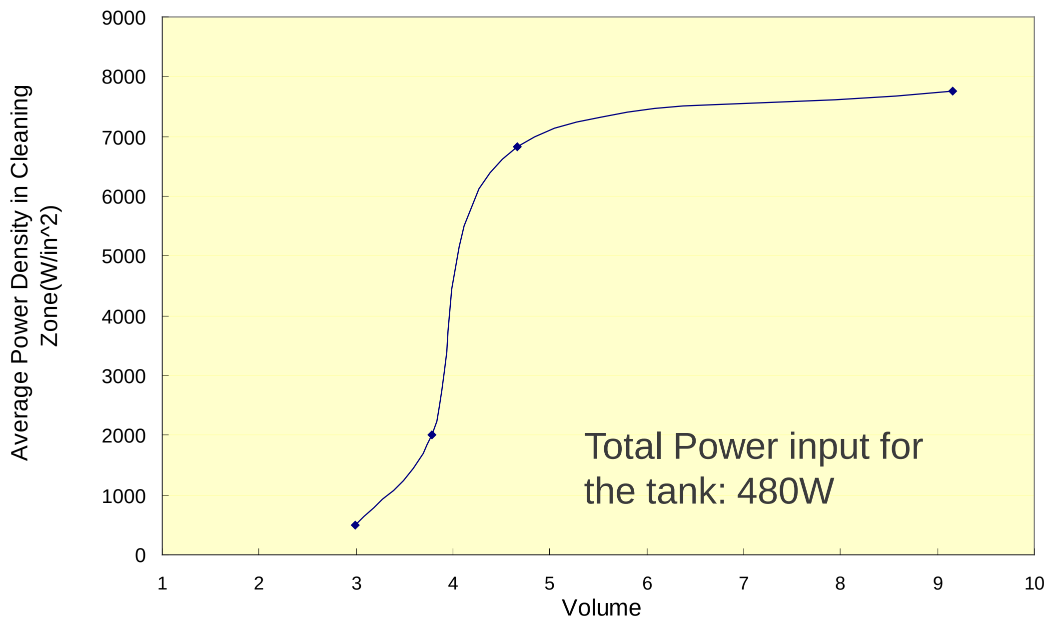
C_c: speed of sound, 1418m/s

Isosurface: total acoustic pressure field



Results and Discussion-Continue

Average power density within the cleaning zone over frequency range is determined
- To estimate the effective ultrasonic density transmitted to the cleaning zone for different tank volume with same power input.



Higher effective power density in the cleaning zone is observed at larger volume despite the lower power input/volume

• Suggesting the ultrasonic energy input that required by cleaning task for a given cleaning system may not be a simple derivative of input ultrasonic energy per unit tank volume

Conclusions

- Ultrasonic energy transmission within the tank is impacted by the tank geometry/volume.
- The ultrasonic energy input that required by cleaning task for a given cleaning system may not be simply described by input energy per unit tank volume
- The model can be applied to match ultrasonic power density input for cleaning tanks of different geometries.
- Further study can include cleaning objects in the tank.

THANK YOU!