

**FUNDAMENTALS**

**OF**

**ULTRASONIC CLEANING**

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## INTRODUCTION

Ultrasonic cleaning offers several advantages over conventional methods. Ultrasonic waves generate and evenly distribute cavitation implosions in a liquid medium. The released energies reach and penetrate deep into crevices, blind holes, and areas that are inaccessible by other cleaning methods. The removal of contaminants is consistent and uniform regardless the complexity and geometry of the part being cleaned.

### **ADDITIONAL FEATURES:**

- 1) **SPEED**, cleaning usually completed in 1 to 3 minutes
- 2) **LABOR**, Tremendous labors savings over conventional cleaning methods.
- 3) **CHEMICAL**, use lower concentration and milder chemicals to complete cleaning task. Does not have to be a low foaming chemical as required in most spray, agitation cleaners.

### **NOTE:**

This paper is written in two parts. Part one contains information for basic knowledge on ultrasonic theory and chemistry. An asterisk (\*) with a number will be found throughout part one on certain topics, these asterisks (\*) with matching numbers will also be found in part two and will give additional information on the specific topic for those who require more in depth detail.

### **WHAT DOES ULTRASONIC MEAN**

Before we go into the theory of ultrasonics let's first get a better understanding of what we mean by ultrasonic. A sound wave (may also be expressed as an acoustical pulse or pressure wave), which is beyond the range audible to human hearing, is the point at which ultrasonic begins. Since 18,000 Hertz (18,000 cycles) per second is the approximate upper limit of the human hearing range it is considered the point at which ultrasonic begins. Most like to refer to the ultrasonic range as a sound wave equal to or greater than 20 KHz or 20 Kilo Hertz, Kilo meaning thousand and Hertz (after H.R.Hertz) meaning cycle per second. Ultrasonic cleaning indicates it uses sound waves at or above the 18/20 KHz range.











## SURFACE TENSION

Like vapor pressure the surface tension should be moderate.

With high surface tension the cavitation bubbles have less elasticity so are very hard to develop. Under these conditions if we have enough power to initiate cavitation development tremendous amounts of energy will be stored and released.

With low surface tension the bubbles have more elasticity so are easy to develop. Because of the ease of development the cavitation bubbles will require lower power levels to initiate cavitation development and so will store and release lower implosion forces.

Tap water without additives is hard to cavitate due to high surface tension. If we add a small amount of wetting agent to reduce the surface tension (make the water wetter) we will have noticeable more cavitation activity. If we add too many wetting agents we can lower the surface tension to a point that we will begin losing cavitation intensity. Most chemicals formulated for use in an ultrasonic cleaning bath have the required wetting agents.

NOTE: We must also wet the product being cleaned to achieve proper cleaning. Without a wetting agent to lower the surface tension in water proper contact between the product and the water cannot be achieved.

## SCENARIO

Trying to develop a cavitation bubble in water with high surface tension is like trying to blow up a balloon for the first time. You have to exert a tremendous force to initiate expansion. If expansion is accomplished a tremendous amount of energy will be stored, if ample power is not available no cavitation will be developed. (Now add a wetting agent to reduce surface tension) Now compare this to a balloon that has been blown up numerous times, it takes less exertion to initiate expansion so the balloon will blow up quite easily so less energy will be stored, but cavitation will be easy to initiate to begin the cleaning process. Surface tension not only affects the cavitation intensity but also allows the item being cleaned to have better water contact for improved cleaning. Expression- makes the water wetter.

## LIQUID TEMPERATURE

The liquid temperature affects the cavitation quantity, intensity and chemical cleaning action. The cooler the liquid the more difficult to go below the point of vaporization to begin the cavitation development process, this is due to the differential between the low temperature and the boiling point of the liquid. The applied energy must be sufficient to drop the pressure within the liquid below its vapor pressure point. If the liquid is too cold and the applied energy is insufficient under these conditions no cavitation cavities will be developed. If we increase the input power enough to initiate cavitation tremendous amounts of energy will be stored and released when the cavitation bubble implodes in the compression half cycle.

If we increase the liquid temperature it makes it easier to go below the point of vaporization so we initiate cavitation with less energy. The number of cavitation events will increase as the temperature is increased but the energy being stored in the cavitation bubble will decrease. As we approach the boiling point cavitation intensity steadily diminishes and ceases or becomes ineffective for most cleaning applications at the boiling point of the liquid.

The liquid temperature will also affect the chemical cleaning ability. Some chemicals work best at elevated temperatures; while others will break down so require lower temperatures. If the temperature is too low the chemical may have trouble dissolving or dispersing. As we increase the liquid temperature most chemicals get more aggressive but we lower the cavitation implosion force. We have to find a temperature / cavitation balance that is right for the application.











## ULTRASONIC POWER (\*5 )

To determine if we have adequate ultrasonic power in a tank we must know both the wattage per square inch of the transducer-radiating surface and the cubic volume measurement of the liquid being ultrasonically activated.

- 1) If the ultrasonic tank bottom measures 10 inch by 14 inch this would give us a radiating surface of 140 square inch. If this tank were driven by a 500-watt generator the watt density would be 3.6 watts per square inch (500-divided by 140) on the radiating surface.
- 2) If we fill this 10 by 14-inch tank to a depth of 10 inch we will now have 1400 cubic inches of liquid (6.1 gallons).  
If a 500-watt generator drives this tank the volume density would be .36 watts per Cubic inch of liquid. This would be considered a standard intensity ultrasonic tank.

If we now install a 1000 watt generator to drive this tank the watt density per square inch on the Radiating surface would be 7.2 watts per square inch on the radiating surface and .72 watts per cubic inch of liquid; this would be considered a high intensity ultrasonic tank.

Now lets take this 10-inch by 14 ultrasonic tank and increase its volume by filling it to up to a depth of 36 inches.(22 gallon). If this tank is once again connected to a 500-watt generator the watt density is again 3.6watts per square inch, but the watt density per cubic inch has dropped from .36 watts per cubic inch to (.099 ) watts per cubic inch. This is a reduction from 1/3 watt per cubic inch to 1/10 watt per cubic inch of liquid. The generator may have enough power to initiate cavitation in the first or second wavelength but will loose amplitude as it travels through this much liquid and will have trouble initiating and maintaining cavitation in the remainder of the tank.

Do to the low ultrasonic power level the only way to help satisfy this condition is to elevate the tank temperature. At the elevated temperature of 180 degrees Fahrenheit the tank will eventually degas and cavitation will be initiated. The precaution that must be taken with this tank is that the high temperature must be retained and the load being cleaned must be kept small or the tank will stall and cavitation will be lost.

Ultrasonic power may be rated as low intensity, medium intensity, standard intensity, and high intensity.

It should be obvious that we can not expect to use the same ultrasonic power level as used in the blind cleaner, (usually in the area of 1500 watts for 25 to 30 gallons) and expect to install this same amount of power into a tank containing 95 or 100 gallons and expect to achieve effective ultrasonic cleaning. If a person is not familiar with ultrasonic activity and power levels one may be deceived into thinking their tank is:

- 1) **WORKING THE WAY IT SHOULD**
- 2) **THE CLEANING TASK IS TOO DIFFERENT**
- 3) **THE LOAD IS TOO LARGE FOR THE TANK**
- 4) **I MUST BE USING THE WRONG CHEMICAL**

As the capacity of an ultrasonic tank increases, the increase in ultrasonic power is not linear. If we drive a 10-gallon tank with 750 watts of power we do not have to drive a 90-gallon tank with 6750 watts of power to archive the same cleaning results.

If we change the configuration of a tank but retain the same volume the ultrasonic power requirements may also change. A tank with dimensions of 24 inch x 24 inch x 9 inch deep (22 gallon) may only require 750 watts of ultrasonic power where a tank with dimensions of 12 inch x 12 inch x 36 inch deep (22 gallon) may require 1500 watts of ultrasonic power to achieve the same cleaning results.

When interested in purchasing a special ultrasonic cleaning tank go to a qualified ultrasonic design engineer for specifications.

If you have a special cleaning application it is recommended that you send a sample to a qualified ultrasonic cleaning lab for evaluation and tank design specifications.

## FREQUENCY (\*6 )

The lower frequencies are more widely used when the product being cleaned is not susceptible to damage by the aggressive cavitation. This aggressive nature of the lower frequencies is best suited for removal of insoluble particles in the middle to upper micron range, and for removal of tenacious deposits.

Ultrasonic intensity is an integral function of the frequency and amplitude of the radiating wave.

1. A 20 KHz radiating wave will be approximately twice the intensity of a 40 KHz wave for a given average power output.
2. The diameter range of a 20 KHz cavitation bubbles is 50/200 micron.
3. The diameter range of a 25 KHz cavitation bubbles is 35/150 micron.
4. At 20 KHz the impact range is 35/70- K Pascal with a streaming velocity of 400 km/hr.
5. At 20 KHz the node, antinode points are one half-wave length or two inches apart.

40 KHz is the most widely used frequency for most ultrasonic cleaning applications. At 40 KHz the node, antinode points are one half wavelength or one inch apart.

60 KHz to 80 KHz is more commonly used in the electronic Industry. Removal efficiency of a one micron and sub micron particle is increased with the higher frequencies. At 65 KHz the removal efficient on a one-micron particle is 95 % compared to 88 % for 40 KHz. The size of a one-micron particle is one thousandth of a millimeter or one millionth of a meter, much too small to see with the human eye without magnification. Under most general ultrasonic cleaning applications these small micron and sub micron particles are of little concern so the lower frequencies are favored. The higher frequencies are favored for use in the electronic Industry for cleaning hybrids; substrates, surface mounts, and disc drive components. This Industry is very concerned with these small micron and sub micron particles and being very susceptible to damage welcome the weak cavitation implosion force of the higher frequencies.

At the higher frequencies of 400 KHz to 800 KHz and higher the removal efficiency of a one micron particle is virtually the same as the 60 KHz and 80 KHz frequencies. These frequencies are also used exclusively by the electronic and optical Industries.

One might expect that the lower frequencies, with their more aggressive cavitation implosion forces to have a greater detachment effect for all particles no matter what their micron size.

Small particles are harder to remove do to both their force of attraction and their ability for lodging into small areas. The weight of the particle is also a major factor in detachment. Although the force between a particle and an adjacent surface decreases with particle size it becomes more difficult to remove a solid particle from a solid surface because of the value of the ratio  $F_a/W$  where  $F_a$  is the force of attraction and  $W$  is the weight of the particle. The value of  $F_a/W$  increases rapidly as the diameter of the particle decreases.

Even highly polished surfaces have some valleys and irregular areas where small micron and sub micron particles can lodge. The low frequency of 20 KHz has a cavitation bubble range size of 50 to 200 microns in diameter. These cavitation bubbles have little chance of penetrating into these small irregular areas to remove small micron particles. The higher frequencies of 60 KHz and 80 KHz with its smaller range of cavitation bubbles and higher number of cavitation events have a better chance of penetrating these areas and removing more of the particles.

On items being cleaned characteristic viscous and thermal boundary layers exist. At 30 KHz the viscous boundary layer thickness is 4.4 millionths of a meter, the thermal boundary layer is 1.1 millionths of a meter.

At the lower frequencies the acoustic field does not penetrate these boundary layers significantly so small micron and sub micron particles do not always feel the effects of the acoustic field

**The boundary layer thickness is inversely proportional to the square root of the frequency.**

The best means of penetrating this boundary layer is to increase the operating frequency. At 900 KHz the viscous boundary layer is to 0.8 millionths of a meter thus increasing the removal efficiency of small micron and sub micron particles.



#### WATER SOFTENERS

Water softeners are sequestering or chelating agents that combine with metallic ions to form water-soluble Nonionic structures. Most alkaline detergents can soften water up to 10 grains of hardness. If available water is harder than this the use of deionized water is recommended.

#### SEQUESTERING or CHELATING AGENTS.

Sequestering or chelating agents are similar in action except sequestering agents are limited to maximum temperatures of 180 degrees F (82 C). They are composed of polyphosphates, usually sodium tripolyphosphate, tetraphosphate or hexametaphosphate.

#### CHELATING AGENTS

Chelating agents are generally organic sodium salts of one of various acids. Unlike the polyphosphates they do not break down or lose potency at high temperatures. Moreover they enable alkaline cleaners to solubilize metallic compounds such as rust, scale, iron, and zinc phosphate conversion coatings, and drawing compounds.

#### BUFFERING AGENTS

Buffering agents or buffer salts maintain the optimum pH range for maximum detergency of soaps and other surface-active agents. Each cleaning solution has a particular pH range of greater effectiveness. Buffering agents are designed to keep the solution within this range despite contamination by acidic or alkaline soils during cleaning.

#### INHIBITORS

Inhibitors are silicates or chromates added to highly alkaline detergents to allow their use with non-ferrous metals such as aluminum, copper, lead, zinc and tin. They are not required when working pieces are composed of ferrous metals of titanium and magnesium alloys. During cleaning inhibitors deposit a thin protective film on the bare metal surfaces as soon as soils are removed to protect attack, pitting or tarnishing.

END

Any questions, comments, suggestions or request for cleaning application laboratory tests please direct to:

#### HESSONIC ULTRASONIC DISTRICT OFFICE

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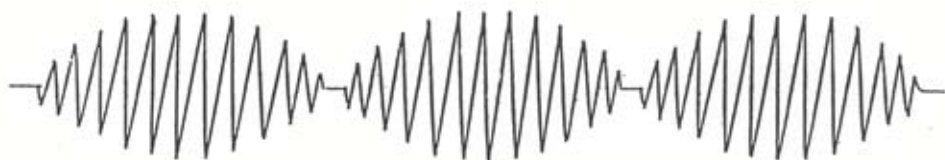
Tel. 435-627-2460    TF 800-552-0372      Fax 435-627-2465

E-mail [Hessoniac@aol.com](mailto:Hessoniac@aol.com)      Web site [www.hessoniac.com](http://www.hessoniac.com)

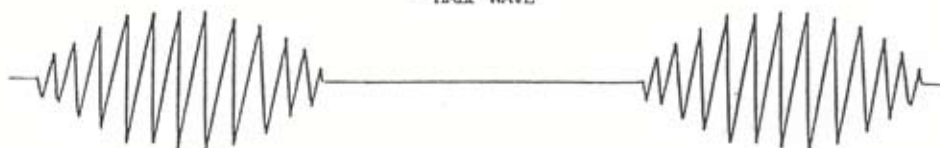
DRAWING A

FORMS OF ULTRASONIC GENERATOR OUTPUTS

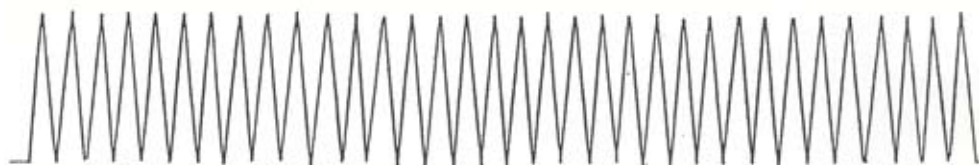
\* FULL WAVE



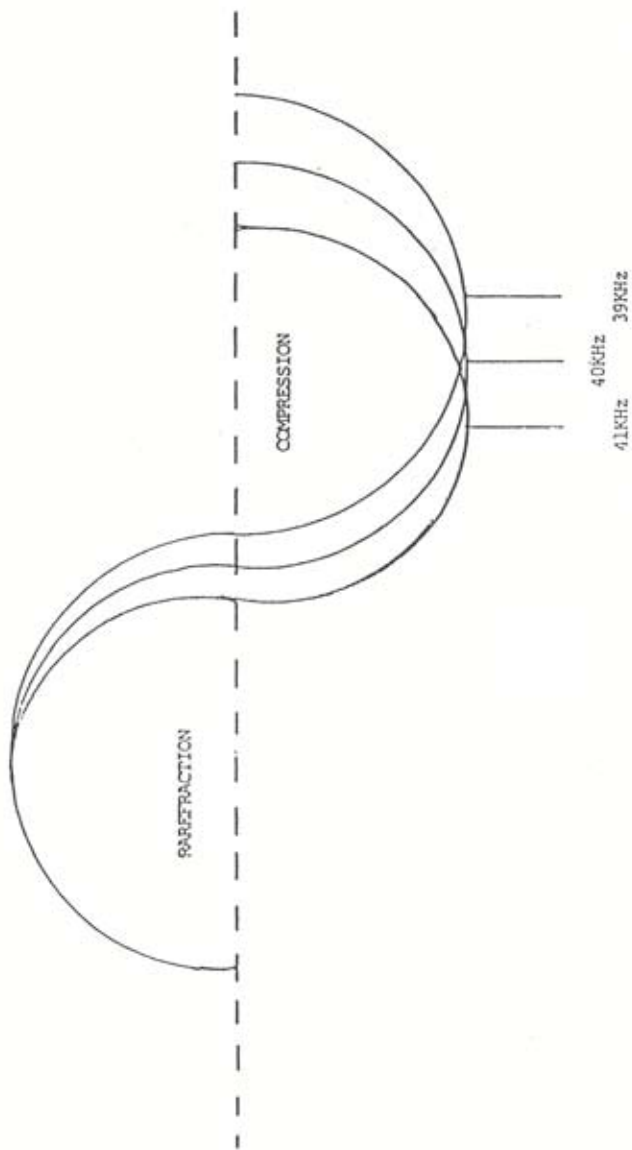
\* HALF WAVE



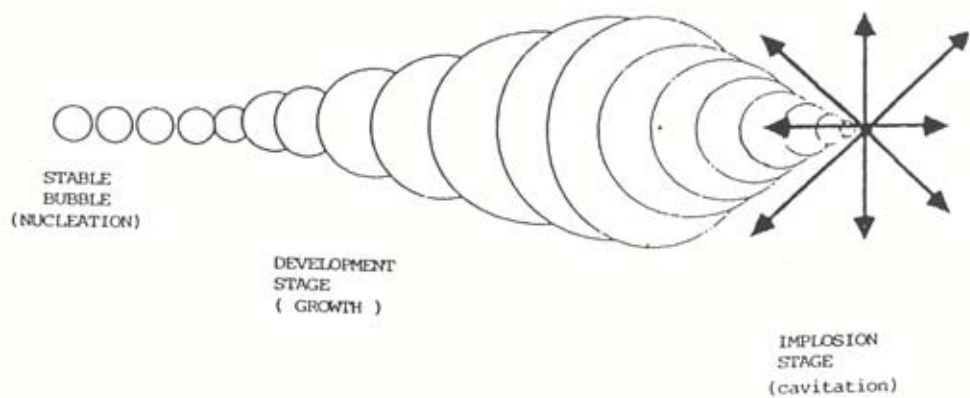
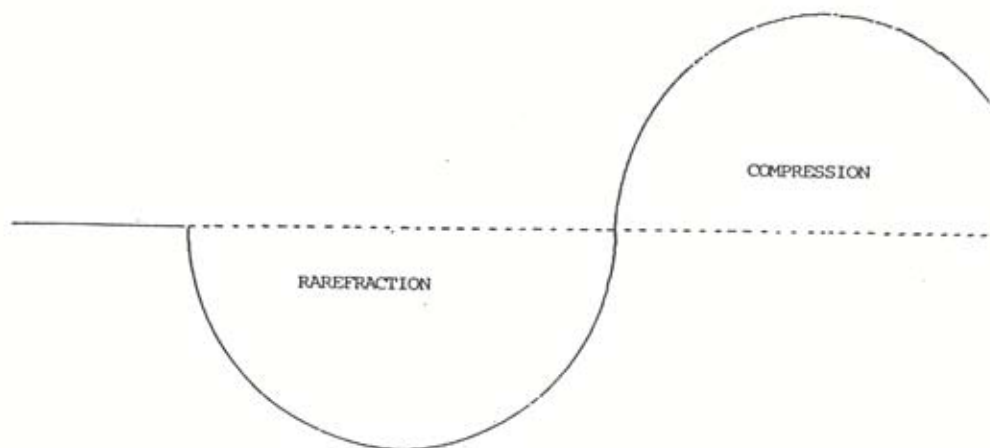
\* CONTINUOUS WAVE



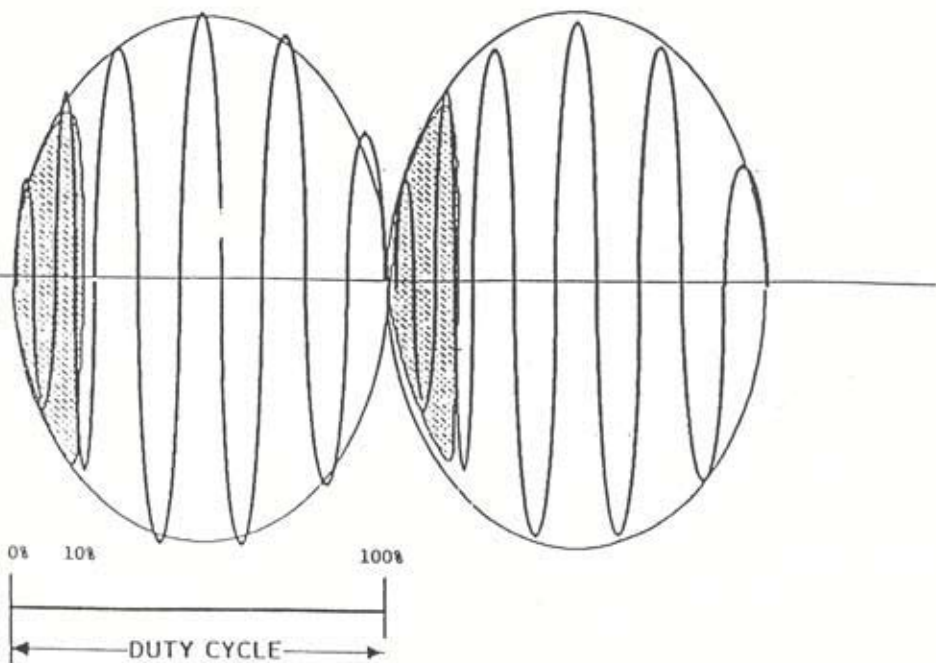
\*SWEEP FREQUENCY



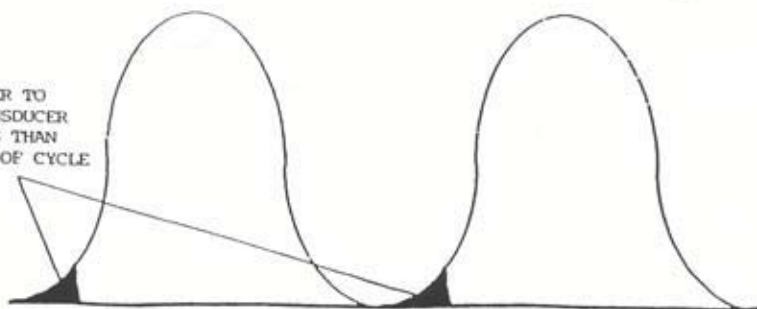
BY CHANGING THE GENERATOR OUTPUT FREQUENCY ( WITHIN LIMITS ) WE CHANGE THE LOCATION OF THE NODE, ANTINODE HELPING TO ELIMINATE DEAD SPOTS ( STANDING WAVES )



\* THIS IS NOT SWEEP FREQUENCY

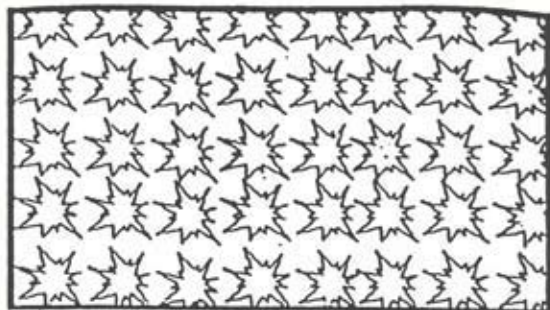


POWER TO  
TRANSDUCER  
LESS THAN  
2% OF CYCLE



# 68 kHz

*70% more  
implosions  
than 40 kHz*

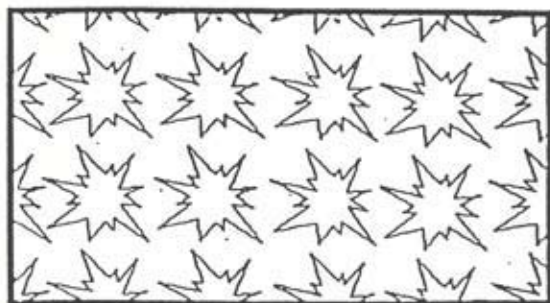


Cavitations at 68 kHz

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# 40 kHz

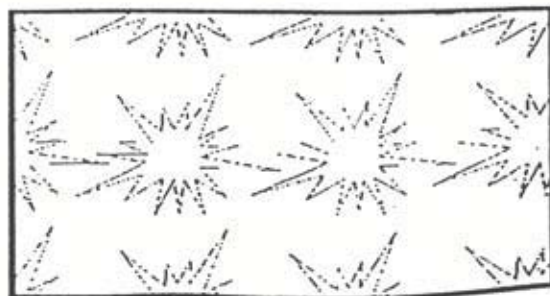
*60% more  
implosions  
than 25 kHz*



Cavitations at 40 kHz

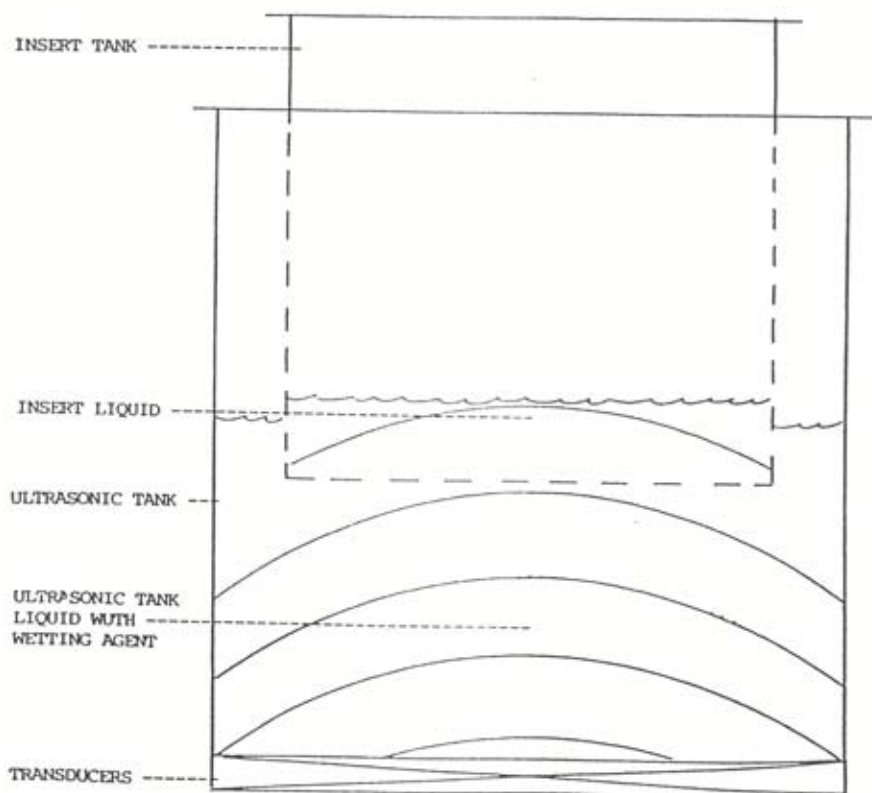
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# 25 kHz

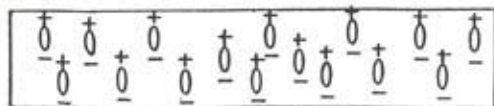


Cavitations at 25 kHz

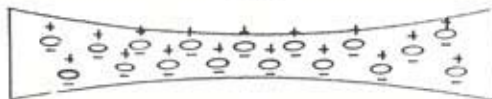
## USE OF AN INSERT TANK TO CAVITATE A SECONDARY SOLUTION



## POLARIZED PIEZOELECTRIC CERAMIC WITH DIPOLES



LIKE POLARITY      CAUSES COMPRESSION



DISSIMILAR POLARITY      CAUSES EXPANSION

