OPERATIONS/OWNERS MANUAL

ULTRASONIC CLEANING SYSTEMS
EW-series - ES-series - SU-series

Most Powerful Ultrasonics In The World!

Syncropower Transducers

ELECTROWAVE ULTRASONICS CORPORATION

The Theory of Cavitation

When a diaphragm or solid object is vibrated rapidly in a liquid, compression and rarefaction waves propagate outward from the radiating surface. At high enough intensity these alternating pressure and vacuum waves cause micron-sized bubbles to form. Since the liquid temperature is below the boiling point, there is insufficient energy to sustain the vapor phase of these microbubbles, and as they condense back to the liquid phase the surrounding molecules rush in to fill the void, in effect colliding and rebounding as a shock wave, this is termed 'Cavitation'.

Shock waves are discontinuities in pressure and temperature, which in a collapsing microbubble may be on the order of 15K - 150K psi. and 5K - 10K °C respectively, these values are more than enough to generate ions and create free radicals.

The cavitation bubble ideally is a bubble of the vapor of the liquid being sonicated, without any air (gasses). While the cavitating bubble contains the gas-phase of the parent liquid (which is steam in aqueous solutions), any other gasses dissolved or suspended as microbubbles will be forced out of the solution and into the cavitating bubble. When the vapor condenses to the liquid phase, these gasses will remain behind in the bubble. The evacuated bubble will then take in any gases of the parent liquid, and upon collapse of the void, these out-gased materials will form visible bubbles. Continued sonication will cause these bubbles to coalesce and rise out, thus degassing and improving cavitational intensity. Solvents with high gas absorption coefficients (Freons) will only degass to a limited extent at atmospheric pressure and will show limited cavitational intensity.

Degassing can be acheived more quickly in aqueous solutions by adding small amounts of surfactant, this will lower the cavitation threshold by reducing surface tension on the cavitating bubble, but may ultimately decrease intensity by reducing the sound propagation velocity in the solution. In general, *increasing* the cavitational threshold *increases* intensity once cavitation is reached, so that the more difficult it is to produce cavitation, the higher the shock wave (intensity) will be if there is enough power available to overcome the hydrostatic pressure.

Hydrostatic Pressure

The cavitation threshold is directly proportional to the hydrostatic pressure applied to the liquid. The threshold of a liquid can be increased if the hydrostatic pressure is maintained long enough for gas to diffuse out of the nucleus.

Surface Tension

The cavitation threshold varies inversely with surface tension.

Temperature

The cavitation threshold varies inversely with temperature. The decrease in threshold with increasing temperature is linear, although near the boiling point the threshold drops to zero.

Solid Contaminates

The cavitation threshold increases with decreasing numbers and size of solid contaminates. Theoretically pure water would require impractically high power levels (>20K psi) to initiate cavitation. Because water is never really pure, less than 18 psi acoustic pressure will cavitate most tap water.

Dissolved Ion Concentration

The cavitation threshold as a function of dissolved ions is not simple or straightforward, however, in general as the concentration increases, the threshold, relative to extremely low concentrations, also increases.

BUBBLES HOTTER THAN THE SUN?

Sound consists of alternating expansion and compression cycles traveling through a medium. Compression cycles push molecules together, while expansion cycles pull them apart. In a liquid, the expansion cycle of ultrasound can generate sufficient negative pressure to create bubbles (cavities) in the liquid. Ultrasonic cleaning is based on the effects caused by the creation and collapse of these bubbles.

The bubbles form at microscopic points where gases are either dissolved in the liquid or are trapped in other contaminating particles. The negative pressure wave causes the gas to expand, creating a bubble, as the expansion cycle continues, the liquid surrounding the bubble begins to vaporize into the negatively pressurized cavity. The importance of cavitation is not so much how the bubbles form; rather, it is what happens when they collapse. As the bubble reaches the size where the internal negative pressure is greater than the external force which created it, and can no longer absorb energy from the sound wave, it implodes.

The rapid compression of gases and vapors inside the bubble creates enormous temperatures which can be measured at the surface on the order of >5000°C, similar to the surface of the Sun and internally may be as hot as the core of a star. At the same time the pressure inside the bubble is approximately 1000 atmospheres, equivalent to pressures in the Mariana Trench, the deepest point in the worlds oceans.

Because the bubbles are so small compared to the volume of the surrounding liquid, the heat dissipates rapidly and the ambient conditions are essentially unaffected. It is estimated that the cooling following the collapse of a cavitation bubble is on the order of 10 billion °C/s, by comparison, plunging red-hot steel into liquid nitrogen produces cooling of only a few thousand °C/s.

The consequences of cavitation vary depending on the materials involved. The presence of a solid renders the implosion asymmetric, with a jet of liquid forming on the side of the bubble opposite the solid. This microjet blows through the bubble at speeds of approximately 350 ft/s, a force strong enough to puncture metals.

In addition to extreme temperatures and pressures, cavitational collapse produces shock waves in the surrounding liquid which may be on the order of 10,000 atmospheres and capable of slamming particles into fussion-type reactions, as evidenced by metal slurries with melting temperatures up to 3000°C which show this effect.

This combination of high temperatures, high pressures and rapid cooling produces conditions unattainable by any other method.

WARNINGS

Do NOT plug unit in until tank is at least HALF full of liquid (3 inches for EW-500 thru EW-1000 series units).

High Voltage [100-1000vRMS]. Do NOT operate without proper grounding.

Do NOT operate the unit dry. Never run heater (optional) if liquid level falls below HALF.

Keep hands OUT of unit while in operation.

While filling or emptying the tank, unplug the power cord.

Keep exterior of unit dry. Do NOT set in liquid.

Do NOT operate without properly functioning timer.

Avoid contact with solutions and provide adequate ventilation.

Do NOT set heavy objects on bottom of tank, use basket.

Do NOT overfill the tank with parts to be cleaned.

Use correct voltage only.

OPERATION

1.) Fill unit at least HALF full of liquid before plugging in (6 inches for EW-500 thru EW-1000 series systems).

2.) Plug into properly grounded outlet.

3.) Turn timer clockwise to 3 - 5 minute mark and allow ultrasound to 'degass' the liquid, prior to cleaning.

4.) Place object to be cleaned into tank. Baskets, beakers and carrier baths may be used.

5.) Fill tank to approximately one-half inch above parts to be cleaned.

6.) Turn timer clockwise to an 'ON' position, cleaning time may be as little as 15 - 90 seconds, or as long as several minutes, depending on the cleaning solution and the particular contaminate.

7.) If heater option is being used, liquid level must be monitored to prevent liquid from dropping below HALF full.

WARRANTY

Electrowave ultrasonic cleaners, when used in accordance with manufacturer's instructions are guaranteed for Eighteen (18) months in ES and SU-series systems, and one year in EW-series systems from date of shipment. Warranty covers all defective parts, including labor. Stainless steel tanks and cabinets are guaranteed for five (5) years in general, and for ten (10) years against cavitational erosion. Transducer bonding is unconditionally guaranteed for the life of the system, which under normal conditions could easily be 10 to 20 years or more.

Normal operation of this unit will not require periodic service. If the unit fails to operate satisfactorily, return it to Electrowave Ultrasonic Corporation for inspection and repair. No user servicable parts inside, unauthorized service of unit may void warranty.

DO NOT RETURN ACCESSORIES (BASKETS, COVERS ETC.) AS WE CANNOT BE RESPONSIBLE FOR THESE ITEMS.

Ultra-Thin Aluminum Metal Erosion Test For Cavitation In Liquids

The most precise method of determining cavitation intensities is by the use of a cavitation meter. ELECTROWAVE EW-100 series cavitation meters can be used in most any liquid at frequency ranges of 5KHz to 500KHz. In lieu of a cavitation meter the following metal erosion test may be employed:

Procedure

To an ultrasonically cavitating body (or suspected one) of water, with reduced surface tension*, is added a 1.5 in.sq. (3.8 cm.sq.) piece of aluminum 'foil' with a constant thickness not to exceed 0.006 in. (0.15 mm).
The 'foil' may float freely within the water, or may be suspended at a standing wave (or half-wave) length [h=nc/2f] by a thin nichrome wire. The test should be conducted with the cavitation intensity at full strength for ten (10) minutes (+-10 seconds), at an optimum temperature of 35°C [See *Comparison Of Ultrasonic Cavitation Intensity In Various Liquids* Chart].
At the end of the test cycle the metal 'foil' is removed and multiple perforations (holes) will be seen as a positive indication for ultrasonic cavitation. Examination may be accomplished with microscope, or simply by eye. If tests are to be conducted at precise wavelengths, the 'foil' may be weighed before and after cavitation.

The above procedure will make an effective test for pronounced cavitation in the frequency range from below 10KHz to over 100KHz. Higher frequencies (>~50KHz) will require more power for this test than lower frequencies [see *Frequency vs. Cavitation Values* Chart]. The failure of this test is indicative only of the power and intensity of the cavitation. Many ultrasonic generators and transducers of low power or intensity may fail this operational checkout, in these cases a cavitation meter of sensitive design must be employed to either prove or discount the presence of cavitation. All ELECTROWAVE ultrasonic cleaners are tested and guaranteed to generate a cavitational intensity of >750µA/sq.cm.
Other methods have been devised for determining ultrasonic cavitation, most of them are at best difficult to repeat and in many cases are subjective. The Ultra-Thin Aluminum Metal Erosion Test should provide the tester with an objective method for determining pronounced cavitation in liquid, any commercially available aluminum foil may be used.
*In the above procedure a nonionic surfactant is added to reduce surface tension and facilitate ultrasonic 'activity', however, better results may be obtained by allowing the water to 'degas'. Tap water has a considerable amount of dissolved air and other gasses which may be largely removed by sonicating for 5 to 10 minutes prior to the aluminum foil test.

Frequency (KHz)	Half-Wavelength Heights [h=nc/2f] (Millimeters)	Bubble Radius (Microns)	Relative Number Of Bubbles At Equal Watt Density (Per Second)
10	74.3	330	10
20	37.2	165	20
30	24.8	110	30
40	18.6	83	40
50	14.9	66	50
60	12.4	55	60
70	10.6	47	70
80	9.3	41	80
90	8.3	37	90
100	7.4	33	100

FREQUENCY vs. CAVITATION VALUES

Values For Water Only

Frequency (KHz)	Bubble Radius $[R_o = (3\gamma p_o/\partial(2\pi f)^2)^{1/2}]$ (Microns)	Bubble Volume (Intensity) (Cubic Millimeters)	Intensity Ratios (Cavitation Deferential)	Surface Area (Square Millimeters)	Surface Area Ratios	Relative Number of Bubbles At Equal Watt Density (Per Second)	Number of Bubbles Per Milliliter At Maximum Watt Density (Per Cycle)
10	330	0.15	(100)	1.37	(100)	10	3.5K
20	165	0.019	(12.5)	0.34	(25)	20	27.8K
30	110	0.006	(3.70)	0.15	(11.1)	30	94K
40	83	0.0024	(1.56)	0.086	(6.25)	40	218.6K
50	66	0.0012	(0.80)	0.055	(4.0)	50	435K
60	55	0.0007	(0.46)	0.038	(2.76)	60	751K
70	47	0.0004	(0.29)	0.028	(2.03)	70	1204K
80	41	0.0003	(0.19)	0.021	(1.56)	80	1814K
90	37	0.0002	(0.14)	0.017	(1.26)	90	2468K
100	33	0.00015	(0.10)	0.014	(1)	100	3478K

As can be seen from the above data, as the frequency increases, the number of bubbles (per second) increase proportionally while the size of each bubble decreases proportionally. The intensity (bubble volume) decreases by a factor of 8x for every doubling of the frequency, while the surface area of each bubble decreases by 4x. So although more bubbles (2x) may be present (per second) at twice the frequency, their total surface area (all bubbles combined) is decreased by half, while the amount of power needed to maintain equal bubble volume increases 4x. This should not be confused with the amount of power required for instantaneous intensity *(cavitation deferential)* which remains 8x.

The cycle of each bubble is inversely related to the frequency (20KHz = 1/20,000th second) while the actual number of bubbles are based on the volume of the liquid, its radiation pressure and the total power output (amplitude or *watt density*) of the transducer. In a theoretically infinite volume of liquid with an infinite amount of power, it would be possible to produce an infinite number of cavitating bubbles for each stroke of the transducer at any given frequency. This, of course, would only work in theory since it would imply an infinitely long transducer stroke. In practice, however, with a limited volume of liquid, increasing the amplitude to its maximum point (negating *cavitational unloading*) would eventually result in the formation of so many bubbles that the radiating surface would be pushing against more gas than liquid, at this point any further input of power would result in a decrease in both efficiency and cavitation. This is termed *maximum watt density* and varies from liquid to liquid depending on the radiation pressure and frequency, which is determined by temperature and sound propagation velocity. It must be understood that *maximum watt density* can never be realized due to the incredible pressures and temperatures involved, as well as *cavitational unloading* which causes (especially at high intensities) more bubbles to be produced at the radiating surface.

COMPARISON OF ULTRASONIC CAVITATION INTENSITY IN VARIOUS LIQUIDS

Liquid	Formula	Boil Point(°C)	Maximum Cavitation Intensity For A Half-Wavelength Liquid Column (46 & 22KHz) %	Temperature At Which Cavitation Reaches Maximum Intensity (°C)	Temperature Range Over Which Cavitation Intensity Reaches From 70% - 100% Of Maximum (°C)
WATER	H2O	100	100	35	20 - 50
STYRENE	C6H5C2H3	146	74	37	24 - 53
TOLUENE	C6H5CH3	111	71	29	10 - 40
TETRALIN	C10H12	207	70	55	30 - 105
CYCLOHEXANONE	C6H10O	155	70	36	0 - 45
XYLENE	C6H4(CH3)2	137	64	26	8 - 48
ETHYLENE GLYCOL	C2H4(OH)2	197	61	93	75 - 120
CYCLOPENTANOL	C5H9OH	141	59	49	38 - 70
Trichloroethylene	C2HCl3	87	58	20	0 - 23
GLYCERINE	C3H5(OH)3	290	57	85	75 - 105
n-AMYL ACETATE	CH3COOC5H11	149	57	18	2 - 32
Tetrachloroethylene	C2Cl4	121	56	42	33 - 63
n-BUTYL ACETATE	CH3COOC4H9	126	56	21	-2 - 27
PYRROLE	C4H5N	130	55	40	25 - 75
METHANOL	CH3OH	65	52	19	4 - 23
CHLOROFORM	CHCl3	61	50	-3	-11 - 15
n-AMYL ALCOHOL	C5H11OH	137	47	23	-32 - 46
ETHANOL	C2H5OH	78	46	21	15 - 27
ETHYL ACETATE	CH3COOC2H5	77	45	9	-5 - 16
ACETONE	(CH3)2CO	56	44	-36	-50 - -20
n-BUTYL ALCOHOL	C4H9OH	118	43	32	10 - 45
BENZENE	C6H6	80	43	19	10 - 32
n-PROPANOL	C3H7OH	97	42	27	8 - 44
1,1,1-Trichloroethane	C2H3Cl3	74	41	18	-7 - 20
Methylene Chloride	CH2Cl2	40	38	-40	-60 - -25
METHYL ACETATE	CH3COOCH3	57	38	-32	-40 - -10
i-PROPANOL	(CH3)2CHOH	82	38	16	0 - 30
FORMIC ACID (85%)	HCOOH	101	37	30	25 - 42
TRI-n-BUTYLAMINE	(C4H9)3N	214	37	31	15 - 38
Carbon Tetrachloride	CCl4	77	35	8	0 - 22
CYCLOHEXANOL	C6H11OH	160	23	37	35 - 40
PROPIONIC ACID	C2H5COOH	141	22	32	12 - 45
TRIETHYLAMINE	(C2H5)3N	89	21	1	-12 - 14
FREON 113	C2Cl3F3	48	15	-20	-30 - -5
FREON 11482	C2Br2F4	47	6	8	-5 - 18
ACETIC ACID	CH3COOH	118	6	48	20 - 60

It should be emphasized that the absolute values of cavitation intensity at 22KHz & 46KHz are different, but after setting the water cavitation in each case to 100, the other liquids have the same relative values. Thus it can be supposed that the maxium cavitation intensity value for half-wavelength heights ($h = nc/2f$) is a characteristic value for a given liquid and does not depend on frequency.

A short comment also needs to be made on the fact that the maximum cavitation intensity of water occurs at 35 °C, while it is well known that ultrasonic cleaning in aqueous (water) solutions can be performed with good effect at temperatures around 50°C - 60°C. It is important to note that the agents involved in ultrasonic cleaning are not only cavitation, but also liquid streaming due to radiation pressure of the ultrasound, and chemical activity from substances dissolved in the water such as acids, alkalis or detergents. The cleaning intensity of these agents increase with temperature, and the total activity may produce a stronger cleaning effect at 60°C than at 35°C.

A similar explanation can be applied to the Freons, which according to the above results support only slight cavitation. Their cleaning power with ultrasound is caused by especially high radiation pressure, this depends inversely on the sound propagation velocity, which in Freons is very low. However, when vacuum degassed, solvents such as Freon will cavitate with an intensity similar to that of water (while held in vacuum) , although within seconds after exposure to air the solvent reabsorbs the gas, due to an extremely high gas absorption coefficient, reducing its cavitational intensity by over 6x. Thus, relative cavitational intensities in the above liquids are not primarily related to frequency, density, viscosity, surface tension, vapor pressure, atoms, ions or other colligative properties, but depend almost entirely on the temperature and the amount of dissolved gas in the solution.

SYNCROPOWER® TRANSDUCERS

Since 1954, the engineers and founding companies of ELECTROWAVE ULTRASONICS CORPORATION have developed, manufactured and used many different types of transducers, including magnetostrictive, piezoelectric, and electrostrictive. Based on extensive research and experimentation with many varieties of these different transducer types, ELECTROWAVE has found its patented *SYNCROPOWER* (Q-3) third generation electrostrictive transducers to be absolutely superior in all respects. Over 90% of all ultrasonics that exist in the world today utilize some type of electrostrictive transducer. ELECTROWAVE is among the few companies in the ultrasonic field that produces its own transducer which has a reputation for the highest quality and modern design. ELECTROWAVE engineers pioneered the use of composite electrostrictive transducers known as *SYNCROPOWER* transducers. *SYNCROPOWER* transducers consist of the highest efficiency lead zirconate titanate elements, designed and produced exclusively by ELECTROWAVE. These composite ceramic transducers are unique in function and possess characteristics [d31,d33,g31,g33,k31,k33] that are singularly applicable to the propagation of high power energy. These transducers, with a 98%+ efficiency in converting electrical input to mechanical output have a very low operating temperature and require no external cooling. Watt densities of over 100 W sq.in. are possible with our transducers, although cavitating-liquid ultrasonics typically range from 5 W sq.in. to 15 W sq.in. and higher for experimental applications. Frequencies are most commonly centered at 25KHz and 40KHz, the 40KHz range being by far the predominant choice, although frequencies from 13KHz to 2MHz are readily available upon request.

Permanently attached across the stainless steel bottom and/or sides of ELECTROWAVE tanks by means of an advanced bonding technique, exclusive to ELECTROWAVE, transducers are bolted in place or permanently fixed with a thermoset ceramic composite. No epoxies, cyanoacrylates, or 'glues' of any type are used in ELECTROWAVE ultrasonics. *SYNCROPOWER* transducers are warrantied never to loosen from the tank for the life of the unit. ELECTROWAVE *SYNCROPOWER* transducers surpass in ruggedness and durability all transducers on the market today. They can run at temperatures exceeding 50°C continuously, far above any normal power transducer, and they may be subjected to temperature variations from 0°C to 100°C in seconds, without harm to the transducer or bond line.