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Fundamentals of Ultrasonic & Megasonic Cleaning

Effectively applying ultrasonic and megasonic energy to enhance a variety of cleaning processes

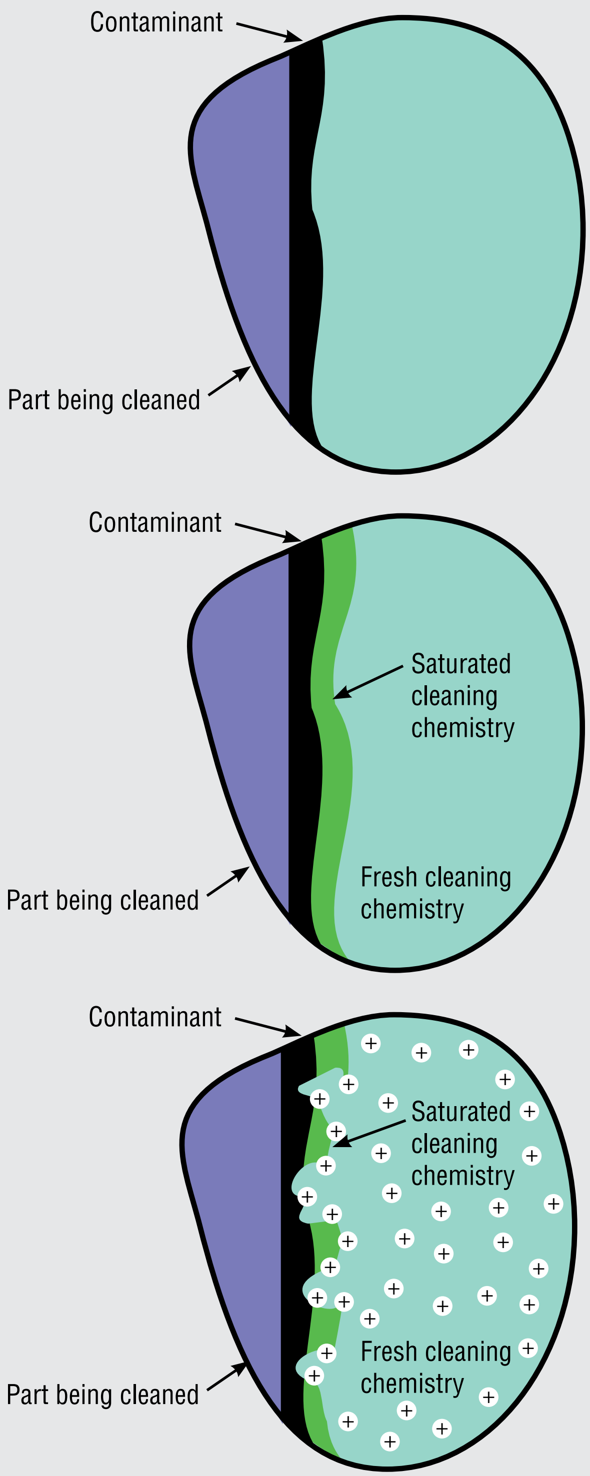
BY BLACKSTONE-NEY ULTRASONICS

Cleaning technology is in a state of change. Vapor degreasing using chlorinated and fluorinated solvents, long the standard for most of industry, was phased out in the interest of ecology. At the same time, cleaning requirements have been continually increasing. Cleanliness has become an important issue in many industries where it never was in the past. And in industries such as electronics, where cleanliness was always important, it has become more critical in support of growing technology. Each advance in technology demands greater attention to cleanliness for its success. As a result, the cleaning industry has been challenged to deliver the necessary cleanliness and has done so through rapid innovation over the past several years. Many of these advances have involved the use of ultrasonic and/or megasonic technologies.

The cleaning industry is in a constant struggle to replace the prior solvent degreasing with alternative "environmentally friendly" means of cleaning. Although water-based, semi-aqueous and petroleum-based chemistries are available as substitutes, they are often less effective as cleaners than solvents and sometimes require a mechanical energy boost to ensure the required levels of cleanliness. Ultrasonic and megasonic energy technology is now used extensively in critical cleaning applications to speed and enhance the cleaning effect of the alternative chemistries.

Ultrasonics and Megasonics

The terms "ultrasonics" and "megasonics" are used to



When removing contaminants by dissolution, the cleaning activity takes place when the cleaning chemistry interacts with the contaminant (top). But as the cleaning chemistry dissolves the contaminant, a saturated layer develops and halts the cleaning action (center). Ultrasonic and megasonic processes can displace the saturated layer to allow fresh chemistry to interact with the contaminant (bottom).

describe the science of sound waves above the limits of human audibility. The frequency of a sound wave determines its tone or pitch. Low frequencies produce low or bass tones. High frequencies produce high or treble tones. Ultrasound is a sound with a pitch so high that it cannot be heard by the human ear. Frequencies above 18 kHz are usually considered to be ultrasonic and frequencies above 350 kHz are often considered to be megasonic. The frequencies typically used for ultrasonic cleaning range from 25,000 cycles per second or 25-270 kHz. The frequencies typically used for megasonic cleaning range from 430 kHz-5 MHz. The most commonly used frequencies for industrial cleaning are those between 20 and 80 kHz. Frequencies above 100 kHz are more commonly used in precision cleaning applications. Self-contained benchtop ultrasonic cleaners are also available and usually operate at frequencies between 46 and 72 kHz.

Benefits in Cleaning and Rinsing

Cleaning in most instances requires that a contaminant be dissolved (in the case of a soluble soil), displaced (in the case of a non-soluble soil) or both dissolved and displaced (in the case of insoluble particles being held by a soluble binder such as oil or grease). The mechanical effect of ultrasonic and megasonic energy can be helpful in both speeding dissolution and displacing particles. Just as it is beneficial in cleaning, ultrasonic and megasonic technology is also beneficial in the rinsing process. Residual cleaning chemicals are removed quickly and completely by ultrasonic and megasonic rinsing.

In removing a contaminant by dissolution, it is necessary for the solvent to come into contact with and dissolve the contaminant. The cleaning activity takes place only at the interface between the cleaning chemicals and the contaminant.

As the cleaning chemicals dissolve the contaminant, a saturated layer develops at the interface between the fresh cleaning chemicals and the contaminant. Once this has happened, cleaning action stops as the saturated chemicals can no longer attack the contaminant and fresh chemicals cannot reach the contaminant.

Ultrasonic cavitation or megasonic microstreaming can effectively displace the saturated layer to allow fresh chemicals to come into contact with the contaminant yet to be removed. This is especially beneficial when cleaning irregular surfaces or internal passageways.

Some contaminants are composed of insoluble particles loosely attached and held in place by ionic or cohesive forces. These particles need only be displaced sufficiently to break the attractive forces in order to be removed.

Cavitation, implosion and microstreaming, as a result of ultrasonic or megasonic activity, displace and remove loosely held contaminants such as dust from surfaces. For this process to be effective, the coupling medium must be capable of wetting the particles to be removed.

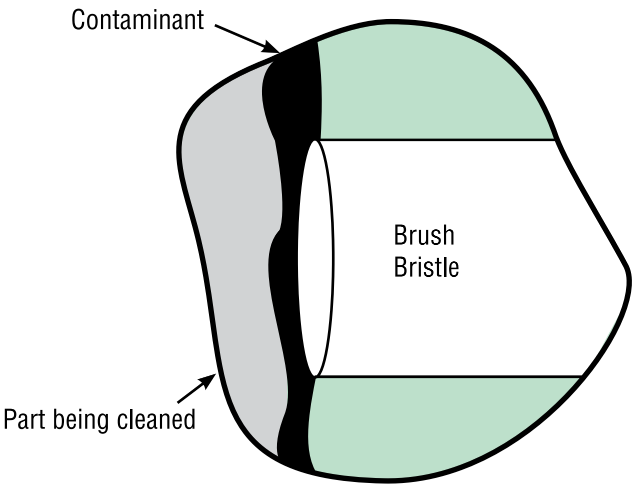
Complex Contaminants

Of course, surface contaminations can be more complex in nature, consisting of both soluble and insoluble components. The effect of ultrasonics or megasonics is substantially the same in these cases, as the mechanical micro-agitation helps speed both the dissolution of soluble contaminants and the displacement of insoluble particles. Ultrasonic activity has also been demonstrated to speed or enhance the effect of many chemical reactions. This is thought to be caused mostly by the high energy levels created as high pressures and temperatures are created at the implosion sites. It is likely that the superior results achieved in many ultrasonic and megasonic cleaning operations may be at least partially attributed to the sonochemistry effect.

It is also important to remember that surfaces that require cleaning are seldom flat, and are more likely to include hills, valleys and other geometric convolutions. In these instances, ultrasonic and megasonic energy technology has been proven to be even more effective at enhancing cleaning than other methods such as spray washing, brushing, turbulation, air agitation and even electro-cleaning. The ability of ultrasonic and sweeping megasonic activity to penetrate and assist the cleaning of interior surfaces of complex parts is also especially noteworthy.

Making it Work

Adding ultrasonic or megasonic energy to an existing cleaning system requires an ultrasonic or megasonic transducer and power supply or generator. The generator supplies electrical



When a surface is not flat, as is typically the case, ultrasonic and megasonic cleaning can prove even more effective than brushing or other methods such as spray washing or air agitation.

Generators are used to convert electrical energy from typical alternating current of 50 or 60 Hz to electrical energy at ultrasonic or megasonic frequencies.

energy at the desired ultrasonic or megasonic frequency. The transducer converts the electrical energy from the ultrasonic or megasonic generator into mechanical vibrations.

The ultrasonic or megasonic generator converts electrical energy from the line, which is typically alternating current at 50 or 60 Hz, to electrical energy at the desired frequency. This is accomplished in a number of ways by various equipment manufacturers. Nearly all current ultrasonic and megasonic generators use solid state technology.

Several innovations in generator technology enhance the effectiveness of ultrasonic and megasonic cleaning equipment. These include slowly or rapidly pulsing the energy on and off; modulating or "sweeping" the frequency of the generator output around the central operating frequency; and "dualsweep," where the sweep rate is constantly changing to eliminate physical resonating of the parts being cleaned. The most advanced ultrasonic and megasonic generators have provisions for adjusting a variety of output parameters to customize the ultrasonic and megasonic energy output for specific tasks.

Cleaning chemical selection is extremely important to the overall success of the ultrasonic or megasonic cleaning process.

In pulse operation, the ultrasonic or megasonic energy is turned on and off at varying rates. The percentage of time that the energy is on may also be changed to produce varied results. At slower pulse rates, more rapid degassing of liquids occurs as coalescing bubbles of air are given an opportunity to rise to the surface of the liquid during the time the energy is off. At more rapid pulse rates, the cleaning process may be enhanced as repeated high energy "bursts" of ultrasonic or megasonic energy occur each time the energy source is turned on.

In sweep operation, the frequency of the output of the ultrasonic or megasonic generator is modulated around a central frequency, which may itself be adjustable. Changing the speed and magnitude of the frequency modulation produces various effects. The frequency may be modulated from once every several seconds to several hundred times per second, with the magnitude of variation ranging from 2-30 kHz. Sweep may be used to prevent damage to extremely delicate parts or to reduce the effects of standing waves in cleaning tanks. Sweep operation may also be found useful in facilitating the cavitation of terpenes and petroleum-based chemistries. A combination of pulse and sweep operation may provide even better results when the cavitation of terpenes and petroleum-based chemistries is required.

Cleaning Equipment

Ultrasonic and megasonic cleaning equipment ranges from small tabletop units often found in dental offices or jewelry stores to huge systems with capacities of several thousand gallons used in a variety of industrial applications. Selection or design of the proper equipment is paramount in the success of any cleaning application.

The simplest application may require only a simple heated tank cleaner with rinsing to be done in a sink or in a separate container. More sophisticated cleaning systems include one or more rinses, additional process tanks and hot air dryers. Automation is often added to reduce labor and guarantee process consistency.

The largest installations use immersible ultrasonic or megasonic transducers that can be mounted on the sides or bottom of cleaning tanks of nearly any size. Immersible ultrasonic and megasonic transducers offer maximum flexibility and ease of installation and service.

Heated tank cleaning systems are used in laboratories and for small batch cleaning needs. Console cleaning systems integrate an ultrasonic or megasonic cleaning tank(s), rinse tank(s) and a dryer for batch cleaning. Systems can be automated through the use of a PLC-controlled material handling system.

A wide range of options is offered in custom designed systems. Large-scale installations or retrofitting of existing tanks in plating lines and other such operations can be achieved through the use of modular immersible ultrasonic or megasonic transducers. Ultrasonic or megasonic generators are sometimes housed in climate-controlled enclosures.

Maximizing the Cleaning Process

Effective application of the ultrasonic or megasonic cleaning process requires consideration of a number of parameters. Time, temperature and chemical solution remain as important in ultrasonic and megasonic cleaning as they are in other cleaning technologies; however, other physical factors impact the effectiveness of the ultrasonic or megasonic process. Variables affecting the intensity of ultrasonic and megasonic energy in the liquid are especially important.

Maximizing cavitation of the cleaning liquid is obviously very important to the success of the ultrasonic or megasonic cleaning process. Several variables affect cavitation intensity.

Temperature is an important parameter to be considered because so many liquid properties affecting cavitation intensity are affected by temperature. Temperature changes result in changes in viscosity, the solubility of gas in the liquid, the diffusion rate of dissolved gases in the liquid, and vapor pressure, all of which affect cavitation intensity. In pure water, the cavitation effect is maximized at approximately 160°F.

The viscosity of a liquid must be minimized for maximum cavitation effect. Viscous liquids are sluggish and cannot respond quickly enough to form the cavitation bubbles and violent implosion required to scrub surfaces. For most liquids, viscosity decreases as temperature is increased.

Gas dissolved in the cleaning solution is released during the bubble growth phase of cavitation and prevents the violent implosion required for the desired ultrasonic or sweeping megasonic effect. For the most effective cavitation effect, the cleaning liquid should contain as little dissolved gas as possible. The amount of dissolved gas in a liquid decreases as the liquid temperature is increased.

The diffusion rate of dissolved gases in a liquid is increased at higher temperatures. This means that liquids at higher temperatures give up dissolved gases more readily than those at lower temperatures, which aids in minimizing the amount of dissolved gas in the liquid.

A moderate increase in the temperature of a liquid brings it closer to its vapor pressure, meaning that vaporous cavitation is more easily achieved. Vaporous cavitation, in which the cavitation bubbles are filled with the vapor of the cavitating liquid, is the most effective form of cavitation. As the boiling temperature is approached, however, the cavitation intensity is reduced as the liquid starts to boil at the cavitation sites.

Cavitation density is directly related to ultrasonic or megasonic power at the power levels generally used in ultrasonic and megasonic cleaning systems. As power is increased substantially above the cavitation threshold, cavitation density levels off due to surface cavitation effects.

The energy in each cavitation implosion is inversely related to ultrasonic or megasonic frequency. As the ultrasonic or megasonic frequency is increased, cavitation energy per implosion is reduced because of the smaller size of the cavitation bubbles and their resultant less violent implosion.

Minimizing Dissolved Gas

During the negative pressure portion of the sound wave, the liquid is torn apart and cavitation bubbles start to form. As a negative pressure develops within the bubble, gases dissolved in the cavitating liquid start to diffuse across the boundary into the bubble. As negative pressure is reduced due to the passing of the rarefaction portion of the sound wave and atmospheric pressure is reached, the cavitation bubble starts to collapse due to its own surface tension. During the compression portion of the sound wave, any gas which diffused into the bubble is compressed and finally starts to diffuse across the boundary again to re-enter the liquid.

This process, however, is never complete as long as the bubble contains gas, since the diffusion out of the bubble does not start until the bubble is compressed. And once the bubble is compressed, the boundary surface available for diffusion is reduced. As a result, cavitation bubbles formed in liquids containing gas do not collapse all the way to implosion, but rather, result in a small pocket of compressed gas in the liquid. This phenomenon can be useful in degassing liquids. The small gas bubbles

Small, self-contained, single-tank and bench-top ultrasonic units are designed to allow ultrasonic cleaning in small-scale parts washing applications, including doctors' offices and jewelry stores.

group together until they finally become sufficiently buoyant to come to the surface of the liquid.

Maximizing Overall Cleaning Effect

Cleaning chemical selection is extremely important to the overall success of the ultrasonic or megasonic cleaning process. The selected chemical must be compatible with the base metal being cleaned and have the capability to remove the soils that are present. It must also cavitate well. Most cleaning chemicals can be used satisfactorily with ultrasonics or megasonics. Some are formulated especially for use with ultrasonics and megasonics. However, the non-foaming formulations normally used in spray washing applications should be avoided. Highly wetted formulations are preferred. Many of the new petroleum cleaners, as well as petroleum- and terpene-based semi-aqueous cleaners, are compatible with ultrasonics and megasonics. Use of these formulations may require some special equipment considerations, such as increased ultrasonic or megasonic power, to be effective.

Temperature was mentioned earlier as being important to achieving maximum cavitation. The effectiveness of the cleaning chemical is also related to temperature. Although the cavitation effect is maximized in pure water at a temperature of approximately 160°F, optimum cleaning is often seen at higher or lower temperatures because of the effect that temperature has on the cleaning chemical. As a general rule, each chemical will perform best at its recommended process temperature, regardless of the temperature effect on the ultrasonics or megasonics. For example, although the maximum ultrasonic effect is achieved at 160°F, most highly caustic cleaners are used at a temperature of 180°F to 190°F because the chemical effect is greatly enhanced by the added temperature. Other cleaners may be found to break down and lose their effectiveness if used at temperatures in excess of as low as 140°F. The best practice is to use a chemical at its maximum recommended temperature not exceeding 190°F.

Degassing of cleaning solutions is extremely important in achieving satisfactory cleaning results. Fresh solutions or solutions that have cooled must be degassed before proceeding with cleaning. Degassing is done after the chemical is added and is accomplished by operating the ultrasonic or megasonic energy and raising the solution temperature. The time required

Immersible ultrasonic transducers are hermetically sealed, modular stainless steel units that can be designed into new systems or retrofitted into existing systems to add ultrasonic capability.

Cleaning equipment for ultra-precision, critical cleaning applications can incorporate high-speed automation; sanitary plumbing; QDRs; capillary, HEPA and infrared drying; filtration systems and environmental enclosures.

for degassing varies considerably, based on tank capacity and solution temperature, and may range from several minutes for a small tank to an hour or more for a large tank. An unheated tank may require several hours to degas. Degassing is complete when small bubbles of gas cannot be seen rising to the surface of the liquid and a pattern of ripples can be seen.

The ultrasonic and megasonic power delivered to the cleaning tank must be adequate to cavitate the entire volume of liquid with the workload in place. Watts per gallon is a unit of measure often used to measure the level of ultrasonic or megasonic power in a cleaning tank. As tank volume is increased, the number of watts per gallon required to achieve the required performance is reduced. Additional ultrasonic or megasonic power may be required to clean parts that are very massive or parts with a high ratio of surface to mass. If a wide variety of parts is to be cleaned in a single cleaning system, a power control is recommended to allow the power to be adjusted as required for various cleaning needs. Exposure of part surfaces to both the cleaning chemical and ultrasonic or megasonic energy is important for effective cleaning. Care must be taken to ensure that all surfaces of the parts being cleaned are flooded with the cleaning liquid. Parts baskets and fixtures must be designed to allow penetration of ultrasonic or megasonic energy and to position the parts to assure that they are exposed to the energy. It is often necessary to individually rack parts in a specific orientation or rotate them during the cleaning process to thoroughly clean internal passages and blind holes.

State of the Art

The latest advance in the field of ultrasonics and megasonics employs the use of generators that produce multiple frequencies and transducers that operate at the frequencies delivered by the generators. An example of this is Blackstone-Ney's multiMeg generator and megasonic transducer array that has two megasonic frequencies and four modes of operation. By supplying a control code to the generator, the multiMEG will operate at 430 kHz, 1.3 MHz, sweeping 430 kHz or sweeping 1.3 MHz. Using a combination of modes in a process has produced better results than is possible with single frequency equipment.

Properly implemented, ultrasonic or megasonic energy can significantly improve the speed and effectiveness of many immersion cleaning and rinsing processes. It is especially beneficial in increasing the effectiveness of today's preferred aqueous cleaning chemistries and, in fact, is necessary in many applications to achieve the desired level of cleanliness. With ultrasonics and megasonics, aqueous chemistries can often give results surpassing those previously achieved using solvents. Ultrasonics and megasonics are not technologies of the future—they are very much technologies of today. **PC**

BLACKSTONE-NEY ULTRASONICS is responsible for many innovations in ultrasonic generator and transducer technology. The company is a division of Cleaning Technologies Group, which can be reached at 513-870-0100 or *ctgclean.com*.

CONTACTS IN ULTRASONICS

To find a list of suppliers of ultrasonic cleaning equipment, turn to page 51, or visit *short.processcleaning.com/usuppliers*

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