An Explanation of Ultrasonic Cleaning

Ultrasonic cleaning is a result of sound waves introduced into a cleaning liquid by means of a series of "transducers" mounted to the cleaning tank. The sound travels throughout the tank and creates waves of compression and expansion in the liquid. In the compression wave, the molecules of the cleaning liquid are compressed together tightly. Conversely, in the expansion wave, the molecules are pulled apart rapidly. The expansion is so dramatic, that the molecules are ripped apart creating microscopic bubbles. The bubbles are not seen by the naked eye since they are so small and exist for only a split second of time. The bubbles contain a partial vacuum while they exist. As the pressure around the bubbles become great, the fluid around the bubble rushes in, collapsing the bubble very rapidly. When this occurs, a jet of liquid is created that may travel at this very high rate. They rise in temperature to as high as 5000 degrees C, which is roughly the temperature of the surface of the sun. This extreme temperature, combined with the liquid jet velocity provides a very intense cleaning action in a minute area. Because of the very short duration of the bubble expansion and collapse cycle, the liquid surrounding the bubble quickly absorbs the heat and the area cools quickly. As a result, the tank and liquid becomes only warm and does not heat up due to the introduction of parts during the cleaning process.

The Application of Ultrasonic Cleaning

Many articles exist describing "how ultrasonic cleaning works". The goal of this article is to help develop an understanding of the various components that ensure good ultrasonic cleaning.

First, establish a cleaning need, along with a determination as to how to measure the level of cleanliness. A few examples of measuring cleanliness include various levels of particle count, miscroscopic inspection, and a variety of adhesion tests, including the clear tape test that has the ability to remove additional contamination. These are just a few examples of cleanliness measurement.

There are seven major concerns related to successful ultrasonic cleaning:

1. **Time**
2. **Temperature**
3. **Chemistry**
4. **Proximity to the transducer/part fixture design**
5. **Ultrasonic output frequency**
6. **Watts per gallon**
7. **Loading - the volume (configuration) of the part being cleaned**

TIME:

Typical cleaning times may vary tremendously - how dirty is the part and how clean is clean.
As a place to start, a normal trial period is two to ten minutes, since very few parts are sufficiently clean within a few seconds. Ultrasonic cleaning is not just a quick dip and zap, it's clean. Pre-cleaning may be required to remove gross contamination or to chemically prepare the parts for a final clean. Some applications require more than one ultrasonic cleaning stage to complete the required cleaning. Ultrasonic agitated rinsing is required in some cases to more thoroughly remove the wash chemicals.

TEMPERATURE/CHEMISTRY:

Temperature and chemistry are closely related. Generally, ultrasonic cleaning in an aqueous solution is optimum at 140 degree F. Some high pH solutions will require the temperature to be higher to enhance the synergistic effect of the chemistry. The chemical pH is a good place to start; however, chemistry is not the subject of this article.

The following should be considered the main components of aqeous ultrasonic cleaning chemistry:

A. **Water - hard, soft, DI or distilled**
B. **pH**
C.
   Surfactants
   Wetting agents
   Dispersants
   Emulsifiers
   Saponifiers
D.
   Optional ingredients
   Sequestrants
   Inhibitors
   Buffering agents
   Defoamers

The chemical formulation must consider all of the above characteristics.

Some chemicals that are designed for spray cleaning, or that include rust inhibitors, are not suitable for ultrasonic cleaning.

PROXIMITY TO THE TRANSDUCER:

The procedure for ultrasonic cleaning is generally as follows: Put parts in basket and place basket through three or four process steps; ultrasonic wash, spray rinse (optional), immersion rinse, dry. Some parts loaded in baskets can mask or shadow from the radiated surface of the ultrasonic transducers. Most ultrasonic cleaning systems are designed for specific applications. Bottom-mounted transducers or side-mounted transducers are decided upon during the process design stage. Automated systems must specifically address the location of the transducers to insure uniformity of the cleaning. Some parts require individual fixturing to separate the part for cleaning or subsequent processes. Some parts require slow rotating or vertical motion during the cleaning to insure critical cleanliness.

ULTRASONIC OUTPUT FREQUENCY:

Many technical articles claim that high frequencies penetrate more and lower frequencies are more aggressive. The majority of the ultrasonic cleaning that is done in industrial applications today uses 40 kHz as the base frequency. Lower frequencies, such as 20 - 25 kHz, are used for large masses of metal where ultrasonic erosion is of little consequence. The large mass dampens or absorbs a great amount of the ultrasonic cleaning power.

WATTS PER GALLON:

In general, smaller parts, requiring more critical cleaning, require higher watts per gallon to achieve the desired level of cleanliness. Most industrial ultrasonic cleaning systems use watt density from 50 - 100 watts per gallon. However, there is what is known as "the large tank phenomenon", which indicates that tanks over 50 gallons usually requie only about 20 watts per gallon. The only explanation available is a point of diminishing returns with regard to ultrasonic power.

LOADING:

Loading of the part(s) to be cleaned must be considered, with regard to the shape and density. A large dense mass will not allow internal surfaces to be thoroughly cleaned (i.e., metal castings). A rule of thumb for loading is that the load by weight should be less than the weight of half the water volume, i.e., in 5 gallons, approximately 40 lbs. of water, the maximum workload should be less than 20 pounds. In some cases, it is better to ultrasonically clean two smaller loads, rather than one larger load.

The above information is not meant to give all the details to utilize ultrasonic cleaning techniques. This information is to help the process designer gain some insight into the variables of industrial ultrasonic cleaning.

CLEANING BATH CARD

A New Acronym is Born for Precision Cleaning Applications

by Malcolm McLaughlin

In the past, TACT — Time, Agitation, Chemistry and Temperature — has been a useful acronym for remembering critical cleaning essentials. However, it leaves out four very important prerequisites for critical cleaning, including rinsing, drying, before-cleaning, and after-cleaning. Therefore, a new acronym that will include these four important activities is needed – BATH CARD:

1. **B**efore cleaning handling
2. **A**gitation
3. **T**ime
4. **H**eat
5. **C**leaner
6. **A**fter cleaning handling
7. **R**inse used
8. **D**rying method

Successful critical cleaning requires understanding and controlling each of these interrelated variables since they all enhance part quality or product purity in critical cleaning operations such as medical device manufacturing, metal surface preparation, optics assembly and electronic component assembly. Think of BATH CARD as your pass to successful cleaning.

Before Cleaning

The way parts and substrates are handled prior to cleaning can have a significant impact on their degree of difficulty in cleaning. Soils can be more difficult to clean if they are:

- Allowed to dry, set up and cross link
- Stored in a dirty environment
- Stored in a humid or corrosive environment.

As a rule, it is important to clean parts as soon as feasible after they are soiled. In some instances it makes sense to take parts directly from a manufacturing process and put them into a soak solution where they may be able to sit for extended periods of time prior to cleaning.

Alternatively, parts can be placed in protective packaging, dipped in a protective coating or immerse in oil or grease to keep them in a state that will not increase the burden on the cleaning process.

As a general rule, parts and surfaces must be cleaned promptly after becoming soiled to avoid drying and setting up the dirt on them. Clean storage conditions for parts, or proper packing of parts by the parts supplier, can make it easier to successfully clean parts or surfaces.

Agitation
Agitation can be a form of no agitation (such as soaking), or performed through manual (cloth, sponge, brush), ultrasonic, flow-through clean-in-place (for pipes, tanks and tubes), spray cleaning and high-pressure spray cleaning. In general, the more agitation, the more effective the cleaning on bulk soils. As far as choosing the right detergent, there is a broad divide between low-agitation or longer contact time cleaning (manual, soak, ultrasonic) where a high emulsifying, high foaming cleaner is often more effective; and high-agitation or short contact time cleaning (spray washing, parts washers, spray CIP systems, etc, where a high-dispersing, low-foaming cleaner is often more effective.

Cleaning often can be enhanced by presoaking, particularly if soils are dried or baked onto the part to be cleaned. It is always desirable, whenever possible, to clean prior to soils becoming dried or baked onto surfaces.

Different agitation methods are often chosen with (1) time required and (2) number of parts being cleaned as the major considerations. If large numbers of parts must be cleaned quickly, then a fast, high-agitation method such as spray washing often is used with an aggressive detergent. For smaller numbers of batch or batch-continuous quantities of parts, ultrasonic soak cleaning with a milder detergent may be used.

Time
In general, the longer the cleaning time, the more thorough the cleaning. Many cleaning mechanisms such as emulsifying, dissolving, suspending, and penetrating are time-dependent. Up to the point where cleaning has been completed, the longer they're employed, the more cleaning is accomplished.

Cleaning time can be accelerated by increased agitation, more aggressive detergents and by increasing temperature. If agitation, detergent or temperature cannot be increased – perhaps because the substrate is too delicate or the proper equipment is unavailable – then one must be prepared to use longer cleaning times to achieve the desired cleanliness. While manual cleaning may take minutes, and spray cleaning might even take seconds, soaking for hours, or even overnight, may be required to reach similar levels of cleanliness.

There are some instances when long cleaning times may promote substrate corrosion, weakening, or swelling. The optimum cleaning time should be chosen relative to the specific substrate, temperature, cleaning method and detergent.

Heat
In general, higher-temperature cleaning solutions result in better cleaning. In practice, there is typically an optimum temperature for a given combination of cleaning variables. Many soak, manual and ultrasonic cleaning methods work best, for example, at 50°C to 55°C. Many spray washing techniques work best at 60°C to 70°C. Waxy or oily soils are more easily cleaned at somewhat higher temperatures above the melting point of the wax. Particulate soils tend to be more easily cleaned at slightly lower temperatures where dispersions are not broken down.

As a general rule, many cleaning mechanisms follow first order reaction kinetics whereby the cleaning speed doubles with every increase of 10° C. Of course you do not want to use so high a temperature that it damages your substrate.

Cleaner

The cleaner or detergent used should be matched to the desired cleaning method, and the surface and types of soils being cleaned. For instance, a low-foaming detergent should be used for spray or machine cleaning, a good anti-redeposition detergent for soak and ultrasonic cleaning, a high emulsifying and wetting detergent for manual cleaning. The detergent, temperature and degree of agitation should be strong enough to remove the soil to the desired level of cleanliness without harming the substrate being cleaned.

There are some particularly critical aspects to understand in selecting and using a low- or non-foaming detergent for spray or machine washing. It is very important to not have foam when cleaning in or with a machine that relies on spraying for mechanical agitation.

Foam may build up and spill over from the machine creating a mess. Foam will also build up on the substrate and interfere with the mechanical cleaning energy of the spray. And finally, foam may get sucked into recirculation pipes causing problems with pumps in the machine. Foam is formed by the presence of agitation at an air/solution interface when a foaming agent is present.

Surfactants are often foaming agents. Most aqueous cleaners have surfactants in them. There are three basic types of aqueous cleaners that are suitable for machine washing: cleaners with no surfactant, cleaners with non-foaming surfactants, and cleaners with low- or controlled-foam surfactants. There are important differences among these types of cleaners. Remember that foam forms in the presence of an agitated foaming agent where air is present.

Many soils are foaming agents. In particular, soap formed by saponifiers in electronic solder flux cleaning is a foaming agent. A surfactant-free cleaner will not protect against foam formed by soils. You should only clean non-foaming soils with surfactant-free cleaners. A non-foaming cleaner usually has a nonionic polymer surfactant. These surfactants have a unique property of coming out of solution at elevated temperatures and forming an oil slick on top of the solution. This oil slick is a barrier to air contact which stops foam from forming or being stable. These cleaners will suppress foam from soils. They only work properly if the temperature is hot enough. You need to know the minimum temperature at which to use these cleaners.

Finally, there are controlled foam cleaners that usually have limited foam suppressing capabilities. The surfactants themselves do not foam excessively, but they will not be able to control much foam that results from soils.

It is critical that the detergent be scientifically formulated to clean effectively and to rinse away without leaving interfering residues. A scientifically formulated detergent will typically have appropriate surfactant ingredients and non-depositing rinse-aids. The surfactant should have sufficient surface tension lowering properties to assist in proper rinsing. A surface tension below 35 dynes per centimeter for the cleaning solution as used is often sufficient for the surfactant to contribute to good rinsing. Non-depositing rinse-aids can help complete a formulation to meet the rinsing requirements of critical cleaning.

In addition, the detergents should be manufactured with appropriate quality-control procedures. In many critical-cleaning applications it is desirable to choose a detergent that has lot number tracking and can be supplied with certificates of analysis from the manufacturer. These certificates document each lot of detergent to assure consistency and quality control from lot to lot in order to control for potential cleaning failure due to inconsistencies in manufacturing or unannounced formulation changes.

It's a good idea to choose a detergent from a manufacturer that maintains quality control on their raw materials and in turn keeps retained samples of each lot of detergent that is used to be able to respond to concerns about a particular batch.

The detergent should be widely available and economical to use (for optimum economy, a concentrated detergent is typically used at 1:100 to 2:100 dilutions). The detergent concentrate should be diluted according to the manufacturer's instructions; typically, warm (about 50°C) or hot (about 60°C) water is used. Ambient temperature water may be acceptable, especially for presoaking. For difficult soils, very hot water should be used (over 65°C), and the recommended detergent concentration doubled.

After Cleaning

The way in which parts and surfaces are handled after cleaning can impact their cleanliness. For this reason it is important to consider how parts are handled and stored to ensure that the purpose of the cleaning process is maintained. Depending on the environment, it may be advisable to make provisions for a clean storage place or conditions.

It may also be appropriate to determine how long a surface or part will stay clean while stored to determine if it needs to be re-cleaned prior to use. Cleanliness testing can be done to monitor and determine how long a surface remains suitably clean. Humid after-cleaning storage conditions can result in corrosion or condensation that promotes microbial contamination.

Obviously, a dirty after-cleaning environment can recontaminate surfaces. Cleanliness can be maintained by as elaborate a process as sterilizing couple with sterile packaging, or as simple a process as putting a clean tarp over a piece of equipment that has just been cleaned.

Rinse

With aqueous cleaning, the last thing to come into contact with the cleaned surface is the rinse water. A thorough rinse will remove soils that have been cleaned from the surface and any residue from the detergent itself. Rinsing is where much of the actual removal of residues from the vicinity of the surface occurs.

After the residue/detergent mixture is rinsed away, whatever contaminants are present in the rinse water to begin with are potentially going to be deposited on the surface if the rinse water is evaporated. For many applications, it is possible to rinse with tap water and then do a final purified water rinse to remove tap water residues. For higher-level medical device, semiconductor, and electronics cleaning, all rinses should be purified water. It is important to understand that rinsing is mostly a mass displacement mechanism. Rinsing should involve exchanges of water—why a running water rinse is typically the most effective type of rinse.

With soak or ultrasonically agitated rinsing, it is desirable to have two counter-flow cascade rinse tanks with dripping "over the tank" to reduce dragout. In all cases, running water or otherwise agitated rinse is better than a static soak-tank rinse.

Higher levels of cleaning may require the exclusive use of deionized or distilled water and in some cases more than three times the volume of rinse water.

For most cleanroom, electronic-component and circuit-board cleaning, deionized water is preferred over either tap or distilled water because of its lesser potential for metallic cation deposition on sensitive electronic components, leaving conductive residues. On metal parts, the use of deionized rinse water reduces the likelihood of depositing calcium, magnesium, or other water spotting salts. For medical device rinsing, distilled or reverse-osmosis grade water is typically used because it has less organic contaminants.

Drying
Drying can be accomplished by physically removing rinse water or by evaporating rinse water. Physically removing by wiping, blowing, centrifuging, drying fluids, absorption or other physical removal techniques will remove the rinse water before it has a chance to evaporate. Such methods avoid precipitating out any impurities or salts that form water spots. Water removing drying methods also minimizes the risk of corrosion occurring during drying.

Evaporation drying methods such as air drying, heat drying, and vacuum drying can potentially deposit any nonvolatile impurities present in the rinse water, resulting in water spots. Although vacuum drying does evaporate water and can lead to deposits, in many cases the deposits themselves evaporate under the vacuum drying conditions

Drying can affect residues and corrosion since impurities from rinse water can be deposited during evaporation. Water, particularly high-purity rinse water, can be corrosive to metal substrates during heat- and air-drying. The use of physical removal or drying techniques, or the addition of corrosion inhibitors (with the tolerance of corrosion inhibitor residues) to the rinse water, can help minimize such corrosion.

Conclusion
By choosing an appropriate cleaning method, using the right rinsing and drying process, then varying the cleaner, concentration, heat and time, an optimized aqueous-cleaning system can be achieved. To sustain successful cleaning, careful control before, during and after cleaning is equally critical.

About the Author
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