Ultrasonic Cleaning and Surface Finishing

Careful preparation and cleaning of various types of components is *indispensable* prior to their surface treatment or final assembly. Various surface treatment operations that require such care include vacuum deposition, electrodeposition, electroless deposition, various dip coatings, etc. Surface preparation is essential for achieving good and firmly adhered coatings. Trace of residual surface contaminants [**1**] or corrosion can drastically alter surface properties such as wettability, adhesion, and optical or electrical characteristics.

Precision Cleaning

Precision or critical cleaning of components or substrates is the complete removal of undesirable contaminants to a desired preset level, without introducing new contaminants in the process [**2**]. The preset level is normally the minimum level at which no adverse effects take place in a subsequent operation. To achieve the desired cleanliness level, it is critical not to introduce new contaminant(s)into the cleaning process. For example, in an aqueous cleaning process, it is important to have high quality rinse water and minimum of two rinse steps. Otherwise, residual detergent and/or ionics from the rinsing water will be the new contaminants. Re-contamination of cleaned parts with outgassed residues produced from packaging or storing materials is another source [**2-3**].

To meet production and quality demands, one must keep in mind that one essential element is choosing the appropriate cleaning chemistry / process. Moreover, rejected parts are the curse of the assembly line and improper cleaning methods are often to blame. Even beyond the factory floor, improper or inadequate cleaning of a component could directly affect warranty claims [**4**].

Cleaning with ultrasonics

Cleaning with ultrasonics offers several advantages over other conventional cleaning methods. The cleaning action relies on cavitations or micro implosions that are being generated in solution by high intensity ultrasonic waves.

Complete removal of contaminants is achievable, particularly when intricate parts with irregular surfaces or internal passages are being cleaned. The micro mechanical scrubbing action of ultrasonic cavitations is direction-less and can reach wherever there is a liquid or wetted surface. The released energies reach and penetrate deep into crevices, blind holes and areas that are inaccessible to other cleaning methods. The removal of contaminants is consistent and uniform, regardless of the complexity and the geometry of the substrates.

Ultrasonic cleaning uses high frequency sound waves transmitted into a cleaning solution / liquid. When a solution is subjected to the rapid oscillation from the high frequency sound waves, minute vacuum bubbles are generated that grow to certain critical size based on number of variables then implodes. This phenomenon is known as cavitations. When cavitation occur in the vicinity of contaminated surface, mechanically held contamination is released from the surface, soluble materials will rapidly dissolved and oil and similar contaminants are easily displaced with the cleaning chemicals. The released energies reach and penetrate deep into crevices, blind holes and areas that are inaccessible to other cleaning methods (**Figure 1**).

Ultrasonic waves are mechanical pressure waves formed by actuating the ultrasonic transducers with high frequency, high voltage current generated by electronic oscillators (power generators). A typical generator produces ultrasonic frequencies greater than 20 kHz (**Figure 2**).

The transducers most commonly used for generating ultrasonic vibrations are piezoelectric, magnetostrictive, electromagnetic, pneumatic, and other mechanical devices. The piezoelectric is the most widely used technology in cleaning and welding applications. It offers wide range of various frequencies from about 20 kHz to the megasonic range. A recent new transducer invention patented by Crest Ultrasonics Corp. discloses a greater sound energy transmission at very low acoustic impedance for various high frequencies. Numerous benefits are realized from this invention include high quality surface cleanliness and efficient submicron particle removal.

Typical piezoelectric (PZT) transducers are normally mounted on the bottom and/or the sides of the cleaning tanks. The transducers can be mounted in various designs and sizes sealed stainless steel containers and immersed in the cleaning solution / liquid (immersibles). The push-pull transducer rod is a recent immersible transducer design patented by Martin Walter Co. (a subsidiary of Crest Ultrasonics Co.). The latter immersible is made of two PZT transducers mounted on the ends of a titanium rod. The generated ultrasonic waves propagate perpendicularly to the resonating surface. The waves interact with liquid media to generate cavitation implosions.

At a higher frequency of 68 kHz, the total time from nucleation to implosion is estimated to be about one third of that at 25 kHz. The energy released from an implosion in close vicinity to the surface collides with and fragments or disintegrates the contaminants, allowing the detergent or the cleaning solvent to displace it at a very fast rate. The implosion also produces dynamic pressure waves, which carry the fragments away from the surface. The implosion is also accompanied by high-speed micro streaming currents of the liquid molecules.

The abundance of cavities generated in a solution increases with frequency but the energy released by individual cavities decreases and becomes milder, thus ideal for small particle removal (**5**). For example, at lower frequencies (20-30 kHz), a relatively smaller number of high energy powerful cavitations are generated (**Figure 3**).

At higher frequencies (40-200 kHz), more cavitations with moderate or lower energies are formed. Low frequencies are more appropriate for cleaning heavy and large-size components, while mid range frequency (40-60 kHz) ultrasonics is recommended for cleaning various surfaces. Higher frequencies are good for cleaning delicate components and as well for the rinse step. For example, at 68 kHz and 132 kHz the cavitation abundance are high enough and mild enough to efficiently remove detergent films and small particles without inflicting damage on surfaces. Selecting the proper frequency for particular application is very important and must be carefully considered **(Figure 4**).

Ultrasonic Cleaning Equipment

Ultrasonic aqueous batch cleaning equipment consists of at least four steps: ultrasonic wash, minimum of two ultrasonic separate or reverse cascade water rinse tanks and heated recirculated clean air for drying.

An appropriate cleaning process must first be developed and then the number and the size of the stations are determined based on the required yield, total process time and space limitation.

Automation of ultrasonic cleaning system is well established. Automation includes a computerized transport system able to run different processes for various parts simultaneously and data monitoring and acquisition Advantages of automation are numerous, including consistency, achieving desired throughputs and full control on process parameters.

Typical tank size ranges from 10 liters to 2,500 liters, based on the size of the parts, production throughput and the required drying time. The whole machine can be enclosed to provide a clean room environment meeting class 10,000 down to class 100 clean room specifications. Process control and monitoring equipment consists of flow-controls, chemical feed-pumps, in-line particle count, TOC measurement, pH, turbidity, conductivity, refractive index, etc. The tanks are typically made of corrosion resistant stainless steel or electropolished stainless steel. Titanium nitride or similar coating is used to extend the lifetime of the radiating surface in the tanks or the immersible transducers.

Cleaning and Chemistry

It is important to realize that the use of ultrasonics does not eliminate the need for the proper cleaning chemicals and the right process parameters.

Furthermore, the chemical composition of the cleaning medium (for aqueous cleaning or solvent cleaning) is an important factor in achieving the complete removal of various contaminants and without inflicting any damage to the components.

Cleaning with Ultrasonics using only plain water is workable, but only for short duration. The question then is for How Long Is Going To Be Before Failing to Clean? Cleaning is more complex in nature than just extracting the contaminants away from the surface. Soil loading and encapsulation of contaminants are determining factors for the effective lifetime of the cleaning medium and the cleaning results.

Reproducibility and consistency of the cleaning results are essential requirements for all cleaning processes. Cleaning chemistry, as part of the overall cleaning process, is a very crucial element in achieving such consistency. Requirements for the selected chemistry are many. It must cavitate well with ultrasonics, compatible with components to be cleaned. Other properties such as wettability, stability, soil loading, oil separation, effectiveness, dispersion or encapsulation of solid residues, rinse freely and disposal of are all important factors and must be addressed when deciding on the appropriate chemistry. As it sounds, an expert in the field better makes this decision.

Both aqueous and solvent cleaning has advantages and disadvantages. Aqueous cleaning is universal and achieves better cleaning results. Solvents are good in removing organic contaminants but short on removing inorganic salts (**6**). Drying and protection of steel components are valid concerns. However, the current available technologies offer effective ways to alleviate these concerns.

Chemistry role is a multi-task - to displace oils, to solubilize or emulsify organic contaminants, to encapsulate particles, to disperse and prevent re-deposition of contaminants after cleaning. Special additives in the cleaning chemistries are used to assist in the process of breaking chemical bonding, removal of oxides, preventing corrosion or enhancing the physical properties of the surfactants or enhance the surface finish. Ultrasonic rinsing with deionized water or RO water is important to achieve spot-free surfaces. Minimum of two rinse steps is recommended (**Figure 5**).

We have developed aqueous cleaning processes for mixed metals using properly formulated chemistries with complete success. For example, aluminum, copper, brass, steel and stainless steel can be all cleaned in the same cleaning chemistry without damage or concern for galvanic interactions.

Parts handling and Orientation

To maximize the use of ultrasonic cavitations in cleaning, parts must be racked on a fixture or arranged in one layer and placed in an open mesh (preferably wire screen) basket and immersed in the ultrasonic tank. Stacking is not recommended. Parts must be at 1 ½ - 2 inches far from the radiating surface. For cleaning with constant rotation, there are special considerations.

For best results, we recommend that the parts to be positioned so that all surfaces receive equal exposure of ultrasonic energy. Parts must be oriented to maximize drainage.

Applications rotation of parts is essential, particularly for small parts with deep blind holes. Designs for fully automated ultrasonic rotation systems are well established and are commercially available. Type of parts vertical oscillation of parts in the wash and rinse steps is required.

Conclusions

Aqueous or solvent cleaning with ultrasonics is valuable and offers several advantages over mechanical and non-ultrasonic traditional methods. Selecting the right ultrasonic frequency, cleaning chemistry and proper process parameters is essential to achieve consistency and reproducibility of cleaning results and in turn better yields.

References

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