

Aqueous-Cleaning Processes

In the past, the acronym TACT—Time, Agitation, Chemistry and Temperature—has been used for remembering the essential cleaning variables involved in aqueous cleaning processes. However, it leaves out four very important variables that must be considered for successful cleaning: Rinsing, Drying, Before-cleaning handling, and After-cleaning handling. A more comprehensive acronym that includes these eight important activities is BATH CARD:

BATHCARD

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

It is important to understand and control these interrelated cleaning variables in all critical cleaning, but particularly in highly sensitive industrial applications such as medical device manufacturing, metal surface preparation, optics assembly and electronic component manufacturing. Use the variables in BATH CARD to evaluate, diagnose and optimize your cleaning process.

BEFORE CLEANING

How parts and substrates are handled prior to cleaning can significantly impact the difficulty, or ease, of cleaning. Soils are more difficult to remove 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 possible 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 sit for extended periods of time prior to cleaning.

Soiled parts can also be placed in protective packaging, dipped in a protective coating or immersed in oil or grease to maintain their current state and avoid increasing the cleaning burden. Clean storage conditions and proper packing by the supplier make it easier to clean parts and substrates.

AGITATION

Soaking is a cleaning method that involves no agitation. Other cleaning methods involve some form of agitation which can be performed through manual (cloth, sponge, brush), ultrasonic, flow-through clean-in-place (for pipes, tanks and tubes), spray cleaning (a dishwasher, for example), and high-pressure spray cleaning. In general, increasing agitation means increasing cleaning effectiveness, particularly when trying to remove heavy, bulk soils.

Agitation is a factor in detergent choice. High emulsifying, high foaming cleaners are more effective for cleaning processes with low levels of agitation and longer cleaning time. These include the manual, soak and ultrasonic processes. Likewise, low foaming, high dispersing cleaners are suitable for high-agitation cleaning with short contact time as found in spray washing, parts washing and when using spray CIP systems, etc.

Presoaking generally enhances cleaning, particularly if soils are dried or baked onto the part to be cleaned. As stated above, it is always preferable, to clean as soon as possible after soiling to avoid dried or baked on soils.

Time constraints and volume of parts being cleaned affect choice of an agitation method and with it detergent. When a large number of parts must be cleaned quickly, then a fast, high-agitation method, such as spray washing, with an aggres-

sive detergent is preferable. Likewise, when cleaning fewer parts or batch-continuous quantities of smaller batches rather than the large quantities from continuous manufacturing of parts, ultrasonic soak cleaning with a milder detergent is more appropriate for the wetting and emulsifying mechanisms that work well in ultrasonics.

The cleaning methods referred to above are discussed below in greater depth:

- **Manual cleaning**—typically chosen for small-volume batch cleaning. High levels of cleanliness that can be achieved by manual cleaning. Though, much depends on the consistency of operators performing the cleaning operation. That's why, rigorous operator training and retraining should be arranged. In addition, there is a need for clearly written cleaning procedures and training procedures. It is even a good idea to go so far as to certify operators in different cleaning methods with periodic recertification.
- **Soak cleaning**—usually chosen for cleaning small volumes, of parts, when time is not of the essence. Typically a slow process, soaking is not labor intensive. Care should be taken, however, when cleaning delicate parts. Because soaking involves longer cleaning times, there more opportunity for corrosion to occur. As a result, soaking is best suited for cleaning robust parts.
- **Ultrasonic cleaning**—particularly effective on small parts with blind holes and crevices that are inaccessible by spray cleaning. This process is essentially soak cleaning enhanced by ultrasonic sound energy. It greatly accelerates the speed of cleaning and can greatly improve cleaning in small spaces or crevices. Ultrasound helps disperse and mass transfer the cleaner. It replenishes fresh cleaning solution to surfaces of parts being cleaned. Ultrasonics also accelerates corrosion, so care with substrates and cleaners with suitable inhibitors is required. Ultrasonic cleaning involves more expensive equipment and is typically suitable for larger volume batches and where a higher level of cleaning is required.
- **Clean-in-place by circulation system**—typically used for piping or small tank systems where a spray clean in

place system cannot be used. It is also an appropriate method for cleaning filtration systems in which filters cannot be accessed by spray nozzles.

- **Spray clean-in-place**—typically used in larger tank systems where the increased efficiency, achieved by using less cleaning solution, justifies the cost of the spray system. Spray cleaning of tanks provides more reliable and more complete coverage of the tank. (An immersion cleaning system may not reach the top of a tank and additional manual cleaning may be necessary.)

When choosing a detergent for tank systems, remember that a detergent that performs well for soak cleaning may not perform as well in spray cleaning. Therefore, if you anticipate scaling up a current system to a spray clean-in-place one, consider using a spray-cleaning detergent that performs adequately in soaking operations.

The choice of a cleaning machine depends both on size of batch and size of parts being cleaned. As batch size increases and ultrasonic machine may no longer be efficient. It often makes sense to choose some form of cabinet, under-counter or floor standing washer.

For very high-volume parts washing, a conveyor cleaning system is a suitable option. Parts, placed on a conveyor, are cleaned using spray nozzles as they pass through the system.

Spray cleaning systems are very good for parts and surfaces that are readily accessible. They are not as effective when there are blind holes and small crevices. When cleaning high volumes of parts, where it makes sense to use spray cleaning, investigate spray under immersion.

For cleaning very, large parts, for example, vehicles or very large assemblies (where an operator can physically move around the part), it makes sense to use a power spray wand or handheld pressure spray device to clean part exteriors.

TIME

In general, the longer the cleaning time, the more thorough the cleaning will be. Many cleaning mechanisms such as emulsifying, dissolving, suspending, and penetrating are time-dependent.

Cleaning time can be accelerated by increased agitation and temperature and by the use of a more aggressive detergent. If none of these variables can be changed—perhaps, because the substrate is too delicate or the proper equipment, unavailable—be prepared for longer cleaning times. While manual cleaning may take minutes: and spray cleaning, seconds: soaking may take hours, possibly overnight, to achieve comparable cleanliness.

There are some instances when long cleaning times may promote substrate corrosion, weakening, or swelling. The optimum cleaning time depends on 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 higher temperatures that are above the melting point of the wax. Particulate soils tend to be more easily removed 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 deg C. Of course, you do not want to use a temperature so high that it damages your substrate.

CLEANER

The cleaner or detergent used should match to the desired cleaning method, 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 and 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.

It is very important to choose a low-foaming or non-foaming detergent when cleaning in or with a machine that relies on spraying for mechanical agitation. Foam is caused by agitation at an air/solution interface when a foaming agent is present. It may build up and spill over from the machine creating a mess. It will also build up on the substrate and interfere with the mechanical cleaning energy of the spray. Finally, foam may get sucked into recirculation pipes causing problems with pumps in the machine.

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. Clean only non-foaming soils with surfactant-free cleaners. A non-foaming cleaner usually has a nonionic polymer surfactant. These surfactants come out of solution at elevated temperatures and form an oil slick on top of the solution. The oil slick is a barrier to air contact preventing foam from forming or being stable. These cleaners will suppress foam from soils. They only work properly if the temperature is hot enough. Find out the minimum temperature at which to use these cleaners.

Finally, there are controlled foam cleaners which usually have limited foam suppressing capabilities. The surfactants themselves do not foam excessively, but they are not be able to control much foam resulting 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 solu-

tion, as used, is often sufficient for good rinsing. Non-depositing rinse-aids can help complete a formulation to meet the rinsing requirements of critical cleaning.

In addition, detergents should be manufactured according to appropriate quality-control procedures. In many critical-cleaning applications it is desirable to choose a detergent with a lot number tracking system and with certificates of analysis available from the manufacturer. These certificates document each lot of detergent to assure consistency and quality control and to prevent cleaning failure from inconsistent manufacturing or unannounced formulation changes. It is also desirable to choose a detergent from a manufacturer who maintains quality control of raw materials and who retains samples of each detergent lot 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.

Chemistry Bath-life extension and control

To avoid potential for cross contamination, only freshly made up cleaning solutions should be used for the highest levels of critical cleaning. For industrial critical cleaning applications, high levels of cleaning can also be achieved with extended bath life. In general, a pH change of 1 unit towards neutral indicates an exhausted cleaning solution. Bath life can be extended by physical filtration of particulates, cooling and settling of sludge and skimming of oils. Bath life can also be extended by adding one half as much detergent, of the initial load, after partially depleting the cleaning life of the bath. With frequent daily use, detergent solutions can rarely be used longer than a week even with these bath life extension techniques. Conductivity, pH and % solids, by refractometer, can be used to control bath detergent concentration.

Free alkalinity titration can be used to control bath life of alkaline cleaners where the soil being cleaned depletes free alkalinity—as is often the case with oily soils. The process:

- Titrate a new solution to determine free alkalinity.
- Titrate the used solution to determine the percent drop in free alkalinity.
- Add more detergent to the bath to bring the free alkalinity back to the level of the new solution. (For example if the initial solution is made up with 100 ml of cleaner concentrate and a 25% drop in free alkalinity is observed, try adding 25 ml of cleaner concentrate to recharge your solution.)

Perform a new free-alkalinity titration to confirm the recharge the first few times this recharging method is used. This is to ensure that the detergent being used is linear with respect to free alkalinity depletion. This form of bath life extension cannot run indefinitely, sludge will eventually form. Fresh solutions must be made up periodically.

Bath lives can also be extended using conductivity. Most cleaners contain conductive salts which can be detected using conductivity. Once the conductivity response of the detergent is determined, the depletion of those conductive salts can be measured.

Many cleaner manufacturers can supply the curves of detergent concentration versus conductivity. By adapting these curves to your conditions and measuring the conductivity, detergent depletion and dilution can be determined. This determination can be used to figure out how much detergent to add to the cleaning solution to restore cleaning performance. Typically, this kind of measure the bath and recharge with detergent process can be done 2-3 times before a new bath is needed.

Keep in mind that, the bath will ultimately reach a point where it forms sludge (or where some other failure occurs). At that point, the bath must be dumped and a complete batch of new cleaner made up. The time to dump the bath, and start over, is generally determined using some sort of cleanliness measurement and defined in terms of number of parts cleaned or time period of bath use. Conductivity does not typically

detect the point of cleaning failure, but only detects concentration of cleaner present, whether depleted or not. The following table gives specific examples of concentration vs. conductivity for several Alconox-brand cleaners. Use this data to derive the concentration of detergent from measured conductivity. Note that, conductivity is temperature dependent. Detergent solutions do not have the same slope as many default settings on temperature-correcting conductivity meters. For best results, allow hot detergent solutions to cool to a consistent temperature for comparison.

Concentration	Alconox	Alcojet	Terg-a-zyme	Alcotabs	Liquinox	Citranox	Detergent 8 (uS)	Detojet
0.125%	1.136	1.354	1.184	1.011	0.108	0.195	21.00	0.614
0.250%	2.08	2.51	2.21	1.912	0.213	0.327	29.70	1.275
0.500%	3.83	4.6	4.1	3.48	0.402	0.475	41.60	2.58
1.000%	6.99	8.34	7.51	6.36	0.747	0.682	63.30	5.05
2.000%	12.71	15.02	13.65	11.55	1.38	0.987	87.60	9.68
4.000%	22.6	26.6	24.3	20.8	2.63	1.47	106.40	18.17

Chemistry, cleaning and corrosion inhibition

Corrosion, during cleaning, is accelerated by the same variables that accelerate cleaning: heat, aggressive chemicals, time, and agitation. To reduce metal corrosion (in approximate order of importance) use less heat, lower pH detergent, shorter cleaning time and less agitation.

In general, use the mildest pH detergent to limit metal corrosion. Higher pH detergents may have metasilicate corrosion inhibitors making them suitable for cleaning soft metals such as aluminum. In general, to reduce plastic corrosion, use less aggressive cleaners, with less solvent or surfactant character; lower concentrations of cleaners; lower cleaning temperatures; less contact time; and finally, less agitation.

After aqueous cleaning, metal corrosion can occur during rinsing and drying. Corrosion inhibitors can be added to rinse water provided that inhibitor residue does not interfere with clean surfaces. Using hot rinse water (to keep clean surfaces hot) and rapid heat or vacuum drying, speeds drying and minimizes metal corrosion. Forced air drying, drying with a hot oxygen-free gas such as nitrogen and using air knives, that physically remove rinse water, can also minimize corrosion.

When rinsing mild steel with hot water and drying with hot air, “flash rusting” can occur. The corrosion actually occurs during rinsing as a result of dissolved oxygen in the rinse water. In some instances, lowering the water temperature or drying temperature can help avoid corrosion. For instance, in a case where flash rusting on mild steel had been occurring, the rusting was avoided by lowering the temperature of the rinse water from 150°F to 120°F maintaining an ambient air drying system. Flash rusting can also be avoided by using a solvent, such as isopropyl alcohol, to rinse with rather than water. Adding corrosion inhibitors, to rinse water, can also prevent corrosion but the corrosion inhibitor may leave residue during rinsing.

AFTER CLEANING

How parts are handled and stored, after cleaning, determines whether cleanliness is maintained. Depending on the setting, it may be necessary to make special provisions to establish a clean storage place or storage conditions. It may also be helpful, if not necessary, to determine how long a surface or part will stay clean while stored to decide whether it needs to be re-cleaned prior to use. Cleanliness testing can be done to monitor a surface and determine how long it will remain 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 and using sterile packaging, to 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 which have been cleaned from the surface as well as detergent residue. 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, any conta-

minants, present in the rinse water, may be deposited on the surface when 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 done using purified water. Rinsing is primarily a mass displacement mechanism and should involve exchanges of water. This is why a running water rinse is typically the most effective rinse.

With soak or ultrasonically agitated rinsing, it is desirable to have two counter-flow cascade rinse tanks dripping “over the tank” to reduce dragout. In all cases, running water or an 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.

In most clean-room, electronic-component and circuit-board cleaning, deionized water is preferred over either tap or distilled water. There is less 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 contains fewer organic contaminants.

DRYING

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

Evaporation methods such as air drying, heat drying, and vacuum drying can deposit nonvolatile impurities present in the rinse water and cause water spots. Although vacuum drying does evaporate water and can lead to deposits, in many

cases the deposits themselves evaporate under vacuum drying conditions. Drying can affect residues and corrosion because impurities from rinse water can be deposited during evaporation. Water, particularly high-purity rinse water, can be corrosive to metal substrates during heated and air drying. Physical removal of rinse water, various drying techniques and the addition of corrosion inhibitors (with tolerance for inhibitor residue), to the rinse water, can help minimize such corrosion.

CONCLUSION

By choosing an appropriate cleaning agitation 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, control before, and after, cleaning are important considerations. If you think about the variables in BATH CARD (before, agitation, time, heat, chemistry, after, rinse, dry) while evaluating your cleaning process, you will be more successful at diagnosing problems and optimizing your process.

REFERENCES

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RESOURCES

www.alconox.com
www.cleansolutions.org
www.corrosionsource.com
www.clean.rti.org