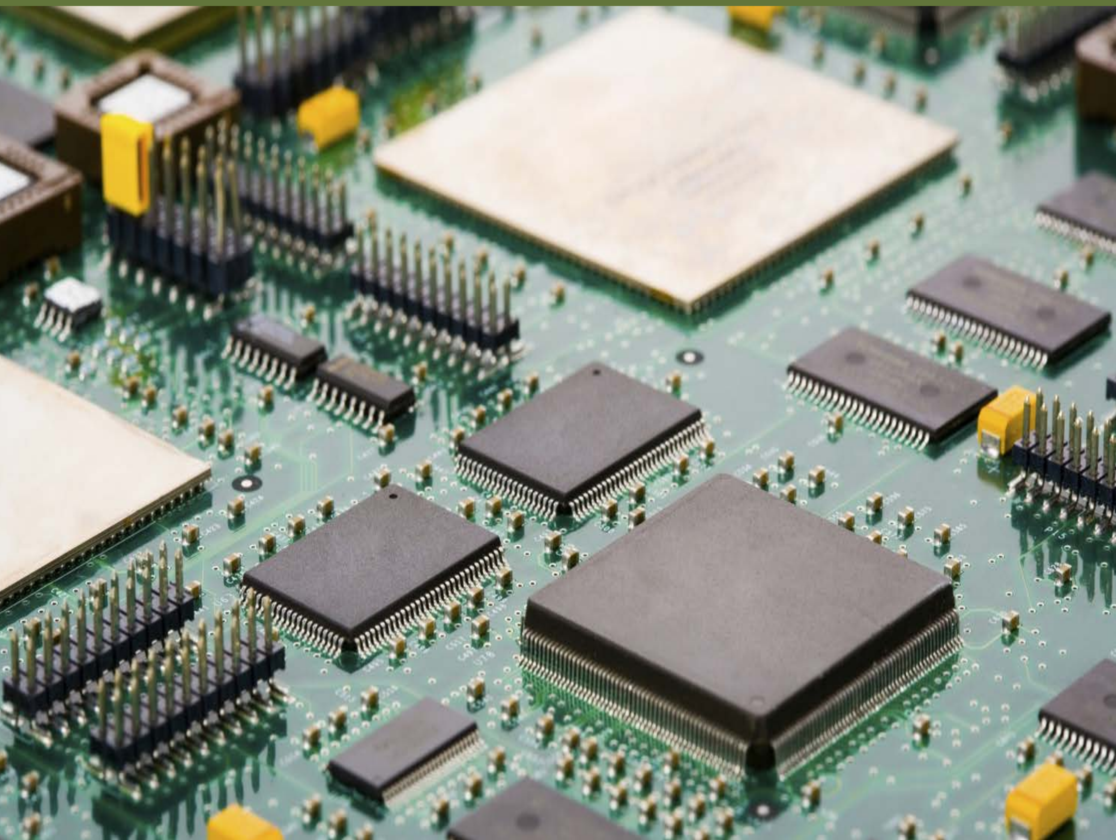
Cleaning and Contamination Equipment & Environment Guide

Michael Konrad



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Mike Konrad has worked continuously within the electronics assembly equipment industry since 1985. He served as Vice President for a manufacturer of soldering equipment from 1985 until 1992. In 1989, Mike designed a new generation of aqueous-based automatic defluxing equipment which remains in production today.

In 1992, Mike founded Aqueous Technologies Corporation, North America's largest manufacturer of fully automated defluxing and cleanliness testing equipment where he serves as President/CEO. Aqueous Technologies manufactures defluxing, stencil cleaning, and cleanliness testing equipment and has built more than 3,900 machines currently in use on six continents.

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I. THE HISTORY OF CLEANING

Past Cleaning Methods (equipment and materials)

Since the beginning of time, or at least the days of through-hole soldering, assemblers stuffed components into printed circuit boards. They covered the board with flux, soldered the components, and then removed the residual flux residue. Cleaning was as much part of the process as soldering and, with very few exceptions, all assemblies were cleaned. Originally solvents were the primary medium used to clean circuit assemblies. The most common cleaning materials used until the late 1980's were chlorofluorocarbon (CFC) based solvents such as Freon® TMS and 1,1,1 Trichloroethane inside Vapor Degreagers *(Figure 1)*

Figure 1. Vapor degreasers were commonly used to remove flux.

In an automated soldering environment, flux was often applied using a foam fluxing system where the entire bottom-side of the printed circuit board (and frequently part of the upper portions) was exposed to flux. Frequently, so much flux was applied to the board that flux would drip onto the pre-heat section of a soldering machine and, in extreme cases, would catch fire. Cleaning was deemed necessary to remove the thick and sticky flux residues present on assemblies after soldering. Even in the exclusively through-hole days, excessive flux residues could lead to unintentional electrical conductivity and electro-chemical migration. Additionally, the sticky flux residue would attract dirt and dust particles and removal was required.

The 1980's witnessed the birth of surface-mount technology. Eventually dip, drag, and wave-soldering machines gave way to vapor phase and convection reflow soldering technologies, changing the flux and solder application methods.

SPF-100

The 1980's provided a variety of electronic achievements, including the proliferation popular electronic gadgets including personal computers, the "Walkman", VCRs, camcorders, video game consoles, answering machines, fax machines, cell phones, and more. This was the "electronic revolution" in full swing (*Figure 2)*.

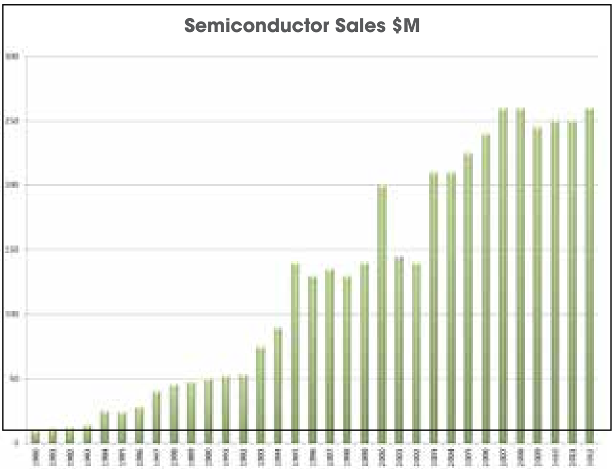


Figure 2. The electronics revolution boosted semiconductor sales.

With the introduction of these products the "electronics revolution" was burgeoning.

In the early 1980's, scientists began publically expressing concern about the apparent shrinking of the Earth's ozone layer (*Figure 3*). Scientists believed that man-made chemical components made their way to Earth's upper atmosphere and eroded the ozone layer, reducing Earth's natural ability to shield harmful UV radiation. It was determined the CFC-based solvent cleaning utilized in electronic manufacturing was contributing to depletion of the ozone.

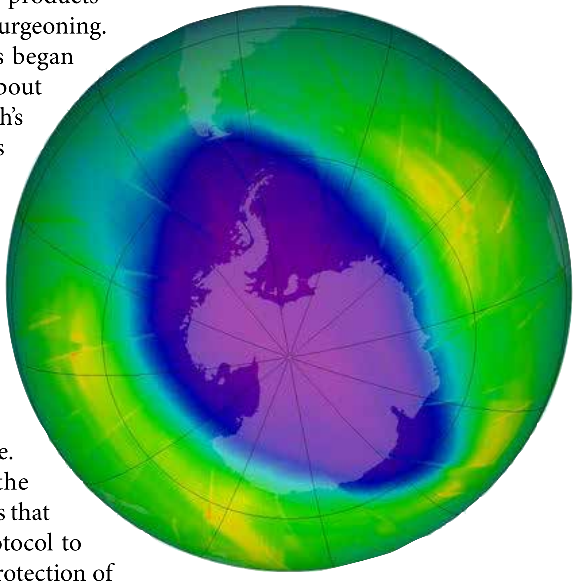


Figure 3. The earth's shrinking ozone layer.

On September 16th, 1987, the "Montreal Protocol on Substances that Deplete the Ozone Layer" (a protocol to the Vienna Convention for the Protection of the Ozone Layer), an international treaty, was opened for signature. This international treaty banned the production of certain CFC-based materials, including the popular cleaning chemicals used within the electronics assembly industry. Today, the "Montreal Protocol on Substances that Deplete the Ozone Layer" treaty has been signed and ratified by all 197 United Nations countries, making it the first universally ratified treaty in United Nations history.

Life After CFCs

By the end of the 1980's, there was widespread panic regarding the future of cleaning. As cleaning was formally considered a "required process" within the electronic assembly industry, a substitute solution was now required. While some chemical companies attempted to develop drop-in replacements to the newly banned CFC-based cleaning solvents, none were entirely successful. New replacement solvents were less effective, required more complex and expensive cleaning equipment, or were scheduled to be banned at a future date. Aqueous-based cleaning processes had been around for some time and were generally considered slower and less effective than their solvent counterparts. It was with this perspective that the concept of leaving soldering residues on assemblies was founded.

Behold "No-Clean"

In the midst of the Montreal Protocol's phase-out and ban on specific cleaning solvents, flux manufacturers began selling lower solids content fluxes labeled "No-Clean" (*Figure 4*). The concept behind these fluxes was simple, reduce the solids content from traditional 15%-30% levels to lower levels of 1%-3%. Lower solids content flux would leave behind fewer residues than those with higher solids content. Almost overnight the process of cleaning ended for those manufacturers who were not otherwise required to clean. Cleaning circuit assemblies after soldering truly became an optional process.

While military, medical, and other high-reliability assemblies were most often cleaned, other assemblies destined for commercial/consumer applications were not cleaned. With more than 80% of electronic assemblies manufactured for commercial/consumer use, it is safe to say that about 80% of assemblies in the 1990's and early 2000's were not cleaned. Despite the cleaning industry's best efforts to malign the no-clean movement, the fact was most no-clean efforts were successful.

Figure 4. The banning of CFCs in the 1987 Montreal Protocol prompted the no-clean revolution

II. ALL GOOD THINGS MUST COME TO AN END

The electronic assembly industry has witnessed a full-circle event. The electronic manufacturing industry transitioned from "Clean Most Assemblies" to "Clean Few Assemblies" back to "Clean Most Assemblies" (*Figure 5*).

Figure 5. The industry has gone full circle. From clean to no-clean and back to clean

The implementation of a no-clean process has been largely successful. One of the results from the past two decades of fast cleaning was the reduction of high-throughput inline cleaning systems and the acceptance and dominance of batch-format cleaning technologies. Electronic assemblies built for military, space, medical, and other high-reliability applications are not built in the same quantities as Gameboys, iPhones, and other popular consumer devices. Batch cleaning processes became ideal for those assemblers where cleaning was required. Ironically, as cleaning requirements expanded and more assemblies demanded cleaning, batch-format cleaning systems became faster to meet the increasing demand. Today's modern batch-format cleaning systems are most often as fast as or faster than their inline counterparts.

In a recent poll conducted by an industry magazine, two thirds of all respondents claim to clean between 25% and 100% of their circuit assemblies (*Figure 6*). The same poll revealed that 53% of respondents soldering assemblies with no-clean flux are cleaning after reflow. To recap:

- Most assemblers are cleaning at least some of their assemblies
- Most (53%) assemblers are cleaning no-clean

Figure 6. Two-thirds of all respondents clean between 25% and 100% of their circuit assemblies

The reason behind this cleaning déjà vu resembles a "perfect storm" of events including:

- Miniaturization of circuit assemblies and components
- Higher component densities
- Lower component stand-off heights
- Higher reflow temperatures caused by lead-free alloy implementation

Miniaturization of Circuit Assemblies and Components

While electronic design and function remains a moving target, there are three constants. Electronic assemblies will continue to be smaller, faster, and cheaper than current standards. This was true in the 1980's, 1990's, and 2000's and will be true throughout the 20-teens, and far into the future. While we all enjoy the benefits of smaller, faster, cheaper electronics, the technology does not come without a price.

Distance between electrical circuits, specifically between cathodes and anodes, allows an assembly to tolerate more contamination. The amount of contamination between a 25 mm space is far more tolerable than the same amount of contamination between a 2.5 mm gap (*Figure 8*). Today's modern circuit assembly designs require minimum spacing between electrical conductors. Modern spacing requirements are so small that even low-level contamination can lead to electro-chemical migration (ECM) and parasitic electrical leakage.

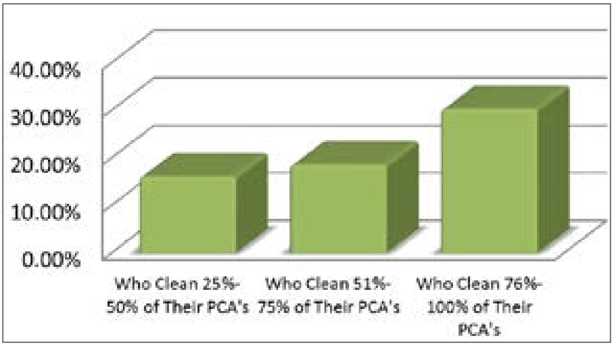


Figure 7. Percentage of assemblers who clean (Source: SMT Magazine May/June 2010)

Are No Clean Flux Residues the Cause of Residue-Related Failures?

Not entirely. Remember the days when all assemblies were cleaned after soldering? While most assemblers considered this a "defluxing" process, a more accurate process name would be a "cleaning" process. When circuit assemblies are cleaned, the cleaning procedure normally takes place at the end of the assembly process. A final cleaning process removes all assembly-related residues. I like to refer to these various assembly residues as "The Usual Suspects"(contaminants or soils)—see *Table 1*.

The fact is, a printed circuit assembly goes through a myriad of processes, each capable of depositing process-associated residues. Residues associated with printed circuit board fabrication, component fabrication, and the assembly process (including flux), are commonly present on a printed circuit assembly. When the electronics assembly industry stopped removing flux residues, it stopped removing *all* residues. It is most commonly the accumulated residues from multiple processes including board and component fabrication, handling and assembly processes, and soldering that lead to intolerable residues.

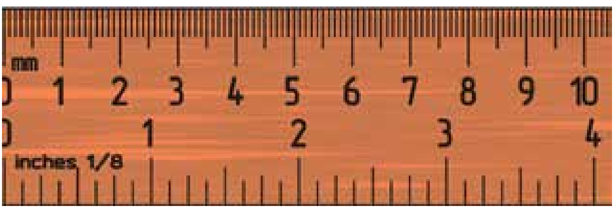


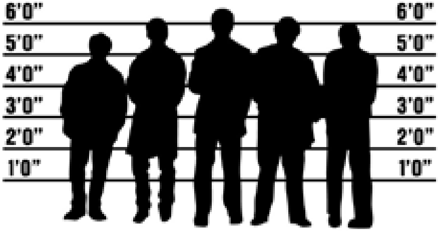
Figure 8. The tolerance gap for contamination has moved from 25mm to 2.5mm

Let's Get One Thing Straight

The term "No-Clean" flux is inappropriate in today's environment. As all flux species leave some quantity of residue behind, who is responsible to determine that the level of flux residue is acceptable or not? The generally accepted IPC level of acceptable contamination is <10 µg NaCl (equivalent) /In2 (<1.56 µg

NaCl (equivalent) /cm2). This standard, originally published in the 1970's, was derived from WS 6536 and MIL STD 2000A and eventually made its way into IPC TM650 as a cleanliness standard. While this standard may still be relevant for some assemblers, to many others, it is obsolete.

Clearly, one should not simply rely on the solder paste's label (No-Clean) to determine if the residues should be cleaned. The issue is the label itself; "No-Clean" should be more appropriately named "Low Residue." Many assemblies can tolerate low residue levels while others can not. The name "No-Clean" implies, often incorrectly, that the residues do not require removal. The more appropriate "Low Residue" label would allow the user to determine, based on the application, the necessity of cleaning or the allowance of residues.



Let's put this into a practical situation. Two companies are assembling circuit assemblies, one of them makes implantable defibrillation devices and the other company makes electronic flea collars for dog and cats. Both companies are soldering their assemblies using the identical no-clean solder paste. The manufacturer of the no-clean solder paste is not aware of the specific end-use for either of their customers. Is the solder paste manufacturer advising that the medical device manufacturer not clean their assemblies before implanting it in humans? A more appropriately named "Low Residue" solder paste would allow the device manufacturer to make a more informed choice when it came to balancing residues with reliability. The cost of failure varies from application to application; therefore the label "No-Clean" does not apply to everyone.

Table 1. (The Usual Suspects) Process-associated residues (Source: Foresite)

Board Fabrication	Component Fabrication	Assembly Process
Etch residues	Plating bath residues	Solder paste
Developer chemicals	Water quality rinses	Flux – wave
Water quality rinses for inner layers	Deflashing chemicals	Cored solder
Water quality rinses for outer layers	Mold release agents	Reworked/repaired fluxes
HASL Fluids (HO) Rand final rinses	Preplating oxide cleaning	Cleaning chemicals
Alkaline cleaners	Pretinning flux residues	Water rinse quality
		Rework cleaner
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final rinses	Preplating oxide cleaning	Cleaning chemicals
Alkaline cleaners	Pretinning flux residues	Water rinse quality
		Rework cleaner

III. THE ECM COOKBOOK

While Electro-Chemical Migration (ECM) is not a new phenomenon, it is on the rise. The most common manifestations of ECM are:

- Dendritic Growth
- Parasitic Electrical Leakage
- Conductive Anodic Filament (CAF)

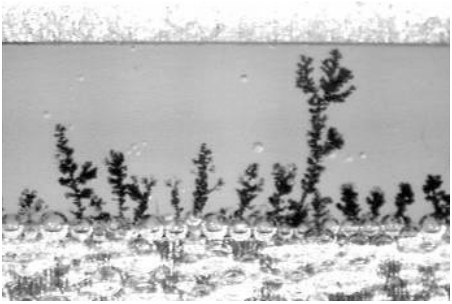


Figure 9. Dendrites are typically tree-like structures that grow from the intermetallic

Dendritic Growth

Dendrite originates from the Greek word "Dendron", meaning "tree-like structure" (*Figure 9*). Dendrites are metal filaments that grow from a cathode towards an anode. If a dendrite connects with an anode, an electrical short is induced. The short may lead to component damage, circuit damage, fire, or a combination of all of these symptoms; at the very least, dendritic growth leads to unintended PCB surface conductivity.

As with all cases of ECM, dendritic growth requires the presence of three elements on the PCB's surface:

- Electrical Current
- Conductive / Corrosive Surface
- Moisture

The first required element required for dendritic growth is electrical current, which is a required element for any printed circuit assembly. Assembly voltages as low as 1.5 volts have, when combined with other required elements, demonstrated the ability to contribute to dendritic growth.

Conductive / Corrosive Surface

Here is where flux residues combined with the "Usual Suspects" (fabrication, component, and assembly residues) become an issue. In an environment where the circuit assembly is not cleaned after reflow, multiple contamination species may be present on the surface of the board, including between and under components. In some cases, flux residue alone is enough to feed a growing dendrite. In other cases, flux residues combined with other residues, fulfill the total contamination requirements. Remember, a traditional "no-clean" process means the board, components, and the completed assemblies were never cleaned after the raw board's initial fabrication, this allows ample opportunity for process residues to accumulate.

Moisture

Moisture (Figure 10) is the third required ingredient in the dendrite cookbook. While some printed circuit assemblies are subjected to harsh envi-ronmental applications such as down-hole, flight, and marine, often simple environmental humidity is sufficient to merge with electrical

Figure 10. Moisture resulting from humidity is another key ingredient in creating dendritic growth

current and residues to allow dendritic growth to take place.

It has been suggested and is widely believed, in order to prevent moisture from wreaking havoc on a board one should conformal-coat the assembly. While it is a fact that without the presence of moisture, ECM (as described) will not take place, conformal coating the assembly will not prevent moisture intrusion.

Conformal coating is a good barrier to fluids. For example, if I spill my morning Starbucks Espresso Macchiato onto my MacBook Pro, I will be at the Apple store the same day purchasing a new laptop. If Apple had the foresight to conformal coat the circuit assembly directly beneath the keypad, my computer would most likely survive (albeit with sticky keys). Conformal coating protects an assembly against short-causing fluids and harsh environments. All conformal coating materials are somewhat permeable. Over time, moisture can penetrate the coating, but not in sufficient volume to create a direct fluid-caused short although in sufficient volume it may activate the residue-moisture-current ensemble cast of characters required for ECM.

Even if conformal coating materials provided an adequate moisture barrier, a required element in conformal coating is a clean surface. As a young person, I recall a US-based company specializing in very low cost car painting. Television commercials throughout the 1970's advertised their slogan "I'll paint any car for $79.95." Obviously, this company was known only for their cheap prices and not for their quality painting. In fact, their lowest price paint job infamously peeled off months after it was applied. What was the reason for the failure? It was lack of proper surface preparation.

Surface preparation is required for any surface adhesion process, and this is true for conformal coating. All suppliers of conformal coating materials advise customers to ensure the board is clean for proper adhesion. Improper adhesion of conformal coating leads to under-coat corrosion and delamination. While conformal coating is an effective process for reducing environmental damage, especially when the assembly is subjected to harsh environments, it is not a substitute for cleaning.

Parasitic Electrical Leakage

Another form of ECM is parasitic leakage, which is a temporary condition. Similar to dendritic growth, measurable unwanted current is present between component or board circuits. While parasitic leakage does not result in hard shorts, it does reduce the resistivity between two polarities. This small, yet measurable increase in unwanted conductivity is achieved by reducing the printed circuit board's dielectric properties. Parasitic leakage frequently results in board errors, calibration errors, battery drainage, and other unwanted issues.

One of the frustrating aspects of parasitic leakage is its temporary nature. Electrical leakage may be present on the board's surface only when the board is operating and subjected to high humidity environments. When the board is re-tested in lower humidity environments, the problem disappears, resulting in "No Trouble Found" (NTF) field returns. When the board is returned to its moisture rich environment, the problem reappears.

Conductive Anodic Filament (CAF)

Bell Laboratories has been credited with discovering Conductive Anodic Filament (CAF) in 1976. Since then, many assemblers remain unaware of its dangers. Similar to dendritic growth, CAF is a form of ECM (*Figure 11*). The primary difference between CAF and dendritic growth is its location. While dendrites grow on the surface of the printed circuit board, CAF grow within the board. The list of required ingredients for CAF to form is identical to dendrites with one addition. In order for CAF to form, the following items

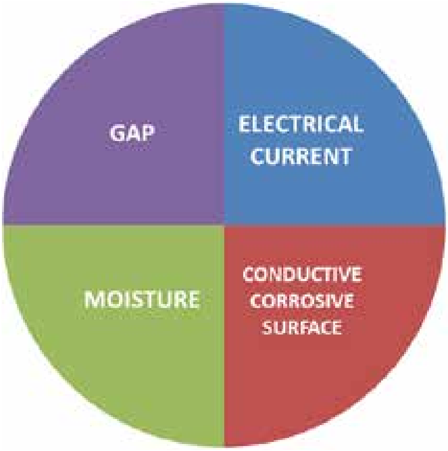


Figure 11. The key ingredients for CAF related failures

must be present within the board's laminate materials:

This list is identical to the required elements for dendritic growth with the addition of a gap. The copper filament that forms CAF needs a place to go. Small micro cracks, voids, or gaps within the laminent allow plating fluids from through-holes and vias to accumulate. If the PCB picked up moisture (all boards can), and if the moisture was not properly removed (ie via a baking process), then it is possible to experience a CAF related failure. Like dendritic growth, CAF can lead to component damage, circuit damage, fire, or a combination of all of these symptoms. Unlike dendritic growth, CAF is not preventable via cleaning. The best post-assembly CAF prevention method is a good baking process (several hours at temperatures exceeding 100˚C). Perhaps the most effective method of avoiding CAF related failures is to follow published guidelines on preventing CAF. Everything from specified board materials (anti-CAF FR4), component spacing, and more can be easily found. One reliability laboratory even offers a CAF prediction test. If the cost of product failure is high (ie injury, death, or destruction) or if the cost of repair is disproportionate to the product's profits, then CAF prevention is crucial.

While it is quite common for assemblers sourcing boards from Asia to re-bake the bare boards when they receive them, care should be exercised to ensure that no additional moisture is allowed to penetrate the boards during storage and assembly time.

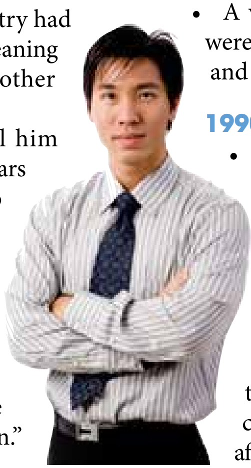
IV. MODERN CLEANING METHODS

When it comes to procuring a cleaning system, there seem to be two types of individuals:

Person number one, let's call him Bob. Bob has been working in the electronics assembly industry since 1975. During Bob's tenure, he witnessed many technological advances including the introduction of surface mount components. Bob was intimately familiar with cleaning. Bob selected the vapor degreasers used in the cleaning processes as well as the Freon TMS solvent. Bob trained his team in the proper use of the vapor degreaser including the proper exit speed of the board basket. After all, too fast an exit speed would cause costly losses in solvent. When cleaning was replaced by no-clean processes, Bob supervised the dismantling of the cleaning department.

Yesterday, six months before Bob's retirement, his employer asked Bob to procure a cleaning system as the need for cleaning has returned. Bob, eager to show off his knowledge of cleaning machines and processes began a search for a vapor degreaser and a compatible solvent. Bob was shocked to learn the electronic cleaning industry had all but abandoned solvent-based cleaning of circuit assemblies in favor of other technologies unknown to Bob.

Person number two, let's call him Tom. Tom graduated college four years ago and was recently promoted to Manufacturing Manager. Tom has been charged with the responsibility of implementing a post-reflow cleaning process. Tom is confused, he has never heard of cleaning and he is unfamiliar with the process. The solder paste used by his department is "no-clean."



The solder paste jars all have the words "no-clean" on the label, and the wave solder machine's spray fluxer is filled with "no-clean" flux. Even the solder wire has no-clean flux in its core. "Why then" Tom asks "are we cleaning no-clean flux?"

Regardless of which person best represents your situation, there is little relevant tribal knowledge when it comes to cleaning circuit assemblies. Let's spend a few minutes and look back then fast-forward to see where we came from and where we are today.

Beginning of Time – 1980's

- Nearly all circuit assemblies were cleaned.
- Most assemblies were soldered using RMA fluxes and cleaned using batch-format vapor degreasers operating with 111-Trichloroethane or Freon TMS (or generic alternatives).
- A smaller percentage of assemblies were soldered with OA (water soluble) fluxes and cleaned using a water-only process (sinks, batch 'dishwasher' machines, or inline cleaning systems).
- A very small (<5%) of assemblies were soldered with a rosin-based flux and not cleaned at all.

1990-2000

- The majority of circuit assemblies were not cleaned. No-clean fluxes and paste dominated the assembly industry. While military, medical, and other high-reliability assemblers largely adopted aqueous-based cleaning solutions, the majority of consumer-based circuit assemblies were not cleaned after reflow.

- Components and boards began a miniaturization process.
- Water-based cleaning machines gained popularity as water soluble fluxes became more accepted.
- Inline-format water-based cleaning machines remained the most popular cleaning method for those assemblers who cleaned.

2000-2010

- The cleaning of assemblies reflowed with no-clean solder pastes became more popular. Water-based cleaning chemicals gain popularity as their ability to remove a variety of assembly related residues is enhanced. Other valuable additives are adjoined to the cleaning chemicals such as corrosion inhibition packages, de-foamers, and others for added performance.
- Batch-format aqueous-based cleaning machines began to dominate the cleaning machine world as assemblers begin to factor the cost-per board and environmental impact of cleaning. Batch-format cleaning systems improved their throughput capabilities, allowing them to be used in higher throughput environments.
- Both batch and inline cleaning systems developed clever methods of cleaning under the ever shrinking space between the bottom of the component and the top of the board.
- Solvent use declined as the EPA and other regulatory bodies enact more stringent restrictions on the use of certain solvents.

2010-Current

- Nearly every manufacturer of inline cleaning machines now sells batch-format cleaning systems.
- Batch-format cleaning systems dominate the cleaning machine landscape.
- More than half of all assemblies with no-clean solder pastes are subjected to a cleaning process.
- More solvents are restricted as the EPA and other regulatory agencies further reduce the impact on the environment.
- Increased concern is expressed by assemblers and environmental regulatory agencies about fluid discharge from modern cleaning machines.
- The cleaning industry responds with zero-discharge technology.
- More assemblies are cleaned today than at any time since the implementation of the Montreal Protocol.

Modern Cleaning Methods

Today, there are many methods, processes, and machines for cleaning circuit assemblies. These can be broken down into four categories:

Manual Cleaning

Manual cleaning of circuit assemblies is normally reserved for light rework, and is not generally recommended for primary cleaning. This is due to the fact that manual cleaning methods tend to disperse flux and other contaminants more than they actually remove them. Solvent-based aerosol cans remain the primary choice for light rework and are not commonly used in a production setting. Additionally, Federal and local environmental regulations frequently control the use of certain solvents, restricting their use to rework and repair.

Automatic Cleaning Machines

Automatic cleaning machines can be divided into two segments: immersion and spray-in-air. While both technologies are generally effective in removing all forms of assembly residues, there are differences in the cleaning materials required, the environmental impact, and the degree of automation provided.

Immersion Cleaning Machines

While there is a plethora of immersion cleaning machines on the market designed for a multitude of industries, the most common iteration of immersion cleaning technology for the electronics industry are vapor degreasers and ultrasonic cleaners.

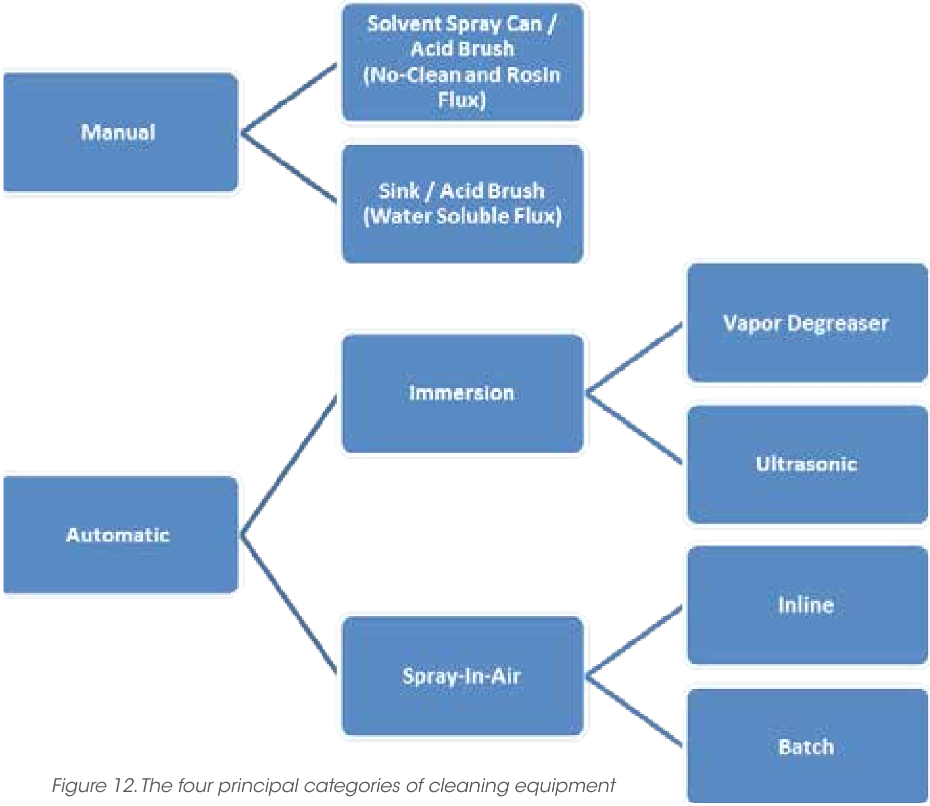


Figure 12. The four principal categories of cleaning equipment

Vapor Degreasers

Formally, vapor degreasers were the most popular cleaning technology in the electronic assembly industry. While the popularity of vapor degreasers has declined substantially over the past three decades, this solvent-based technology remains a viable alternative to other cleaning methods for certain assemblers.

Vapor degreasers consist of one deep tank filled half way with a low boiling-point solvent, and the top of the tank contains refrigeration coils (*Figure 14*). The vapor degreaser is equipped with a heating system which heats the solvent causing it to boil. As the solvent boils, the clean solvent vapor raises toward the top of the tank. Refrigeration coils cause the solvent to condense and return to the solvent below.

Figure 13. Batch Format Defluxing Systems

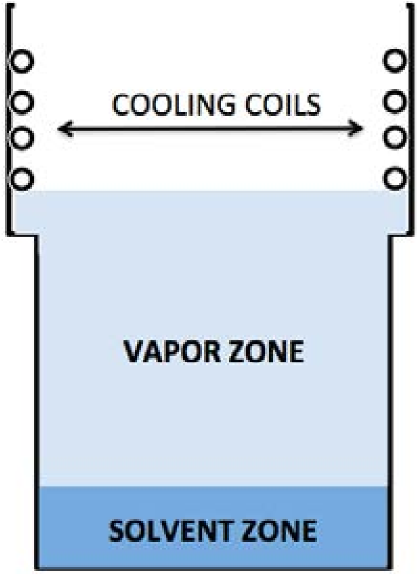


Figure 14. A schematic of a typical vapor phase cleaning system

Circuit assemblies are lowered into the boiling solvent and left for a period of time. After a suitable time immersed in the boiling solvent, the circuit assemblies are lifted out of the boiling solvent and are then exposed to the solvent vapor. The solvent vapor acts as a pseudo-rinse cycle. When the assemblies are removed from the solvent vapor section of the machine, the remaining solvent on the assemblies evaporates rapidly and the assembly is now clean and dry.

Since the original signing of the Montreal Protocol in 1987, several additional solvents have been either eliminated or are scheduled for elimination due to their volatile organic compound (VOC) levels or their ozone depletion capabilities. Today, legal solvent remain effective, expensive, and highly regulated.

Ultrasonic Cleaning

Ultrasonic cleaning has served a wide variety of industries for decades (Figure 15). Utilizing sound waves rather than pumps, ultrasonic technology remains an effective means of removing residues. In the electronic assembly industry, ultrasonic cleaning technology has been largely reserved for the cleaning of surface mount stencils. Despite its adequate cleaning performance, it is less commonly used in circuit assembly cleaning applications.

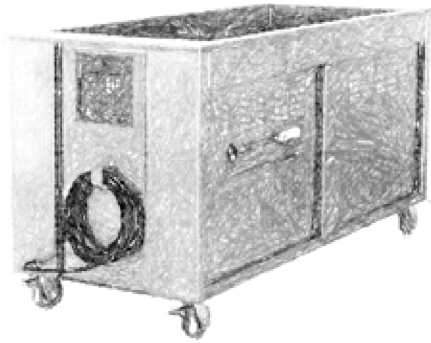


Figure 15. An ultrasonic cleaning system

Many years ago, a well-known military contractor published a report indicating potential damage to wire bonds and other sensitive components on an assembly as a result of the ultrasonic energy produced by an ultrasonic cleaning machine. While the report was real and the expressed concerns valid, the ultrasonic machines have changed and the concerns have been alleviated.

Early ultrasonic cleaning machines emitted ultrasonic energy at specific frequencies damaging some circuit assemblies. If one attends a live concert and sits anywhere near a speaker, they know first hand the power of sound waves. Sound waves, when too amplified and at certain frequencies can cause damage. Modern ultrasonic cleaning machines in the electronic assembly industry generate ultrasonic frequencies of 40 kHz, which is considered safe on circuit assemblies and components. Unfortunately, the perception that ultrasonic energy damages circuit assemblies or electronic components remains and usually negates its use as a viable post-reflow cleaning option.

Another immersion cleaning format function to consider is its lack of full automation. Most immersion cleaning machines are semi-automatic in nature. A user loads assemblies into a basket, lowers the basket into a wash tank and waits. When the appropriate immersion time has expired, the operator lifts the basket out of the wash tank and places it into the rinse tank. The cleaning machine may have multiple rinse tanks in which case the rinse process would be repeated. Some machines are equipped with programmable hoists that provide the "heavy lifting." Automation features such as automatic cleanliness control, assembly drying, and statistical process control (SPC) are not normally available.

Spray-In-Air Cleaning

Spray-in-air cleaning machines are the most common type of post-reflow cleaning machine used today. The majority of spray-in-air cleaning machines use water, either exclusively or more commonly mixed with a chemical additive.

Wash solution is sprayed under pressure onto the assembly's surface causing the flux and other forms of contamination to be "solubilized." A rinse process is then performed

Figure 16. A batch format automatic defluxing system

displacing the wash solution with pure deionized rinse water. Finally, a drying process is initiated to remove the rinse water. In its most basic form, it's a wash, rinse, dry procedure.

Spray-in-air technology comes in two forms, conveyorized (inline) and batch. There was a time when inline cleaning systems were more common due to their superior throughput and cleaning capabilities. However today much has changed. There are specific factors that will drive a decision toward inline or toward batch.

Batch or Inline... A Selection Guide

First, let's address one common misconception. Most modern electronic assembly lines are at least partially conveyorized. Frequently, the solder paste printer is conveyorized. The majority of reflow processes and/or wave solder processes are conveyorized. Selective solder, AOI, and other process steps may also be conveyorized. So it is natural to think that a newly added cleaning process should also be conveyorized.

While it is accurate to say that most assemblers seeking a cleaning solution first consider an inline cleaning technology, it's also accurate to say that very few actually acquire an inline cleaning machine and if they do, the machine rarely operates in an inline capacity. In fact, most inline cleaning systems operate in a batch format with operators hand-carrying assemblies from production lines to and from the inline cleaner. Today's modern cleaning format is batch, whether or not the cleaning machine is equipped with a conveyor. The reason is actually quite simple. Let's consider some real-life scenarios.

Scenario #1 Large EMS Company

As a large EMS company, there are four full surface mount lines on the production floor. Each line is completely contiguous, connected by a series of conveyors. A large customer is demanding a cleaning process be added to their assemblies and the EMS company must purchase a suitable machine.

Figure 17. An inline defluxing system

Due to the fact all four production lines are conveyorized, a similarly conveyorized cleaning system seems logical. Here are the process-related questions that need to be asked:

- Of the four production lines, which one(s) should get the cleaning system?
- What if the boards that require cleaning are produced on another production line?
- All chemical-compatible inline cleaners require a drain. Is there one on the shop floor?
- Does my facility/municipality allow process fluids to be sent to drain?
- Do I need to obtain a discharge permit?
- All inline cleaners require deionized water to operate. Deionized water is produced by running water through multiple ion-exchange resin tanks. Where will those tanks go?
- Do I have access to a water connection where the cleaner will be located?
- Inline cleaners require substantial ventilation. Is there access to adequate ventilation where the cleaner will be located?
- Is there room within the production line to insert 20'-30' (610cm – 914cm)?
- If the cleaning machine requires a drain connection, do I have a floor-drain under the machine or will I have to install a pumping station to pump the effluent to another part of the building?

If an automatic cleaning process is desired, keep in mind that old conventions may not be appropriate for today's electronic manufacturing environment. Both batch and inline format cleaning machines have the capabilities to adequately clean assemblies. Implement a level of due diligence and confirm that your facility has the infrastructure to support the specific cleaning machine and process desired.

Things to Ponder When Selecting a Cleaning Process/Machine

When selecting a cleaning process, one should consider the following relevant factors:

1. Effectiveness of the cleaning process
   a. How clean is clean enough?
   b. How will I evaluate cleanliness (visual, function, ROSE test, etc)
   c. Cleaning power (impingement, shadow-reduction, drying, etc.)
2. Required level of automation
   a. Manual cleaning
      i. Solvent spray-cans or IPA with acid brush
      ii. Sink with acid brush
   b. Dedicated machine operator
   c. Multiple machine operators

   d. Process control
      i. Process times
      ii. Process temperatures
      iii. Chemical concentration control
      iv. Effluent management
   e. SPC
      i. Data capture and search
      ii. Assembly barcode scanning
3. Environmental & regulatory restrictions
   a. Drain or no drain
   b. Odor, noise, safety
4. Throughput capabilities
   a. Boards per hour/shift
   b. Start-up times
5. Chemical Selection
   a. Solvent, aqueous-chemical or water-only
   b. Compatibility of chemical with all target residues
   c. Compatibility of chemical with cleaning machine
   d. Compatibility of chemical with humans (MSDS, odor, etc)
   e. Compatibility of chemical with environment
      i. Can it be used in my locality?
      ii. Can it be used in my building?
      iii. Can it be discharged?
6. Safety
   a. Is the process safe (flammability, toxicity, etc)
7. Flexibility

Perhaps the most important factor in choosing a cleaning machine is flexibility. The fact is with OEM's, it is often difficult to predict exactly what the assembly needs, much less cleaning needs will be six months or one year from now. In a contract manufacturing environment, one may not accurately predict the cleaning needs thirty days from now. Factors such as flux type, assembly designs, customer cleanliness requirements and other edicts, environmental requirements, etc all affect the cleaning process. What ever type of cleanliness process is chosen must be effective today, tomorrow, and as far in to the future as possible. A cleaning machine designed around a specific chemical or capability may become obsolete much sooner than anticipated or desired.

IV.MODERN CLEANING CHALLENGES

There are many modern cleaning challenges and most of these challenges have been created within the past few years. Modern challenges include:

- Polymerization of flux
- Impingement of low-profile components
- Shadowing
- Effluent discharge regulations

Polymerization of Flux

First, let's consider the purpose of flux. Flux reduces oxidation during the reflow process when solder changes from a solid state to a liquid state. The flux's responsibility is to reduce oxidation and to encapsulate the metal salts that form when solder is in a liquid state. Historically, flux had a solids content of 15%-50%. A higher solids flux maintains a greater usefulness during the entire reflow process. Today's no-clean fluxes maintain very low solids content, normally 1-3%. Lead-free solder requires a higher reflow temperature compared to traditional 63/37 alloys. An increase of 50˚-60˚C on a low solids content flux may result in the flux volatilizing or polymerizing too early in the reflow process. This action may result in the flux's inability to encapsulate the metal salts that are generated during the reflow process. This failure will result in un-encapsulated metal salts on the surface of a circuit assembly. These metal salts and other residue species, have the potential, when combined with electrical voltage and moisture to produce a fertile breeding ground for dendritic growth or electrical leakage.

A flux which has polymerized is more difficult to remove than non-polymerized fluxes. Higher impact pressures are required to effectively break down and solubilize the polymerized flux. Careful consideration must be given to the selection of the cleaning machine to ensure it has the required power to effectively and thoroughly breakdown and solubilize even polymerized flux residues.

Impingement of Low-Profile Components

It is a modern fact that the amount of space between the bottom of a component and the top of the circuit board's surface is little to none (look under a QFN recently?). After reflow, flux residues are present in both easily accessible areas of an assembly and not-so easily accessible areas such as under components. It is critically important to not only wash from under these tight spaces but to also rinse from under them as well. Washing underneath a component is easier than rinsing under it. This is due to the reduction of surface tension caused by the use of a defluxing chemical (Figure 18). The lower the surface tension, the easier for fluid to penetrate a tight gap. Compared to water's

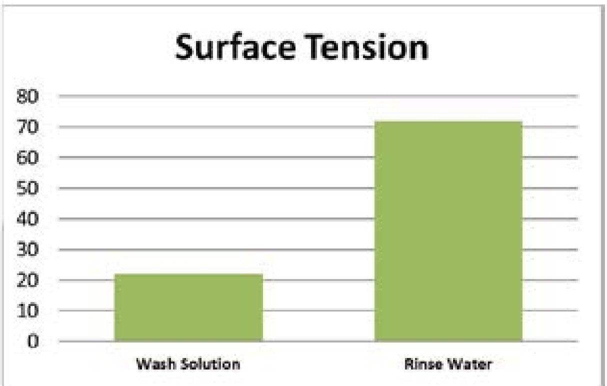


Figure 18. The surface tension of DI rinse water versus wash solution (dynes)

surface tension of 72 dynes, wash solution (water and chemical mixed together) has a reduced surface tension of 22 dynes; therefore washing is easer than rinsing.

Now that we know that rinsing is more difficult than washing, one should evaluate a cleaning machine not primarily on its ability to wash, rather on its ability to rinse. After all, it is worse leaving flux and other processes residues on a board than to leave wash chemicals on a board. Proper rinsing is not an option, it is a requirement.

In spray-in-air cleaning machines, fluid delivery varies. Common fluid delivery techniques include high pressure/low flow, low pressure/high flow, or a combination of both (inline cleaning systems). Pressure is an often misunderstood aspect of a cleaning machine. Many believe high pressure is required for adequate cleaning. While high pressure and adequate cleaning are commonly synonyms, where pressure is measured is key.

Don't Chase the Needle

Nearly all spray-in-air cleaning machines are equipped with pressure gauges. While it may be reassuring to know that the wash system pressure gauge indicates an impressive 120 PSI, that reading may be meaningless. Spray-in-air cleaning machines measure the spray system's pressure at the plumbing manifold. Pressure measured at the plumbing manifold is excess pressure, not necessarily indicative of pressure hitting the assembly. Case in point:

If one removed all of the spray nozzles and replaced them with plugs, the indicated manifold pressure would soar yet the assemblies would remain dry. While manifold pressure is an important reading to ensure that the spray nozzles are receiving adequate pressure to properly form the required fluid diffusion, the relevant pressure reading is the impact pressure at the assembly.

Impact pressure is a vital component in effective contamination removal from circuit assemblies cleaned in spray-in-air

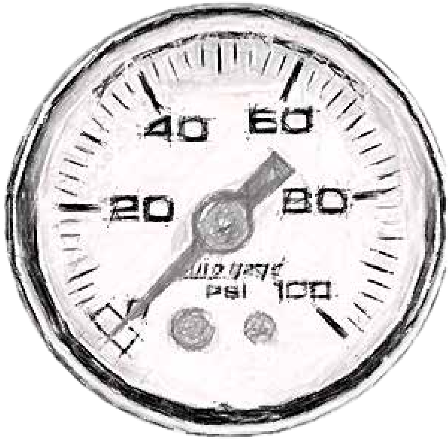


Figure 19. Pressure gauges do not measure the impingement pressure hitting the assembly

cleaners. The majority of spray-in-air cleaning machines utilize aqueous-based cleaning chemicals. Unlike the solvents of past decades which relied mainly on heat and contact, aqueous-based cleaning chemicals require heat, contact, and the application of mechanical energy.

Mechanical energy is required for two purposes.

1. Mechanical energy is required to effectively solubilize the flux and other contamination and place the contamination into a solution. Contact alone will not fully solubilize the contaminants.
2. Mechanical energy is also required to allow wash solution and rinse water to effectively penetrate below and between components. With ever-decreasing component stand-off heights and ever-increasing component densities, more mechanical energy is required to provide adequate under component impingement both during wash and during rinse.

The amount of required mechanical energy is determined by the cleaning machine's fluid delivery configuration. There are two common fluid delivery designs used in modern cleaning machines: solid stream and diffused.

Figure 20. A solid stream spray pattern

Solid Stream

Solid stream (sometimes referred to as coherent) fluid delivery designs produce a solid stream of fluid directed to the assembly's surface. Normally, a solid stream spray pattern is accomplished by simply directing fluid through a round hole (Figure 20). This design may be reviewed by inspecting the spray arm at the bottom of most dishwashers. Solid stream spray patterns do not normally require a large pump as the pumped fluid received little resistance exiting the hole. Because the fluid is not diffused, fluid droplet size is irrelevant. Because the fluid is contiguous and not produced in droplet form, target impact pressure remains high. The high impact pressure produced by a solid fluid stream is required to ensure adequate under component penetration of non-diffused fluid. While a cleaning machine equipped with steady-stream fluid delivery will not indicate a high plumbing manifold pressure, it will deliver high impact pressures at the target assembly.

Diffused

Diffused fluid spray causes the fluid's droplet size to be reduced. The greater the diffusion angle the smaller the droplet size (VMD, or Volume Median Diameter). VMD is a means of expressing drop size in terms of the volume of liquid sprayed. The VMD droplet size when measured in terms of volume is a value where 50% of the total volume of liquid sprayed is made up of drops with diameters larger than the median value and 50% with smaller diameters. The VMD of a common diffusion nozzle used in modern cleaning machines is 430 VMD microns. Because the fluid droplets are very small, the impact pressure at the target assembly is relatively low, reducing the risk of assembly damage. Likewise, because the fluid droplet size is very small, the required amount of impact pressure required for adequate impingement is also low. Small droplet sizes more easily penetrate the gap between the surface of the printed circuit board and the lower surface of the component. This is particularly beneficial when rinsing with higher surface tension water.

Shadowing

Shadowing is unique to spray-in-air cleaning technologies. Shadowing was not an issue back in the "good-ole" vapor degreaser days. As spray-in-air cleaning methods represent the clear majority of modern cleaning practices, let's discuss how to mitigate shadowing.

Shadowing occurs when the fluid spray directed at one component blocks the fluid spray to another. Like an umbrella in the rain, complex assembly geographies create multiple "umbrellas" effectively blocking the fluid spray to some components in the shadowed areas of the assembly.

Shadowing is possible in all spray-in-air cleaning technologies, including both batch and inline formats.

How assemblies are loaded into a cleaning system may partially determine the cleanliness results (*Figure 21*). For example, on an inline cleaning system, assemblies should note be loaded front to rear edge-to-edge. A minimum space of two inches (5cm) should be kept to ensure the assemblies do not create a trough, allowing wash solution to travel across the assembly's surface, contaminating the rinse section with wash solution.

On a batch-format (dishwasher) configuration, if the fluid delivery technology includes diffused fluid sprays, then assemblies may be loaded with less attention to specific distribution as the fluid spray pattern is wide and more easily reaches the extreme ends of the cleaning chamber. If the cleaning machine is equipped with steady-stream (non-diffused) sprays, then there is a greater reliance on a fluid "ricochet" action, frequently reducing the acceptable assembly loading capability.

Some manufactures have created shadow-mitigation technologies utilizing varying techniques including mid-rack sprays, oscillating assembly racks, asymmetrical spray nozzles, etc. These shadow-mitigation techniques manipulate the fluid flow to provide increased angles of attack. While the brand-specific technique may vary, the result of the applied technology should be the reduction or elimination of shadow-produced post-cleaning residues. "How does this machine reduce or eliminate shadowing?" is a fair question to ask cleaning equipment manufacturers.

Figure 21 The loading technique can have an effect on the cleanliness results

Are Batch Cleaning Machines Just Dishwashers?

A section dedicated to batch-format spray-in-air (dishwasher) cleaning machines seems sensible due to the fact the this is the most common cleaning format in use today. So, are batch cleaning machines just dishwashers? Like so many answers in our industry… It depends. During the initial phase-out of solvents back in the 1980's and early 1990's, a new breed of aqueous-based batch-format defluxing systems hit the market. While many of those early machines had more in common with a dishwasher than not, assemblies were far easer to clean and required much less power and technology compared to today. Dishwasher-type cleaning machines, whether literal dishwashers or mildly modified dishwashers have gained in popularity. Today, there are two types of "dishwasher" cleaning systems. There are machines that held on to much of their dishwasher DNA and are suitable for low volume, geographically simple circuit assemblies. There are also others that are powerful, highly sophisticated machines with low, medium, or high throughput capabilities that shed their dishwasher lineage. Due diligence is advised with choosing any cleaning process or machine. Within the popular batch spray-in-air category, one should determine the wetted materials (ie pumps, plumbing, solenoids, assembly racks, etc). Cleaning chemical additives and deionized water is tough on wetted surfaces. Materials including many plastics, (Viton, Butyl rubber, Acrylics, Fluoroelastomers, Polycarbonate resins, to name a few) and certain metals including copper and aluminum should be avoided. Additionally, cleaning is accomplished at elevated temperatures, as high as 160˚F (71˚C). Construction materials and wetted surfaces should be compatible with all potential operating temperatures.

Throughput capabilities on batch-format cleaning machines vary widely. Some batch-format spray-in-air cleaning machines may require an hour or more to clean a batch of assemblies while other machines may require only twenty minutes. Some batch-format spray-in-air cleaning machines are equipped with a single process chamber while others are equipped with multiple process chambers, allowing simultaneous cleaning in multiple chambers. Some inline cleaners are longer than others, allowing higher conveyor speeds, increasing throughput. Be sure to determine that maximum effective throughput and not the maximum theoretical throughput.

Effluent Discharge Regulations

Effluent discharge is a modern day "hot" topic. Not long ago, we proclaimed ourselves as green because we phased out those "nasty" solvents and switched our cleaning to a cleaner aqueous-based process. Then in later years, we considered ourselves green because we stopped discharging wash solution down the drain, limiting drainage to relatively clean rinse water. Today, we are green only when nothing goes down the drain.

While most of the effluent produced by modern aqueous-based defluxing machines is generally considered to be "safe" (metals PPM, TDS, etc), the act of connecting any process machine to a drain line is frowned upon by many health and safety officers, company management, and an increasing number of water agencies and municipalities. The fact is, connecting a process machine to a sanitary sewer is risky. What is considered safe and legal to send down the drain today may not be in the future. What is the risk? The hazard comes from a regulatory agency retroactively regulating effluent control, and holding a company responsible for retroactively imposed regulations. Think this can't happen? Just refer to the retroactive regulations imposed by the United States EPA. For example, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) allows for retroactive fines and other remedies. The US Supreme Court stated "The court also holds that the retroactive application of CERCLA does not violate due

Project Number:	Not Specified	**Report Date:**	06/23/10

SAMPLE RESULTS

Lab ID:	L1009093-06	Date Collected:	06/15/10 14:00
Client ID:	#6 TD ZESTRON	Date Received:	06/16/10
Sample Location:	Not Specified	Field Prep:	Not Specified
Matrix:	Water		

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Prep Method	Analytical Method	Analyst
Total Metals - Westborough Lab											
Arsenic, Total	ND		mg/l	0.100	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Barium, Total	ND		mg/l	0.200	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Cadmium, Total	ND		mg/l	0.100	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Chromium, Total	ND		mg/l	0.20	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Copper, Total	ND		mg/l	0.200	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Lead, Total	ND		mg/l	0.200	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Mercury, Total	ND		mg/l	0.0010	--	1	06/21/10 17:45	06/22/10 13:20	EPA 245.1	3,245.1	EZ
Nickel, Total	ND		mg/l	0.500	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Selenium, Total	ND		mg/l	0.200	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Silver, Total	ND		mg/l	0.140	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG
Zinc, Total	ND		mg/l	1.00	--	1	06/21/10 11:00	06/23/10 10:19	EPA 3005A	19,200.7	MG

Figure 22. A typical lab report on effluent discharge

process." Additionally, consider the number of companies having to spend millions on soil remediation for long unregulated past actions. The lowest risk for any cleaning process is zero discharge. With today's advances in cleaning technology, there is absolutely no need for a drain connection. Modern technology is capable of filtering and re-using process fluids without a reliance on a drain line, therefore eliminating the regulation—and cost—that comes with any discharge.

If effluent will be connected to a drain it is imperative to know what is in the fluid (*Figure 22*). Send a sample of the effluent to a lab for a complete evaluation and then submit the lab results to your local municipality to obtain a discharge permit. Cover your bases and reduce the risk of unnecessary liability. Once again, it is better yet, to operate zero discharge and completely eliminate environmental liability.

The Mechanics of Zero Discharge

When it come to fully automated cleaning machines (batch and inline), both machine formats are capable of operating in a completely zero discharge configuration under certain conditions.

Chemical-Free Defluxing

Both batch and inline cleaning machines are capable of operating in a completely zero discharge configuration as long as no defluxing chemicals are utilized. When deionized water is the only fluid ingredient utilized for flux removal, the process of filtering the process water and reusing it is relatively easy. Simple carbon and resin beds remove the organic and ionics respectively.

Chemical Enhanced Defluxing

If a cleaning process requires the use of a defluxing chemical (most cleaning processes require the use of a defluxing chemical or at least benefit from it), then a zero discharge configuration becomes more complicated.

Inline Cleaning Machines and Zero Discharge

Inline cleaning machines operating with a defluxing chemical are not considered to be zero-discharge capable. All inline cleaning machines are designed to operate with a defluxing chemical are equipped with a chemical isolation chamber. The purpose of the chemical defluxing section is to allow wash solution dragged from the wash section to be removed using tap water, compressed air or both prior to the boards entering the rinse section. The action of "pre-rinsing" the boards prior to entering the main rinse section prevents the defluxing chemical from contaminating the rinse and final rinse sections of the cleaning machine. If the inline cleaning machine's rinse and final rinse section were to be "closed-loop" (zero discharge), and the machines was not equipped with a suitable chemical isolation section, the carbon and ion-exchange resin beds would prematurely fail due to excess defluxing chemical contamination of the filter beds. So, if the rinse sections of an inline cleaning system are configured as zero discharge, then the chemical isolation chamber must discharge dragged-out wash solution (water and defluxing chemical). The chemical isolation section is most often connected to a drain as the average discharge rate is between two and three gallons (8–11 liters) per minute.

Batch Cleaning Machines and Zero Discharge

While a zero discharge configuration is complicated by the use of defluxing chemicals, it is only possible when utilized in batch cleaning machine configurations.

There are two different methods of preventing cleaning effluent from being sent to a drain when used in a batch-format, chemical-enhanced defluxing operation.

- Batch cleaning system connected to an evaporator
- Batch cleaning system connected to a rinse water recycler

Evaporator

Most batch-format defluxing machines are capable of reusing the wash solution, and the technology is relatively simple Batch machines simply capture and reuse the wash solution repeatedly until the wash solution holding tank runs low due to evaporation and drag-out. The rinse water will enter the machine, be used for one single cycle, and then will be directed to an evaporator, never to be used again.

While this approach has been common, it is not without drawbacks including:

Slow Evaporation Rate

Most commercially available evaporators are capable of evaporating rinse water at a rate of five gallons (19 liters) per hour. There is no way an inline cleaning system with its constant water output could be connected to an evaporator. No evaporator would be able to keep up with the output of an inline cleaner. Most batch-format cleaning machines are capable of sending rinse water to an evaporator at a volume of thirty gallons (114 liters) per hour. If an evaporator has an evaporation rate of five gallons (19 liters) per hour and it is receiving water at a rate of thirty gallons (114 liters) per hour, then the evaporator's internal storage tank will begin to rise at a rate of twenty-five gallons (95 liters) per hour. So for example, the evaporator has a storage tank capacity of eighty-five gallons (322 liters), then the cleaning machine can operate for 3.4 hours before it has to stop and allow the evaporator to catch up.

Sludge Removal

All evaporators reduce the volume of fluid by causing the fluid to boil, converting the fluid to vapor and directing the vapor into the atmosphere. The effluent directed to the evaporator by the defluxing machine contains ingredients that do not boil at 212˚F (100˚C). When fluids are boiled, the majority of the fluid converts to vapor and the balance remains in the evaporator's tank. Over time the amount of non-boiling fluid begins to rise and at some point, the evaporator's entire storage tank of fluid ceases to boil. At this point the evaporator is considered to be full of "sludge." This "sludge" must be removed from the evaporator, drummed, and hauled away as hazardous waste.

While the use of an evaporator may avoid a cleaning machine's connection to a drain, it still has a waste stream.

Rinse Water Recycler

The use of a rinse water recycler in chemically-enhanced defluxing applications is only possible when the cleaning machine's rinse water contains very low volumes of wash solution. There are two methods of ensuring a very low volume of wash solution in the rinse water:

Bypass the First Rinse

Batch-format cleaning machines allow the user to direct the first rinse to the drain and send the second and subsequent rinses to a rinse water recycler. The first rinse normally contains dragged out volumes of wash solution from two sources. The sources include the surface area of the assemblies being cleaned as well as the surface area of the cleaning wetted surfaces of the machine, this drag-out is relatively low. The second and more substantial volume of drag-out comes from the cleaning machine's plumbing. Spray pumps, plumbing lines, solenoids, and other plumbing components can capture a larger volume of fluids. The large volume of fluids captured within the plumbing of the cleaning machine would be dragged into the next cycle. That means chemical-containing wash solution will be mixed into the rinse water and sent to the rinse-water recycler, causing premature depletion of the carbon and ion-exchange resin beds. In order to avoid excess wash solution drag-out into the carbon and ion-exchange resin beds, the first rinse, and all of its dragged out wash solution is sent to the drain.

This first rinse bypass feature, while beneficial for the rinse water recycler, prevents a cleaning machine from being fully zero discharge. One may also argue against the logic of sending the dirtiest of the rinse water down the drain in order to prevent the cleanest water from going to drain.

Full Rinse Filtration via Drag-Out Mitigation

As previously mentioned one method of preventing dragged-out wash solution from entering a rinse water recycler is to segregate the first rinse from the recycler. Another method is to reduce the volume of drag-out in the first place. Some batch-format cleaning machine manufacturers have identified the cause of excessive drag-out and designed mitigation techniques and technologies for reduction. If the wash solution drag-out volume can be reduced to an acceptable level then all rinse cycles, even the first rinse, can be directed to a rinse water recycler. A low drag-out cleaning machine with wash solution reuse technology combined with a rinse water recycler operates completely zero discharge without the need for waste disposal. While this technology exists now, it is expected to become more widely available over time. This author believes in the near future, all defluxing systems will operate in a zero discharge capacity and the days of effluent discharge will go the way of CFCs.

IV.IN CONCLUSION...

A Review of Conventional Wisdom

Cleaning has historically been a reactive process. Over the years, the volume of residues an assembly can tolerate has declined and the environmental restrictions have increased, causing cleaning equipment and chemical manufacturers to react. In recent history, assemblies have become more densely populated while components have been mounted closer to the board's surface and the equipment and chemical companies responded. History has taught that a reactive approach to cleaning challenges is not the best solution, rather it is better to be proactive addressing forthcoming concerns. A proactive approach considers the current trajectory of cleaning challenges and anticipates additional challenges. It is safe to assume that assembly residues will continue to cause harm, cleaning will be more challenging than it is today, and environmental restrictions will all but eliminate the ability to send anything to the drain.

Cleaning equipment manufacturers and buyers of their products should ensure that a machine, chemical, and process meet their current requirements and their needs and challenges well into the future. The evidence is very clear; cleaning is not going away and is becoming less of an optional process. Cleaning adds value, increases reliability, and reduces liability for contract manufacture, OEM and end user alike.

A Word to the Wise

As with any new or replacement process, one should practice due diligence. Looking for a manual, low volume cleaning solution? Looking for a fully automated cleaning process? Looking for a solvent or aqueous solution, batch or inline? Looking for low discharge or zero discharge? Each technology offers unique benefits. The most important concern is that the cleaning process or machine fit your company's specific cleanliness requirements, throughput requirements, safety and environmental requirements, and of course, budget requirements. Once a specific process or machine configuration is determined, inspect it. If it is a machine, go see an example, look under its skin and "kick the tires." Consult with the equipment supplier and ensure that the machine meets all of your company's requirements today and as far into the future as reasonably viewable. Confirm its cleaning capabilities, level of automation, effluent discharge requirements (if any), throughput capabilities, and total cost of operation. As Benjamin Franklin said, "An ounce of prevention is worth a pound of cure."

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