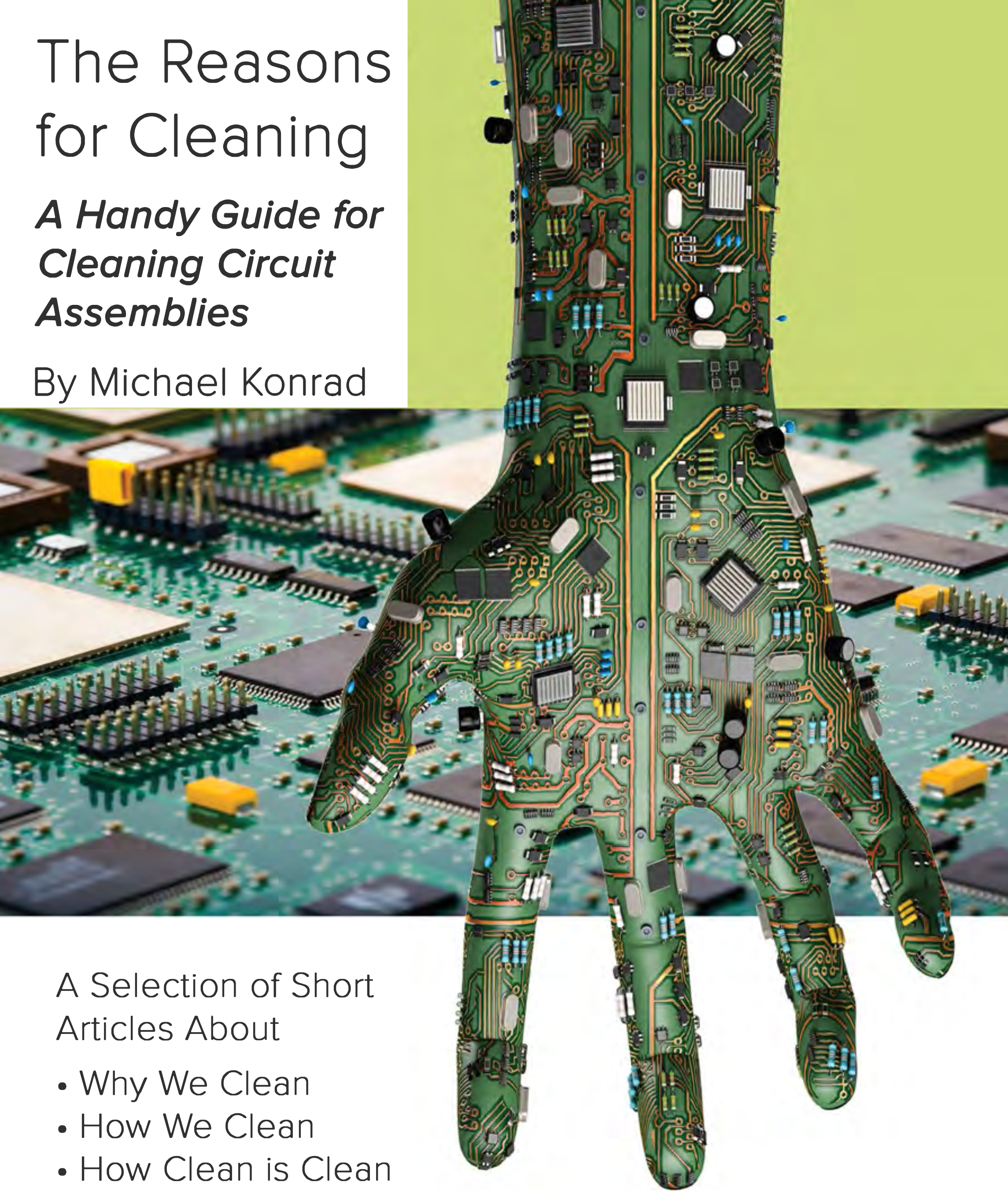
The Reasons for Cleaning

A Handy Guide for Cleaning Circuit Assemblies

By Michael Konrad



A Selection of Short Articles About

- Why We Clean
- How We Clean
- How Clean is Clean

Aqueous® TECHNOLOGIES

CONTENTS

Mike Konrad has worked continuously within the electronics assembly equipment industry since 1985. In 1989, Mike designed a new generation of aqueous-based automatic defluxing equipment, which remains in production today.

In 1992, Mike founded Aqueous Technologies, 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 4,000 machines that are currently in use on six continents.

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Preface

This book is a compilation of many articles I have published on the subjects of cleaning, reliability, and cleanliness testing. Throughout these articles, I promote a common mantra: Clean is better than dirty. Less contamination is better than more contamination. Some assemblies can tolerate more contamination; others, less.

The popular "How clean is clean?" question can no longer be answered in black-and-white terms. Like the popular book series, there are many shades of gray when it comes to contamination and reliability.

This book, and its predecessor (Cleaning and Contamination – Equipment and Environment) attempts to quantify how clean is clean. It also dispels several myths associated with cleaning.

I began my career in the electronics cleaning industry in 1985. Then, virtually all assemblies were cleaned after soldering. The late 1980s through the mid-1990s witnessed the slow decline of cleaning as a normal assembly process. This was due to two combined forces. First, the largest environmental treaty in the world's history (Montreal Protocol) was signed into affect, abolishing the primary cleaning mediums utilized by the electronics assembly industry. As necessity is the mother of invention, a new lower-solids flux species was introduced (No-Clean) whereby the lower volume of residues left behind after soldering/reflow were nearly invisible and almost harmless. With the exception of certain military and high-reliability applications, this spelled the death — or, as we now know, the long deep coma — of the electronics cleaning industry.

Today, cleaning is very close to mainstream. Manufacturing surveys indicate more than 50% of assemblers now clean their assemblies after reflow. The electronics cleaning industry has awoken from its coma and the world is a very different place.

Higher reflow temperatures, smaller and faster assemblies, increased reliability expectations, and a greater adherence to quality standards (causes tied to symptoms) combine to increase the likelihood that cleaning will be a standard requirement.

Happy Reading!

Michael Konrad

"Even low-residue (so-called no-clean) solder pastes leave behind residues that provide no benefit but rather add a bullet in the chamber in a Russian roulette version of quality control."

In almost every context, “clean” is good and “not clean” is bad. In almost every industry, internal components are cleaned before installation. At times, the electronics assembly industry is an exception to the rule.

As I have mentioned in more than one past article, I have been involved in electronics assembly cleaning — more specifically, defluxing — for 30 years. Perhaps that is why I look at the world in terms of clean or not clean.

When an Olympic athlete’s drug test comes back clean, that’s good. One is relieved to receive a clean bill of health. A clean sweep by your favorite sports team is cause for celebration — and who doesn’t want to “clean up” in Las Vegas?

The most common dictionary definitions of clean include “free from dirt, extraneous matter, irregularity, defects, etc.” In almost every industry, internal components are cleaned before installation. When substances are left on a part — grease on a gear for example — the substance specifically adds value to the component. At times, the electronics assembly industry is an exception to this rule. In many segments of our industry, cleaning and maintaining a clean environment are considered vital to the successful production of a product. Anyone who has to don cleanroom garments knows the costs of contamination. Yet, there is a segment of our industry that seems to ignore the value of a clean product.

When electronic components are soldered to a PCB, flux is applied to prevent oxidation of the heated molten solder, improving a solder joint’s integrity. Flux has a distinct and specific purpose. Once that purpose has been achieved, the remaining flux residue serves no other purpose. In fact, the remaining residue is a contaminant, still conductive and corrosive.

Virtually without exception, all manufacturers of electronics assemblies used in high-reliability applications remove flux after reflow. The military requires defluxing to specific cleanliness levels, and so do many other industries. Manufacturers of medical devices remove flux residues from their assemblies to improve product reliability.

Commercial aircraft manufacturers clean all flight boards to eliminate residue-caused defects. Space, broadcasting, emergency response, and hundreds of other high-reliability industries all implement flux residue removal procedures within their assembly processes.

The turn of the 21st century introduced an interesting phenomenon into our industry. Defluxing, formally a practice of high-reliability manufacturers, began to trickle down to manufacturers of less-critical devices. For example, manufacturers of audio amplifiers determined that removing flux from circuit assemblies resulted in truer sounds, with less distortion.

One major amp manufacturer informed me that their version of cleanliness testing was plugging in a guitar and listening to the amplified sound. They can hear the presence of flux residue on the board.

Unfortunately, flux residue does not often expose itself audibly. In most applications, remaining flux residues attack the assembly over time. The time required to generate a failure can be accelerated when heat and humidity are factors, because both accelerate corrosion and dendritic growth.

As electronic components shrink (01005s), so does the electronics assembly. High-density, low-standoff technology combined with ever-increasing demands for increased reliability, even in consumer products, has forced assemblers to reconsider the perceived benefits of leaving flux residue on an assembly. Even low-residue (so-called "no-clean") solder pastes leave behind residues that provide no benefit; as mentioned, they rather add a bullet in the chamber in a Russian roulette version of quality control.

Search through popular technical forums, and you'll see that a common demand for cleaning prevails. IPC's Tech-Net yields 5,590 search results for "cleaning," while SMT-Net's Electronics Forum archive produces 4,242. Clearly, people are asking a lot of questions about cleaning. Foresite, a Kokomo, Ind.-based consulting service and analytical test laboratory, profits by "specializing in residue characterization and its impact on performance and reliability of electronic applications." While it is no doubt an oversimplification — perhaps even a fallacy — to suggest that all contamination is caused by flux, or that all reliability issues are caused by flux, it is safe to say that the majority of in-field mortality issues regarding circuit assemblies are caused by flux-related residues. To paraphrase a former 1992 U.S. presidential candidate, "It's the flux, stupid."

Conclusion

Removing flux from post-reflowed circuit assemblies remains a rapidly adoptive process. Recent advances in defluxing processes — equipment and chemical — have lowered the cost of defluxing to literally pennies per board. Advances in equipment efficiencies and chemical "environmentalness" make defluxing an environmentally responsible process. Reductions in equipment size and cost have allowed assemblers to implement this value- added process with little impact on space and budgets.

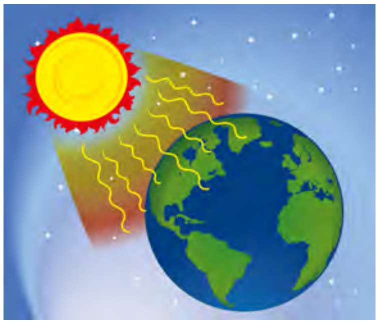
Finally, because modern defluxing systems commonly are outfitted with on-board cleanliness testers, the question "how clean is clean?" can be answered.

"Unwanted electrical conductivity on a board between two undesired locations can easily cause a board to fail."

While the origin of the phrase "may you live in interesting times" is widely disputed, the fact that we indeed live in an interesting time is certainly not. It is a time of record bank failures and declines in stock values, only rivaled by the Depression era, that wreak havoc on consumer confidence. The economic trickle-down effect translates to reductions in production output and, ultimately, the consolidation of many industries, including electronic assembly.

In the face of budget cuts and the resulting reduction of approvals of new capital equipment requisitions, at least one industry failed to falter. The cleaning industry, specifically post-reflow defluxing and cleanliness testing equipment, experienced a surge of new business in 2008. Who's cleaning boards? The answer is unconventional.

Before the Montreal Protocol (the ban of CFC- based defluxing agents), most electronic assemblers removed the flux from assemblies. With few exceptions (high-solids-content rosin- based fluxes in commercial applications), all boards were cleaned after soldering. The post-Montreal-Protocol era brought no-clean flux, and cleaning became the near-exclusive activity of the military and a small handful of other high- reliability assemblers. They cleaned because military specifications required them to do so. The cleaning equipment market became highly specialized, with many previously-familiar high-speed in-line (conveyorized) defluxing equipment manufacturers either going out of business or merging with surviving companies.



Lower-volume, batch-format cleaners replaced larger, faster in-line models due to their suitability and efficiencies in lower-volume/higher-mix applications common in military and other high-reliability applications.

The introduction of lead-free legislation has once again rocked the cleaning industry, this time in an opposite direction. 2008 was a banner year for many defluxing equipment manufacturers and compatible chemical suppliers. In the midst of an economic downturn, the cleaning industry actually grew. What forces caused the entire industrialized world to rethink their defluxing strategies? The answer lies between two electrical components mounted on a circuit board. It is a small metal crystal called a dendrite.

A dendrite is a metal crystal that can grow between two electrical points on a circuit board. Because the dendrite is comprised of metal, it conducts electricity. Unwanted electrical conductivity on a board between two undesired locations can easily cause a board to fail. A board failure in a cruise missile produces obvious detrimental repercussions, hence the cleaning requirement.

But dendrites know no application-based boundaries. The fact is, it only takes three basic ingredients to produce a dendrite: voltage (as low as 1.5 volts); a corrosive material; and ≠moisture.

Dendrites grow on a board by way of a plating process whereby a conductive and corrosive residue (flux) provides a current path between a cathode and an anode.

We call this "miniaturization." Perhaps no other industry is better known for miniaturization than the electronics industry. The other contributing factor is lead-free solder alloys. Lead-free alloys require higher reflow temperatures compared to eutectic alloys. Combine higher reflow temperatures and very-low-solid fluxes and what do you have? You have flux that polymerizes too soon in the reflow process, preventing the encapsulation of metal salts that are created when metal turns to liquid. Traditional high-solids-content rosin fluxes (more common in days gone by) capture and encapsulate the metal salts. In contrast, low-solids no-clean fluxes, when combined with higher heat, can harden, preventing the encapsulation of metal salts. These free metal salts become fertilizer for dendrites.

How can one prevent dendritic growth? The answer is painfully simple. There are three potential methods:

- Remove voltage from the board. Yes, I'm being facetious.

- Prevent contact with moisture and/or humidity. This can be accomplished by either controlling the board's environment (not always possible) or conformally coating the board (which, ironically, requires a clean surface for proper adhesion).

- Remove the conductive residue (flux).

I'll pick door number three, Monte. So did much of the electronic assembly industry. In just the past few years, more assemblers began to clean their assemblies after reflow to remove flux and other conductive residues picked up in board fabrication from components, and during the assembly process.

Because defluxing is new again, there is a newfound desire among engineers to learn more about modern defluxing alternatives. In October 2008, (and every two years since), IPC and SMTA produced the "High Performance Electronics Assembly Cleaning Symposium" to a sold-out crowd. To the surprise of many, commercial and military assemblers alike attended and participated in this event.

Board failures due to the lack of proper post-reflow cleaning are no longer exclusively the problem of super-high-reliability manufacturers

Manufacturers of military hardware, medical devices, cell phones, train control equipment, digital signs, and countless more applications traveled from several states and countries and paid a fee to participate in the two-day Chicago event.

With cleaning once again part of the EMS vernacular, suppliers of cleaning equipment and chemicals have provided manufacturers with suitable choices to match any cleanliness, throughput, and environmental requirement. With fewer field failures and increased reliability, perhaps our time can be a little less interesting.

"Perhaps the greatest attribute of batch-format de-fluxing is its ability to monitor, control, and record cleanliness results."

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There are several advantages to using a contract assembler. One of them is maintaining the ability to dictate desired results. Therefore, how those results are achieved becomes someone else's concern. When you combine this with the fact that many contract assemblers are not accustomed to saying "no," you become a witness to the birth of innovation.

No-clean technology has gained acceptance in many applications, but it remains taboo in others. Ironically, the same OEMs that institute no-clean processes "in-house" prohibit them in "outsourced" products or services. The challenge of implementing an effective de- fluxing program, in many instances, is directed to the contract assembler. Because OEMs can standardize a process over a range of products, they can maintain an inherent advantage over contract assemblers. Fortunately, there are no shortages of cleanliness specifications, or means of measuring cleanliness. The challenge for contract assemblers lies in the multiple applications, processes, materials and, in some cases, expatiations that their customers set.

Frequently, customers predetermine much of the pre-clean process: flux, paste/alloys selection and board design. These pre-clean processes are factors in the downstream cleaning/ de-fluxing process. It is not uncommon for an OEM to require the use of a no-clean solder paste as well as its complete removal. The white residue and moderate ionic contamination levels frequently associated with a no-clean process seldom are tolerated, and normally are rejected by an OEM upon incoming inspection. With process optimization, no-clean results are considered "acceptable" in many applications. However, this optimization process is difficult for contract assemblers because they are running multiple production lines, i.e., using multiple processes for multiple customers.

Because a contract assembler operates various production lines and associated processes and profiles, it is unreasonable to expect the processes and profiles to align themselves with the requirements of a de-fluxing system. It is more reasonable to use a de-fluxing system that can adapt to multiple applications and related processes.

De-Fluxing Methods

There are two basic de-fluxing methods available to contract assemblers: manual and automatic. A manual process may consist of saturating a post-reflow board in an IPA or alternative solvent media, either by soaking it in a pan or applying it using a can of pressurized de-fluxing chemical.

A technician must scrub the board in hopes of making the flux residues more soluble. Boards then are manually rinsed and placed into an oven for drying. This manual cleaning process is non-consistent, labor-intensive and lacking in both immediate process control and statistical process control (SPC).Batch-format de-fluxing systems give contract assemblers and OEMs a high level of process flexibility. Proper defluxing utilizes a four-step process:

The wash process uses a specialized wash solution that is compatible with the board's flux residue, and directs it onto the board's surface and beneath its components. While some boards are reflowed using "normal" oven profiles, others may have been subjected to "aggressive" profiles. This equates to longer wash times on some boards, and shorter wash times on others.

A batch-format de-fluxing system can accommodate different wash times and temperatures for each specific load of boards. Rather than adjusting conveyor speed — which also affects rinse and dry times — batch technology allows independent wash, rinse and dry parameters. Unlike in-line technology, one parameter has no effect on the other, allowing for greater process control and flexibility.

Similar to the wash cycle, batch technology allows independent control over the time and quantity of each rinse. A small load of boards may require fewer rinse cycles than a large load of boards. An automatic rinse-water resistivity (cleanliness) sensor monitors the cleanliness of each rinse cycle, allowing rinse processes to terminate when boards are clean and further optimizing the cleaning process.

Historically, batch de-fluxing technology has not been synonymous with effective drying. Recent improvements in batch drying technology have rivaled the effectiveness of in-line drying technology. Batch-format de-fluxing technology offers a point-of-use cleaning method. Unlike in-line cleaning systems, whereby numerous production lines are funneled into one cleaning system, batch-format cleaners physically are small enough to be placed where needed. Lower acquisition costs and operating expenses associated with batch-format technology allows for the possibility of multiple machine installations when required at a cost normally less than a single comparable in-line cleaning system.

Perhaps the greatest attribute of batch-format de-fluxing technology is its ability to monitor, control and record cleanliness results. As OEMs have their own cleanliness expectations, batch-format de-fluxers can meet each customer’s cleanliness criteria. Moreover, batch technology allows OEMs to use captured cleanliness data for inspection. Valid SPC is vital for ISO, TQM and other quality standards and practices.

Conclusion

The contract assembly industry is highly competitive. It is expected to keep up with customer needs, as well as the demands and restrictions of evolving technologies. Contract assemblers often are subjected to quality standards exceeding those of many OEMs. Fortunately, cleanliness-related demands can be met more easily. This is due to the evolution of batch-format de-fluxing technology.

"If specified correctly, a defluxing process should yield a per board cost of mere pennies. Needless to say, the cost of contamination always exceeds the cost of cleaning."

So, You Need to Clean?

We have witnessed the perfect storm of events that have dovetailed to compel OEMs and contract assemblers to reinstate flux residue removal from circuit assemblies. I have written at length about the forces that have combined to mandate a defluxing process.

These modern trends include the adoption of lead-free alloys, board and component miniaturization, increased reliability expectations, increased reliance on quality standards, and even the increased level of product liability. Be it by requirement (military/IPC cleanliness specifications) or by necessity, defluxing is once again part of the mainstream assembly processes.

If you must implement a cleaning/defluxing strategy, there are now a number of factors one must consider. Hence the need for a practical roadmap. Our roadmap consists of several key factors. This chapter focuses on type of flux, type of assembly, product flow, volume, staff competency, facility restrictions, environmental restrictions, and budget.

For the purpose of relevancy, I disregard manual cleaning, as it represents a small segment of the total sum of defluxing processes and is more common in touch-up and repair.

Type of Flux

Ironically, the most common flux cleaned today is no-clean. Rather than switching flux types, most assemblers have chosen to maintain their flux/paste selections and add a defluxing process. One must choose a defluxing process compatible with no-clean flux. No-clean flux will not be removed with water alone; a chemical additive is required. Aqueous-based (water and chemicals) processes remove all flux types, including water-soluble (OR) fluxes.

Why, if the flux is water-soluble, should a chemical be added to the wash solution? In any post-reflow cleaning process, while the primary goal is to remove flux residues, there are many other process-oriented residues on the assembly. Residues from board fabrication, component fabrication, and assembly all contribute to contamination. These “stowaway” contaminants are often insoluble in water and consist of polar and non-polar contaminants, requiring a chemical additive. If you use a lead-free alloy, the reflow temperatures are normally 30°C hotter than lead-based alloys. This frequently leads to flux polymerization during reflow, preventing the flux from encapsulating the metal salts. A chemical additive is required to break down the polymerized flux and remove the surrounding contamination.

Flux Materials of Composition	*Flux/Flux Residue Activity Levels*	*% Halide (by weight)*	*Flux Type*	*Flux Designator*
ROSIN (RO)	Low	0.0%*	L0	ROL0
		< 0.5%	L1	ROL1
	Moderate	0.0%	M0	ROM0
		0.5-2.0%	M1	ROM1
	High	0.0%	H0	ROH0
		>2.0%	H1	ROH1
RESIN (RE)	Low	0.0%	L0	REL0
		< 0.5%	L1	REL1
	Moderate	0.0%	M0	REM0
		0.5-2.0%	M1	REM1
	High	0.0%	H0	REH0
		>2.0%	H1	REH1
ORGANIC (OR)	Low	0.0%	L0	ORL0
		< 0.5%	L1	ORL1
	Moderate	0.0%	M0	ORM0
		0.5-2.0%	M1	ORM1
	High	0.0%	H0	ORH0
		>2.0%	H1	ORH1
INORGANIC (IN)	Low	0.0%	L0	INL0
		< 0.5%	L1	INL1
	Moderate	0.0%	M0	INM0
		0.5-2.0%	M1	INM1
	High	0.0%	H0	INH0
		>2.0%	H1	INH1

Cleaning equipment should be compatible with chemical use. Equipment capable of reusing the chemical-containing wash solution will lower the overall cost of operation and reduce or eliminate chemical down-drains, making the entire process more environmentally friendly.

Type of Assembly

This is an easy selection. Are you cleaning through-hole or surface mount assemblies? For through hole, less pump power is required, as the clearance between the bottom of the component and the board surface is relatively large. On SMT assemblies, the component's standoff height may be significantly lower, as little as 2 or 3 mils. SMT requires more mechanical energy to produce fine-wash-solution particles and direct them under (and out from under) a component.

While some glassware washers have been modified for defluxing, nevertheless, exercise caution. They may claim that high-power pumps may not be required because the wash solution's chemical additives lower the surface tension, allowing wash solution to penetrate under fine-pitch components. However, that thin 25-dyne wash solution must be flushed out with thick 72-dyne rinse water.

The only thing worse than leaving flux on an assembly is leaving behind wash solution. Good mechanical pump and nozzle designs are required for a successful defluxing process. Some equipment manufacturers also equip their machines with cleanliness-testing capabilities that test for the presence of ionic residues during rinse.

Product Flow

There are two types of automated defluxing systems: batch format and conveyorized. Batch or conveyorized does not necessarily mean batch or in-line. Batch and conveyorized defluxing systems are capable of operating in a batch process. In fact, more than 80% of all conveyorized defluxing systems in North America operate in a batch format.

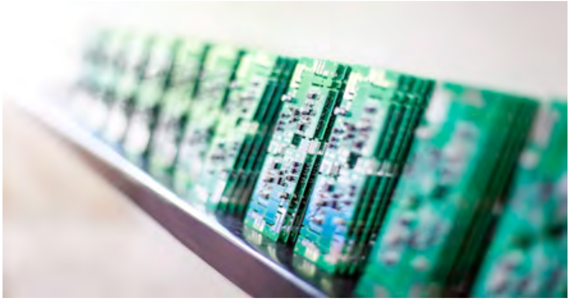
Inline (Conveyorized) Cleaning System

Batch Cleaning System

If an in-line defluxing process is desired, one must consider where to place the equipment. Many manufacturers install the in-line defluxer on the exit of the reflow oven. Others place it after selective soldering and still others after rework. The fact is, no matter where you place the in-line defluxer, someone will carry assemblies to it “out of sequence,” turning it into a batch process. It is more common in today’s workplace to use a defluxing system in a batch process, regardless of the machine’s intended configuration.

Volume

In years past, volume determined which technology one would purchase: batch or inline. Batch machines were designed for low-volume, high mix applications while inline defluxing systems were designed for high volumes. Today, this has changed.



Batch format defluxing systems, while still suitable for low-volume, high-mix applications have been engineered to produce throughput rates as great or greater than inline systems. This technological advance has pushed out the volume threshold used to justify one technology over the other. There are three choice configurations to choose from: batch, high-yield batch, and conveyorized (inline) defluxing systems. As energy consumption, water consumption, chemical consumption, and environmental noise are added to the usual list of technical considerations, and because most defluxing process are utilized in a batch format, more companies are choosing batch-format defluxing equipment.

Staff Competency

This is an oft-overlooked criteria. Modern defluxing equipment, like other assembly equipment, has become highly automated. Some equipment allow operators to only choose from a library of recipes (designed by manufacturing or process engineer), reducing the chance of operator error. Modern defluxing systems are equipped with password protection, preventing an operator from modifying critical settings such as final cleanliness and desired chemical percentages. SPC functions record every cycle, including set and actual cleanliness, a valuable asset in today's TQM/ISO/Six Sigma world.

Different brands and configurations offer varying degrees of process control and user control. Regardless of the level of control and automation, one must ask, Who controls the process?

Facility Restrictions

Every automated defluxing system requires the following items: electrical power, water (DI), drain or recycling equipment, and exhaust. The amount of these resources vary widely based in the defluxing system's configuration (batch or conveyorized).

Electrical Power

Electrical utility requirements vary from 15 KW (high-performance batch) to 170 KW (high-performance conveyorized).

Water Requirement

Water requirements vary from 30 gallons per hour (high-performance batch) to 300 gallons per hour (high-performance in-line).

Drain or Recycle Equipment

Keep in mind: all water that goes in must go out. This means that the water input requirement must be matched with a suitable drain requirement or an equivalent recycle (closed-loop) capacity. Zero-discharge evaporators are a popular choice on batch configurations due to their low discharge rates.

Environmental Restrictions

Environmental liability is a modern concern. Many municipalities monitor the volume of industrial effluent being directed to drains. Every gallon sent to drain counts, even if it is relatively "clean."

In years past, many defluxing systems, particularly conveyorized models, operated on just water, no chemicals. Water-only defluxing systems were easily and efficiently closed-looped with traditional carbon and ion-exchange resin technology. Today, with chemical additives representing the conventional wisdom, close-looping the process is costly due to the fact that the defluxing chemicals must be completely segregated from the carbon and resin media, lest it destroy the expensive resins. This normally means that an isolation section must be added to conveyorized cleaners to provide better separation between the wash chemical and the rinse sections. This results in a longer machine and, frequently, a non-closed-loop section.

If a zero-discharge configuration is desired, a batch configuration is preferred as there is normally internal segregation of the wash and rinse sections, which prevent excess cross-contamination without the need for isolation drains. Because the total effluent volume is low, fluid recycling systems can be connected in lieu of a drain.

Budget

As equipment prices vary from the tens of thousands to the hundreds of thousands, the important calculation is the cost per clean board. If specified correctly, a defluxing process should yield a per-board cost of mere pennies. Needless to say, the cost of contamination always exceeds the cost of cleaning.

"Although rinsing seems to be easier than washing, the opposite is true."

What is the most important aspect of de-fluxing?

If I had a nickel for every time someone called their de-fluxing system a “board washer,” I could buy my own island! The fact is, “washing” is the easy part. The real test of a machine is its ability to rinse.

Consider de-fluxing a four stage process:

1. Wash
2. Rinse
3. Verify cleanliness
4. Dry

The purpose of a wash cycle is to “solublize” the flux — or, if you are using a saponifier, to convert the flux to soap. In other words, the flux must become part of the wash solution. Getting the wash solution under fine pitch parts is always challenging, but the low surface tension of the wash chemical assists with under component penetration (impingement).

Now that the flux has been properly “solublized”, the next challenge is to rinse the boards. Rinsing is a process that displaces wash solution with rinse water. Although rinsing seems to be easier than washing, the opposite is true. Modern aqueous de-fluxing chemicals have proven to be extremely effective in the removal of flux residues. Many modern de-fluxing chemicals, equipped with corrosion inhibition (brightening) packages, produce brilliantly shinny solder joints. The best aqueous de-fluxing chemicals, suitable for difficult lead-free de-fluxing applications, share one critical component with standard de-fluxing chemicals: They are extremely detrimental to the board’s life if left on the board.

De-fluxing chemicals contain ingredients that produce high pH levels, frequently in excess of 11 pH. The high pH levels are required to react with the acids in the flux. De-fluxing chemicals are highly conductive and corrosive if allowed to remain on a board. Therefore, proper rinsing is crucial to a board’s cleanliness, reliability, and life expectancy.

Rinsing is more difficult than washing. During the wash cycle, the surface tension of the wash solution is reduced by the de-fluxing chemical, making it easier to penetrate under fine pitch devices. Unlike wash, the rinse cycle is not aided by the surface-tension-lowering properties of a wash chemical. As the wash solution rinses off a board, the rinse water’s surface tension begins to rise, making it more difficult to reach tight areas under components. This challenge can be overcome with an adequately-sized rinse pump and specially designed spray nozzles that deliver high-velocity rinse water to the board.

To ensure proper removal of de-fluxing chemistry, one's cleaning system (specifically the rinse section) must contain an adequate level of power. Contrary to popular belief, power is not measured by a pressure gauge. In the past, de-fluxing equipment companies have boasted high-pressure spraying systems of 50 PSI, 75 PSI, 150 PSI, etc. The problem is, the method of measuring spray pressure involves placing a pressure gauge on the plumbing manifold. This actually measures the back pressure (the pressure NOT hitting the boards). To prove this point, simply insert plugs into the nozzle locations. You will experience NO water flow while measuring maximum PSI

The real measurement is "board impact pressure". This is the pressure of the water actually contacting the board. Board impact pressures of 6-8 ounces per square inch (measured a distance of 6 inches) produce ideal results on lead-based solders. Board impact pressures of 12-15 ounces per square inch produce exceptional results on lead-free and other high-temperature solders.

Impact pressures are relevant only to the areas of contact with the board. Delivering adequate impact pressure to only part of a board will not yield proper cleanliness results. The de-fluxing system must be capable of delivering the proper impact pressure to all areas of the board. Some modern de-fluxing systems are equipped with technology that allows both the spray nozzles and the board to move. By moving the spray nozzles and the boards, complete "shadow-free" results are ensured.

To ensure the complete removal of wash solution, many de-fluxing systems (batch format) are equipped with resistivity sensors that measure the electrical resistance of the rinse water draining off the boards during the rinse cycle. Because de-fluxing chemicals are extremely conductive, they are easily detected. By comparing the electrical resistance of the incoming rinse water with that of the water draining from the rinsed board, one may accurately determine if the boards are free from wash solution and, therefore, flux.

Once a board has been thoroughly rinsed and verified as clean, the boards may then be dried. Fortunately, modern-day automatic de-fluxing systems are capable of providing automatic wash, rinse, cleanliness testing, and drying. When evaluating a de-fluxing system, consider the machine's impact pressure ratings both in wash and in rinse. Also consider a machine's ability to deliver high-impact fluids to all areas of the boards. With the correct de-fluxing machine, the proper chemical, and the correct cleaning profile, complete de-fluxing can be achieved literally at the push of a button.

...high-yield, predictive cleanliness-enabled defluxing systems can reduce the reliance on such testers and the frequency of negative results.

The overused phrase, "How clean is clean?" most frequently refers to cleanliness in the past tense. Literally, it would be more accurate to ask: "How clean was clean?" In the world of surface mount assembly, cleanliness normally is determined after the cleaning process has been completed. As with so many things, we exert effort and hope for the best. Then, when the work is complete, we validate the process.

In other segments of surface mount assembly, process validation is accomplished in real time. Pick-and-place machines, for example, are equipped with vision technology, ensuring that the component is placed correctly and reducing the need to inspect the assembly for accuracy.

When it comes to defluxing circuit assemblies, many assemblers rely solely on post-process cleanliness testing. Surface insulation resistance (SIR), ionic contamination (resistivity of solvent extract), and ion chromatography (IC) are respectable and common methods to determine the cleanliness after the defluxing process.

If the cleanliness testing procedures determine inadequate levels of cleanliness, then one or more processes are modified. Failed boards are re-cleaned, while new boards are subjected to modified or corrected cleaning processes — the results of which are re-verified by more cleanliness testing. In some situations, process modifications solve cleanliness issues. Often, additional modifications and verifications are required. More hits and misses.

There are two conventional methods associated with defluxing: inline (conveyorized) and batch. With both methods, high-pressure sprays direct wash solution onto a board's surface and under its components to solublize flux and other contamination. Wash chemistry and the flux it contains are left on the board's surface and are removed during the rinse process. As with many technologies, the two primary defluxing methods provide both benefits and disadvantages. Inline format defluxing systems normally are selected when high production rates are required.

Although conveyorized defluxing machines consume considerable operating expenses, they can produce high levels of throughput. Modern batch technology (Figure 1), on the other hand, produces equal levels of cleanliness, but has historically suffered from a substantially reduced product-throughput capability.

Batch-format technology does offer several advantages over other defluxing technologies. For example, many batch format systems feature real-time cleanliness control, allowing an operator to program a desired level of cleanliness prior to the defluxing process. This process called "predictive cleanliness." On systems with predictive cleanliness capabilities, the cycle time required to rinse the assemblies is adjusted based upon the actual cleanliness of the assemblies, as determined by the ionic reading (resistance) of the rinse water. This technology forces the rinsing cycle to lengthen until programmed cleanliness is achieved. The result is a predicted cleanliness level that eliminates the element of surprise.

Batch-format defluxing methods are uniquely adaptable to predictive cleanliness technologies, as they do not rely on a fixed-length conveyor. Inline defluxing processes, by design, do not allow for on-the-fly adjustments to rinse-nozzle contact times — a fact that precludes them from real-time cleanliness testing. It mandates the reliance on post-defluxing cleanliness verifications.

The advent of lead-free technologies has created two challenges. The need for cleanliness testing has been increased due to hotter reflow profiles frequently required by many lead-free solder pastes, and the resulting rise of post-reflow flux residue. This, in turn, increases the quantity of assemblies requiring defluxing. The increase in the quantity of assemblies being subjected to thorough defluxing processes, and the simultaneous increase in the need for cleanliness testing, creates a paradox. Does one increase throughput capability by using high-throughput inline-defluxing technology, thereby losing real-time cleanliness testing abilities? Or does one suffer the bottlenecks afforded by conventional batch technology, but retain the advantage of predicted cleanliness?

Recent advances in defluxing technology have produced defluxing systems capable of providing both high product yields and predicted cleanliness technology. High-yield defluxing systems use multiple process chambers, each of which subjects assemblies to wash, rinse, cleanliness test, and dry functions. Each of the multiple process chambers can accommodate multiple post-reflow assemblies. Multiple process chambers may be operated simultaneously or autonomously to suit the user's specific throughput requirements. Regardless of the chosen operational configuration, each process chamber provides individual cleanliness testing, resulting in individual automatic process modifications to ensure predictive cleanliness results.

Conclusion

While the need for independent cleanliness verifications can never — nor should ever be — completely eliminated, high-yield, predictive cleanliness-enabled defluxing systems can reduce the reliance on such testers and the frequency of negative results. This combination of high throughput and predictive cleanliness provide a viable solution for environmentally responsible electronics assemblies.

Being involved in the electronics assembly industry for more than 30 years, specifically in the field of defluxing and cleanliness testing, I have seen my share of environmental regulations. Long before the debate over lead-free alloys, there was the Montreal Protocol.

Back in the late 1980s and early 1990s, the elimination of CFC-based defluxing solvents dominated the covers of industry trade magazines. Emissions from Freon- and Trichlorethene-based defluxing solvents threatened the Earth's ozone layer and would soon be banned from use.

The electronic assembly industry responded with two alternative strategies: no-clean fluxes/pastes and aqueous-based defluxing. No-clean fluxes and solder pastes proliferated in the market and many solvent-based defluxing systems were replaced by no-clean processes. History has taught us that no-clean technology is not compatible with all applications. High-reliability (medical, military, space, aviation, etc.) manufacturers have historically embraced a cleaning/defluxing process to improve product reliability and decrease potential liability. Additionally, when electronic assemblies are operated in harsh environments — heat, cold, humidity — a defluxing process normally is required.

While much of the assembly industry adopted no-clean processes, industries not suited for no-clean embraced aqueous defluxing techniques, considered environmentally superior to solvent-based technologies. In the late 1980s and throughout the turn of the millennium, any defluxing process that did not send emissions into the atmosphere was viewed as "green." Science proved the negative effects of CFC emissions, and aqueous-based defluxing methods were CFC-free.

For the high-reliability industry, where defluxing is required, there are basically two choices: low volume and high volume. This translates to batch processing or in-line (conveyor) processing. Early batch processing defluxing equipment, although environmentally superior to CFC-based defluxing systems, lacked the throughput required for much of the high-reliability manufacturing sector. As a result, aqueous-based in-line defluxing systems gained popularity.

Today, CFC emissions as they relate to defluxing are a distant memory. However, governments and local municipalities have focused their attention on another byproduct of defluxing: effluent discharge. High-profile Environmental Protection Agency (EPA) enforcement operations have caused manufacturers to become more concerned about what is going down their drains. Ever-increasing punitive penalties associated with improper discharge have caught the attention of health and safety officers and corporate management. Modern assemblers seek defluxing alternatives that reduce or even eliminate effluent discharge.

In addition to reducing discharge-related liability, there are other factors that have impacted manufacturers and users of aqueous-based defluxing equipment. Consumers are becoming more aware of the environmental impact of various assembly processes, particularly defluxing. Aqueous-based defluxing systems use water as the primary medium. The water, when spent, must either be recycled or disposed of. Energy costs, environmental noise, and chemical usage are among the other environmental considerations when choosing a defluxing process.

The electronic assembly industry frequently uses an in-line process for assembly. The defluxing process was no exception. In one of our industries' strange ironies, in-line defluxing systems were rarely in line with other equipment. This was due in part to logical requirements

of DI water, drain lines and vapor exhaust and ambient noise issues. Most assemblers placed the in-line cleaner in an area more suitable for a defluxing environment rather than in the assembly line.

While in-line defluxing technologies were environmentally attractive compared to CFC-based solvent cleaning systems, the standards by which we define "green" have changed. Today, water is a precious commodity in many parts of the world, particularly in my part of the U.S. (Southern California). Many inline machines require as much as 19 liters of water per minute,

a politically incorrect requirement in the western U.S. The rising cost of energy forces assemblers to consider electrical current requirements and the volume of discharge to drain determines if a user requires a special discharge permit (19 liters per minute in equals 19 liters per minute out).

Over the past two years, assemblers who require clean (flux-free) assemblies in medium to high quantities have begun to embrace new high-yield batch defluxing technology. Unlike traditional low-volume batch defluxing processes, high-yield batch processes are capable of high-volume defluxing. High-yield batch processes gained popularity in Europe where environmental regulations carry considerable weight in process and equipment selection. Users of high-yield batch defluxing processes are able to process equal quantities of electronic assemblies while consuming only a fraction of the water required by in-line processes. Less water in translates to less water out, thus reducing the volume of effluent discharge and associated liability. Because less water is required, zero-discharge configurations utilizing evaporative technology are implemented easily. Also, because most defluxing applications require a chemical additive as a percentage of wash water, less chemical input is required, reducing consumable expenses.

North America is beginning to embrace high-yield batch defluxing technology for a combination of reasons. Like Europeans, North Americans are increasingly cognizant of the environmental impact of modern manufacturing techniques. It doesn't end there. Americans are uniquely aware of the liability associated with environmental negligence. The U.S. is a litigious society; as such, manufacturers are keenly aware of the repercussions associated with litigation. Any process that reduces product liability and environmental liability, while reducing a company's carbon footprint and reliance on natural resources, is valuable indeed.

Conductive crystals, white residues, and decreased reliability

The Rush to Clean No-Clean

Just as the little girl in the 1982 film "Poltergeist" eerily exclaimed, "They're back." The electronics assembly industry has witnessed the return of a familiar yet unappreciated process step: cleaning.

Once commonplace, then relegated to military and other high reliability applications, today defluxing has once again moved toward the mainstream. The miniaturization of electronic assemblies and their components, implementation of lead-free alloys, combined with improved quality standards and higher reliability expectations, have culminated to form a growing demand for ionically clean electronic circuits.

This chapter will review the major causes of residue-related failures including dendritic growth, electrical leakage, and under-coating adhesion failures. Why we clean, what we are removing, and how clean is clean will be presented.

Context

The concept of personal hygiene was greatly enhanced by the Romans in 312 BC with the invention and introduction of public baths. This was further enhanced by the end of the second century AD with the introduction of soap, invented by the Greek physician Galen. In 467 AD, Rome fell, as did many of its then-modern inventions and influences. This included public baths. The fall of Rome and its public bathing is cited by modern-day historians as one contributing factor to the spread of the great plagues of the Middle Ages and, in particular, the Black Death of the fourteenth century.

Modern Day

Today, thankfully, cleanliness has entrenched itself into all aspects of human civilization. In fact, the word “clean” has become part of our modern vernacular. We admonish our boxers to “have a clean fight.” We wish upon our favorite sports teams a “clean sweep”. When at the doctor we hope for a “clean bill of health”. We admonish confessors to “come clean”. and innocent people's “hands are clean”.

This author has spent 30 years in the electronics cleaning industry and has seen many trends. Today’s modern cleaning trend is particularly curious. If I ask an audience of engineers “What is the most common flux removed from circuit assemblies today?” I can rely on the consistency of the answers. The most common answer is water-soluble (OA). Second-most common is RMA. Actually, neither answer is accurate. The correct answer is no-clean. No-clean flux is the most common flux removed after reflow. Why? The answer is ironic.

Déjà vu

To understand why no-clean fluxes are being removed from assemblies after reflow in record numbers, we need to understand the history of flux removal and assembly designs from an historic perspective. Let’s travel back in time, specifically to pre-1989. Before 1989, nearly all assemblies were cleaned. Components were “stuffed” into assemblies. Assemblies were soldered, leads were trimmed and assemblies were cleaned to remove the flux residues. Cleaning was an integral part of the assembly process. With few exceptions, assemblies were cleaned using one of three media: 111 Trichloroethane, Freon TMS (or generic equivalent) or water.

The great buzzkill of the 20th century arrived in 1989 in the form of an international treaty entitled the Montréal Protocol. Apparently, these CFC-based cleaning solvents were busy destroying the Earth’s ozone layer (Figure 1); the United States, Canada and about nine other countries were determined to stop it. As a result, many CFC-containing products were banned under this treaty, including the two major cleaning solvents used in electronics production.

Amidst the industry-wide panic, fueled by several trade magazines cover stories with dire countdowns to the end of CFCs, came a new technology called “No-Clean Flux.” More than just a technology, it was a concept. Reduce the volume, visibility and affect of residues and leave them on an assembly. Problem solved!

Assemblers of military, medical and other high-reliability products continued to remove flux residues by cleaning their assemblies (using alternative technologies). However, the greater commercial industry, having no specific mandate to clean, abandoned cleaning by switching to a no-clean process.

This bi-polar approach (cleaning is required/cleaning is not required) was largely successful.

This bi-polar approach (cleaning is required/cleaning is not required) was largely successful. No-clean technology, in most cases, left behind mostly benign residues that did not negatively affect most electronics assemblies. In recent years, however, a growing number of commercial assemblers have rejoined the ranks of military and medical processes and turned back to cleaning in an industry resurgence. Because RMA and OA flux residues have always been removed via a cleaning process, the growth in cleaning is represented by commercial assemblers removing no- lean flux residues. There are many times more commercial products being built compared to specifically high-reliability products, so the growth in cleaning is no-clean-based. As a result, no-clean represents the highest share of flux cleaning today.

Houston, We Have a Problem

As previously mentioned, there is a modern migration toward a cleaning process. No-clean processes have been popular for 22 years. Why then are no- lean processes now being replaced with cleaning processes? What changed? Today, there are two primary problems associated with residues left on a circuit assembly — electrical migration and electrical leakage. These problems are hitting many assemblers hard and, in a growing number of cases, have led to a rush to clean no- lean. Electrical migration can occur when three key elements combine on an assembly:

- Voltage differential (power to ground). As little as 1.5 V
- Moisture
- A corrosive or conductive residue

When the three key elements are present with other factors, it is possible to experience electro-migration, commonly in the form of dendritic growth between two electrical connections on the assembly. A dendrite is a metal crystal that forms as metal dissolves at an anode and is electro-deposited at a cathode. The electro-deposited metal takes the form of metal crystals.

Dendritic growth on component with 5 VDC applied (courtesy Foresite).

Dendrites are harmful because they increase electrical conductivity between two points, causing instrument errors and/or electrical shorts.

The nefarious nature of dendrites comes from the fact that they are extremely slow-growing. While rapid dendritic growth can be demonstrated in a lab environment, in a "normal" environment, they may take from 8-18 months to grow. Unless accelerated age testing (e.g., steam-age testing) is performed, it is impossible to predict the likelihood of dendritic growth until a catastrophic event occurs.

Electrical Leakage

The other issue associated with assembly residues is electrical leakage. This is a particularly difficult diagnosis to confirm, because the results of electrical leakage tend to be of a temporary nature. At issue is the fact that electrical leakage is a temporary problem. Its effects are witnessed only when the assembly adsorbs moisture. When the moisture is removed, the problem disappears, frequently resulting in no-trouble-found (NTF) field returns.

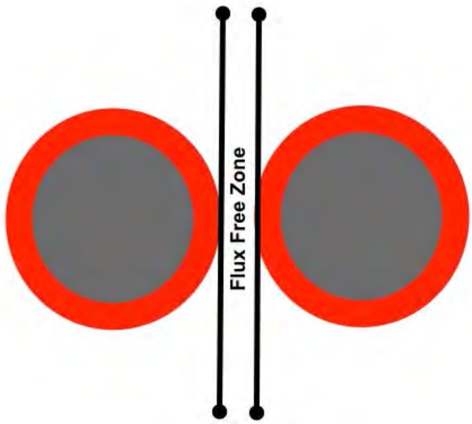
A typical scenario goes like this: An assembly is tested and shipped to a customer in Mississippi in February. The customer begins to use the product, a hand-held portable instrument. By August, the customer notices that the instrument is not working properly and returns it to the manufacturer for inspection. Upon receipt by the manufacturer, the product is tested within the air-conditioned and humidity-controlled environment of the test lab. Of course, the problem cannot be duplicated because the humidity-caused moisture has disappeared. This results in a NTF status, and the product (and the problem) is returned to the customer. At issue is the flux residue that becomes more active when subjected to moisture, allowing increased conductivity to alter a product's function — but not enough to create a short.

Why Now? What Changed?

As previously stated, we have been using no-clean flux, mostly successfully, for 22 years. Why is our industry seeing an increase in electro-migration and electrical leakage now? The answer is simple. There are two reasons for the increase in residue-related failures. One factor is the implementation of lead-free alloys.

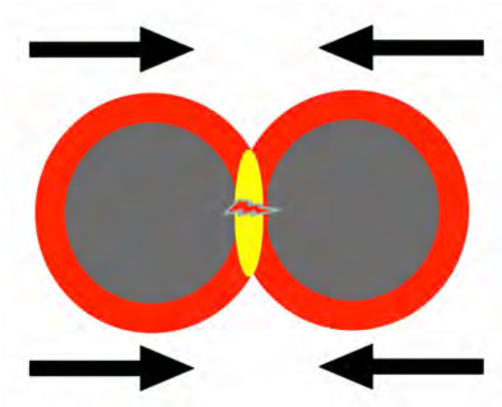
First, let's consider the purpose of flux. Flux reduces oxidation during the reflow process when solder changes from a solid state to a liquid state. The flux's responsibility is to reduce oxidation and to encapsulate the metal salts that form when solder is in a liquid state. Historically, flux had a solids content of 30%-50%. A higher-solids flux maintains a greater ability to remain useful 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 as 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, resulting in unencapsulated 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.



Components with spacing between provide a flux-free zone

Another contributing factor is miniaturization. Our assemblies are getting smaller and, as a result, the component densities are getting higher. In any reflow process, flux, embedded into the solder paste, oozes from a pad when subjected to heat. Like ice melting on a table, flux will drain from a pad. Historically, this was not a major issue because the assembly's pads were physically far enough apart to leave a flux- free gap between two pads.



Components with less spacing provide a "flux bridge" between components

As assemblies were miniaturized and component densities increased, the flux residue would spread from pad to pad, forming a bridge of residue between cathodes and anodes. Even though no-clean flux residues are ionically weak and are hardly corrosive, the physical close proximity between components, combined with excessive heat and its negative effects on flux, create the perfect storm for potential failures.

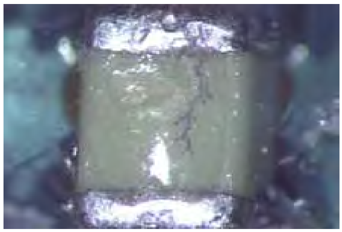
Preventing Residue-Related Failures

There are three proven methods to prevent residue-related failures:

1. Remove the electrical voltage.
   While this method is highly effective, it is absurdly unpractical.

2. Prevent assembly contact with moisture.
   This is commonly accomplished by the application of conformal coating. Contrary to popular belief, conformal coating, while providing an excellent barrier to fluids, does not prevent all contact with moisture. Over time, moisture can penetrate coatings, resulting in residue-related failures as previously described. Even if coatings did provide an effective barrier to all forms of moisture, coating manufacturers require clean, residue-free surfaces for good adhesion. Failure to provide a residue- free surface can result in coating delamination and/or under-coat corrosion.

3. Remove the residues that contribute to electro-migration and electrical leakage.
   With option #1 not on the table and options #2 and #3 all requiring cleaning, it is clear that a cleaning/de-fluxing process is the best method of preventing assembly failures due to electro-migration and electrical leakage.



Dendritic Growth Under Coating

Typical Assembly Residues

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

Additional Benefits of Cleaning Electronics Assemblies

In addition to the elimination of post-reflow residue-related product failures, the cleaning of electronic assemblies, while intended for the removal of flux residues, actually provides for the removal of other contamination species. While the emphasis of a cleaning program is flux removal, it is important to consider the many other sources of potential contamination.

It is highly possible for residues to remain on a circuit board as a result of the board fabrication process. Additional residues may contaminate components from the component manufacturing process. The assembly process, in addition to flux residues, also contributes to excessive assembly contamination by way of machine and human contact. Contact with industrial and human sources can transfer residues that carry a reliability-lowering potential.

A robust cleaning process can eliminate all or most of the residues that become stowaways on an assembly during its journey through the fabrication and assembly processes.

The science of post-reflow cleaning of circuit assemblies is an all-or-nothing proposition. If you cannot fully clean an assembly, do not clean it. The only thing worse than assembly-related residues on an assembly is a partially cleaned assembly. There are numerous reasons for this. First, the most critical part of a cleaning process often is thought to be the wash cycle. This is not accurate. The most critical function of any cleaning process is the rinse.

Defluxing chemicals are highly ionic and corrosive. During a wash cycle, flux and other residues are solublized and held in solution within the wash chemical. After wash, the assembly is covered with wash solution that contains the flux and other residues. If an assembly were removed from a wash cycle without the benefit of rinse, the assembly would soon fail. Solder joints would be attacked, and electrical migration and leakage could become rampant. Only a thorough rinse process would adequately displace the wash solution and the residues within it. A high-quality DI water rinsing process will ensure that all solublized residues and the corrosive wash solutions have been removed. Ionic verification of the absence of wash solution during a rinse cycle will confirm that the assemblies are free from wash solution — and, presumably, free from flux and other forms of contamination. A weak cleaning process may actually increase assembly residues and, consequently, the risk of failure.

How Clean is Clean?

This is one of the most popular questions. The military attempted to measure it in the form of WS6536, MIL STD 2000A and other standards.

IPC has also attempted it in the form of J-STD001-TM650 and other standards. The reality is that all these standards were written in the 1970s and 1980s.

Consider the magnitude of evolution that has occurred in the design of electronic assemblies over the past 30+ years and ask yourself if you feel comfortable with these cleanliness standards. The real answer relies on another question: what happens if it fails?

A failure in a GameBoy carries far different consequences than a failure in the Hubble Telescope. Mobile phones and defibrillators each have their own unique level of consumer confidence and degrees of liability if failure occurs. There is considerable debate about which cleaning standard and cleanliness testing method to adopt. Ion chromatography, ROSE testing, SIR, visual and other methods are all valuable tools to determine if an assembly is clean; each carry both benefits and drawbacks. While ROSE testing remains by far the most popular and accessible method of post-reflow cleanliness testing, it is not without its faults. Many assemblers rely on ROSE testing results based on the standards designed in the late 1970s (10 µg NaCl/in2).

The fact is that ROSE testers, while fast and inexpensive, are not capable of detecting all forms of possible contamination. Additionally, they assume that all detected contamination is evenly spread across the assembly. In reality, contamination frequently is concentrated in or under high-density assembly areas. For these reasons, one should consider an internal standard that is much lower than the ones published.

How clean is clean? On a ROSE tester, 0.0 is clean. Every value above 0.0 is a step toward possible contamination and related consequences.

Conclusion

Post-reflow residue-related failures are on the rise, as are quality expectations. A cleaning process will increase reliability and, therefore, decrease potential assembly failure liability. Cleaning materials and equipment have evolved significantly over the past 22 years. Today's modern cleaning materials and processes provide an environmentally responsible alternative to the processes of the last century. With the ever-decreasing size of a circuit assembly, the increasing densities of components, and the increasing demand for reliability, it is time to return "clean" to the electronics manufacturing vernacular.

"The cost of replacing a video game console is less than retrieving a part from space or even from a down-hole application. The higher the cost of failure, the lower the allowable contamination value."

We Ask Again: How Clean is Clean?

As with many important questions, there is an awkward yet completely accurate answer. The answer, while frustrating, can actually lead the way to a better understanding of assembly contamination and its relationship to failures — and in turn, higher product reliability, lower product liability, and happier customers. So, how clean is clean? It depends!

First, let's discuss the method in which post-reflow assemblies are measured for cleanliness. The most common method of determining cleanliness is to perform a Resistivity of Solvent Extract (ROSE) test. ROSE testing has been the most popular method of cleanliness testing since the 1970s. ROSE testing was cited in the US weapons specification (WS6536), in military specifications, (MIL-STD 2000A), and is currently the only "approved" post-reflow cleanliness test per IPC J-STD001 TM650. There are thousands of ROSE testers in use today. All of them produce a Pass/Fail result; in many instances, those results are misleading. In order to accurately interpret the results of a ROSE test, one must take several factors into account.

ROSE testers work by submerging the subject assembly into a highly calibrated, high-resistance test solution comprised of IPA and deionized water.

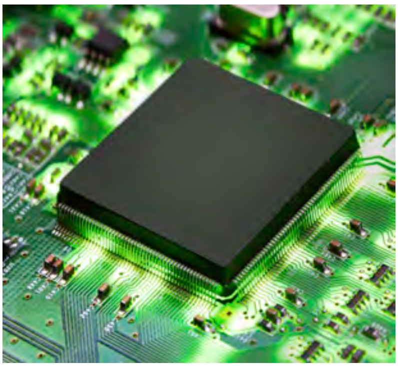
The test solution is purified using ion-exchange resin to remove nearly all ionic properties from the solution. That causes its electrical resistivity to rise, normally in excess of 100 MΩ. As contamination is dissolved from the assembly into the test solution, the test solution becomes more conductive, lowering the resistivity. Changes in the test solution's resistivity over time are run through a complex algorithm which will express assembly contamination as micro grams of sodium (equivalent) per square inch/cm (µgNaCl/in2 or µgNaCl/cm2). Basically, the expression of contamination is the amount of sodium one would have to add to the test solution to change its electrical resistance by the amount of change caused by the assembly's dissolved residues.

Factors To Consider When Interpreting a ROSE Test Result:

- The Cost of Failure
- The Assembly's In-Use Climatic Environment
- Component Density/Spacing
- Component Geographic Diversity

Component Density/Spacing

Past military and current standards dictate a pass/fail criteria of 10.06 µg NaCl/in2 or 1.56 µg NaCl/cm2. While this pass/fail value is still considered valid, it was first published in the 1970's. It's safe to say that electronic assemblies have changed considerably since the 1970s. When the standard was first introduced, there were no surface-mounted components. Spacing between components and between component terminations were much larger than today.



As the distance between conductors lowers, so does the volume of residue deemed tolerable by the assembly. While 10.06 µg NaCl/in2 (1.56 µg NaCl/ cm2) was deemed tolerable thirty years ago, many modern-day assemblies would find that value to be problematic. The fact is, the amount of residue tolerable to an assembly is based, in part, on the spacing between conductors — more specifically, between cathodes and anodes. The closer conductors are to each other, the less contamination can be tolerated by the assembly. Higher-density assemblies normally benefit from lower contamination readings.

The Assembly's In-Use Climatic Environment

Another factor is the assembly's in-use climatic environment. Excessive contamination on an assembly's surface may lead to electrochemical migration (ECM). ECM may manifest itself in the form of dendritic growth and/or parasitic leakage. In order for ECM to manifest, there must be three basic elements present on the assembly. These elements are an electrical bias (voltage), corrosive/conductive residue, and moisture. As voltage is not a removable option, the factors that determine the possibility of ECM are residues and moisture.

More contamination is tolerable if the assembly is not exposed to higher degrees of moisture. Likewise, contamination is less tolerable if the assembly is exposed to a higher degree of moisture (i.e., humid environments). Assemblies subjected to a higher humidity or moisture in-use environment will benefit from lower contamination readings.

Component Geographic Diversity

Another factor in determining a suitable pass/fail rate is component geographic diversity. ROSE testers extract all ionic contamination from an assembly, then quantify the results by dividing the total volume of contamination by the assembly's surface area (length x width x 2). While this simple formula quantifies the contamination, it falsely assumes that the contamination is evenly distributed throughout the assembly's surface area. Obviously, contamination is most likely concentrated in higher-density areas on the assembly's surface. If, for example, one tests a double-sided assembly with a high density of components on the "A" side of the board and only three components on the "B" side, more contamination will likely be present on the "A" side than the "B" side. The tester however, will divide the contamination value evenly over the entire surface area. If an assembly is evenly populated, then the results produced by the ROSE tester are more accurate. If the assembly's component density is uneven, then one must take this into account when interpreting the results and lower contamination values are vital to reduce the chance of ECM

The Cost of Failure

Finally, and perhaps most importantly, when interpreting the ROSE test results, one should consider the cost of failure. To some, failure is expected. Planned obsolescence may require a product to stop working after a period of time. To others, failure is not an option.

Clearly, the cost of failure for an electronic flea collar is different than an implantable defibrillator. The cost of replacing a video game console is less than retrieving a part from space or even from a down-hole application. The higher the cost of failure, the lower the allowable contamination value.

The Perfect Answer

The perfect answer to the question of How Clean is Clean is 0.0 µg NaCl/in2 (0.0 µg NaCl/cm2). If one achieves a 0.0 test result, then there is no concern about cost of failure, climatic environment, etc. If 0.0 is not possible, then for every unit of measured contamination, consider the factors listed above. There is little doubt that a contamination value significantly less than 10 and more than 0.0 will be suitable.

Dishwashers used as circuit board cleaners, particularly when used with defluxing chemicals, end up rapidly in a state of leaky disrepair and the assemblies they "cleaned" become fertile dendrite farms.

As with many things in life, there is good news and bad news. The good news is that while cleaning in most commercial applications took a 20+ year hiatus, substantial advances were made to defluxing technologies. Many modern batch defluxing systems now provide cleaning and cleanliness testing in one unit. Many batch cleaners are capable of removing any and all flux residues from all alloys. Additionally, advances have been made in the inline spray-in-air marketplace including better control platforms, quieter operation and better chemical isolation to name a few. In the past, there were differences between the residue removal capabilities between batch and inline. This is no longer the case. Both batch and inline generally share identical cleaning performance capabilities while some batch cleaners actually out-perform inlines. The justification for batch or inline comes down to the cost per assembly cleaned.

As mentioned earlier, I should issue a "buyer beware" here. While there have been few recent newcomers into the in-line cleaning system world, there have been some newcomers into batch cleaning. In my 30 years in the electronics cleaning industry, I have seen the introduction of many dishwashers offered up as defluxing systems. When I say dishwasher, I don't mean "dishwasher-like". All batch cleaners use square chambers and all resemble dishwashers. What I mean is a dishwasher or glassware washer relabeled as a defluxing system. I can think of half a dozen brands of dishwashers that entered the market only to rapidly fade away.

So, as the late Yogi Berra said, "It's déjà vu all over again". My advice is the same today as it was 25 years ago--dishwashers (aka glassware washers) are for dishes, not circuit assemblies. Dishwashers used as circuit board cleaners, particularly when used with defluxing chemicals, end up rapidly in a state of leaky disrepair and the assemblies they "cleaned" become fertile dendrite farms.

Why won't a dishwasher work? Many reasons exist. First, the seals and multiple plastic parts used in a dishwasher are not generally compatible with the chemicals used to remove flux. Use of these chemicals will quickly remind the user of the China Syndrome (chemicals eat through the wetted materials and leak out of the machine). Next, dishwashers lack something found in nearly all effective cleaners--nozzles. Dishwashers and glassware washers do not normally utilize spray nozzles, rather, they have simple holes drilled in tubes. While this is terrific for dishes, the water particle size is frequently too large for effective fine pitch impingement. That said, watch out for myths. One common myth is that nozzles are not required because the cleaning chemical lowers the fluid's surface tension. While it is true that the chemical-enriched wash solution's surface tension is 25 dynes verses water-only's 72 dynes, the theory falls apart when it comes to rinse water. Rinse water with its 72 dyne surface tension is "fatter" than the "thinner" 25 dyne wash solution. Without mechanically altering the fluid's particle size, it is difficult to effectively rinse out the wash chemical (and the contaminants contained within) from below components with low standoff heights. Why not add nozzles to a dishwasher arm? Bending fluid and producing small fluid droplet sizes requires power. This mandates the need for large pumps. Dish and glassware washers are generally equipped with small pumps not capable of directing fluid through multiple diffusion nozzles.

Another rapidly growing cleaning trend is the ability to provide detailed SPC data on the assemblies being cleaned. Because many cleaning systems are equipped with built-in cleanliness testing technology, many assemblers need to capture the cleanliness and other process data. Because there is no need for dishwashers to provide SPC data, generally, no SPC data is recorded.

Best practices require the capability to record individual assembly serial numbers that are cleaned and the relevant process data associated with their cleaning.

This may be accomplished by choosing a cleaning system capable of scanning assembly barcodes and associating specific process data, including actual cleanliness results with a specific assembly. The monitoring of detailed SPC data will ensure that cleaning results remain consistent and process-related variables remain within specifications.

To conclude... Dishwashers are for dishes. Glassware washers are for glassware. Defluxing systems improve your assembly's reliability by removing harmful contamination while verifying and documenting the process.

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