Cleaning For Tomorrow

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Abstract
As technologies evolve with the onset of smaller and smaller components, different flux residues, and the no-lead solders, manufacturing companies are asking questions regarding what they need to consider for the future to effectively clean *and* dry circuit board assemblies. The physical obstacles encountered in the cleaning process are described in detail herein. This abstract will provide examples of the components and the technologies used to achieve acceptable cleanliness and drying while using No-Lead solder, water-soluble and no clean fluxes, and evolving component packages.

Introduction
The evolving technology of component packaging necessitates manufacturers to address how they will be able to maintain acceptable standards of cleanliness. Today's assemblies are comprised of sophisticated technology and are becoming more and more densely populated. Manufacturers are faced with numerous types of fluxes as well as alloys. And let's not forget those manufacturers that feel the need to clean their no clean fluxes.

The questions become simple: "Will I be able to implement a cleaning process for tomorrow's technology?" "What can I do to my current system to survive without an enormous investment?" In this article I explain what factors need to be addressed, which components have been cleaned successfully, and how you can meet the future need of electronic assembly.

Traditional Cleaning Systems
Off-the-shelf cleaning systems are defined as being manufactured within the last 1-5 years. Some smaller inline cleaning systems with lower pressures and flow, and older cleaning systems that are not supplying ideal process parameters may be able to produce satisfactory results *as long as* the conveyor speed allows the assembly to see the wash, rinse and dry sections for a reasonable amount of time. This is application specific.

Cleaning Factor
An inline cleaner should consist of a Prewash, a heated, recirculating wash section, final rinse and at least 1 centrifugal blower. High volume application and some critical cleaning applications should include a second heated recirculated section. If a cleaning agent is being used, a wet isolation with anti-drag out airknives and a heated, recirculated rinse should follow the wash section. Each recirculated section is recommended to apply a minimum of 40 gallons per minute (GPM) at 80 pounds per square inch (PSI) or above).

Pressure measurement at the nozzle is only part of the cleaning equation. The impingement force produced by the flow and velocity of water at the board is of the utmost importance and it is where the flow rate becomes essential. Today's complex assemblies reveal these weaknesses within equipment wash and rinse configurations.

If there is not enough flow, the momentum is lost underneath the components, and in some cases the water will not reach some of the residues, leaving behind contaminates. Likewise, if there is not enough pressure to produce the velocity, water may reach underneath the devices, however the lack of impingement force will most likely leave the contaminates attached. When water is applied with high impingement force, the water flows underneath the component to the other side.

Enhanced Cleaning Systems
In the recent past, board complexity has necessitated equipment manufacturers to review the effectiveness of the wash/rinse sections. Although most traditional cleaning systems are effective in removing all contaminates from common assemblies, the level of cleanliness is slipping with the increasingly more complex assemblies. Some inline systems can still maintain the same level of cleanliness as long as the process is slowed down to allow for longer soak times. Equipment manufactures have started to apply water by other means that the traditional spray wand with fan jet nozzles.

Theories range from high volume (100 GPM or greater), low pressure (less than 60 PSI) to high pressure (greater than100 PSI), high volume (greater than 70 GPM), Flooding the assembly. Figure 1 visualizes the effects of some available flooding devices.

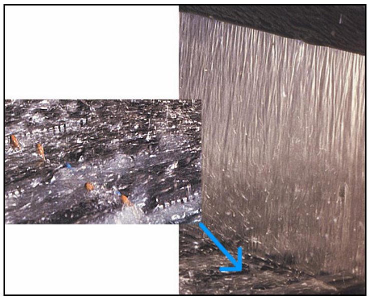

Figure 1 - Applying Water with a Sheeting Action

The testing conducted during this evaluation showed that in some applications better cleanliness results were obtained by using other non-conventional methods of applying water to the assembly. In some applications, results were less than satisfactory, when all other parameters (temperature, cleaning agent, and belt speed) stayed the same. The testing shows cleanliness level improvement when water is applied to the board with high volumes.

Cleanliness can be achieved with the lack of pressure or flow by increasing the soak time of the wash and/or using a cleaning agent. This will compensate for the lack of the pressure or flow. Using a curtain of water that when used in conjunction with a standard wash and/or rinse section, improves end results significantly can enhance the cleaning step. The testing proved this recommendation.

Modern batch systems are able to achieve satisfactory cleanliness levels simply by adjusting length of cycle. Older batch systems may or may not be flexible enough or have enough mechanical power to allow long enough exposure for sufficient results. A drying oven may be required in some applications

Drying Factor

The ability of airknives in the inline process to literally sheet off any excess water has become critical. In the last few years with the introduction of smaller, more populated assemblies drying has become more challenging

Airknives were adopted when tests proved contaminants could be baked onto an assembly. The introduction of the airknife enabled the majority, if not all, the moisture to be removed from the assembly. The airknife not only removed excess moisture, but also any loose contaminant not rinsed during the cleaning stages. IR heating elements proved to be inefficient and ineffective. Generally equipment manufacturers recommend each dry chamber to contain 2 upper airknives and 1 lower airknife.

Predominantly, airknives consist of a tubular extrusion made of anodized aluminum or stainless steel. These extrusions are made into the shape of a teardrop, circular teardrop, octagon, or tapered rectangular shape. Generally speaking, a slot runs the length of the knife to apply warmed air. The width and length of the airknife slot will directly determine how long the air will maintain a constant velocity and remain effective. New development shows some advantages of a modified design that include an internal device will apply the air force at the same velocity for a greater period of time. Most of these designs are propriety.

The friction generated by the blower elevates the air temperature between 120°F and 140°F (*depending on the temperature of the ambient air supplied to the blower)* before being channeled to a plenum, or preferably each individual airknife. In most applications the traditional airknives are capable of achieving bone-dry boards depending on the number of blowers and the board complexity.

With a very high-density board, populated with connectors and sockets, the use of *a heated airknife* is necessary more often than not, especially when component height requires the airknives to be fixed greater than two (2) inches above the conveyor. By placing a heating element with the configuration of the centrifugal blower and the airknives, the air applied at the conveyor can be elevated up to 210°F. This assists in flashing off small droplets of water trapped in areas not directly exposed to the sheeting effect of the airknife. This is offered as an option with most equipment manufacturers. With some board assemblies populated with tall capacitors, heat sinks, and other high profile components, Airknives are place their at a fixed height of 4" and higher. The experts have proven that standard airknife configurations loose their efficiency as they move further away from their product. The development of an airknife that would carry the same high velocity for a longer distance is inevitable. Effective removal of excess water, regardless of the height position of the airknives will increase throughputs and quality. A unique airknife design as described shows promising results when combined with standard drying technology.

Test Vehicles

There are many variables involved in the achieving the optimal cleaning results and these variables change with each different process. This test will help determine the best combination of equipment, process settings, and chemistries for each of 4 representative printed circuit boards.

Various test coupons were used during this evaluation. Each coupon helped in the evaluation of residues remaining on the test coupon and enabled us to determine the assemblies' ability to meet SIR and ionic cleanliness requirements according the latest J-STD requirements and IPC specifications.

Testing Vehicle #1 used an IPC-B-36 standard test coupon. The assembly is a mixed technology board and measures approximately 4.0” x 4.375”, made of.060” FR-4 laminate with copper conductors on the topside of the assembly. Various components were placed on the assembly. Components included solder mask standoffs for three leadless ceramic chip carriers (LCCs) with an approximate standoff of 5 mils. Coupons were assembled using a water-soluble paste; a no clean solder paste and an RMA solder paste followed using the same guidelines.

Test Vehicle #2 coupon is a printed circuit board material with four (4) 1” x 1” square lab glass adhered to the board. The test vehicle is designed to reveal the cleaning capabilities of components with both large footprints with standoff heights of 10-mil, 5-mil and 2-mil. Each coupon was populated with glass slides reflecting one 10-mil, one 5-mil, and two 2-mil standoffs. Each slide was injected with an RMA flux. The testing was repeated using a water-soluble and later a no clean flux.

Test vehicle #3 coupon is populated on both sides with multiple SOIC’s, Capacitors with less than a 1-mil standoff, encapsulated coils with less than 2-mil standoff, and various other fine pitch components. These coupons were processed using a water-soluble paste only.

Test vehicle #4 coupon is populated with numerous fine pitch components, multiple LQFPs, PLCC, SOICs, QFP, BGAs and other similar devices. Samples were processed using water–soluble and no clean, as well as with no lead solder paste.

Testing Tool

All testing was completed using a Technical Devices Inline Aqueous Cleaning System. This system consists of a prewash that is powered by the wash pump, a wash section powered by a 15 HP pump, a curtain of water located in the middle of the wash spray wands and powered by its own independent 5 HP pump, a wet isolation section, Rinse section powered a 15 HP pump, a final rinse section supplied with high quality De-ionized water, 2 standard airknife sections each powered by a 15 hp blower, and a heated airknife powered by 15 HP blower. The system configuration is illustrated in Figure 2:

Testing was preformed using various cleaning agents at the manufacturer’s recommended concentrations and temperature set points. Tables 1 and 2 optimized cleanliness results.

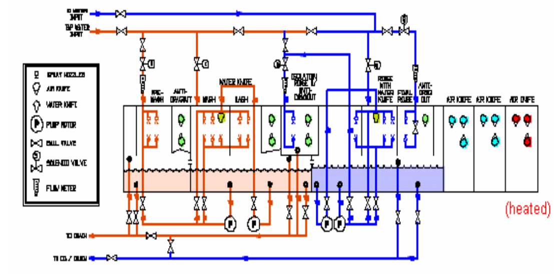

Figure 2 - Test Tool Configuration

Table 1 - Test Parameters of Testing Tool

	Wash	Water Knife	Rinse	Water Knife
PSI	88	38	110	38
GPM	79	70	84	70

Table 2 - Test Parameters of Cleaning Agents

	De-Ionized Water	Agent A	Agent B
Concentration	18 megohm	30%	20%
Temperature	140°F	145°F	140°F

Geometry Role

Many common assemblies with connectors, Quad Flat Packages (QFP), various fine pitch components, and BGA’s, can be successfully cleaned with off-the-shelf cleaning systems, both inline and batch. Nothing special is considered necessary. Most of us would even agree that standard Ball Grid Arrays (BGA) can be successfully cleaned and dried with a spray-in-air cleaning system. BGA’s generally have standoff heights in the 15-mil to 25-mil range. In a water-soluble process, De-ionized (DI) water will effectively penetrate underneath these types of devices. Some even venture to say it can be done with tap water. A no clean process requires a cleaning agent to completely remove all residues, including white residues.

Typical inline conveyor speeds for most of these types of assemblies are in the range of 2-6 feet per minute in a water-soluble application and 2-4 feet per minute with a no clean and/or RMA application (dependant upon system configuration). A batch type process generally requires cycle times of 20-30 minutes. The rising use of micro devices and complexity of the assemblies is going to change these rules.

With the introduction of more complex micro components, engineers are once again questioning the point at which they reach the inability to successfully remove all contaminates with their existing equipment. Can a spray-in-air cleaning system successfully remove all flux residues from components (as shown in Figure 3) with less than a standoff of 5-mil, or even less than 1-mil?

The simple answer is: Yes.

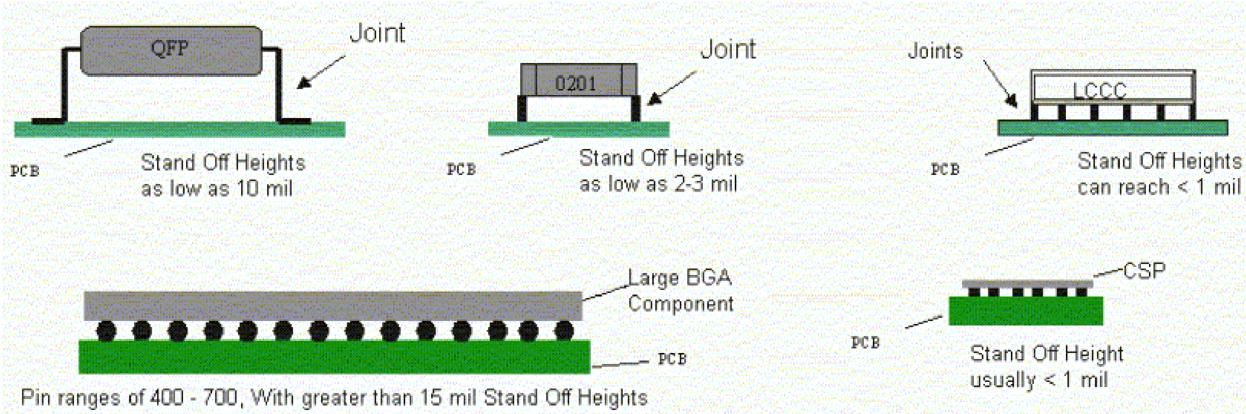

Figure 3 - Today's Cleaning Challenges

Geometry of the Printed Circuit board is becoming a more vital function in tomorrow's cleaning environment. No question - lowering the surface tension of ultra small devices such as Leadless Chip Carriers (LCC), Chip Scale Packages (CSP), Micro BGA's, SMT 0201 chip resistors and capacitors is difficult all by itself. As the ratio of components to real estate keeps narrowing, cleaning becomes more challenging. Keep in mind; spacing between components can be as little as 0.2 mm (similar to shown above in Figure 4). Deflection from other components occurs, requiring more exposure to each stage of the cleaning process. This slows down the process. Longer soaking, higher pressures, substantially more flow, and possible use of chemistry are essential to achieve no visual residue or ionic contamination.

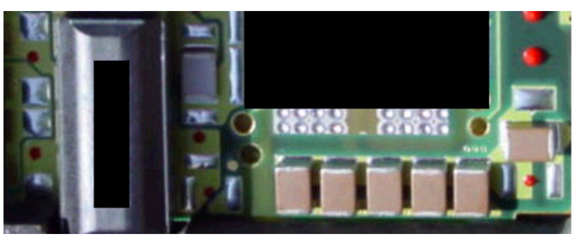

Figure 4 - Components Ranging < than 1-mil to 5-mil Stand Off Height

Cleaning most micro devices, especially CSP's, is not recommended. Thankfully, most of these devices are manufactured with a no clean process. On occasion, a water-soluble process is used, requiring the assembly to be cleaned. Occurring more frequently, manufacturers are finding themselves being asked to clean their no-clean fluxes for various reasons. Process residues can be completely removed from underneath such devices in the correct environment. Some devices may require special handling while inside the cleaning system. Getting the product bone-dry with conventional airknives after cleaning is unlikely.

On the flip side: Large Footprint components

Large footprint BGA's, present other cleaning issues. These components can be as wide as 2.5"x 2.5". Since these devices generally have 15-mil stand off heights or better.

Pushing water underneath the component is quite simple; however removing the water and the residues is where the challenge begins. It is even more critical to pay attention to the spacing of components surrounding these devices.

Results and Recommended Solution

During the preliminary trials, various process variables were manipulated: conveyor speed, cleaning agent, cleaning agent concentration levels, and temperatures. The process was fine tuned for each test vehicle. Once the system reached optimization, all test vehicles, as previously described, had an average ionic cleanliness level substantially less than 1-microgram per square inch. A destructive test showed no visual residue when inspected under a microscope with 10X magnification. (See Table 3.)

Table 3 - Test results with Optimum Configuration

	#1	#2	#3	#4
Average Ionic level (microgram /in^2)	.5	.23	.001	.009
Visual Residue	No	No	No	No
Moisture left	No	Yes	No	No
Cleaning Agent (with water soluble)	DI	Yes	DI	DI
Cleaning Agent (with No Clean/RMA)	Yes	Yes	N/A	Yes
Cleaning Agent (with No Lead)	N/A	N/A	N/A	Yes
Water curtain Used	Yes	Yes	Yes	Yes
Belt speed (DI only)	3.0	N/A	2.0	4.5
Belt speed (with cleaning agent)	2.0	2.5	2.5	3.0

The complexity in the assembly, combined with micro devices, revealed that the combination a curtain of water and a series of spray wands with fan jet nozzles lowered ionic levels significantly--in some cases as much as 5-micrograms per square inch. In all cases, cleanliness levels were more favorable when using the water knife, especially when processing components with less than a 5-mil standoff or large foot print devices.

Flux/ Paste Contaminant Role

Wide ranges of flux and paste compositions are currently available. Studies have shown a direct correlation between the type of flux and/or paste selected and the difficulty in cleaning one over the other. Until recently, manufacturers concerned themselves with cleaning Water-Soluble and RMA fluxes and pastes. Modern technology has pushed the envelope to include the cleaning of no cleans fluxes and high temperature used in lead-free solder applications.

Water-soluble Applications

Water-soluble pastes are by far the easiest to clean. New formulations have relaxed the time constraints between soldering and cleaning. In some instances, cleaning up to a 36 hours after a board is soldered is no problem. Micro components can be cleaned successfully with straight DI water by combining a water-soluble flux with the right system configuration. Ionic Cleanliness tests often reveal a zero contamination within a controlled environment.

RMA Applications

RMA fluxes have also become a little easier to clean with the newer formulations. The majority of cleaning agents successfully remove all traces of residue, as long as the assembly is cleaned within a short amount of time.

No Clean Applications

With the launch of No Cleans, many companies felt their cleaning process would go by the wayside. Although the majority of manufacturers successfully use a true no clean process, an increasingly large number of companies are resorting to cleaning the no clean fluxes to resolve manufacturing issues:

1. Removal of solder balls.
2. Removal of all residues prior to conformal coating.
3. Possibility of growth or corrosion during extended exposure to extreme environments.
4. Cosmetics.

No Cleans undoubtedly are the most difficult residues to remove. There are two main distinctions of no clean compositions, those containing Halide and Halide-free:

No clean fluxes that contain Halides tend to have more residues and allow for a wider cleaning process window. Milder cleaning agents maybe used. The length of time required in removing all contamination maybe less than that of other types of no cleans. Lower concentration levels of the cleaning agent will most likely produce satisfactory results. It is possible that less aggressive cleaning agents will be able to remove all residues. In theory these halides could lead to corrosion. Hence, some manufacturers choose to clean the assemblies.

No clean fluxes that are Halide-Free tend to have less residue and a more narrow cleaning process window. This type of composition presents the most difficult to remove contamination. These types of fluxes and pastes necessitate longer exposure to the cleaning agent.

Within each category, there are variations. The way in which this affects the cleaning aspect is very minor. Matching the cleaning tool and the cleaning agent with the residue is critical. The equipment manufacturer, the cleaning agent, and the flux/paste manufacturers must work together as a team to optimize the process and ensure superior cleanliness levels.

High-Temp Applications

High Temp Solders are used in a few select industries. Exposure to high temperatures for extended periods of time generally has a propensity to bake on flux and paste residues, which can make it slightly more difficult to remove. Conventional soldering process temperatures are increased significantly (greater than 260°C). Since the residues bake for a longer period of time, a slightly longer wash period maybe required.

No-Lead Applications

No Lead applications present two main concerns:

1. How do the elevated temperatures effect the cleaning
2. Availability of comprehensive long-term data in relation to cleaning.

The no lead solder is not what presents the cleaning issues. It is the composition of the activating forces (paste/flux) and process temperatures that create the challenge. Just as in high temperature applications, many no lead processes require elevated reflow temperatures (reaching as high as 260°C) Considerable efforts are being made to produce an alloy with a lower melting point. Currently some paste manufacturers offer alloys that successfully solder at 217°C - 220°C. No lead flux and pastes vary as much as in leaded fluxes and pastes. Unfortunately, there is very little information available about removing the flux and paste residues in a no-lead process.

Results and Recommendations

In relationship to cleaning water-soluble and RMA fluxes/pastes with less complex assemblies, there is nothing mysterious in cleaning. Such devices as QFPs, BGAs, capacitors and resistors placed on test vehicle #4, demonstrated a standard wash configuration resulted in no visual residue. The testing was completed using the testing tool conveyor speed at a rate of 5 foot per minute to remove water-soluble paste, and 3 foot per minute to remove RMA and No Clean paste.

Table 4 illustrates the results of the coupons run with the testing tool without the curtain of water. Cleanliness levels are well within the limits of IPC and J-STD guidelines.

Table 4 - Lead-Free and High Temp Paste on Test Coupon #4, Water Curtain not Used

Flux Chemistry	Cleaning Agent	Ionic Levels	Visual Residue
Water Soluble	DI	2.23	Some visual residue underneath devices with < 5 mil
Water Soluble,	Aqueous Based Chemistry	.07	No Visual Residues
High Temp, RMA	Aqueous Based Chemistry	1.66	Minimal residues present underneath components < 5mill
Lead Free, No Clean	Aqueous Based Chemistry	1.73	Minimal residue present underneath components < 5mill

To demonstrate the effects using the water knife, the same testing parameters were followed only this time adding the water knife. (See Table 5.)

Table 5 - Lead-Free and High Temp paste on Test Coupon #4, Water Curtain Used

Flux Chemistry	Cleaning Agent	Ionic Levels	Visual Residue
Water Soluble	DI	.78	No visual residues
Water Soluble,	Aqueous Based Chemistry	.013	No Visual Residues
High Temp, RMA	Aqueous Based Chemistry	1.08	Minimal residue present underneath components < 2 mill
Lead Free, No Clean	Aqueous Based Chemistry	1.12	Minimal residue present underneath components < 2 mill

Further testing of these coupons was completed using the water curtain as well as reducing the conveyor speed to 3 foot per minute to remove the water-soluble paste and 2 foot per minute to remove the high temperature and Lead Free. All tests at these belt settings resulted in no visual residues underneath and ionic levels less than 1 microgram per square inch.

Evaluation of the test samples using a high temperature/no lead process verified similar visual findings to that of the No Clean process. Ionic cleanliness levels showed no significant difference between the high temperature and the no lead flux/pastes with or without the use of a water curtain.

All data collected during this test supports that the addition of a water curtain increases the cleanliness.

Conclusion

Cleaning with more is better. Additional capability to use a cleaning agent will most likely prove to be a good investment. Include a water curtain mechanism is a cost effective method to increase throughputs and adds insurance that the complex components can be processed with no residues.

Including additional drying capacities with innovative airknife designs to provide robust delivery of airflow at the board will prevent extensive processing time.

Complete moisture and contamination removal is necessary to meet IPC and SIR cleanliness specifications. Field failures and rework is more expensive that the upfront costs of using the right configuration. Work with all of your suppliers to help optimize your process, reduce your long-term investment costs and increase productivity.

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