Continuous Improvement: The Task That Never Ends in the Cleaning World

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ABSTRACT

The job of a cleaning agent is to remove an unwanted contaminant, or simply some kind of "dirt". How can you efficiently remove that soil while minimizing total waste and improving worker safety? While that answer evolves based on updated impact studies and new regulations, the goal of removing those undesired contaminants remains fixed. Responsible environmental stewardship challenges businesses to continuously evaluate safer or preferred process alternatives. Such as reducing waste or selecting products that are safer for their employees and the environment. This paper investigates a methodology for developing new processes that achieve the required cleaning effectiveness while balancing the environmental, human, and machine impacts for longevity.

Key words: Cleaning, Reliability, ESG

INTRODUCTION

Proper cleaning of an electronic board or assembly can be critical to its long-term performance and reliability. The need to remove potentially harmful ionic residues from the board surface is well understood. In other cases, residues such as mold release agents, oils, dust, and flux residues left behind may impact subsequent processing steps and potentially performance and reliability as well.

Selecting a cleaning agent is a reactionary decision. It starts with a couple of questions:

"What am I cleaning"

- a car
- a floor
- a PCBA, stencil, pallet, etc

"What residue is being removed?"

- mud, bugs
- dirt, food
- flux residue
  - Reflowed or raw paste
  - "No Clean" or water-soluble
  - Eutectic, lead-free, etc.

Answering those two questions, as well as understanding the cleaning process or mechanical energy to be employed allows the user to select a cleaning agent.

Figure 1: Selecting A Cleaning Agent

There can be many other influencing factors, but the key takeaway is that selecting a cleaning agent is almost always a reactionary decision.

Rarely does a user select their soldering material(s) or board design based on a particular cleaning agent; rather they pick the cleaning agent that best fits their needs and equipment. Therefore, it is critically important for cleaning agent manufacturers to stay well-informed of industry trends when developing new products.

EVOLUTION OF "GREEN"

We often think of changes in technology and miniaturization driving the way manufacturers build their electronic devices. However, environmental regulations created several fundamental shifts in our industry. Starting with the Montreal Protocol that was signed in 1987 and went into effect on January 1st, 1989. Studies found that Chlorofluorocarbons (CFC's) and other halogenated hydrocarbons were depleting stratospheric ozone, leading to a hole in Earth's ozone layer.

While the passage of the Montreal Protocol was targeted are reducing CFC usage in the refrigerant and foam industries, it also created upheaval and opportunity for improvement in electronic assembly manufacturing. For decades, CFC-113 was the primary cleaning agent used to remove RMA (rosin, mildly active) flux residues from electronic assemblies. Environmental studies found it to be a very stable molecule that could exist in the atmosphere for approximately 90 years.

While the passage of the Montreal Protocol was targeted are reducing CFC usage in the refrigerant and foam industries, it also created upheaval and opportunity for improvement in electronic assembly manufacturing. Shortly after enacting the Montreal Protocol, several companies were founded offering alternative cleaning options. Many of the first aqueous, or water-based, cleaning materials were highly alkaline reactive saponifiers. They were effective in removing acidic RMA flux residues by reacting them with a base to form a water-soluble soap. While these often caustic chemicals did not deplete the ozone layer, they required special handling for operator safety and transport, as well as additional waste-disposal treatment. They also introduced previously unseen compatibility concerns, where the solvent-based CFC-113 processes were essentially unreactive with the solder alloy and components.

The manufacturers of soldering materials also found the opportunity for product improvement in the 1990s by developing the class of “no clean” solders. These materials are formulated to leave a lower amount of residue behind and encapsulate ionic material in a polymeric shell to render it more benign. This was a huge success for many commercial electronic assemblies as it simplified the manufacturing process and mostly removed the cleaning process.

However, many Class II & all Class III electronics still need to be cleaned to achieve the desired reliability. The saponifiers which worked well for removing traditional RMA residues had minimal efficacy on these new encapsulated residues. The cleaning agent manufacturers adapted by developing sprayable materials that incorporated solvents diluted in water. These engineered aqueous blends of solvent were good at solubilizing the no-clean shell with sufficient water to suppress flammability concerns. They typically contained a reduced but still moderate level of alkalinity to improve overall cleaning speed and provide longer bath life than had previously been the norm. By reducing the pH, they could ship as non-hazardous, and be safer for general handling and use by the operators. In many cases, the operating concentration could also be reduced which further reduced generated waste and potential environmental impact.

The next major shift due to environmental regulation was the Restriction of Hazardous Substances Directive (RoHS) which restricted the use of lead and other harmful metals in the production of many things including electronics.

Like the change from CFC-113, this was a tremendous shift for the industry as it transitioned from traditional eutectic tin-lead solder to pb-free alloys. The solder manufacturers each developed their flux vehicles around the new alloy(s) and to protect against oxidation with the higher reflow temperatures.

Again, as these new soldering materials were developed and launched, the cleaning agent manufacturers would benchmark their existing portfolio of products and then optimize the formula around the new material soldering material sets.

As the no-clean flux technology matured with SAC 305 and similar lead-free alloys, makers of cleaning agents were able to optimize their solvent sprayable aqueous products for improved performance and compatibility.

To this point, many of the leading aqueous cleaning solutions remained similar. They had subtle performance differences and occasionally slightly different compatibility or effectiveness on a particular flux package. However, the build of these products was similar. This was the point when the approaches started to diverge.

A TALE OF TWO PATHS

One approach was towards creating pH-neutral cleaning agents. Using and handling these materials sounds safer, but they still require standard PPE. pH-neutral gives the impression that you will have improved material compatibility and easier waste disposal. pH alone is not what drives the cleaning, compatibility, or disposal. The wash solution makeup can have a larger impact than the pH alone. As acidic fluxes are dissolved into solution, pH neutral materials can often shift rapidly below pH 7, into an acidic range. The cleaning bath should be changed when this occurs. This can result in more complicated waste disposal, changes in materials compatibility, and overall increased cost.

Another approach was to buffer the cleaning agent for a stable pH over a higher level of acid (flux) loading. The buffered solutions result in a product that is mildly alkaline in pH. In Figure 2 below, the pH of several cleaning agents is plotted as a function of flux loading. The material starting out with a pH of ~7.5 is rapidly affected by just a percent of flux loading, while the more moderately alkaline products with an initial pH in the 10-10.5 range were minimally affected by up to 4% flux loading. The mildly alkaline products, with an initial pH of about 9, were also well buffered to hold 4% and remain just above neutral.

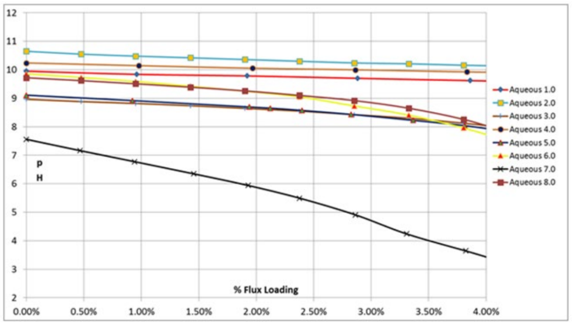

Figure 2: pH vs Flux Loading

It is easier and less costly to dispose of a mildly alkaline wash bath than an acidic solution.

While traditional alkaline cleaning agents (saponifiers) can attack thin or sensitive metals such as: aluminum, copper, lead, etc., robust compatibility can be achieved with a balanced inhibition package. Inhibitors can be added to provide a temporary layer of protection to the thin or sensitive metals often used in electronic assembly products. This protection package will not interfere with downstream processes or product reliability. Inhibition is a highly effective way to enhance the overall cleaning process.

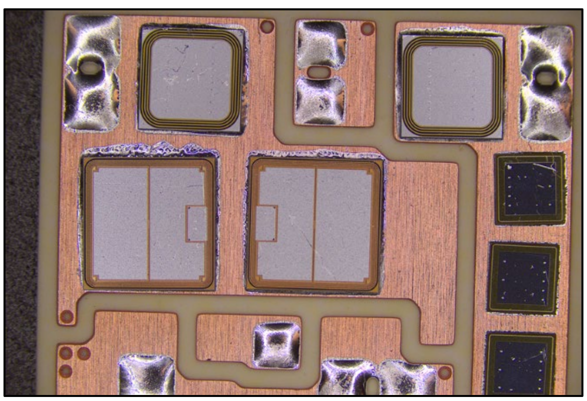

Image 1: Copper, Die, & Solder Compatibility

Environmental regulation and a better understanding of how materials affect both users and our environment have significantly influenced the way we build electronics over the past 40 years. Cleaning agent manufacturers must continue to adapt to the evolving residues, materials, and regulatory landscapes. Cleaning agents must continually be optimized for minimal waste, emissions, and overall impact to humans and the environment.

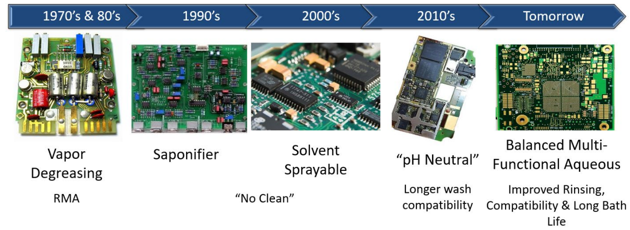

Figure 3: Timeline of Cleaning Technologies

CONTINUOUS IMPROVEMENT

We've discussed how the residues to be cleaned are constantly evolving. Today there are well over 1,000 different soldering materials available from manufacturers around the world. Each one with its own unique soldering properties, and thus different cleanability.

How does the responsible cleaning agent manufacturer adapt to this ever-evolving environment?

First and foremost, a cleaning agent must improve the process performance of the user while keeping an eye towards improving ESG (Environmental, Social, Governance) impact.

A good example of this can be in removing organic acid (OA) flux residues. These materials are designed to be removed with water alone. Other than not cleaning, what could be better than cleaning with water alone?

As board designs become increasingly more complex, with smaller and smaller components that are packed more densely with each new product design iteration, it can be difficult for water alone to effectively penetrate under the components for complete cleaning. This is because water has a relatively high surface tension, meaning it forms larger droplets.

- Surface Tension:
  - DI Water ~72 dynes/cm = large droplet
  - Cleaning agent 28 – 35 dynes/cm = small droplet

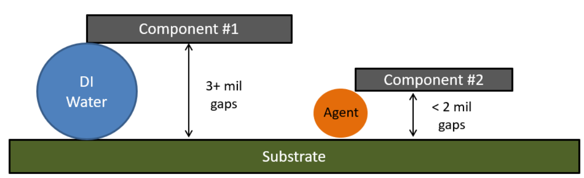

Figure 4: Surface Tension Comparison

With enough wash time, water alone may be successful. However, this often results in 2 to 3x more water consumption, longer processing times, and higher heat meaning more electricity. Where an optimized cleaning agent used at 3-5% can enhance the properties of water for a faster more robust cleaning result as well as reduce the water and electrical consumption. On the surface, water alone may seem to be a better solution but rarely provides a holistic look at the cleaning and overall impacts on the environment and cost.

Likewise, for removing a no-clean residue optimizing the match between the cleaning agent and residue(s) can significantly impact your total process. Responsible cleaning agent manufacturers should be to provide the user with data to identify the most effective cleaning agents with the best EH&S properties for their unique applications.

BATH LIFE AND PROCESS CONTROL

Critical Parameters To Not Overlook

For example, if cleaning agents A and B are similarly effective at 15%, and "A" provides consistent results up to a 6% soil load, while "B" starts to decline at 3% flux loading, then the total process waste, operator exposure, and process downtime can be significantly impacted based on the choice of material. Both may have an acceptable result, but one could offer better ESG benefits for the process.

A 3-5% increase in the concentration of cleaning agent "B" as well as increasing the wash temperature will often time match the performance of cleaning agent "A," but this has only further exacerbated the overall demand on costs and the environment.

As you consider the Total Process, it's important to consider more than just the initial process qualification but how does the process behave in the production environment after days, weeks, or months? The production environment is often very dynamic whereas the qualification process is tightly controlled.

This brings forth perhaps the two most common questions in cleaning:

- How clean is good enough?
- When should I replace the cleaning bath?

These are also some of the most subjective questions to answer definitively because each user's process and requirements are unique.

A key measure of bath life has been NVR, or non-volatile residue, analysis. Essentially a sample of the wash bath is baked down to dryness and weighed. By comparing the NVR mass of a production bath versus the NVR of a virgin solution, one can quantify how much more material (contamination) has been solubilized in the cleaning solution. It is important to compare to a virgin/fresh sample as the difference between a fresh and used bath will tell you how much NVR you have added to the bath.

When combined with some other measure like pump hours or the number of parts washed, this approach can help provide a useful tracking mechanism for bath usage and a replenishment schedule based on a value other than simple calendar days.

MAINTAINING QUALITY

"How clean is clean" can be very subjective. Cleaning can be determined in many different ways, most of which are very subjective and depend on operators and feel. There are better ways to quantify how "how clean is clean" and determine when the bath should be replaced?

The revised IPC J-Standard 001 defines the need for Objective Evidence when qualifying or altering a Class III manufacturing process. Several techniques are available for generating objective evidence, including Ion Chromatography (IC) and Surface Insulation Resistance (SIR) analysis. There have been many papers and discussions on the capabilities and benefits of these technologies for determining assembly cleanliness, so the intent here is to share a practical application of how a cleaning agent formulator can use these tools to support product development.

SIR can provide a formulator with valuable insights into the potential behavior of different material sets. Using duplicate test cards to eliminate the influence of flux, how does a card washed in material A compare with material B?

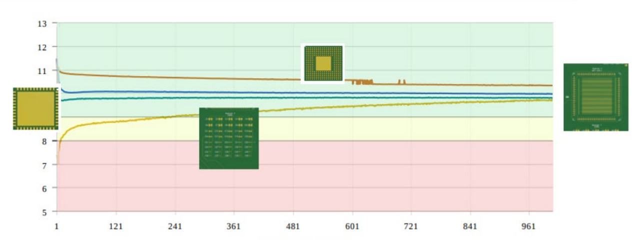

Figure 5: Cleaning Agent A

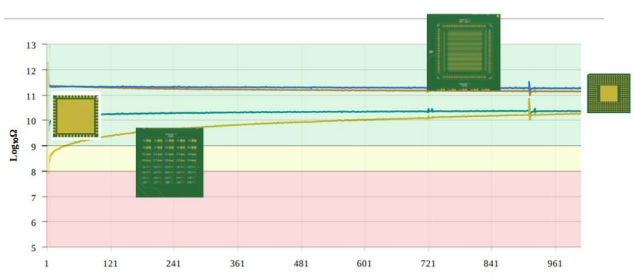

Figure 6: Cleaning Agent B

While both are well above 8 log-ohms, Cleaning Agent B produced higher overall SIR values. Investigating these results can provide better insight into product rinsability or reduced ionic potential on the PCB surface.

Extending this to the longevity of the cleaning bath, here is an example of a SIR plot performed on a fresh wash bath:

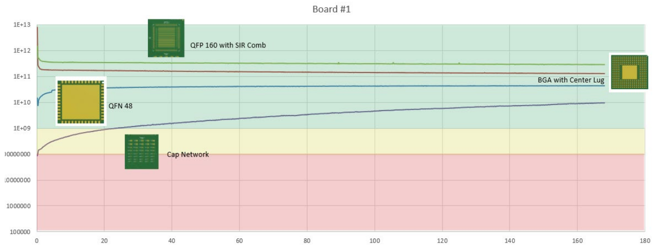

Figure 7: SIR @ Week 1 (Agent X)

Over a 10-week study, SIR samples were run weekly to monitor the process and profile the bath's aging. The following figure shows the final SIR panel:

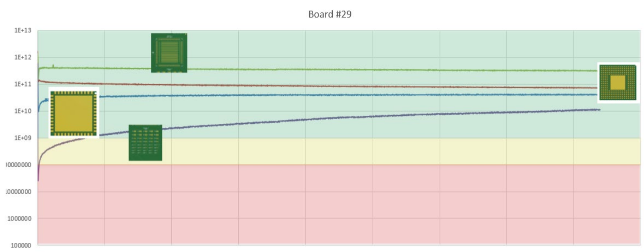

Figure 8: SIR @ Week 10 (Agent X)

The SIR plots remained very consistent over more than two months of production. Cleaning was consistent over time by visual inspection, and there were no reported issues with rinsing.

For comparison, SIR monitoring was performed on a similar in-line cleaning process with a different cleaning agent. The initial Week 1 SIR patterns were as expected, all well above the 8 log-ohm level. However, after five weeks there was a notable change in the SIR patterns and some electrical shorts were detected:

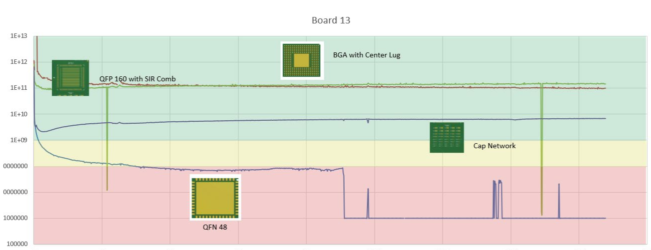

Figure 9: SIR @ Week 5 (Agent Y)

Changing the bath yielded the expected result of restoring the clean SIR patterns:

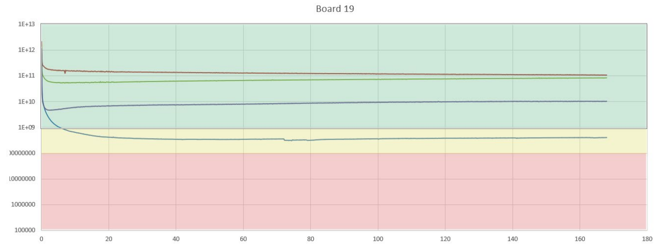

Figure 10: SIR @ Wk 7 / Wk 1 (Agent Y)

This type of Objective Evidence data can help users make informed decisions about bath life and maintain a robust wash process.

For the formulator, this data is also important in understanding how materials sets behave when fresh but also over time in a dynamic environment.

Longer bath life and reduced consumption can have a significant impact on waste generation and operator handling of chemicals.

The key to objective evidence is that it helps to identify trends in the dynamic production environment as compared to the static and tightly controlled qualification.

FUTURE TRENDS

There are multiple environmental and industry trends that will no doubt influence the next generation of cleaning agent formulations.

Environmental regulation can be region-specific, such as with the definition of VOC (volatile organic compounds) and their associated emission limits or RSLs (Restricted Substance Lists) that can be country and/or company specific. Consequently, because many of the regulations are regionally specific, they are also often misinterpreted. Regulation in one area can sound remarkably similar to a regulation in another area, however, the nuance in the differences is often overlooked or misinterpreted. This means that you can be at risk of not complying.

To help address these challenges, IPC-1402, *Standard for Greener Cleaners Used in Electronics Manufacturing* is nearing its initial release. This guidance can assist formulators and developers of cleaning agents in selecting ingredients as well as engineers and decision-makers in evaluating product choices.

The responsible chemical manufacturer must be constantly aware of new requirements and pay close attention to new and pending concerns, such as PFAS materials.

As soldering materials continue to advance and evolve with jettable pastes, lower melting point alloys, and synthetic resins the nature of the flux residue(s) will continue to present different cleaning challenges and opportunities to improve cleaning agents.

Developing higher-performance, lower-cost cleaning agents which minimize environmental and human impact requires continuous improvement. It's a task that never ends.

References:

IPC-1402, *Standard for Greener Cleaners Used in Electronics Manufacturing*