BEYOND ECM
ADDITIONAL REASONS FOR CLEANING CIRCUIT ASSEMBLIES

Michael Konrad
Aqueous Technologies
CA, USA
konrad@aqueoustech.com

INTRODUCTION
Today, in modern times, society values cleanliness. The recent pandemic has exaggerated the degree to which we desire, expect, and even demand cleanliness. Even in "normal times", cleanliness is revered. We wash our bodies, dishes, cars, and pets. We expect cleanliness in our hotels and restaurants. We require cleanliness, to the point of sterility, in our operating rooms. In many public restrooms, we even hire people to inspect for cleanliness and publish inspection reports.

Cleanliness has become a normal part of life, except in one aspect of our life. Part of our life that ensures our safety, prepares our food, transports us to work and play, monitors our health, and so much more. I'm referring to electronics. Once regarded as vital, the level of importance of a clean circuit assembly has been demoted. How did the cleanliness of circuit assemblies, once required, get shoved aside? There's one simple answer; the environment.

During the 1980's, scientists discovered a "hole" in the Earth's ozone layer and attributed it to, among other things, chlorofluorocarbons (CFC's). In order to protect the ozone layer, or at least slow down the shrink-rate, a treaty was signed, referred to as the Montreal Protocol [figure 1], originally by eleven countries, that would phase out production, and consequently availability, of most CFC-based solvents within a ten-year time frame. That was 1989. By law, these CFC-based solvents would be no longer produced by 1999.

Figure 1. The Montreal Protocol International Treaty

The wildly popular cleaning/defluxing chemicals of the day were largely CFC-based and therefore subject to the ban. Necessity being the mother of invention, a new flux was introduced promising to leave behind an invisible and benign residue, not harmful to circuit assemblies. This new "no-clean" flux would eliminate the cleaning requirement. Almost instantly, the electronic assembly industry switched to no-clean fluxes and abandoned their cleaning processes. While some high-reliability manufacturers such as military and medical maintained their cleaning processes, the majority of the industry exchanged their cleaning systems and processes for the promise of a "clean without cleaning" circuit assembly.

OUR CONTRACT WITH NO-CLEAN
When most of the electronic assembly industry abandoned their cleaning processes in favor of the new no-clean fluxes, there was an implied "contract" with no-clean. The contract promised the residues would be both invisible and benign. It's important to note the "fine print" in the so-called contract. The fine print was based on the circuit board and component designs common in the late 1980's. Assemblies common in the early days of no-clean fluxes were almost exclusively populated with through-hole components. Surface mount was in its infancy, featuring course pitches and tall stand-off heights.

The implementation of a no-clean strategy was largely successful and soon became mainstream.

PARTY'S OVER
Over the years since no clean flux was introduced, much has changed in the assembly industry. Increased reflow temperatures as a result of the use of lead-free solder alloys as well as the miniaturization of circuit assemblies and the components mounted to them, combined with the explosion of IOT devices, frequently putting electronics into harsh environments. The perfect storm of higher component densities, increased residues as a result of the abolishment of a cleaning process, and more and more assemblies headed into harsh environments, has created a scenario where modern circuit assemblies have far less tolerance for residues than their historical predecessors.

Because modern circuit assemblies have far less tolerance for residues than assemblies en vogue at the time no clean flux was introduced, one needs to pay closer attention to the volume of residues on a circuit assembly. While modern no-clean fluxes do leave behind a residue, it's usually benign or close to it. The proverbial fly in the ointment is not the flux residue rather it is the totality of all process residues. One should consider when the decision was made to not remove the flux residue, no other process residues would be removed. The decision not to remove one residue species (flux) was a decision not to remove anything (and there's a lot of "anythings"). In addition to flux residue, there are a host of "usual suspect" residues common on all circuit assemblies. Residues from board fabrication, component fabrication, handling, humans, and, of course, flux all contribute to the totality of contamination on assemblies less and less residue tolerant.

CLEANING AS A MAINSTREAM PROCESS

Today, cleaning is once again considered to be a mainstream process. While some assemblies remain uncleaned, and perform reliably, many others require contamination removal in order to function reliably. Most assemblers who clean their assemblies perform this value-added process to prevent electro-chemical migration (ECM) issues, namely dendritic growth and parasitic electrical leakage. Both ECM manifestations are both well-known and well documented. But there are many other reasons to clean circuit assemblies, beyond ECM prevention. Cleaning provides numerous specific benefits. Recent history has shown us the numerous failure mechanisms that can occur when residues are allowed to remain on a circuit assembly after reflow.

BEYOND ECM -ADDITIONAL REASONS TO CLEAN

While this paper lists eight reasons to clean circuit assemblies, there are indeed more reasons to justify a cleaning process. Consider these to be the "Poster Child" reasons for cleaning.

1. **ECM Prevention**
   The removal of ionic residues prevents the occurrence of dendritic growth and parasitic electrical leakage.

2. **Conformal Coating Adhesion**
   Assemblers apply conformal coating materials to a circuit assembly to protect it from harsh environments and materials. Successful protection requires an adequate bond between the target surface and the protective coating. Failure of such bond may cause the assembly to be exposed to harmful environments and substances and lead to assembly failures.

Figure 2. Advertisement featuring Earl Scheib with his famous offer

3. The infamous Earl Scheib [figure 2] of *"I'll paint any car for just $29.95"* fame taught me the value of surface preparation. Shortly after having my car repainted by Earl Scheib, the paint began to peel off. Apparently, sanding, priming, and other forms of surface preparation were optional.

4. **Corrosion Prevention**
   While corrosion may occur with the presence of moisture, many of the "usual suspect" residues species commonly found on un-cleaned circuit assemblies are corrosive. Removal of corrosive residues reduces the likelihood of corrosion.

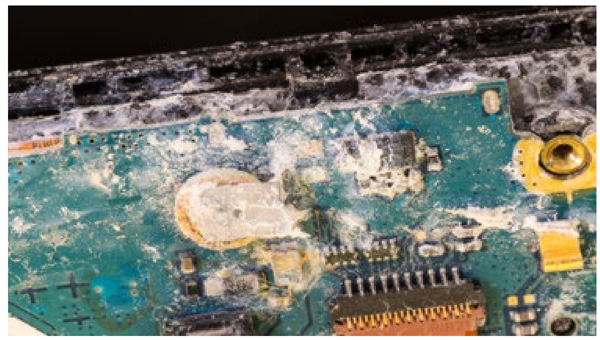

Figure 3: Residue-induced corrosion

5. **FREQUENCY DISTORTION**
   Changes in Impedance / Frequency Distortion can be caused or exacerbated by ionic residues and/or foreign object debris (FOD) on the assembly.

   Frequency distortion can result in Flicker Noise or Burst Noise.

   Flicker Noise[2]
   Surface defects, contamination and other imperfections often can create traps for charge carriers to accumulate. Flicker noise is the characterization of the random emission of electrons associated with these imperfections.

   Burst Noise (Popcorn Noise)
   This source of noise is quite similar to flicker noise in that it is due to contamination and other imperfections that lead to carrier traps, with the exception of the magnitude and mode of emission of the charge carriers. Often heavy ion implantation can lead to these defects.

   Removal of both ionic residues and FOD will reduce the chances of frequency distortion.

6. **COSMETIC APPEARANCE**
   Cosmetic blemishes on an assembly may or may not lead to failure. Not all residues are harmful. One potential risk of cosmetic blemishes is if it's noticed by the end user. If the end user notices a blemish, they are not so certain to immediately assume its non-fatal. When the customer notices one blemish, the assembly will be under a high

magnification microscope in lightning speed. One thing most suppliers do not want is for their customers to scrutinize their products because when they look, they find.

7. LARGER REFLOW PROCESS WINDOW

There is one commonly overlooked part of the assembly process which affects the volume of residue on an assembly after reflow. Minor variations in reflow temperatures could have an effect on detectable ionic residue on the assembly after reflow.

To confirm this, the decision was made to produce a DOE[1] whereby multiple identical assemblies with identical components reflowed with an identical no-clean solder paste would be subjected to minor variations in peak reflow temperatures. These assemblies would then be subjected to IPC required surface insulation resistance testing to determine if there would be any differences in SIR results. For this DOE, we built test boards using the Foresite Umpire Test Board [figure 4].

Figure 4: Foresite Umpire Test SIR Board

We selected a SAC305 no-clean solder paste which required a peek reflow temperature of 230°C. We reflowed 16 assemblies, 4 each using four different peak reflow temperatures as follows:

- 218°C (.947% of correct temperature)
- 220°C (.956% of correct temperature)
- 225°C (.978% of correct temperature)
- 230°C (correct temperature)

Each reflowed assembly would be subjected to a 168-hour surface insulation resistance (SIR) test under heat and humidity conditions to simulate a harsh environment (per IPC standards).

The results of the SIR testing [figure 5] confirmed lower-level SIR test results proportionate to the decline in Peak reflow temperatures. The correct reflow peak temperature for this assembly was 230°C. We used the IPC standard for SIR testing results of 1.0E8 ($1x10^8$).

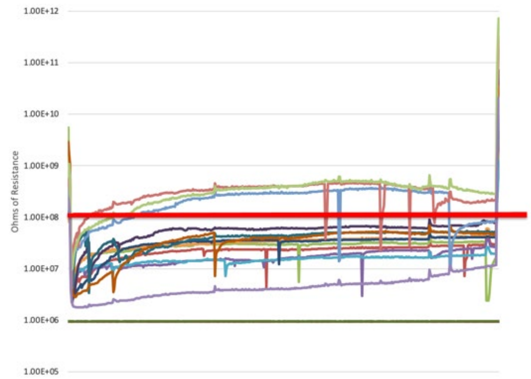

Figure 5. Failed SIR test results

The results of the DOE indicated a lowering of a peak reflow temperature of just 5% resulted in drastic changes in SIR test results, causing the assemblies reflowed at a slightly lower temperature to fail SIR testing per IPC SIR test criteria. When the assembly was reflowed at the correct peak reflow temperature, the SIR test results indicated a strong PASS [figure 6]. Likewise, a cleaning process would have removed the residues, changing the SIR test results to a strong PASS, and allowed the assembly to function free of residue-caused reliability concerns.

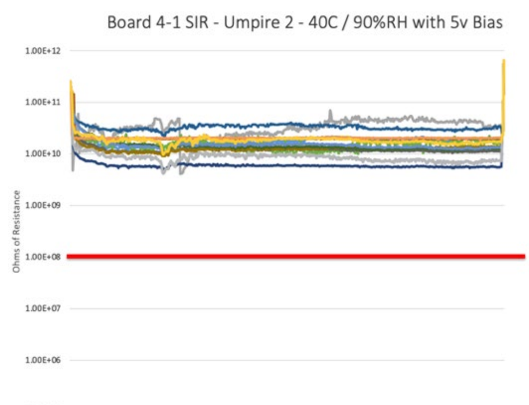

Figure 6: SIR test results (PASS) when proper reflow provide was achieved.

8. IMPROVED COMPATIBILITY WITH HARSH ENVIRONMENTS

In order for ECM to form, there must be three elements:
- Electrical bias
- Corrosive / conductive residue
- Moisture

Harsh environments are frequently associated with increased levels of moisture. To mitigate the possibility of moisture-triggered ECM issues, one may either remove moisture and protect the assembly from moisture re-incursion or, alternatively, remove the residues. Frequently, assemblers choose to protect the assemblies from moisture, a process more difficult than it sounds.

While removing moisture from a circuit assembly is effective in ECM prevention, preventing moisture reoccurrence is challenging. Even the application of conformal coating does not prevent moisture intrusion as most conformal coating materials are permeable, allowing small amounts of moisture (not otherwise problematic) to permeate through the coating and onto the assembly.

The removal of assembly residues via a cleaning process provides for maximum residue tolerance in harsh environments as, and, without ionic residues, moisture alone cannot cause ECM.

9. INCREASED RELIABILITY

Reasons to clean, numbers one through seven provide the rational for number eight… Increased reliability. By removing residues, our circuit assemblies and the products they are installed in are more reliable.

CONCLUSION

Time and technology have worked in tandem to reduce the volume of residues a typical circuit assembly can tolerate. Given the three primary ECM prerequisites (electrical bias, ionic residue, and moisture), residue removal is the only practical and reliable method of ECM prevention and other residue-related reliability issues.

REFERENCES

1- DOE published at SMTAI 2022. Authors: Mike Konrad (Aqueous Technologies) and Eric Camden (Foresite)

2- Patrick Powers
ECE 480 – Senior Design Michigan State University