KEMET® ENGINEERING BULLETIN

Alternative "Surface Mount Cleaning" Processes – Squeaky Clean and "ODS" Free! Any Concerns?

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EXECUTIVE SUMMARY

Some of the more urgent and challenging projects in the electronics industry today are those involved with the elimination of the use of Ozone Depleting Substances (ODSs). KEMET fully supports the need to move quickly in this direction.

> KEMET Electronics products do not contain and are not manufactured with ODSs.

ALTERNATIVE CLEANING MATERIALS

Three classes of alternate cleaning systems have emerged: "no clean," "semi-aqueous," and "aqueous wash" systems. Complementary solder pastes and fluxes are also being developed.

1. *"No Clean"*

   Requires no cleaning step or waste treatment.

   Major challenges with the use of no clean systems:
   - Development of solder pastes and fluxes.
   - Non-corrosive additives.
   - Process control of the no clean solder process.
   - Improvements in wave soldering equipment.
   - Improvements in parts storage and use of FIFO.

> KEMET capacitors are compatible with materials used in no clean processes when the circuit assembly itself proves acceptable.

2. *"Semi-aqueous"*

   The semi-aqueous option, commonly used with RMA fluxes, involves several stages. In the first stage, an organic emulsion or liquid dissolves and removes rosin flux residues. The second and third stages are water rinses to remove remaining organic materials, water soluble contaminants, and the organic solvent itself.

   Many of the semi-aqueous solvents are also compatible with OA (organic activated) and SA (synthetic activated) fluxes.

   Major challenges with the use of semi-aqueous systems:
   - Investigation and selection of the cleaning solvent.
   - Investigation and selection of cleaning equipment.
   - Recycling and reclaim of the materials.
   - Material and assembly incompatibilities.
   - Overall costs (compared to the other alternatives).

> To our knowledge, KEMET capacitors are compatible with semi-aqueous solvents.

3. *"Aqueous"*

   "Water wash," or aqueous, systems operate much like semi-aqueous: when the solder flux is an RMA or RA, saponifier materials are added. If the solder flux is water soluble, the saponifier may be eliminated.

   Water-soluble solder fluxes are either organic activated (OA) or synthetic activated (SA). Water-soluble fluxes may have as much as 10 to 15% added inorganic acids as activators. Water-soluble solder fluxes are corrosive and must be fully cleaned from the assemblies and components.

   Major challenges with the use of aqueous wash cleaning systems:
   - Humidity control of the solder paste.
   - Control of boards in queue after the solder paste process.
   - Complete removal of the water-soluble flux residues.
   - Process control of the chemistry in flux applicators.
   - Development of water-soluble fluxes that meet all needs.
   - Treatment of the waste stream to meet environmental requirements.
   - Avoiding an increase in spray pressure.

> To our knowledge, KEMET capacitors are compatible with saponifier and other materials of aqueous cleaning systems. Residues of OA and SA fluxes must be removed, and the cleaning process must be controlled to prevent ingress of these fluxes into plastic molded parts and other crevices in the assembly.

PROCESS VARIABLE COMPATIBILITY

Understanding the effects of cleaning process variables on the performance and reliability of the parts is hampered by the lack of data over time for the new systems. Some problems may be inevitable.

One difficulty involves the combination of aqueous wash and OA or SA fluxes. These fluxes and residues are corrosive and must be fully removed from the assemblies to prevent damage.

Process variables can result in some of these corrosive residues being trapped within spaces, crevices, parts, and the top layer of the board itself. The process variables most important in creating this hazard are:

- soldering temperatures
- temperature of the parts/boards as they enter the first cleaning stage
- type and amount of flux used in the first cleaning stage
- temperature of the liquid in the first stage.

CONCLUSION

The electronics industry is moving quickly to eliminate the use of ODS materials. This move is fully supported by KEMET Electronics. Because the changes being made are rapid, not much data exists to prove one alternative better than another.

The greatest current concern regarding parts' performance after cleaning relates to residues of OA or SA corrosive fluxes entering areas where they cannot be removed by subsequent rinsing. Process variables must be appropriate to prevent this.

SURFACE MOUNT "CLEANING PROCESSES" AND CONCERNS

INTRODUCTION

Some of the more urgent and challenging projects in the electronics industry today involve the elimination of the use of Ozone Depleting Substances (ODS). Solvents such as chlorofluorocarbons (CFC) and methylchloroform (TCA) have been widely used for cleaning electronic assemblies and components. These have been particularly effective as solvents for removing rosin-based solder flux residues and other contaminants. However, due to their adverse environmental effects, these solvents are no longer a choice for continued use. They must be replaced as soon as possible.

As one of the leaders in the electronics industry, KEMET shares the responsibility for eliminating the use of ODS materials. This includes the materials used in capacitors as well as those used to process the parts through manufacturing.

As with all new technologies, developments can be rapid and far-reaching. This is especially true given the urgency of CFC replacement. KEMET is concerned with the effects of the alternative materials on KEMET capacitors, and the effects of the new cleaning process variables on the performance of KEMET capacitors. This article discusses the alternative cleaning systems KEMET has investigated, and analyzes the effects of the new cleaning process variables on our product.

KEMET Electronics products do not contain and are not manufactured using ODSs.

Many articles have been published regarding the elimination of ODSs. The Surface Mount International and IPC proceedings, and the Surface Mount Council publications,[1] are excellent references for the more technically inclined. Only the simplest outline is presented here for information and reference to KEMET objectives.

ALTERNATIVE CLEANING MATERIALS

The surface mount process most affected by ODS material elimination is the "cleaning" process. Many in the industry are well on the way to using alternative cleaning processes and solvents. Like KEMET, they have already replaced ODS cleaning materials with an alternative system. Three classifications of alternative cleaning systems appear to have emerged: "no clean," "semi-aqueous wash," and "aqueous wash."

The change to alternate cleaning materials, processes, and equipment, is quite complex. Much of what is known about cleaning is empirical, based on many hours of process trials. Changing materials and processes will require rebuilding this empirical data base.

Along with the development of the cleaning solvents must come a change in solder fluxes. In the case of reflow solder processes, solder fluxes are a portion of the solder paste screened on the board before soldering. In wave solder processes, solder fluxes are applied to the board in the wave solder equipment, typically using foam flux or spray nozzle applicators.

Once a cleaning solvent and process have been determined, cleaning equipment appropriate for the combination must be selected. The choice of a cleaning system, therefore, involves the compatibility of materials, processes, and equipment.

ALTERNATIVE CLEANING SYSTEMS

1. *"No Clean"*

The no clean alternative would appear to have distinct advantages: this material needs no cleaning step or waste treatment. Cleaning is a non-value added process; it is in place only to remove solder flux residues and other contaminants. If these residues are not harmful, they could remain on the board.

The no clean process uses no clean or low residue solder fluxes, formulated to be left on the board after soldering. Although these fluxes are labeled "no clean," they all leave some residue after soldering. The amount of residue depends on the type of flux used. Some no clean residues are also reported to be oxidation-sensitive and to discolor with time and temperature. This oxidation is not harmful. Some of these residues can be removed by further cleaning, but all are meant to be left on the board and to be harmless.

The major challenges with the use of no clean systems appear to be:

- Development of solder pastes for high volume reliable printing. New formulations are being developed regularly. Some versions are reported to have achieved excellent results.
- Resins and additives that are non-corrosive and have low residue content. Testing must usually be done, as the literature reports various results.
- Process control of the no clean solder process. Some articles report that modified solder profiles are needed. This appears to be a function of the solder paste or flux version selected.[2] It has also been widely reported that the forced air convection solder processes, with a blanket of inert gas, greatly improve the results. Various reports discuss the maximum amount of oxygen that can be present in the inert gas before degradation in results occurs.

- Improvements in wave soldering equipment that minimize the need for precise monitoring of the low residue flux. New flux sprayers are already demonstrating excellent results.
- Storage of components to prevent early aging and deterioration of termination finish. Improvements might include better use of FIFO inventory and JIT delivery.

KEMET capacitors are compatible with materials used in no clean processes when the circuit assembly itself proves acceptable.

2. *"Semi-aqueous"*

Another alternative becoming popular is a "semi-aqueous" system, most commonly used to clean Rosin Mildly Activated (RMA) fluxes. Recent literature indicates that many of the semi-aqueous solvents are compatible with other flux types such as OA (organic activated) and SA (synthetic activated); however, use of these alternative flux types in semi-aqueous systems seems minimal to date.

The semi-aqueous cleaning process involves four stages. In the first, the wash stage, an organic emulsion or liquid dissolves and removes rosin flux residues. The temperature of this first wash is typically 150°F (65°C). The higher temperature increases the dissolution rate of the flux residues and minimizes the cleaning time. The spent cleaning liquids are decanted and separated to remove rosins and other contaminants. Even so, after a short time the contaminant level in the first stage will stabilize at about 10 to 15% of the solvents.

The second and third stages are water rinses to remove remaining organic materials, water soluble contaminants, and the organic solvent itself. Most cleaning equipment includes at least two zones of water rinse. The first zone of water rinse is also contaminated with the solvent and contaminants. These levels depend on the volume being run and the dragout, but are usually less than 100 ppm. To assist the penetration of the cleaning solvents into tight spaces, the equipment usually incorporates high-pressure sprays in each of the stages. A further option includes ultrasonics.

The water rinse stages are followed by a hot air drying stage. Filtering, reclaim systems and water purifier systems are typically included with the cleaning system.

Semi-aqueous cleaning agents are reported to have excellent solvency for the rosin components and excellent wetting characteristics to reach the hard-to-get crevices and spaces on the assemblies. Recent studies have also shown that cleaning under parts and in close tolerance areas can be improved dramatically. To accomplish this, the first stage temperature should be high enough to increase the dissolution rate of the specific flux residues. These temperatures are reported to be between 149° and 180°F (65° to 85°C). [3]

Examples of semi-aqueous solvents include Dupont AXAREL, Petroferm BIOACT® and EC-ULTRA®, Kyzen IONOX™, ISP MICRO-PURE™ and Martin Marietta MARCLEAN™.

The major challenges with the use of semi-aqueous cleaning systems appear to be:

- Investigation and selection of cleaning solvents to meet application needs.
- Investigation and selection of cleaning equipment. This is closely related to the type of solvent selected. Safety was an early concern; however, it now appears that this hurdle is better addressed by the design of the equipment and development of solvents with higher flash points.
- Recycling of cleaning materials. Recent advances in solvent separation and waste contaminants have greatly improved recycling opportunities.
- Material and assembly incompatibilities. While many tests have been conducted on base material compatibility, the empirical data base of many hours of actual use under varied process conditions remains to be generated. (See the discussion in the Process Variable Compatibility section.)
- Means of compensating for the higher material costs. These costs appear high compared to other alternatives.

To our knowledge, KEMET capacitors are compatible with the semi-aqueous solvents.

3. *"Aqueous"*

The third basic cleaning alternative is the water wash or aqueous system. This process flow is very similar to that of the semi-aqueous cleaning systems.

If the solder flux is an RMA or RA type, saponifier materials are added to alter the residues in the first stage of cleaning. The altered residues then become water soluble and are rinsed from the board in the subsequent cleaning stages. Some cleaning systems use conventional detergent saponifier materials; however, other options are becoming widely available. One cleaning system (Hughes RADS) is a water-based flux removal system. In this case, the saponifier is assisted by a proprietary alkaline base emulsion (trade name ECOSOLVE®). Alcohol-based saponifiers, that seem to eliminate many of the concerns with conventional saponifiers, are now becoming available. Trade names include AQUANOX™ and INONX™ from Kyzen.

If the solder flux is water soluble, then the saponifier may be eliminated. In some cases, a smaller amount of saponifier is still included in the first wash zone. This helps clean off fingerprints and other non-water-soluble contaminants.

In the first stage, the assemblies are typically sprayed with high pressure solutions and immersed. Ultrasonic agitation is also sometimes used to assist in cleaning. The temperatures of the fluids in the first stage are maintained near 150°F (65°C).

The second stage consists of a deionized water high pressure spray. Again, the water is near 150°F (65°C). Saponifiers may be added in lower concentrations in the second stage as well. The third and sometimes fourth stages consist of high temperature deionized water rinses followed by high temperature and high pressure air drying.

Water-soluble solder fluxes are either organic activated (OA) or synthetic activated (SA). Water-soluble fluxes may have as much as 10 to 15% inorganic acids (such as hydrochloric acid) added as activators. The low-residue no clean fluxes have no inorganic acids.[4] The water-soluble solder fluxes are corrosive and harmful, and residues must be fully removed from assemblies and parts.

The major challenges with the use of aqueous wash cleaning systems appear to include:

- Humidity control of the solder paste. Storage at humidities in excess of 50-60% RH greatly degrades the performance of the solder paste.[5]
- Control of boards in queue after the solder paste process and prior to soldering. Humidity control in the room is important, as is the length of time the boards sit prior to soldering.
- Process control monitoring of the chemistry of the water-soluble flux in the wave solder process. As the flux applicators are in the wave solder equipment, the heat from the process can drive off solvents and increase the relative acidity of the flux.
- Complete removal of the water-soluble flux's corrosive residues, both from the surface of and from spaces and crevices in the assembly.
- Development of water-soluble fluxes that meet all process needs and do not harm the assembly or parts.
- Treatment of the waste stream to ensure that heavy metals and other contaminants meet environmental requirements. This usually includes a filter to eliminate solder particles. Saponifiers add a high degree of biological oxygen demand (BOD) on the waste treatment system. This is regulated in some communities. In addition, the pH level of saponifiers is in the range of 10 to 11. These must be neutralized before exiting in the waste stream.
- Resisting the temptation to increase pressure in the sprays to improve the cleaning process. Some equipment has sprays that can be adjusted as high as 500 psi, enough to damage small leaded parts.

To our knowledge, KEMET capacitors are compatible with saponifier and other materials of aqueous cleaning systems. Residues of OA and SA fluxes must be removed. In addition, the cleaning process must be controlled to prevent ingress of these fluxes into plastic molded parts and other crevices in the assembly where they cannot be removed.

PROCESS VARIABLE COMPATIBILITY

Determining the effect of cleaning process variables on the performance and reliability of the parts is crucial to the success of the cleaning process. However, this area is the most difficult to investigate completely. The most obvious hurdle is access to the necessary variety of equipment needed to perform evaluations. Another problem is the large number of variables and process parameters involved with these new cleaning technologies. Sometimes these processes vary significantly within a given company.

At present, no parts manufacturer (including KEMET) has the necessary historical data base to be able to declare that degradation will not occur under all cleaning conditions. This data will be generated as experience is built up. Confidence is already established in RMA fluxes and CFC class cleaning systems. It has been built up over a long time. Problems and continuous improvement programs led to the performance of the flux materials and cleaning solvents in use today. Unfortunately, this lack of data for the new alternative cleaning systems means that a certain number of problems are inevitable. As other cleaning process variables that may lead to degradation are found, we will continue to investigate these and to report the results.

Of course, it would be best if capacitors could be improved to make them robust under all conditions. This improvement in robustness is always our goal. However, typically when a problem is manifested in one part type, other parts and package types are also susceptible. Analyzing these experiences will lead to modifications of the cleaning processes, the solder fluxes, and the parts as well.

ONE PROBLEM: TRAPPED CORROSIVE FLUX RESIDUES

One problem identified with alternative cleaning systems involves the combination of aqueous wash and OA or SA fluxes. These fluxes are corrosive and must be fully removed from the assemblies to prevent damage. This damage may be detected in first circuit tests or later in life. Humid environments tend to accelerate the corrosive action and damage.

The cleaning systems have been tested to ensure that they are capable of removing the corrosive residue. However, these tests usually focus on ionic contamination as the output measure. Process variables can be such that some of these corrosive residues are trapped within spaces, crevices, parts, and within the top layer of the board itself. These can remain even after the board is cleaned, rinsed, and dried.

The process variables most critical in creating this threat are:

- soldering temperatures
- temperature of the parts/boards as they enter the first cleaning stage
- type and amount of flux used
- amount of corrosive flux residues in the first cleaning stage
- temperature of the liquid in the first stage.

One hypothesis for the development of this problem is as follows:

1. As the assembly passes through preheat and peak temperatures in the soldering process, various materials expand. These temperatures exceed the glass transition temperatures of many of the plastic materials. Areas subject to this include the plastic-to-metal interfaces of parts, spaces under parts, spaces within connectors or other relatively open parts, and adhesives. The temperature within these spaces approaches the high temperatures of the soldering process.
2. As the assembly exits the solder equipment, it begins to cool and then enters the first cleaning stage.
3. The temperature of the cleaning solvent in the first stage is approximately 150°F (65°C).
4. If the air temperature in these expanded spaces is higher than the temperature of the first cleaning stage, the air in the space will be immediately cooled. This creates a partial vacuum in the expanded areas. *This appears to be one key variable.*
5. The pressure difference created by the partial vacuum induces a pumping action, drawing in the liquid of the first stage. High-pressure sprays may also assist in driving the liquid into these spaces. The liquid brings with it some degree of flux residue and other contaminants.
6. The spaces and gaps then contract as the unit is further cooled. This tends to trap the cleaning liquid and contaminant.
7. Over time, the corrosive nature of the OA and SA flux residue can lead to damage. *Another key variable.*

To date, this problem has been identified only with aqueous cleaning systems. If the use of OA or SA type fluxes is expanded to semi-aqueous systems, a similar situation may occur.

The degree to which the problem may manifest itself depends on the following factors:

a) Coefficient of Thermal Expansion (CTE) of the plastic and metal materials.
b) glass transition temperatures of the materials
c) time and temperature peaks in the solder process
d) acidity of the OA or SA flux residues
e) difference in temperature between the assembly and the first cleaning stage
f) amount of contaminant/flux residue in the first cleaning stage
g) susceptibility of the materials reached by the corrosive residues.

> To minimize the chances of this problem, it is strongly recommended that:
> 1. the acidity of fluxes be minimized
> 2. the temperature of the board/parts as they enter the first clean stage be less than the temperature of the first stage.

OTHER PROBLEMS

The list below references other reported problems and potential concerns with changing process variables.

1. Many cleaning assessment studies have found that residues were trapped under MLCC IC packages and passive parts (resistors and capacitors). The residues were not indicated in the conventional ionic contamination tests used to assess cleanliness. Many of the alcohol solvents used to assess cleanliness were developed to be compatible to RMA flux residues; those from OA and SA fluxes are not always apparent with these alcohol rinses.

2. Some adhesives used to attach parts before wave soldering have been determined to be water absorbent. If these adhesives are at a high temperature and absorb the contaminants of the first wash stage, degradation could later occur. These require evaluation.

3. OA and SA fluxes attack some dry film solder masks. As the solder mask expands during the solder process, some of the flux residue may be trapped in or under the solder mask.

4. Raising the circuit board above the glass transition temperature [about 125°C (255°F) for FR-4 materials] causes the polymer matrix to expand. It acts like a sponge, allowing materials in the soldering operation to wet and diffuse into the surface layers. These materials can only be extracted by extended cleaning or etching of the surface. These materials have been tested and found to lower the Surface Insulation Resistance of the circuit board. (Results of extended moisture testing have not been reported.) In addition, a concern exists for trapped OA and SA materials in the circuit board. [6]

5. HAST tests of SOT 23 diodes, wave soldered with different types of water soluble fluxes, show an increase of failure rates when the flux had higher activity and higher solids components. [7]

6. Plastic body parts with metal terminations, such as solid tantalum chip capacitors and fuses from more than one manufacturer, have failed in some applications. This was due to an ingress of acid contamination from the OA or SA fluxes used in combination with an aqueous cleaning system. These failures have resulted in opens and shorts.

7. Problems with parts "spitting" in soldering operations subsequent to water wash cleaning have been observed. "Spitting" is thought to be due to moisture trapped in the part.

8. Some assemblers have had to use compressed air nozzle cleaning to remove cleaning liquids trapped in connectors, etc. The residue left after this has not been evaluated.

CONCLUSION

The electronics industry is moving quicky to eliminate the use of ODS materials. This move is fully supported by KEMET Electronics. Our concerns include eliminating ODS cleaning materials, ensuring that the new cleaning materials are compatible with the capacitor materials, and informing our customers of issues found in the industry.

The greatest current known concern regarding parts' performance after cleaning relates to the residues of OA or SA corrosive fluxes. These can be left in the part itself (in the case of plastic molded parts), or under the part as mounted on the board, or in various crevices of the assembly. Process variables must be appropriate to prevent this.

Should any reader have additional comments and suggestions, the author is anxious to hear from you. Your comments will be evaluated and considered for the next revision of this bulletin.

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