SMArT SONIC®

June 1, 2000

To whom it may concern:

This letter is meant to convey the known safety and guidelines for cleaning populated SMT assemblies with ultrasonic technology.

Smart Sonic Corporation is a world leader in providing stencil cleaning equipment and chemistry to the SMT industry. While expert in cleaning technologies, Smart Sonic does not profess to be expert in the assembly or test of printed circuit boards We can only site what industry experts have published and shared with our technical staff.

The U.S. Military established the caution of cleaning PCB assemblies with ultrasonic technology nearly 50 years ago. At that time the wire bonds and certain components were delicate and the new technology of ultrasonic cleaning, using low-fixed frequencies 20 - 25 kHz, was aggressive and uncontrollable. However, present day SMT assemblies are very robust and durable and ultrasonic cleaning technology has matured to become the most controllable precision cleaning technology available. Now, the two technologies are reported to be very compatible.

Experts such as William G. Kenyon (*SMT Magazine*, May 1995), Les Hymes (*Circuits Assembly*, Sept. 1999), and the late Charles L Hutchins (*SMT*, Nov. 1992) have all expressed their opinions and generally conclude that ultrasonic cleaning is a very viable option for cleaning modern electronic assemblies.

Established guidelines for safe ultrasonic cleaning of electronic assemblies include using:

- Power densities of 11 watts per liter or less
- Frequencies of 40 kHz or higher (multi or sweep frequencies)
- Wash cycle times of 10 minutes or less
- Thorough rinses to remove wash solution. An ultrasonic DI water rinse may be necessary because sprays cannot reach into the same tight tolerance areas as ultrasonics.

As with any new process, thorough testing prior to implementation is a good practice. IPC standard test methods IPC-TM-650 2.6.9.1 and 2.6.9.2 may be used.

For in depth technical data, I also recommend the following articles:

- MIL-STD-2000A, Feb. 1991, "Standard Requirements for Soldered Electrical and Electronic Assemblies
- B.P. Richards, P. Burton and P.K. Footner, "Does Ultrasonic Cleaning of PCBs Cause Component Problems: An Appraisal" IPC Technical Review, June 1990.

Yours truly,

William C. Schreiber
President

WILLIAM G. KENYON

Ultrasonic Cleaning Acceptance Accelerates

Although ultrasonics is a commonly used tool in the cleaning industry, it has been controversial in the electronics industry because of damage recorded by the military in 1950s and '60s. Since then, electronic component and ultrasonic technologies have improved markedly. The single or fixed frequency, 25 kHz ultrasonic systems used 30 years ago damaged components because of their higher cavitation energy and ability to resonate wire bonds and other delicate components.

"...ultrasonics is a very viable option for defluxing modern electronic assemblies."

With the phase-out of CFCs and the increase of intricate surface mount technology geometries, the use of ultrasonics is becoming mandatory in many cases to achieve the required cleanliness levels. Dr. Brian Richards of GEC Hirst Research Center (UK) plus Ayche McClung and Bill Vuono of the Electronics Manufacturing Productivity Facility have done extensive testing to qualify the use of ultrasonics. Their research has shown there is little risk of damage from ultrasonics. Richards now recommends the use of ultrasonics as an incoming inspection tool for components, since failures are considered as indicators of infant mortality in the field. This same screening method has been used to check heart pacemaker assemblies, since field failure is generally considered unacceptable by the end user.

Honeywell Military Avionic recently reported their extensive ultrasonic qualifications studies. Twenty different components were tested, many of which were selected because they were thought to be susceptible to damage. A minimum of 100 components of each type were evaluated. The research was performed using two generators which use sweeping frequencies in the 40 kHz range. The test method used was IPC-TM-650 2.6.9.1, "Test to Determine Sensitivity of Electronic Assemblies to Ultrasonic Energy," which uses water as the testing medium, since it represents a "worst case" condition. Out of over 4,000 components tested, only four failures were found after an excess of 100 hr exposure. No prescreening was done prior to testing. A failed wire bond on a transistor appeared to be related to the quality of the wire bond. The other type of component which saw failure was a mechanical relay. Failure analysis concluded that it was not due to ultrasonic degradation, but either possible contamination in the contacts, resulting in an open circuit or a mechanical switch alignment problem.

The conclusion reached from this experiment and similar work on high frequency microwave device cleaning was that ultrasonics is a very viable option for defluxing modern electronic assemblies. The combination of sweeping frequency/power control ultrasonics, good process control and component verification with the specific equipment to be used in production will ensure a damage-free process.

Use of Saponifiers

While "white residues" on printed wiring assemblies were usually associated with the milder CFC-based solvents used to remove rosin fluxes, the literature does contain references to white filmy residues from water soluble fluxes. Studies of this phenomenon showed that certain flux constituents could form high molecular weight polymeric networks that were totally water insoluble, possibly catalyzed by the strong, acidic flux residues. A recent paper proposes the use of an inorganic saponifier to prevent the formation of such residues on printed wiring assemblies and provide lower ionic levels. While all the steps in the mechanism have not been elucidated, it is quite likely that the mild alkaline nature of this cleaning agent reacts with acidic flux residues to preclude white residue formation and the entrapped ionics usually found therein. If this is the case, there is an excellent opportunity for flux formulators to develop aggressive fluxes that can have all their reactive components quenched by the cleaning agent, similar to the way that photographers use a fixer to stop the development process of photographic film. This will provide a safer process that can still effectively solder marginal components.

Cleaning Supercomputer Assemblies

A "TechBrief" on the cleaning studies done by Cray Research Inc. (CRI) to find a CFC alternative for their large, densely populated printed wiring assemblies provided

Equipping for the Cleanup

by Charles L. Hutchins, C. Hutchins & Associates, Raleigh, North Carolina

Cleanup is probably the most technologically dynamic of the basic SMT processes. As one indication, last month I stated that perhaps the most popular cleaning fluid is based on a citrus-derived hydrocarbon. However, at the Surface Mount *International* (SMI) Technical Conference last September, a trend toward different hydrocarbons that minimize concerns and problems with process control, volatility, and flammability is apparently in force.

In any case, the first decision in specifying cleaning equipment is governed by board size and volume requirements. Cleanup of small boards produced in low volumes is costly and inefficient within a large in-line system environment. On the other hand, large boards may not fit in some of the smaller systems.

Benchtop Cleaning

For small-volume manufacturers, a system compatible in size and cost to the rest of the manufacturing equipment is best. This system also could be used for cleanup after manual operations, such as manual installation of special components, test, and rework. In the past, this was usually accomplished with a single vat system and either CFC-113 or a 1,1,1-trichloroethane type of solvent, and may have included a heater and/or ultrasonic agitation. Although systems of this type are slated for elimination due to environmental reasons, semiaqueous cleanups in general were not on display at SMI. Private discussions, however, indicate that development and market availability of alternate semiaqueous cleaning systems are possible in the near future.

Assuming the trend toward semiaqueous cleanup continues, future systems will likely feature two vats, either in one external shell or, possibly, two similar systems. The first vat would contain the solvent; the second, a water rinse. Again, heat or ultrasonic agitation can be used to increase cleaning efficiency.

Since board volumes will be small and the corresponding flux usage low, the solvent and water can be used for a reasonably extended period, minimizing the need for filtration and/or recovery. After the solder balls are filtered out, the spent cleaning solvent can be returned to the vendor for disposal as waste fuel.

Batch Cleaning: Three-Vat System

A floor-standing system that can handle larger boards in higher volumes works well for batch cleaning. Typically, this is a three-vat system including a wash station, a first rinse station, and a final rinse/dry station. The arrangement permits use of a decanter with the first rinse to reclaim the solvent. (Because of the higher volume water requirement, consideration also should be given for an integral closed-loop water reclamation system.) Heat and ultrasonic agitation improves the process, while spray rinsing would be indicated in the final step.

High-volume in-line systems use the basic concepts of benchtop and batch cleaning but add a transport belt and, perhaps, one or two additional rinse stations to increase throughput and maintain cleaning efficiency. The emphasis on improving the cleaning process, however, now shifts to spray technology, since ultrasonic assistance (see below) is generally difficult. Some older systems use "spray under immersion" to minimize solvent volatility and flammability concerns. The larger semiaqueous process in-line systems, having been pioneered by the larger firms, have the greatest number of operational hours. Their combination of resources and technical capability, including collaboration with fluid and equipment vendors to perfect the equipment and processes, has succeeded in significant upgrading of operating and environmental safeguards.

Specifying systems now may save money later.

Ultrasonic Agitation

Although there are specifications prohibiting its use, ultrasonics to improve cleaning efficiency has spawned several "old wives' tales" about possible problems. For my part, I have not seen any credible evidence backing these claims with respect to the equipment on the market. Work conducted at the GEC-Hirst Research Center (Middlesex, England) showed damage could be induced with power levels and process times two to three times that normally used. However, with the exception of those with faulty wire bonding, no damage to components was found. In fact, ultrasonic agitation serves as a good environmental "screen" for poor quality in component design and assembly.

For those who wish to know more, the Institute for Interconnecting and Packaging Electronic Circuits (IPC) has a task group that is exploring the technology further. For more information, contact Task Group leader Carroll Smiley, Du Pont Electronics, Raleigh, N.C.; telephone: 919/248-5076.

Better Sooner Than Later

To my knowledge, there is no equipment of proven capability available for small-volume manufacturing. Yet, when one considers the number of systems that currently use CFC-based solvents, a huge number of such systems obviously are needed. Although on the high side, this scenario perceives a need for new equipment adjudged to be three to five times that which the equipment industry can now provide. Obviously it certainly behooves the prudent plant manager to make his decision to convert to the new processes and select the appropriate equipment as soon as practical. And now just may be the most economical time! **smt**

METRIC
MIL-STD-2000A
14 FEBRUARY 1991
SUPERSEDING
MIL-STD-2000
16 JANUARY 1989

MILITARY STANDARD

STANDARD REQUIREMENTS FOR SOLDERED ELECTRICAL AND ELECTRONIC ASSEMBLIES

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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ULTRASONIC CLEANING OF MILITARY PWAs

by

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ABSTRACT

Ultrasonic cleaning is a successful method for cleaning printed wiring assemblies (PWAs) to a level required by both industry and military standards. Unfortunately, it is also a controversial technique due to possible component damage. Studies performed in the 1950s determined that ultrasonic energy can damage fragile wire interconnects between the die and the terminal of microelectronic devices. Based on these studies, the Department of Defense (DOD) has not allowed ultrasonics to be used when cleaning military PWAs. However, recent technological changes in both component manufacturing and board assembly have caused the military to reevaluate this position.

The Electronics Manufacturing Productivity Facility (EMPF), in cooperation with industry, has taken the initiative to conduct a comprehensive study to determine the effects of ultrasonic cleaning on PWAs. Metal-cored boards affixed with leadless chip carriers (LCCs) and compliant pin surface mount devices were subjected to ultrasonic energy during cleaning. The assemblies were then subjected to various environmental tests to observe detrimental effects that ultrasonic energy may have on sensitive components. These findings and the potential application for ultrasonic cleaning on military hardware are presented in this paper.

INTRODUCTION

The increasing trend toward surface mount technology has added new challenges in the area of cleaning electronics. Dense packaging and smaller component standoff heights have created areas that are large enough to entrap corrosive flux, but too small to clean using conventional solvents and equipment. Surface tensions prevent most solvents from penetrating small areas to dissolve and remove contamination. Capillary action can sometimes aid in drawing the solvent to the contamination, but then the softened residue is too viscous to be removed by simple draining. Additional force is needed to

NOTE: Chlorofluorocarbon (CFC) based solvents have been proven to be hazardous to the environment. Their continued use is not recommended and should be phased out. Use of solvent reclamation systems is encouraged.

5.3.4.1 Ultrasonic cleaning. Ultrasonic cleaning is permissible:

a. on bare boards or assemblies, provided only terminals or connectors without internal electronics are present, or

b. on electronic assemblies with electrical components, provided the contractor has documentation available for review showing that the use of ultrasonics does not damage the mechanical or electrical performance of the product or components being cleaned.

5.3.5 Cleanliness testing. Periodic testing of ionic cleanliness of the product after final cleaning (i.e. the cleaning prior to conformal coating, encapsulation, or incorporation into the next higher assembly) shall be conducted to ensure the adequacy of the cleaning process(es). As a minimum, a representative sample of each product type (i.e. part number, etc) or the most complex assemblies processed through final cleaning shall be tested on a daily basis. If any assembly fails, the entire lot shall be recleaned and retested. The resistivity of solvent extract test, or the sodium chloride (NaCl) salt equivalent ionic contamination test, or an equivalent test, which is fully documented and available for review by the government, shall be used to test for ionic cleanliness. The resistivity of solvent extract test shall have a final value greater than 2 megohm-centimeters. The sodium chloride salt equivalent ionic contamination test shall have a final value less than 1.55 micrograms per square centimeter (2.2×10^{-8} lb_m/in^2) of board surface area. There shall be no visible evidence of flux residue or other contamination. The resistivity of solvent extract test and the sodium chloride salt equivalent ionic contamination tests are defined in Appendix C. Alternative equipment, with the appropriate equivalence values, may be used to verify cleanliness.

NOTE: 2.2×10^{-8} lb_m/in^2 is equivalent to 10 micrograms/in^2.

5.3.5.1 Qualification of cleaning and cleanliness testing processes for surface mounted assemblies. Prior to use on production hardware which includes surface mounted components, the manufacturer shall test representative control assemblies and define acceptable ionic cleanliness testing equipment, processes and control parameters. The combined action of the equipment, process and controls shall consistently verify that the sodium chloride or equivalent ionic contamination test value for the production hardware is less than 1.55 micrograms per square centimeter (2.2×10^{-8} lb_m/in^2) of board surface area. The representative control assemblies used for establishing the test method shall be processed using the same materials, parts

The "approved" list of solvents comprise a starting point to determine what works best for a specific operation.

An Update on Phase 2 Testing of CFC Alternatives

By Tim Crawford

The Electronics Manufacturing Productivity Facility (EMPF) is a U.S. Navy Center of Excellence tasked to do research in electronics manufacturing. For the past seven years, it has been involved with other Department of Defense agencies, the Environmental Protection Agency and the Institute for Interconnecting and Packaging Electronic Circuits (IPC) to find alternatives to CFC-based solvents for cleaning electronics. The group established a three-phase test plan: Phase 1 characterized the cleaning ability of a CFC-based solvent and established the cleanliness results as a benchmark by which alternatives are compared. Phase 2 uses the same processes and procedures established in Phase 1, changing only the cleaning process to the alternative candidate. Finally, Phase 3 examines the potential use of water-soluble fluxes with aqueous cleaning, low-residue fluxes with no cleaning and controlled atmosphere soldering using adipic and formic acids as a "flux" with no cleaning.

Figure 1. The test boards in Phase I alternative cleaner evaluation emerge from the system's curtained section. Because the various materials performed best under conditions that varied widely, final selection may require more than filling the machine and starting the process.

Phase 1

Initial testing characterized the cleaning ability of a nitromethane-stabilized, CFC-based solvent. The cleanliness tests were ionic conductivity, residual rosin, High Performance Liquid Chromatography (HPLC), Surface Insulation Resistance (SIR) and visual inspection. The test assembly, designated as IPC B-36 (figure 1), was designed primarily around the SIR test. The board measures 4 x 4 x 0.060" and is configured on FR-4 laminate. It features four quadrants, each with a comb pattern of 0.006" lines and spaces and via holes to allow flux to flow to the top of the board. The two left quadrants are identical as well as are the two right quadrants, but only the top quadrants are populated with 0.050" pitch, 68-pin leadless chip carriers (LCC). The pads and via holes on each left quadrant are linked in a daisy chain pattern to measure ionic residues between the pads; they represent through-hole technology. The right two quadrants represent SMT and contain a set of parallel traces running outside of the pads. This reading is a measurement of solder paste residue. Each quadrant has four copper lands covered by soldermask to set a fixed component standoff height of 0.005".

All aspects of the test are rigidly controlled and carefully monitored. The flux type and the paste type are specifically identified as is the quantity (weight), thermal profile and cooling time between manufacturing steps. The five assembly sequences (figure 2) mimic both surface mount and mixed technology. The first group ("A" group) acts as a control to measure cleanliness levels prior to manufacturing. The two "B" groups measure how much flux and paste residues are placed on the test assemblies prior to cleaning — important because the cleanliness test results from these groups establish that all Phase 1 and Phase 2 tests are conducted under similar conditions. The "C" and "D" processes measure the solvent's cleaning ability.

Phase 2 is designed so that an evaluation to get an alternative cleaner "Phase 2 Approved" is possible if the proper equipment capabilities are on hand. To verify that all candidates are tested on similar grounds, a Test Monitoring and Validation Team (TMVT) is incorporated. The team is made up of members from an ad hoc group that acts as a neutral party to verify the test results and to certify that all aspects of the test plan are adhered to.

The Phase 1 schedule is very aggressive. Organized in March 1988, it completed the testing by February 1989. By October, the final report was published for international comment. Phase 2 also began in 1989 and by July 1994, fully 23 alternative cleaner candidates were tested.

Phase 2

As mentioned, the only change allowed for Phase 2 is in the cleaning process. To date, the 23 CFC alternatives have achieved a rating "as good as" or "better than" CFC-based solvents. (Five are either not commercially or no longer available for various reasons.) The 18 remaining alternatives are listed in table 1.

EMPF has tested 14 of the 18 alternatives on this list. Though all were found to be successful, the circumstances of operation varied. Some work effectively at room temperature while others work better (or only) at elevated temperatures. Some work effectively in relatively short process times while others require longer washes and/or rinses. Still others are dependent on spray pressures. Accordingly, selecting the "right" alternative may require more effort that filling the machine and beginning the process. The "best" solvent or even a "possible" solvent will depend on the specific operation. One may use this list as a starting point, select a few possibilities, and see what works best.

In addition to cleaning capacity, there are other concerns that must be considered. Material compatibility examines how these solvents will react to materials on the PCB, such as part markings, soldermask, laminates and some components. Industrial hygiene and safety address odor, flammability and exposure limits. From an environmental standpoint, is the waste treated as hazardous or can it be merely sent to drain, recycled or even close-looped? Considering the regulations already in effect in some areas, is the alternative a volatile organic compound (VOC) or a global warmer? Finally, the costs associated with the new process must be considered: those for equipment costs, materials, operational, maintenance, engineering, labor and training. There are also costs associated with support equipment for water, air and waste management.

Cleaning with Ultrasonic Energy

Using ultrasonic energy to satisfactorily clean tough situations or to improve on a less-aggressive solvent's cleaning ability may also be an option. Historically, the military has been against the use of ultrasonic energy due to studies performed in the 1950s that showed its frequencies were causing fragile wire interconnects of microelectronic devices to fatigue and eventually break. Additionally, in most cases ultrasonic energy was not necessary for the relatively easy-to-clean technology of that time. The evolution from through-hole to surface mount to fine-pitch and now ball grid array, however, has made the use of ultrasonic energy a tool to be considered. At the same time, newer wire bonding techniques have provided a more robust component able to withstand the harsh vibrations of ultrasonic energy.

More recent studies conducted by the EMPF and others yield a better understanding of ultrasonics such that a "change of heart" by the military has prompted these revisions to some specifications:

> *"Ultrasonic cleaning is permissible on electronic assemblies with electrical components provided the contractor has documentation available for review showing that no damage results in the mechanical or electrical performance of the product or components being cleaned."*

This is not to say ultrasonics is 100 percent safe. Under proper conditions ultrasonics can be a useful tool, but fatigue is a definite part of the technology, and some components under certain applications will fail. Best advice: "Test clean" a safe sample of the product using ultrasonic energy before a large investment is made.

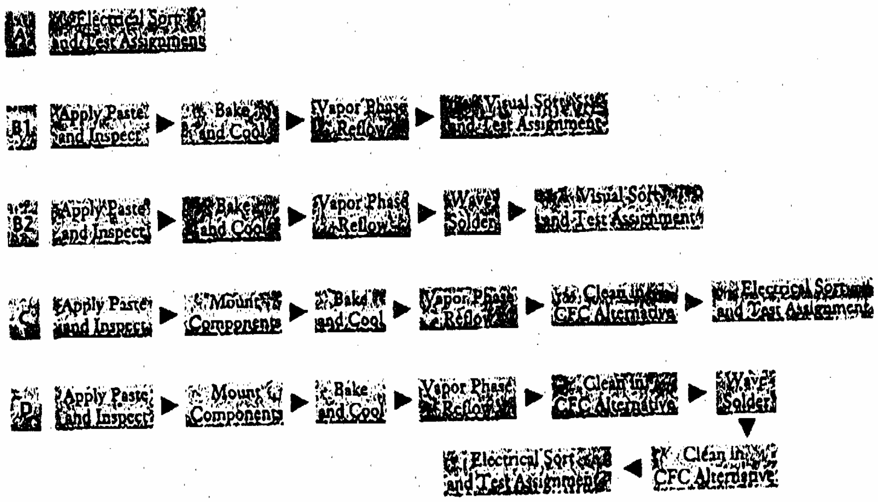

Figure 2. The five assembly sequences of Phase I. The A group serves as control; B groups measure flux and paste residues before cleaning; C and D measure the alternative's cleaning ability.

SMT Stencil Cleaning – A Decision that Could Affect Production

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ABSTRACT — SMT stencil cleaning has traditionally been thought of as a 'maintenance' procedure with little or no impact on production. Today, CFC and VOC cleaning processes are being replaced because of environmental concerns, and fine-pitch and ultra fine-pitch assemblies are commonplace. These changes in cleaning processes and product specifications have shed new light on the importance of properly cleaning SMT screens and stencils in order to prevent damage to the stencil and potential production-related problems.

This paper takes an unbiased look at the different stencil cleaning processes available through the eyes of an SMT stencil manufacturer. The paper outlines the advantages and disadvantages of using 'jet spray' washers *vs* 'ultrasonic' washers, aqueous and semi-aqueous *vs* solvent cleaning agents, and the effects of hot wash solutions and hot drying air *vs* ambient wash solutions and drying techniques.

Specific criteria evaluated include: cleaning effectiveness of the process; potential adverse effects of the process on the integrity of the stencil; production down-time and other potential production-related problems; potential health hazards to users; environmental impact of the process, and waste stream management.

Magnified photography is used to demonstrate the relative effectiveness of various cleaning technologies. Third party references of other industry experts, along with the author's own experiences, are cited to support the information provided.

INTRODUCTION

Because of the environmental concerns driving today's technology decisions, the once simple decision of selecting a stencil-cleaning process is now clouded with different chemicals, different cleaning machines and various types of solder paste, all with specific environmental, health and safety related issues and regulations. Now that CFCs are undesirable, many companies that clean PCBs have changed to using saponifiers and hot water to clean RMA flux from post soldered boards.

Since CFCs worked to clean solder paste when the PCB cleaners were using CFCs, it seemed only natural to follow the lead of the PCB cleaners when the switch was made to saponifiers and hot water to clean solder paste from SMT screens and stencils. However, a major variable was overlooked – the effect on the stencil. PCBs travel through a 200°C reflow oven and are not sensitive to elevated temperatures. The SMT stencil, on the other hand, is manufactured utilising heat cured adhesives that bond the metal foil to the screen and the screen to the frame. If a stencil is washed in hot water or dried with hot air, the 'heat sensitive' adhesives will tend to break down and the stencil will fall apart.

However, this is not the main concern with using hot wash water or hot drying air. If the stencil begins to break apart, the problem is obvious and the stencil can be replaced at an added expense. The real problem stems from the fact that screens and stencils are constructed of different metals. The frame is aluminium, the screen is either stainless steel or polyester, and the metal foil (metal mask) is either stainless steel, brass or nickel. When stencils are washed in hot water or dried in hot air, the different metals will expand and contract at different rates and cause minor distortion to the etched image, stress on the adhesive bond and loss of tensioning which, in turn, can lead to mysterious misprints, causing downtime due to troubleshooting a problems that could have been prevented if only hot water or hot air had not been used.

ALTERNATIVE SOLVENTS

The stencil-cleaning equipment manufacturers soon realised the dilemma and tried to remedy the situation by incorporating other chemistries that were used for cleaning PCBs, i.e., alcohol and terpenes. Alcohols and terpenes were both used at ambient temperatures, just like CFCs. The problem was thought to be resolved. Then along came 'no-clean' solder paste and the realisation that IPA alcohol and terpenes are very selective regarding the type of paste they can clean and they are both flammable and potentially explosive.[1] Neither is very effective at cleaning most 'no-clean' type fluxes. To complicate things even more, fine-pitch and ultra fine-pitch apertures were becoming a reality.

The SMT assembler has always been faced with the responsibility of first selecting a stencil-cleaning machine from one vendor, then selecting a chemistry to address the particular flux and then, hopefully, finding a waste treatment process to handle the mess that was created. Finally, when the process did not work, the assembler was confronted with two or three different vendors pointing fingers at one another, and nobody taking any responsibility for correcting the situation. The solution to the assembler's problem seemed to lie in a complete process that could be offered by one vendor: the right cleaning machine, the correct chemistry, and the proper waste handling system all in one. Then, at least if it did not perform to specification, the assembler would know whom to blame and that vendor would be responsible for correcting the process.

WHAT'S IMPORTANT TO THE USER

When selecting an SMT screen/stencil-cleaning process, it is critical to prioritise the deciding factors that are most important to the user:

- Can the process effectively clean fine and ultra fine-pitch apertures?
- What flux do I need to clean now and will it be necessary to clean a different flux in the future? Can the process support these potential changes?
- Can the process clean dried paste as well as fresh paste?
- Are there other objects to clean, such as misprints, pallets, adhesives, etc.?
- What is the environmental impact?
- What is the capital investment?
- What is the operating cost?
- Are there any health or safety hazards to consider?
- Does the process have any detrimental effects on the stencil?
- What is the maintenance and potential downtime?
- Are there any special handling or storage requirements for flammable or hazardous chemistries?
- Who will take responsibility for correcting the process if it fails to perform?

TYPES OF STENCIL CLEANERS

In general, there are only a few stencil-cleaning machines from which to choose, namely those using spray in atmosphere technology, spray under immersion or ultrasonic agitation.

The chemistries range from solvents (alcohol, terpenes and hydrocarbons) to saponifiers that require hot water solutions, to specially formulated detergents that clean in hot, cold and/or warm water solutions.

Waste handling can be complicated. Depending on the cleaning process, the waste handling process can range from hauling the waste away and creating a long-term liability, to the purchase of an expensive filtration/clarification system that may or may not resolve the waste problem.

SELECT THE CHEMISTRY FIRST

When selecting a cleaning process, the chemistry should be selected first. Most people make the mistake of selecting a cleaning machine first when the important element in the cleaning process is the cleaning chemistry. If the chemistry does not address the contaminant, the mechanical action of the machine will do little to remove the solder paste. A simple example would be washing one's hands. Water and hard scrubbing will do little to clean the hands until soap (chemistry) is used. Only after the proper chemistry has been identified is the method of application of that chemical selected.

Isopropyl alcohol (IPA) and terpenes are solvents that have been used to replace CFCs. However, IPA and terpenes have numerous concerns of their own. They are both volatile organic compounds (VOCs) and therefore smog producers. VOCs are becoming as regulated in many parts of the world as CFCs because of their air polluting qualities.[1] Areas such as California have limited the consumption of VOC solvents to one pound of solvent per day per cleaning site. Since it is common for IPA and terpene using machines to consume more than one pound of solvent simply in the idle state, they are not permitted in many areas.

In addition to contributing to air pollution, they can be very dangerous. Spraying alcohol or terpenes within a closed chamber can result in a fire and/or explosion in the presence of an ignition spark. Several incidents have already been reported. The naive vendor providing an IPA system may feel it to be completely safe because the electronics have been isolated from the atomised solvent. However, an ignition spark can result from the moving metal spray nozzles unexpectedly hitting a metal stencil that has become dislodged from its securing fixture. Metal hitting against metal inside a chamber containing IPA vapours = BOOM!

Caution should also be taken as to where an alcohol cleaner is placed. An ignition spark can be very easily generated by surrounding non-related electrical equipment. In most cases, the manufacturer has provided a fire suppression system in case of such emergencies. Such a fire suppressor system would be useful — if it should survive the explosion! IPA and terpenes are also very selective regarding what fluxes can be cleaned. If down stream the user should decide to change flux types, or if VOCs should become regulated in the area, the user may be faced with exactly the same dilemma of seeking a new stencil-cleaning system.

Another chemistry that has been tried is the aqueous saponifier. A saponifier is an alkaline chemistry (usually 13 pH+) that combines with the rosin in the solder paste to form a water soluble soap. This soap can then be cleaned in water and the lead/tin solder balls can be removed by the mechanical action of the cleaning machine. Unfortunately, saponifiers require elevated temperatures in excess of 60°C in order to react with the rosin (temperatures above 43°C will most likely damage the stencil). The alkaline saponifier is thus consumed during the cleaning process and requires constant replenishment. The high pH and hot solution of a saponifier can also cause a black oxidation to the aluminium frame of the stencil and can be a hazard to the user.

The waste stream of a saponifier is particularly complicated because of the combination of hazardous ingredients contained within the saponifier, and the lead from the solder paste that becomes dissolves in the wash solution. The resulting multiple hazardous waste will require expensive anion exchange or reverse osmosis filtration and chemical neutralisation prior to disposal. The discharge to drain is undesirable in many locations and may require a permit.

Various hydrocarbon-based solvents have been tried with little success. Hydrocarbon solvents are very selective in the flux types that can be cleaned and, because these solvents do not dry 'film free', they require a water rinse. The waste stream treatment can be very sophisticated, costly and provide a long-term liability when hauled away. If the process requires water rinsing, then one may as well wash with water and eliminate the solvent, if possible. This would at least limit the types of waste streams generated.

DETERGENTS WORK BEST

An aqueous process, utilising a specially formulated detergent, seems to be the answer. Detergents can be chemically formulated to achieve a multitude of cleaning objectives. Unlike saponifiers that require heat to induce a chemical reaction, detergents can clean in cold water. Detergents are surfactants (wetting agents) designed to 'cut through' a particular contaminant (in this case flux) and allow the mechanical action of the cleaning machine to release the soil. Detergents are alkaline by design. Alkalinity may range from 8 to near 14 pH. OSHA (Occupational Safety and Health Association) requires the pH of a detergent to be less than 12.5 in order to be considered non-hazardous. Detergents designed to remove solder paste are usually between 11 and 12.5 pH and non-ionic. They may emulsify the soil and become 'loaded', requiring filtration. Alternatively, detergents may not interact with the contaminant at all, in which case separation of the waste solder paste is very convenient and accomplished by gravity. The solder paste simply falls to the bottom of the wash tank, where it remains until removed by recycling.

Because there is no chemical reaction, the chemistry consumption will be much lower when detergents are used instead of saponifiers. The liquid hazardous waste stream created by non-hazardous detergents and hazardous lead/tin solder paste can be easily eliminated by routine evaporation equipment. The non-hazardous liquid is evaporated to atmosphere as distilled water, and the hazardous lead is left behind as a solid for recycling. The resulting dehydrated detergent has a high BTU content and can be easily incinerated as a solid waste. On the other hand, if the user has an in-house filtration system to handle lead-laden liquid waste generated from a batch or in-line PCB cleaner, the liquid waste from the detergent based stencil cleaner most likely can be handled within the same filtration equipment. In either case, the waste stream is virtually hassle-free!

Alcohol (IPA)

Pros	*Cons*
Readily available	VOC (volatile organic compound)
Cleans at room temperature	Flammable (can be explosive)
Non ozone depleting	Contributes to air pollution
Does not oxidise/corrode stencil	Need to haul hazardous waste
Minimal liquid waste disposal (due to evaporation)	Need to use full strength
Dries fast	Cleans limited types of solder paste
Can close-loop	Cannot be used with ultrasonics
	Cannot clean most SMD adhesives
	Cannot clean flux build-up on tooling
	Emits solvent vapours into work area
	Becoming highly regulated by AQMD (Air Quality Management District)
	Requires explosion-proof equipment
	Requires special storage

Terpenes

Pros	*Cons*
Readily available	VOC
Non ozone depleting	Flammable/Explosive
Does not oxidise stencil	Need to haul hazardous waste
Can close-loop	Need to use full strength
	Requires a water rinse
	Cleans limited types of solder paste
	Cannot be used with ultrasonics
	Cannot clean most adhesives
	Cannot clean flux build-up on tooling
	Emits solvent vapours into work space
	Becoming highly regulated by AQMD (Air Quality Management District)
	Requires explosion-proof equipment
	Requires special storage
	Strong odour

Saponifiers

Pros	*Cons*
Readily available	Requires elevated temperatures
Non-flammable	Cleans limited types of solder pastes
Non ozone depleting	Contains hazardous ingredients
Low VOC	Caustic pH levels
Dilute with water	Some contain VOCs
Can use with ultrasonics	Complicated & expensive waste treatment
Can clean flux from tooling	Consumed during cleaning process
	Does not clean most adhesives
	Strong odour
	Concentrate requires special storage
	Requires large quantities or rinse water
	Steam can contaminate SMT assembly area
	Dries more slowly than VOC solvents
	High chemical consumption

Pros	*Cons*
Detergents	
Readily available	Dries more slowly than VOC solvents
Non ozone depleting	
No VOCs	
Can clean at low temperatures	
Cleans broad spectrum of solder pastes	
Can clean SMD adhesives	
Can clean flux from tooling	
Dilute with water	
Rinses with small amounts of water	
Contains no hazardous ingredients	
Can use with ultrasonics	
No steam or water vapour contamination	
Liquid waste can be evaporated or filtered	
Will not oxidise/corrode stencil	
Normal storage	
Low chemical consumption	
Mild to pleasant odour	

SELECTING THE MACHINE

Once the appropriate chemistry has been identified, the method of applying or delivering that chemistry to the contaminated stencil can be selected. There are basically three different types of machines from which to choose: (1) spray in atmosphere, (2) spray under immersion and (3) ultrasonic. The selection process should answer the following questions: Can the agitation effectively deliver the chemistry to all of the surfaces to be cleaned — inside the apertures and etched-back areas of a fine-pitch stencil? Will the agitation adversely affect the integrity of the stencil?

When stencil apertures were 50 mil pitch and larger, the traditional solvent vapour degreaser was effective. The solvent vapours dissolved the RMA flux, and the hand-held solvent spray wand could effectively spray through the relatively large aperture openings to remove the solder balls. However, now that stencil apertures are 20 mil pitch and smaller, it is extremely difficult to 'spray' through tiny holes (see Figure 1). If the machine cannot deliver the chemistry to the surface to be cleaned, the chemistry will not be able to contribute to the cleaning process, and the impingement action required to remove the solder balls will be absent. The results will be a fine-pitch stencil with fugitive solder balls contaminating a large percentage of the apertures, adversely affecting the print quality of the next stencil print. Attempting to clean a fine-pitch SMT stencil with spray technology is like trying to clean a keyhole with a fire hose. You cannot effectively deliver the cleaning solution through the contaminated apertures.

SPRAYS CAN DAMAGE A STENCIL

If a spray system is used to clean fine and ultra fine-pitch apertures and there is limited success, supplementary measures are usually incorporated. The pressure of the wash solution can be increased and/or a small bristle brush could be used to abrade the residual material left in the apertures. However, in either case the opportunity for damaging the stencil increases significantly. The land mass between the aperture openings in a stencil can be from 0.001 in.–0.006 in. in width and from 0.040 in.– 0.70 in. in length for ultra fine-pitch, or 0.007 in.–0.010 in. in width and from 0.040 in.– 0.090 in. in length for fine-pitch printing. When these dimensions are coupled with a stencil thickness of 0.001 in.– 0.003 in. for ultra fine-pitch applications and 0.004 in.–0.006 in. for fine pitch applications, the care, storage and damage factor to the stencil becomes a critical part of the manufacturing process.

The fine-pitch (0.016 in.–0.020 in.) stencils can withstand the light pressures of current stencil cleaners. However, any type of wash/rinse pressure increase will bend the land mass between the apertures, which will render the stencil useless because of the lack of coplanarity and the gasketing feature required during the printing process. The use of stencil cleaners in the printing environments mentioned above using high pressure sprays could introduce process downtime for any or all of the following reasons:

- Underside stencil cleaning due to stencil 'bleeding' caused by bent or damaged land bridges;
- Possible premature stencil wear caused by printer blade abrading damaged land bridges protruding above stencil surface;
- Actual aperture land bridge breakage ruining the utility of the stencil;
- Increased solder paste bridging due to lack of intimate board contact during the printing process;
- Possible increase of insufficients caused by hardened solder paste in the apertures which was not removed from the previous wash, which then causes a change in the printing aspect ratio, yielding bad paste release generating the insufficients.

As the industry migrates toward microminiaturisation, especially for device manufacturing (i.e. flip chip, micro BGAs and other direct chip attach components), the usage of thinner (0.001 in.– 0.003 in.) stencils will increase. The care, cleaning and handling of these stencils become even more critical as part of the printing process one defines on the manufacturing floor. Picture land bridges between apertures which will be 0.001 in.–0.003 in. width, 0.040 in.– 0.070 in. length and only 0.001 in.– 0.003 in. thick. This is not science fiction. Stencils with these dimensions have been supplied for the past two years. It will not take much wash/rinse pressure to damage these bridges, causing the types of manufacturing process problems previously mentioned. The only way to avoid these problems is to use an ultrasonic based stencil-cleaning system. The ultrasonics clean uniformly and without exerting the trauma that high pressure sprays can cause. The microscopic cleaning action of ultrasonics is also more effective in cleaning the tight tolerance areas of fine and ultra fine-pitch apertures.

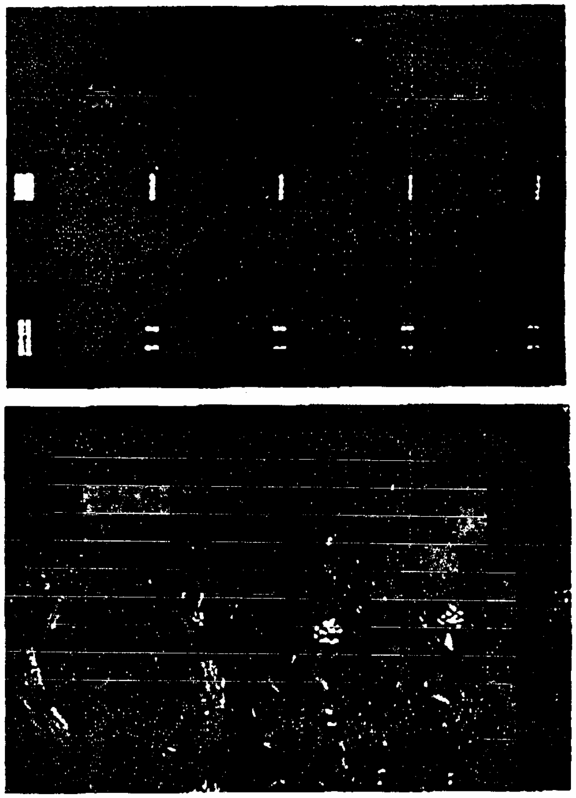

Fig. 1 *(a) A matrix of stencil apertures ranging from 50 mil pitch down to 15 mil pitch. Fine-pitch apertures of less than 25 mil pitch are difficult to clean with sprays. Improper cleaning can result in insufficient solder paste transfer and poor paste release. (b) Illustration that high pressure sprays from behind the stencil cannot effectively penetrate the fine-pitch apertures, resulting in a potential for residual solder ball contamination and misprints*

ULTRASONICS CLEAN BETTER THAN SPRAYS

Ultrasonics clean so well that the coloured emulsion used to coat the screen portion of the stencil can be eliminated. The primary purpose of the emulsion is to fill in the tiny holes of the screen's mesh because, if solder paste were to contaminate the screen, it would be very difficult to clean it out if using a spray type stencil cleaner. An ultrasonic stencil cleaner can clean the screen mesh just as well as the fine-pitch apertures. Many stencil manufacturers no longer apply the emulsion coating if it is known that the customer will be using a good ultrasonic stencil cleaner. By eliminating the necessity for screen emulsion coatings, the cost of providing an SMT stencil may be reduced.

OTHER USES OF AN SMT STENCIL CLEANER

Obvious applications include cleaning misprinted substrates, squeegee blades and other tooling of virgin solder paste. If a company has decided to utilise a 'no-clean' solder paste flux, all other cleaning equipment from the factory floor has probably already been eliminated. In-line or batch PCB cleaners are no longer required because the low residue left behind on the board does not require cleaning. However, tooling that repeatedly travels through the reflow oven accumulates flux residue that should be cleaned periodically. A good aqueous detergent, designed to clean fresh and even dried solder paste, should also be able to remove polymerised flux residue from pallets and other tooling. Alcohol and terpenes do not perform well at cleaning flux build-up from wave solder pallets and other tooling.

A SOLDER BALL NIGHTMARE

Attempting to use a stencil cleaner as a 'final clean' for assembled PCBs should be discouraged. When using a stencil cleaner that relies on high pressure sprays to do the cleaning, one can experience what could amount to a 'solder ball nightmare'!

When cleaning SMT screens and stencils, the contaminant is millions of solder balls within the paste flux. When final cleaning post soldered PCBs, the contaminant is primarily flux residue with just a few fugitive solder balls. A traditional spray style stencil cleaner relies on a series of filters to strain out the contaminants as the cleaning solution is recirculated for reuse. Even if the filtration system is 99.9% efficient, assembled boards could potentially be bombarded with hundreds or thousands of solder balls left in the system after cleaning virgin solder paste from a screen or stencil. For similar reasons, a stencil cleaner using sprays should not be used for cleaning misprinted solder paste from double-sided boards. The sprays will broadcast the solder balls throughout the wash chamber, allowing them to become lodged under and around the components located on the reflowed side — another solder ball nightmare!

Cleaning populated boards in an ultrasonic stencil cleaner poses a completely different concern. While there has been some concern over the years about cleaning populated boards with ultrasonics, this is not the case with today's ultrasonic systems.[2,3] Even the United States military has acknowledged the benefits of cleaning high density SMT assemblies with ultrasonics over spray technology.[4-6] The concern over cleaning populated assemblies in an ultrasonic stencil cleaner stems from the fact that ultrasonics are so efficient in driving the cleaning solution under and around components; it now requires an ultrasonic rinse in order to remove the wash solution. Ultrasonic stencil cleaners are designed to rinse the smooth geometry of a stencil and therefore only incorporate spray rinses.

Ultrasonic rinses would add too much cost to the manufacture of the machine and render it non-competitive in the marketplace. Some users of ultrasonic stencil cleaners do occasionally clean assembled boards in their stencil cleaner and use a separate ultrasonic tank filled with DI water as a final ultrasonic rinse. If the detergent is a non-ionic surfactant, rinsing becomes less of an issue and standard spray rinsing may be adequate. The concern about solder ball contamination with an ultrasonic stencil cleaner does not arise as the solder balls fall safely away from the board to the bottom of the tank by gravity where they remain because the wash solution of an ultrasonic system does not normally require recirculation.

SUMMARY

It has been estimated that 51-72% of all solder defects are a results of the screen-printing operation.[7] Thus, having a clean and accurate stencil is a major concern. An SMT stencil that has maintained good structural integrity and has zero contamination within the apertures will produce a better and more consistent print, resulting in a reduced incidence of misprints and downtime.

Alcohol and terpene solutions are not recommended for cleaning SMT screens and stencils because of the high risk of fire and/or explosion, their selective cleaning characteristics and VOC concerns.

Saponifiers are not recommended as they require elevated temperatures to activate and will damage the heat-sensitive stencil, and the resulting waste stream is particularly cumbersome.

Ultrasonics, coupled with an aqueous detergent solution that cleans at low temperatures (below 43°C), would be considered as the ideal process combination for cleaning fine-pitch SMT screens and stencils. Detergents are wetting agents that can be formulated to attack specific contaminants, given specific cleaning parameters such as low temperature and type of cleaning agitation.

Ultrasonics provide the best possible cleaning agitation to deliver the cleaning solution into and 'scrub' the fine and ultra-fine apertures and cause the least possible trauma to the etched image.

The resulting liquid waste can be easily filtered in an existing filtration system designed to handle lead contaminated water, or safely eliminated by standard evaporation equipment. The non-hazardous liquid component safely goes to atmosphere as distilled water vapour, and the hazardous lead solid is left behind to be recycled as a dross, or melted down in a wave solder pot. The dehydrated detergent has a high BTU value and can be conveniently incinerated as a solid waste. An aqueous detergent process, when coupled with the cleaning action of ultrasonics, can clean faster and more effectively than solvents, with little or no environmental impact!

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