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## Guidelines for Cleaning of Printed Boards and Assemblies

Supersedes IPC-CH-65A

September 1999

*A standard developed by IPC*

*Association Connecting Electronics Industries*



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IPC-CH-65B

# Guidelines for Cleaning of Printed Boards and Assemblies

Developed by the Cleaning and Alternatives Subcommittee (5-31) of the  
Cleaning and Coating Committee (5-30) of IPC

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Users of this publication are encouraged to participate in the  
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Any standard involving a complex technology draws material from a vast number of sources. While the principal members of the Cleaning and Alternatives Subcommittee (5-31) of the Cleaning and Coating Committee (5-30) are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

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# Guidelines for Cleaning of Printed Boards and Assemblies

## 1 OVERVIEW

**1.1 Scope** This manual will only include assembly process printed wiring assembly cleaning. The corresponding information on printed wiring board cleaning will be contained in a separate companion document.

**1.2 Purpose** The purpose of this document is to collect and update all the pertinent information on printed wiring assembly (PWA) cleaning in a single, easy to revise/updated document.

**1.3 Background** Information on cleaning printed circuit boards (PCBs), printed wiring boards (PWBs), and printed wiring assemblies (PWAs) during manufacture could be found within a number of IPC documents and handbooks, specifically:

- CH-65 Guidelines for Cleaning of Printed Boards and Assemblies
- SM-839 Pre and Post Solder Mask Application Cleaning Guidelines
- SC-60 Post Solder Solvent Cleaning Handbook
- SA-61 Post Solder Semi-Aqueous Cleaning Handbook
- AC-62 Aqueous Post Solder Cleaning Handbook

While collecting relevant information in various places was recorded for its members to use, one was never sure that one had all the needed information at hand.

**1.4 Current and Emerging Cleaning-Related Challenges** With the advent of low residue (i.e., no-clean) flux/paste in the early 1990s, many concluded that cleaning was no longer needed. This conclusion neglected the continued drives toward tighter spacing, higher reliability requirements, higher density packaging, underfill adhesion and reduced costs. Since post assembly cleaning normally removed all upstream soils as well, the industry had to convert to clean printed wiring board and clean component manufacturing processes, clean packaging and ultraclean workplaces. Often this became more cumbersome and complicated than post assembly cleaning had been.

Recently, the conversion of soldering processes to lead-free platings/finishes and soldering alloys, often with much higher soldering process temperatures, have further complicated the demands made on solder flux/paste compositions, to accomplish a no clean joining operation, while burning away completely without voids, solder balls or other reliability issues.

The advent of halogen-free laminates, as well as other possible restrictions on the industry's processing chemicals, will generate new processing challenges to be met.

The ability to effectively clean stencils has become significantly more important. Greater demands on stencil printing have emerged with the advent of fine and ultrafine parts, as well as ball grid arrays. Clean stencils are a must in delivering the proper amount of paste. A partially or fully obstructed aperture on a stencil is more likely to occur with today's finer pitch devices. It has been estimated that approximately 70% of SMT solder defects are due to solder paste printing problems. Stencil cleaning processes are covered in a separate document.

Environmental and worker safety issues are very much a part of today's cleaning picture. Assemblers must consider factors such as VOCs, BODs, CODs (Volatile Organic Compounds, Biological Oxygen Demand and Chemical Oxygen Demand, respectively), waste water treatment, heavy metals, close-looping and pH. Because of demanding official regulations (federal and/or local), it can be one or more of these factors that determine the choice of a cleaning process and associated equipment.

## 1.5 Document Chapters

**1.5.1 Section 2: Applicable Documents** This section contains references to industry standards, federal regulations, test methods and vehicles that are applicable to post solder cleaning of electronic assemblies. Not all of these are cross-referenced in the text. They are listed below for the convenience of the readers.

**1.5.2 Section 3: Assembly Cleaning Value and Applicability** This section discusses the pace of surface mount technology development and innovation in response to market pressures for higher functionality, cost reduction, cycle time reduction, and improved quality. To achieve increased functionality, today's circuit assemblies pack more performance into smaller board designs. Advanced package designs require an increasing number of interconnects to support power requirements and bandwidth. With active and passive component size reduction as well as many area array pitches and standoff heights also reducing, this increases the risk of dendrite formation and electrochemical migration. At the same time, there is also expanded functionality driving package sizes and I/O counts higher on the boards. The critical metric for consideration is the surface area to z-height ratio which as this ratio increases, makes getting into and removing residue from large area/tight z-height spaces more difficult.

Technology-based market pressures increase reliability demands as electronic assemblers move upstream from conventional designs and toward threshold and leading edge technologies. Over the past two decades, conventional surface mount technologies successfully adopted low residue no-clean soldering practices. Today's challenge for printed circuit board manufacturers hinges on density, lead-free, and miniaturization. High performance electronic assembly designs will be driven by multilayer and stacked package density, increasing number of I/Os, decreased area array pitches, and tighter component standoff heights. Additional demands include control of costs, process restrictions and changes impelled by safety and environmental regulatory constraints (including national and international constraints as well as the local regulatory microclimate), and the need to control the processes performed by an ever-increasing supply chain.

**1.5.3 Section 4: Designing Assemblies for Cleaning** Designing printed circuit assemblies for cleanability has become an extremely challenging task due to the miniaturization as well as the complexity of leading-edge products. Design for manufacturability (DFM) includes a set of techniques to modify and improve printed circuit and cleaning process designs in order to match the cleaning process to the substrate, contaminant, and available cleaning methods. The desire to make electronic products smaller and lighter drives designers toward highly dense assemblies with reduced spacing between components. The objective of this section is to provide design rule methodologies for cleaning leading edge printed circuit designs.

**1.5.4 Section 5: Materials Compatibility** Engineers responsible for the cleaning process must be aware of possible material compatibility problems. The information contained in this section seeks to provide the process engineer with awareness of the material compatibility risks when cleaning electronic hardware. Factors of concern are circuit board laminates, surface finishes, components, metal alloys, adhesive bond strength, part markings, plastics, the mix and configuration of materials in the assembly and the impact of entrapped contaminants. Other factors must also be considered, such as the chemical characteristics of the cleaning material, cleaning temperature, impingement energy, and exposure time to the cleaning process, including rework cycles. The possible interactions of all these factors are especially challenging today with the much wider availability of board and component lead finishes, as well as joining metals. The difficulty of locating data on each and every possible combination of factors associated with this issue creates a high level of complexity.

**1.5.5 Section 6: Process Development and Verification** In any manufacturing process, it becomes necessary, from time to time, to change the materials of construction or the manufacturing processes/parameters used to make printed assemblies. This may be due to many possible factors:

- A material becomes unavailable, either through environmental regulation, through market factors or the material formulation changes.
- New materials, representing improved performance or price, become available.
- Manufacturing equipment wears out, requiring replacement.
- Buying less expensive materials in an attempt to save money could result in an inferior product.
- All materials must be qualified prior to entry into the manufacturing process.

Consequently, a manufacturer is faced with the task of determining whether the "new" assembly material/process produces products that are as good as or better than the "old" or "qualified" assembly materials/processes, and generating data to support such an evaluation. There are many elements which should go into this decision. The approach outlined in this chapter works best in a Process A vs. Process B comparison evaluation, rather than development of a completely new process, though it can be used as such.

**1.5.6 Section 7: Contamination and Its Effects on PWBs** Increased electronic device functionality results from smaller spacing between conductors and requires more active circuitry within small, high-functionality devices. Contamination and its effects become more problematic as the spacing between adjacent conductors decreases. The purpose of this section is to discuss the risks of contamination and its effects on printed wiring assemblies.

**1.5.7 Section 8: Assembly Residues/Cleaning Considerations** Assembly materials consisting of adhesive, fluxes, and solder alloys may vary depending on the mounting, attachment of components, assembly type and component grouping. When considering soldering and cleaning, assembly residues result from the choice of soldering method and the use of lead or lead-free solder. The choice of flux that is compatible with the solder method and solder will itself determine the cleaning methods used. Final cleanliness will be determined by the end-use environment, and in some cases, the contract quality requirements.

The electronic assembly process ranges from the very simple to the very complex, and involved a wide range of materials. Each step in the process, and each material used will have some impact on the assembly, most affecting the chemical residues remaining on the assembly surface. Materials to be considered include fluxes, cleaning solutions, labels, adhesives, masking materials, component residues, out-gassing residues, etc. This chapter covers many of the common materials used in most manufacturing processes.

The purpose of this section is concerned with the types of residues which accumulate during the printed circuit board fabrication and during the assembly processes; especially as they apply to post solder cleaning. Additionally, issues pertaining to inspection of remaining residues, root cause of those residues, and preventative actions are discussed.

**1.5.8 Section 9: Environmental Considerations** Although this section focuses primarily on US legislation and codes of practice, most other nations have similar regulations. These may be considerably more or less severe and may be applied differently. The general theme of this section is universally applicable, but it should be read with an understanding that local regulations require primary compliance, and that state and federal compliance is a parallel requirement to any regulated operation. The selection of the cleaning agent must incorporate the inherent impact on air emissions, water discharges and waste generation from the facility. Each of these three environmental mediums may require a permit depending on the usage rate and existence of other air emissions, water discharges and waste generation at the facility.

**1.5.9 Section 10: Solvent Cleaning Agents** This section addresses solvent cleaning of electrical/electronic assemblies, parts and application tools after soldering. The content of this text is intended to provide a basic understanding of the subject and to serve as a guide to users or prospective users of solvent cleaning technology, allowing selection or improvement of solvent cleaning processes.

**1.5.10 Section 11: Semi-Aqueous Cleaning Agents, Equipment, and Process Optimization** This section addresses semi-aqueous cleaning of electrical/electronic assemblies, parts and application tools after soldering. Semi-aqueous cleaning is a process in which flux residues and other contaminants are removed from printed wiring assemblies by first washing the assemblies in an organic solvent and then rinsing the organic solvent from the assemblies with water. Type I uses a water-insoluble organic solvent, while Type II uses a water-soluble organic solvent. Type I features an emulsion phase formation step following the wash and first rinse, while Type II systems do not. (The semi-aqueous process specifically does not include cleaning with aqueous solutions of organic or inorganic saponifiers or detergents; these are included in the section on aqueous cleaning processes.) Other objectives are removal of process residues and materials used as production aids, such as water soluble maskants.

**1.5.11 Section 12: Aqueous Cleaning Agents, Equipment, and Process Integration** This scope of the aqueous section addresses aqueous cleaning agents, aqueous cleaning machines, and process integration when cleaning electrical/electronic assemblies, packages, components and application tools after soldering. The content of this text is intended to provide a basic understanding of aqueous cleaning agents, cleaning equipment, and process integration and to serve as a guide to users or prospective users of aqueous cleaning technology, allowing selection or improvement of aqueous cleaning processes.

**1.5.12 Section 13: Cleaning for Rework, Repair, and Restoration Operations** Normal cleaning operations that circuit card assemblies go through during production operations have been outlined in proceeding sections of this guideline. The cleaning operations that occur as part of rework, repair and restoration operations can be much different than those found in production. Assemblies are often built up to include components that are sensitive to heat, chemicals and water. In addition, assemblies can be conformally coated, components can be staked down with adhesives, marking and labels can be applied to assemblies that were not intended to be subjected to production cleaning operations. Attention to details become increasingly more important during the cleaning operations associated with rework, repair, and reconditioning of circuit card assemblies. Most electronic assemblies at this point in the process have achieved their highest level of functionality as well as maximum value. Cleaning with poor methods and improper process and materials can result in scrapping high value assemblies.

## 2 APPLICABLE DOCUMENTS

This section contains references to industry standards, federal regulations, test methods and vehicles that are applicable to post solder cleaning of electronic assemblies. Not all of these are cross-referenced in the text. They are listed below for the convenience of the readers.

The following documents, of the issue in effect on the date of contract agreement, form a part of this handbook to the extent provided herein:

### 2.1 Industry Standards

#### 2.1.1 IPC Standards<sup>1</sup>

**IPC-B-24** Surface Insulation Resistance Test Board

**IPC-B-25** Multipurpose 1 & 2 Sided Test Board

**IPC-B-36** Cleaning Alternatives Test Board

**IPC-T-50** Terms and Definitions for Interconnecting and Packaging Electronic Circuits

**IPC-B-52** Standard Test Board

**IPC-TP-383** Organic Surface Contamination Its' Identification, Characterization, Removal, Effects on Insulation Resistance and Conformal Coating Adhesion

**IPC-TR-580** Cleaning and Cleanliness Test Program Phase 1 Test Results

**IPC-A-600** Acceptability of Printed Boards

**IPC-A-610** Acceptability of Electronic Assemblies

**IPC-TM-650** Test Methods Manual<sup>2</sup>

2.3.1.1 Chemical Cleaning of Metal Clad Laminates

2.3.25 Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract

2.3.27 Cleanliness Test - Residual Rosin

2.3.27.1 Rosin Flux Residue Analysis-HPLC Method

2.3.28 Ionic Analysis of Circuit Boards, Ion Chromatography Method

2.3.30 Solvent pH Determination in Anhydrous Fluorocarbon Solvents

2.3.38 Surface Organic Contaminant Detection Test

2.3.39 Surface Organic Contaminant Identification Test (Infrared Analytical Method)

2.5.27 Surface Insulation Resistance of Raw Printed Wiring Board Material

2.6.3 Solder Masks - Moisture and Insulation Resistance

2.6.3.3 Surface Insulation Resistance, Fluxes

2.6.9.1 Test to Determine Sensitivity of Electronic Assemblies to Ultrasonic Energy

2.6.9.2 Test to Determine Sensitivity of Electronic Components to Ultrasonic Energy

2.6.13 Assessment of Susceptibility to Metallic Dendritic Growth: Uncoated Printed Wiring

2.6.14 Resistance to Electrochemical Migration, Solder Mask

**IPC-PE-740** Troubleshooting for Printed Board Manufacture and Assembly

**IPC-2223** Sectional Design Standard for Flexible Printed Boards

**IPC-4202** Flexible Base Dielectrics for Use in Flexible Printed Circuitry

**IPC-4203** Adhesive Coated Dielectric Films for Use as Cover Sheets for Flexible Printed Circuitry and Flexible Adhesive Bonding Films

**IPC-4204** Flexible Metal-Clad Dielectrics for Use in Fabrication of Flexible Printed Circuitry

**IPC-6012** Qualification and Performance Specification for Rigid Printed Boards

**IPC-9191** General Guideline for Implementation of Statistical Process Control (SPC)

1. [www.ipc.org](http://www.ipc.org)

2. Current and revised IPC Test Methods are available on the IPC Web site ([www.ipc.org/html/testmethods.htm](http://www.ipc.org/html/testmethods.htm))

### 2.1.2 Joint Industry Standards<sup>3</sup>

- J-STD-001** Requirements for Soldered Electrical and Electronic Assemblies
- J-STD-002** Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires
- J-STD-003** Solderability Tests for Printed Boards
- J-STD-004** Requirements for Soldering Fluxes
- J-STD-005** Requirements for Soldering Pastes
- J-STD-006** Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications

### 2.1.3 Telcordia Technologies<sup>4</sup>

- GR-78-CORE** Physical Design and Manufacture of Telecommunications Products

## 2.2 U.S. Federal Regulations<sup>5</sup>

### 2.2.1 Federal Laws

- CAA** Clean Air Act
- CWA** Clean Water Act
- RCRA** Resource Conservation and Recovery Act
- CERCLA** Comprehensive Environmental Response, Compensation and Liability Act
- SARA** Superfund Amendment and Reauthorization Act
- SNAP** Significant New Alternatives Program

### 2.2.2 Federal Standards

- O-A-51** Acetone, Technical
- O-E-760** Ethyl Alcohol (Ethanol) Denatured Alcohol; Proprietary Solvents and Special Industrial Solvents
- O-M-232** Methanol (Methyl Alcohol)
- O-T-236** Tetrachloroethylene (Perchloroethylene); Technical
- O-T-620** 1,1,1 - Trichloroethane, Technical, Inhibited (Methyl Chloroform)
- O-T-634** Trichloroethylene, Technical, Inhibited
- TT-B-848** Butyl Alcohol, Secondary, (For Use in Organic Coatings)
- TT-I-735** Isopropyl Alcohol Grades A & B
- TT-M-261** Methyl Ethyl Ketone
- TT-N-95** Naphtha, Aliphatic
- TT-N-97** Naphtha, Aromatic Types 1, 2, and 3 (Grade A)
- TT-T-548** Toluene Technical

### 2.2.3 Department of Defense<sup>6</sup>

- MIL-C-81302** Cleaning Compound, Solvent, Trichlorotrifluoroethane
- MIL-C-85447** Cleaning Compounds, Electrical & Electronic Components
- MIL-N-15178** Naphtha, Solvent
- MIL-T-81533** Trichloroethane 1,1,1 (Methyl Chloroform) Inhibited, Vapor Degreasing

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3. [www.ipc.org](http://www.ipc.org)

4. [www.telcordia.com](http://www.telcordia.com)

5. [www.sae.org](http://www.sae.org)

6. [www.mil-standards.com](http://www.mil-standards.com)

#### 2.2.4 Occupational Safety and Health Administration (OSHA)<sup>7</sup>

OSHA 29 CFR 1910.1000 Air Contaminants

OSHA 29 CFR 1910.134 Respiratory Protection

OSHA 29 CFR 1910.106 Flammable and Combustible Liquids

#### 2.2.5 Environmental Protection Agency (EPA)<sup>8</sup>

EPA 40 CFR 63 National Emission Standards for Hazardous Air Pollutants for Source Categories

EPA 40 CFR 82 Protection of Stratospheric Ozone

EPA 40 CFR 117.3 Determination of Reportable Quantities for Hazardous Substances

EPA 40 CFR 131.36 Toxic Criteria for those States not Complying with Clean Water Act Section 303(c) (2) (B)

EPA 40 CFR 261 Identification and Listing of Hazardous Waste

EPA 40 CFR 302.4 Designation of Hazardous Substances

EPA 40 CFR 355.30 (b) Emergency Release Notification

EPA 40 CFR 370.20 Hazardous Chemical Reporting: Community Right-to-Know - Applicability

EPA 40 CFR 370.21 Hazardous Chemical Reporting: Community Right to Know - MSDS Reporting

EPA 40 CFR 370.25 Hazardous Chemical Reporting: Community Right to Know - Inventory Reporting

EPA 40 CFR 372 Toxic Chemical Release Reporting: Community Right-to-Know

EPA 40 CFR 423 Steam Electric Power Generating Point Source Category

EPA 40 CFR 433 Metal Finishing Point Source Category

EPA-453/R-94-081 Guidance Document for the Halogenated Solvent Cleaner NESHAP (updated 2007)

#### 2.2.6 Department of Transportation<sup>9</sup>

DOT 33 CFR 153.203 Procedure for the Notice of Discharge

#### 2.2.7 American Conference of Governmental Industrial Hygienists (ACGIH)<sup>10</sup>

Documentation of the Threshold Limit Values and Biological Exposure Indices

#### 2.2.8 National Institute of Occupational Safety and Health (NIOSH)<sup>11</sup>

Permissible Exposure Limit (PEL) (eight-hour exposures) Short Term Exposure Limit (STEL)

### 2.3 Other

#### 2.3.1 American Standards for Testing Materials<sup>12</sup>

ASTM Method D-56 Standard Test Method for Flash Point by tag Closed Cup Tester

ASTM Method D-92 Standard Test Method for Flash and Fire Points by Cleveland Open Cup tester

ASTM Method D-93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

ASTM Method D-1078 Standard Test Method for Distillation Range of Volatile Organic Liquids

ASTM Method D-1133 Standard Test Method for Kauri-Butanol Value of Hydrocarbon Solvents

ASTM Method D-1320 Method of Tensile Strength of Paraffin Wax (withdrawn without replacement)

ASTM Method D-2106 Standard Test Methods for Determination of Amine Acid Acceptance (Alkalinity) of Halogenated Organic solvents

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7. [www.osha.gov](http://www.osha.gov)

8. [www.epa.gov](http://www.epa.gov)

9. [www.dot.gov](http://www.dot.gov)

10. [www.acgih.org](http://www.acgih.org)

11. [www.cdc.gov/niosh](http://www.cdc.gov/niosh)

12. [www.astm.org](http://www.astm.org)

- ASTM Method D-2109** Standard Test Methods for Nonvolatile Matter in Halogenated Organic Solvents and their Admixtures
- ASTM Method D-2111** Standard Test Methods for Specific Gravity and Density of Halogenated Organic Solvents and their Admixtures
- ASTM Method D-2942** Standard Test Method for Total Acid Acceptance of Halogenated Organic Solvents (Non-reflux Methods)
- ASTM Method D-2989** Standard Test Method for Acidity-Alkalinity of Halogenated Organic Solvents and their Admixtures
- ASTM Method D-3401** Standard Test Methods for Water in Halogenated Organic Solvents and their Admixtures
- ASTM Method D-3443** Standard Test method for Chloride in Trichlorotrifluoroethane

### 2.3.2 Standard Specification of Materials

- ASTM D 329** Acetone
- ASTM D 362** Toluene (withdrawn without replacement)
- ASTM D 740** Methyl Ethyl Ketone
- ASTM D 1153** Methyl Isobutyl Ketone
- ASTM D 1836** Commercial Hexanes
- ASTM D 3622** n-Propyl Alcohol
- ASTM D 4079** Vapor-Degreasing Grade Methylene Chloride
- ASTM D 4080** Trichloroethylene, Vapor-Degreasing Grade
- ASTM D 4081** Dry-cleaning Grade Perchloroethylene
- ASTM D 4126** Vapor-Degreasing and general Solvent Grade 1,1,1-Trichloroethane
- ASTM D 4376** Vapor-Degreasing Grade Perchloroethylene
- ASTM D 4701** Technical Grade Methylene Chloride
- ASTM D 5309** Cyclohexane 999
- ASTM D 6368** Vapor-Degreasing Solvents Based on normal-Propyl Bromide and Technical Grade normal-Propyl Bromide

### 2.3.3 National Fire Protection Association (NFPA)<sup>13</sup>

- NFPA 30** Flammable and Combustible Liquids Code
- NFPA 35** Standard for the Manufacture of Organic Coatings

### 2.3.4 American National Standards Institute (ANSI), American Society for Quality Control (ASQC)<sup>14</sup>

- ANSI/ASQC Z-1.15** Generic Guidelines for Quality Systems

## 2.4 Other Considerations

- 2.4.1 ISO Standards** especially for medical devices

- 2.4.2 REACH** Registration, Evaluation and Authorization of Chemicals (<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32006R1907:EN:NOT>)

- 2.4.3 Cal/OSHA** (and other local restrictions)

- 2.4.4 FDA/EU cGMP** for medical devices

**2.5 Terms and Definitions** All terms and definitions used throughout this handbook are in compliance with IPC-T-50. Other basic terms and definitions, essential for the discussion of the subject, are provided below or are defined in appropriate sections of this handbook.

13. [www.nfpa.org](http://www.nfpa.org)

14. [www.ansi.org](http://www.ansi.org)

**Note:** Any definition denoted with an asterisk (\*) is a reprint of the definition defined in IPC-T-50

**2.5.1 Solvent Cleaning** The removal of organic, inorganic and particulate soils from printed wiring assemblies using a blend of polar and non-polar organic solvents. In solvent cleaning, drying is application and equipment dependent. In vapor defluxing (solvent cleaning in the electronics industry), spot-free drying is accomplished by evaporating residual liquid solvent on the part being cleaned into the vapor zone generated by the boiling solvent, taking care to keep the vapor in air levels within recommended limits. Correct matching of the equipment design and work throughput is required to maintain solvent levels in the workplace within desired limits.

**2.5.2 Defluxing** The cleaning process designed to remove solder flux and by-products. Other objectives are removal of process residues and materials used as production aids, such as solvent soluble maskants. Impurities left by board or component fabrication processes or other operations may be removed during the process, thus the defluxing process widens the process window for printed wiring assemblers.

## **2.6 Solvent Cleaning Steps**

**2.6.1 Wash or Washing** The primary cleaning operation that removes undesirable impurities (contaminants) from surfaces by chemical and physical effects, mainly dissolution of the contaminants. In the case of stubborn residues or very mild solvents, a pre-wash or soak step may precede the wash step. Various methods of qualified ultrasonic agitation can be employed in the wash step to enhance contaminant removal.

**2.6.2 Rinse or Rinsing** A cleaning operation (usually following the wash step), where fresh solvent replaces—via a dilution mode—any residual contamination, leaving surfaces wet with pure solvent.

**2.6.3 Drying** The process of removing and recovering any residual liquid solvent on the surface of the washed and rinsed parts. In a vapor defluxing process, drying is accomplished in the vapor zone created by the boiling solvent in the wash zone of the cleaning machine. Drying can be augmented by passing superheated solvent vapor across the surface of the parts, to ensure complete removal of residual liquid solvent. This technique is especially effective with complex geometries that can entrap liquid solvent.

**2.6.4 Solvent Cleaning Agent Recovery and Recycle** Dirty solvents can often be sent to a recovery still for distillation and reuse, while concentrating the contaminants for disposal. If several pieces of cleaning equipment are used on a site for removal of the same soil with the same solvent, all the solvent can be piped to a single still for recovery.

**2.6.5 Solvent Agitation Methods** Typical agitation methods can involve boiling solvent, high pressure or high volume sprays or both, single frequency ultrasonics, sweep frequency or several combined frequency ultrasonics. All these agitation methods are carried out below the vapor blanket to minimize solvent losses into the workplace.

## **2.6.6 Solvent Cleaning Agent Acronym Definitions**

**2.6.6.1 HCFC** Hydrochlorofluorocarbon

**2.6.6.2 HFC** Hydrofluorocarbon

**2.6.6.3 HFE** Hydrofluoroether

**2.6.6.4 nPB** Normal Propyl Bromide

**2.6.6.5 CFC** Chlorofluorocarbon

**2.6.6.6 TCA** Trichloroethane

**2.6.6.7 TCE** Trichloroethylene

**2.6.6.8 PCE** Perchloroethylene

**2.6.6.9 Trans -1,2-dichloroethylene**

**2.6.6.10 Alcohols** Any class of chemical compounds having the general formula ROH, where R represents an alkyl group and -OH a hydroxyl group, as in methyl alcohol, CH<sub>3</sub>OH or ethyl alcohol C<sub>2</sub>H<sub>5</sub>OH.

**2.6.6.11 Esters** A class of organic compounds formed by the reaction of alcohols with organic acids.

**2.8.6.12 Hydrocarbon** An organic compound containing only hydrogen and carbon.

**2.6.6.13 Ketones** A class of organic compounds in which the carbonyl group is attached to two alkyl groups. Ketones are used as solvents, and some common examples are acetone and methyl ethyl ketone.

**2.7 Solvent Cleaning Process Definitions**

**2.7.1 Carbon Adsorption** A technique to remove impurities from liquid or gas streams by absorbing the contaminants in the stream on activated carbon.

**2.7.2 Combustible** This term is applied to liquid materials that have flash points greater than 38°C [100°F] by the closed cup method.

**2.7.3 Co-solvent (Bi-solvent)** Using a second solvent as a rinse agent for the first solvent. Co-solvent can refer to two solvents in the same tank but sometimes is used to refer to sequential operations; bi-solvent is a trade term that refers specifically to sequential application in separate tanks.

**2.7.4 Dragout** A liquid cleaning agent which adheres to assemblies or transport devices and which is carried from one section of a cleaning machine into another section of the machine and ultimately out into the workplace atmosphere.

**2.7.5 Semi-Aqueous Cleaning** A process in which flux residues and other contaminants are removed from printed wiring assemblies by first washing the assemblies in an organic solvent and then rinsing the organic solvent from the assemblies with water. Type I uses a water-insoluble organic solvent, while Type II uses a water-soluble organic solvent. Type I features an emulsion phase formation step following the wash and first rinse, while Type II systems do not. (The semi-aqueous process specifically does not include cleaning with aqueous solutions of organic or inorganic saponifiers or detergents; these are included in the section on aqueous cleaning processes.) Other objectives are removal of process residues and materials used as production aids, such as water soluble maskants.

**2.8 Semi-Aqueous Cleaning Steps Definitions**

**2.8.1 Hydrocarbon-Surfactant (HCS, HC/S, HC-S) Cleaning** An alternative nomenclature, synonymous with semi-aqueous cleaning, preferred by some international authorities.

**2.8.2 Wash or Washing** The primary cleaning operation that removes undesirable impurities (contaminants) from surfaces by chemical and physical effect.

**2.8.3 Emulsion or Emulsification** This step is found following the first water rinse in a Type I process. The first rinse converts the organic solvent wet surface to a water wet surface by forming a water-in-oil type emulsion. Upon settling in the emulsion tank, the heated organic cleaning agent/water emulsion then separates and the two materials are returned to their respective reservoirs in the cleaning equipment for reuse. Emulsification/separation minimizes any organic material sent to the waste stream. Type II processes do not employ the emulsion step since all the chemicals are water soluble.

**2.8.4 Rinse or Rinsing** A cleaning operation (usually following the wash step) where fresh pure rinse water replaces any residual emulsion, leaving a water-wet surface. Several rinses are usually employed to minimize any residual contamination. Rinses are also employed with co-solvent or bi-solvent cleaning.

**2.8.5 Dry or Drying** The process of removing any residual water or solvent from the washed and rinsed surfaces. The surfaces should be spot-free after drying.

## 2.8.6 Semi-Aqueous Cleaning Agent Acronym Definitions

**2.8.6.1 Alcohol, Non-Linear** Non-Linear alcohols are derived naturally from spent rice hulls, sugar cane or corncobs. When referring to this alcohol as non-linear, the term denotes that this compound has a ring structure. Such organic compounds have low molecular weights and contain both an alcohol group and an ether linkage. The alcohol and ether groups enhance this compounds effectiveness in removing polar soils and provide hydrogen bonding sites which allows the compound to be completely soluble in water.

**2.8.6.2 Alcohol, Synthetic** The synthetic alcohol derived for semi-aqueous electronic cleaning processes has both the ether group and the alcoholic hydroxyl group in its molecular structure which forms intramolecular and intermolecular hydrogen bonds and exhibits hydrophobic (water-insoluble) and hydrophilic (water-loving) properties. This molecule has low toxicity, low odor and a flash point ranging from 66-77°C [150-170°F].

**2.8.6.3 Esters** A class of organic compounds formed by the reaction of alcohols with organic acids.

**2.8.6.4 Hydrocarbon** An organic compound containing only hydrogen and carbon.

**2.8.6.5 Hydrocarbon-Surfactant** A hydrocarbon which exhibits hydrophobic (water-insoluble) and hydrophilic (water-loving) properties. It alters the wettability of surfaces and hence, is useful as a cleaning agent.

**2.8.6.6 Ketones** A class of organic compounds in which the carbonyl group is attached to two alkyl groups. Ketones are used as solvents, and some common examples are acetone and methyl ethyl ketone.

**2.8.6.7 Propylene Glycol Ether** Propylene Glycol Ethers are oxygenated hydrocarbons that provide formulation flexibility due to the wide range of chemical structures available. Selection of the structures that fit the evaporation rate, solvency characteristic, flash point and water solubility desired is available. For semi-aqueous cleaning products two chemical structures have been selected which have low vapor pressures, flash points ranging from 74-110°C [165-230°F] and are completely water-soluble. Glycol ethers in general have good solvency for both polar and non-polar soils, which allow them to be good candidates for electronic cleaning processes. The propylene-series glycol ethers offer lower toxicity than the ethylene-series products.

**2.8.6.8 Terpene** An unsaturated hydrocarbon based on the isoprene unit with the general formula  $C_{10}H_{16}$ . Terpenes are commonly found in citrus fruits or pine trees.

## 2.9 Semi-Aqueous Cleaning Process Definitions

**2.9.1 Carbon Adsorption** A technique to remove impurities from liquid or gas streams by absorbing the contaminants in the stream on activated carbon.

**2.9.2 Combustible** This term is applied to liquid materials that have flash points greater than 38°C [100°F] by the closed cup method.

**2.9.3 Decanting** The process separating two immiscible liquids by drawing a top layer of liquid material off of another layer of liquid without disturbing the lower liquid layer.

**2.9.4 Dragout** Liquid cleaning agent or water which adheres to circuit assemblies or transport devices and which is carried from one section of a cleaning machine into another section of the machine.

**2.9.5 Emulsion** A mixture of two or more immiscible liquids, such as oil and water, which is stable and uniform under conditions of use in the cleaning process.

**2.9.6 Organic Solvent Emulsions in Aqueous Media** Uniform dispersions of small amounts of organic solvents in water.

**2.9.7 Water Softening** A water treatment process used to remove calcium and magnesium salts from water.

## 2.10 Environmental Definitions

**2.10.1 BOD Biological Oxygen Demand** The amount of oxygen required for the biochemical degradation of organic material under controlled test conditions.

**2.10.2 COD Chemical Oxygen Demand** The amount of oxygen required to oxidize organic materials to carbon dioxide and water, reported in mg of oxygen/liter of tested solution.

**2.10.3 Volatile Organic Compounds (VOC)** United States EPA defines VOCs as any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.(40CFR51.100(s)) Regulatory agencies may differ on what constitutes a VOC.

**2.10.4 HAPs Hazardous Air Pollutants** Air pollutants that can cause serious health and environmental hazards

**2.10.5 Global Warming** Common term for Climate Change. Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

**2.11 Aqueous Cleaning** A process in which flux residues and other contaminants are removed from printed wiring assemblies by first washing the assemblies in either pure water or a solution of organic or inorganic saponifier and then rinsing the contaminant bearing water from the assemblies with pure water. Other objectives are removal of process residues and materials used as production aids, such as water soluble maskants. Should specify (or not and make separate) water-soluble organics.

### 2.11.1 Aqueous Cleaning Steps Definitions

**2.11.1.1 Wash or Washing** The primary cleaning operation that removes undesirable impurities (contaminants) from surfaces by chemical and physical effect. The wash can consist of either pure water or water containing mildly alkaline chemicals.

**2.11.1.2 Rinse or Rinsing** A cleaning operation (usually following the wash step) where fresh pure rinse water replaces, typically by dilution, any residual contaminated wash solution. Several rinses are usually employed to minimize any residual contamination.

**2.11.1.3 Dry or Drying** The process of removing any residual water from the washed and rinsed surfaces. The surfaces should be spot-free after drying.

### 2.11.2 Aqueous Cleaning Agent Acronym Definitions

**2.11.2.1 Non-Reactive Additives** Compounds which do not react chemically with solder flux and other process residues. These additives may serve to lower surface tension, assist in the removal of water insoluble residues, exercise foam control, or inhibit wash medium attack on construction materials.

**2.11.2.2 Propylene Glycol Ether** Propylene Glycol Ethers are oxygenated hydrocarbons that provide formulation flexibility due to the wide range of chemical structures available. Selection of the structures that fit the evaporation rate, solvency characteristic, flash point and water solubility desired is available. For semi-aqueous cleaning products two chemical structures have been selected which have low vapor pressures, flash points ranging from 74-110°C [165-230°F] and are completely water-soluble. Glycol ethers in general have good solvency for both polar and non-polar soils, which allow them to be good candidates for electronic cleaning processes. The propylene-series glycol ethers offer lower toxicity than the ethylene-series products.

**2.11.2.3 Reactive Additives or Reactants** Water soluble chemical compounds which react chemically with the contaminants that are to be removed by the wash medium. Examples are chelating agents, saponifiers, or chemical etchants.

**2.11.2.4 Saponifier** Saponifiers were typically formulated using mono-ethanol amine (MEA), which reacted chemically with rosin to form a water-washable “soap” or with an inorganic equivalent formulation. Since this is a chemical reaction, the concentration of MEA (or inorganic equivalent) should be carefully monitored to ensure maximum cleaning efficiency at the design cleaning line speed.

## 2.12 Other Definitions

**2.12.1 Assembly** A number of parts or subassemblies or any combination thereof joined together.

**2.12.2 Batch Cleaning** The cleaning of multiple parts or “batches of parts” as a group where process cycle times are controlled.

**2.12.3 Fine Cleaning** A final cleaning step that removes contaminants introduced after defluxing and or which improves the degree of surface cleanliness achieved by defluxing or other previous cleaning operations and to improve conformal coating adhesion.

**2.12.4 In-Line Cleaning** The cleaning method where parts are processed continuously on a conveyor and process cycle time is controlled by the conveyor speed.

**2.12.5 Manual Cleaning** A cleaning step where parts are processed manually with process cycle time controlled by operator.

## 3 ASSEMBLY CLEANING VALUE AND APPLICABILITY

**3.1 Introduction** The pace of surface mount technology development and innovation is a response to market pressures for higher functionality, cost reduction, cycle time reduction, and improved quality.<sup>1</sup> To achieve increased functionality, today’s circuit assemblies pack more performance into smaller board designs. Advanced package designs require an increasing number of interconnects to support power requirements and bandwidth. With active and passive component size reduction as well as many area array pitch and standoff height also reducing, this increases the risk of dendrite formation and electrochemical migration.<sup>2</sup> At the same time, there is also expanded functionality driving package sizes and I/O counts higher on the boards. The critical metric for consideration is the surface area of the component to z-height ratio which as this ratio increases, makes getting into and removing residue from large area/tight z-height spaces more difficult.

Technology-based market pressures increase reliability demands as electronic assemblers move upstream from conventional designs and toward threshold and leading edge technologies.<sup>3</sup> Over the past two decades, conventional surface mount technologies successfully adopted low residue no-clean soldering practices. Today’s challenge for printed circuit board manufacturers hinges on density, lead-free, and miniaturization.<sup>1</sup> High performance electronic assembly designs will be driven by multilayer and stacked package density, increasing number of I/Os, decreased area array pitches, and tighter component standoff heights. Additional demands include control of costs, process restrictions and changes impelled by safety and environmental regulatory constraints (including national and international constraints as well as the local regulatory microclimate), and the need to control the processes performed by an ever-increasing supply chain.

**3.2 Technology Innovation** The pace of technology development and innovation has created an expectation that products will perform upon demand.<sup>4</sup> Technology advances create the need for highly complex circuitry driven by improved performance, improved reliability, miniaturization, and circuit density. Manufacturing complexity increases with the continuous drive for smaller, lighter, and more advanced features. In order to pack more circuits into a smaller device, everything within the device has to shrink in size.<sup>5</sup> Intelligent and interactive electronic devices create a renewed focus on reliability.

Semiconductor devices can be embedded practically everywhere: in vehicles to monitor the need for replacement parts, in humans to detect heart beats and brain activity, and even in growing plants to communicate needs for water or fertilizer. With no end in sight to ubiquitous computing and embedded networks and controls, the complexity of electronic devices continues to grow. The following examples illustrate the complexity and challenges faced by product designers:

- **Military/Defense:** The demands for reliability in the military/defense sector are unprecedented. Mission-critical information systems, weapons systems, and other critical assemblies represent complex electronic devices needed to secure the world from terrorists. Highly dense circuit designs must hold up to ruggedness and reliability when operating in harsh environments or after prolonged periods of storage. There are increasing drivers to eliminate Hazardous Air Contaminants (HACs) from the manufacturing process.

(HAPs), to minimize Volatile Organic Compounds (VOCs), and to avoid using chemicals that have an unfavorable worker safety profile. Coordination of processes among the military services is growing; and defluxing processes might productively be harmonized with efforts of the Joint Services Solvent Substitution Working Group (JS3WG).<sup>29</sup>

- **Aerospace:** Avionics technology demands operational efficiencies in materials and failure avoidance.<sup>6</sup> Future aerospace demands increase the use of chip scale avionics, in an effort to reduce size, weight, power, and cost while improving reliability. Safety improvements are needed to detect, predict, and avoid hazards. Meeting safety and environmental regulatory requirements represents another challenge. For example, regulatory constraints are decreasing the availability of cleaning agents with the appropriate wetting characteristics and efficacy in removing flux residues. Restrictions on VOCs will also limit the availability of effective cleaning agents.
- **Medical:** Medical device innovations improve the quality of life and reduce health care costs. Advanced packaging has been instrumental in the progression of reduced size, increased functionality, and improved reliability. Electronic technology is a critical enabler for treating chronic diseases. Remote monitoring and disease management devices rise from electronic innovations that integrate logic to expand the range of remote monitoring options for patients. Integrating electronics assemblies into implantable devices magnifies the importance of reliability, compatibility, and surface cleanliness/surface quality issues.
- **Automotive:** The automotive sector is in the midst of significant change, with increasing challenges in consumer demands, technology development, globalization, and integration. Consumers are becoming more empowered and sophisticated with their wants and needs evolving at an exponential pace. Consumers will expect their vehicles to provide information, entertainment, safety, and convenience. To meet these demands vehicles will become more intelligent, offer greener operation, and be customizable to greater buyer self-expression.
- **Networks and Information Technology:** Enterprise system innovations provide improved interface for connecting people around the world. Enabled by common IT standards, the lines between telecommunications, media/entertainment, and electronics industries are blurring as next generation networks enable consumer-friendly and industry efficient crossovers. These converged providers are expected to demand more and more electronic solutions such as Internet videos on mobile telephones and MP3 music downloads. Reliable networks and information technology are also required by industry, law enforcement, medical, government agencies, and national/international security. In those areas, reliable, secure, long-term, and readily-accessible storage of information is a must.
- **Mobile Devices:** Market penetration of mobile devices is worldwide. The market penetration for mobile telephones in developed nations is at an incredibly high 90 percent. Mobile devices will be increasingly important in underdeveloped and third world countries where there is a paucity of traditional “wire” technology. Technology and features have evolved to the point where device makers are able to integrate hardware and software with network providers. Mobile Internet devices will deliver the mobile Internet with smaller, lighter, and powerful Internet-enabled devices that ultimately fit right into ones pocket.

**3.3 Process Residues and Their Impact on Product Reliability** Product reliability represents the functionality of a device under environmental conditions for a given time period. Higher density, larger, smaller and stacked components, and lower standoffs are changing the definition of circuit board cleanliness. The traditional view of quality assurance equated circuit board reliability to visual residue and the resistivity of solvent extract measurements. With the reduction in component size and low standoff clearances, the ability to extract and see measurable residues that correlate to product quality is much more suspect. Alternative tests may need to be qualified.

As the complexity of circuit board designs increase, there are greater risks for reliability concerns.<sup>6</sup> Notable industry changes increasing the value of cleaning include<sup>6</sup>:

- Increased circuit sensitivity with tighter spacing (small amount of contamination, both visible residue and gaseous contamination can shift the circuit output).
- Chemical changes in fluxes that reduce the level of high solids rosin needed to seal and encapsulate fabrication residues. Many of today’s flux compositions use less resistant activators. Low solid flux compositions, commonly formulated with weak organic acids, leaves a chemical residue that does not directly correlate to the ionic conductivity/resistivity testing measurements.
- Assembly board integration that subjects assemblies to multiple assembly operations which may bake residues onto the surfaces prior to cleaning. For example, it is not uncommon for an assembly to see SMT reflow for top and bottom components, wave soldering, selective soldering, underfill applications, rework, and localized brush cleaning that may allow pockets of residue in precise and critical areas due to secondary processing.
- The risk of residue sources coming from the bare board, components, and secondary processing residues.

- Climatic reliability concerns from high-power devices designed to work in harsh environments.<sup>24</sup>
- The impact of non-ionic residues will need to be assessed; appropriate test protocols will have to be established.

**3.4 No Clean vs. Clean** Driven by the advent of low solids flux/paste (sometimes referred to as “no-clean”), there is a common misconception that cleaning has become a concern of the past. The reality is that the overall need for cleaning has not diminished. Cleaning needs have either shifted or remained where they were and, in addition, new needs have developed. More specifically, a no-clean process does not mean cleaning is not necessary. Cleaning plays a key role in the successful implementation of a no-clean process. Low residue (“acceptable dirt”) assembly has shifted cleaning from the assembly stage, back to the bare board fabrication and even the component manufacturing stages. Meeting the reliability demands of today’s electronic circuits very often require cleaning. In fact, the no-clean approach is often not a viable option.

Many users now clean low residue soldered assemblies prior to shipment. Contract assemblers performing low residue soldering have found that some customers demand cleaned assemblies, regardless of the nature of the flux used to perform the assembly operation. While some flux/paste manufacturers state that low residue fluxes/pastes need not be cleaned, the reality is that there are assemblers who are cleaning “no-clean materials” with specific cleaning agents to meet design and performance requirements.

Continuing developments in the area of surface mount (SMT) have brought about additional cleaning needs. Spaces on electronic assemblies have become increasingly confined. Cleaning under standard BGAs does not appear to be a problem because of their relatively high standoff height. However, with increased size, density, and lower stand-off heights, cleaning, rinsing or drying will become a significantly greater challenge. There is also a rapidly emerging need for cleaning under flip-chips in order to ensure the adherence of underfill. Similarly, cleaning is still an important operation for the optimum adherence and performance of conformal coatings.

Environmental and worker safety issues are very much a part of the today’s cleaning picture. Fabricators and assemblers alike must consider factors such as HAPs (Hazardous Air Pollutants), and other air toxics, PELs (Permissible Exposure Limits) and other worker safety requirements, VOCs (Volatile Organic Compounds), BOD (Biological Oxygen Demand) COD (Chemical Oxygen Demand), waste water treatment, heavy metals, close-looping and pH. Because of Federal and/or local regulations, one or more of these factors can determine the choice of a cleaning system.

Conformal coating provides a protective layer over conduction to prevent water molecules from migrating to metallic surfaces.<sup>25</sup> Protective coatings help prevent electrochemical migration, retard tin whisker growth, and protect against dust, dirt, and other contaminants. Post assembly cleaning prior to conformal coating improves wetting and adhesion. Poor adhesion and de-wetting occurs when coating over contaminants from flux or maskant residue, and ionic contamination around components.<sup>26</sup>

**3.4.1 Factors Involved with Implementing No Clean Technology** No-clean trends were adopted when parts were much bigger and spacings were much greater.<sup>2</sup> Everyone jumped on the band wagon to save both operating and capital costs plus eliminate having to find and qualify new, non-ozone depleting cleaning processes in the early '90s. Today, it appears that no-clean may no longer be the assembly process of choice with the propagation of CSP and flip chip assemblies; and perhaps no-clean processing should be reserved for the low voltage, large pitch, disposable, consumer products (Classes 1 and 2). Cleaning of no-clean flux residues for higher reliability applications (Class 3) may be required to meet cleanliness and reliability needs.

No-clean technology is no different from other manufacturing approaches from the standpoint that the user must intimately know the materials, how they change during the manufacturing process, and how they impact the form, fit, function, and reliability of the product in the end-use environment.

Electronics manufacturers are now employing combination processes such as “reduced clean” in which some flux residues are left on, usually hand soldering in a connector that is cleaning agent intolerant.<sup>7</sup> In some cases, a true no-clean assembly, where it simply does not make sense to clean is used. In the latter case, it is prudent to optimize the process to minimize residues, and verify effects on product robustness in the end-use environment. No-clean processes can also be a real source of concern in the high RF application where residual flux acts as a dielectric material and can alter wave shape and propagation characteristics.

Rework and repair represents an area that requires consistent training to accepted workmanship standards. Industry leaders address this by intensive operator training, especially those operators who are in the “reduced clean” or “true no-clean” programs. The training modules and workmanship standards should all emphasize adding as little additional flux as possible. Post-solder rework cleaning must be accomplished with the defined processes. That is, the cleaning agent is a cleaning

techniques must be clearly specified and defined; and personnel must be trained and educated to perform the rework processes in a correct, consistent manner. Any flux used must be fully activated during soldering to minimize or eliminate any problems.

**3.4.2 Cost Drivers** The usual cost driver cited is elimination of the cleaning process including materials, equipment, personnel and training. The assumption is that cleaning is a “zero value added” process. While this “zero value added” claim was often cited, it totally ignores any possible associated reliability and possible warranty repair issues. These issues include excessive rework, the costs of product that cannot be reworked, and the costs and company liability associated with in-use failure including catastrophic product failure.

**3.4.3 Selecting Materials for No Clean; Product Design** Anything associated with the assembly must be considered as part of an integrated system. Thus, laminate, solder mask, legend ink, components and conformal coating comprise the system. Since solder flux and solder paste residues are not removed, but stay on the assembly for its design lifetime, the residues must be compatible with any of the materials comprising the system. There should be appropriate demonstration of such compatibility, for example by testing after accelerated aging.

Both the designer and the assembler must keep this in mind during the entire process from concept prototype to final release to the ultimate customer. The assembler must also take into account any materials added during “parts add” processes, rework, repair or engineering upgrades for long lifetime assemblies. We now have updated tools (SIR, IC, etc.) to more effectively assess the performance characteristics of assembly “systems.” Additional analytical testing may be required, depending on the end-user requirements. Users can quantitatively compare various combinations of soldering materials and coatings to ensure the completed assembly meets design goals in the end-use environment.

#### **3.4.4 What are the Perceived No-Clean Cost Benefits and Drivers?**

##### **3.4.4.1 What are the (Perceived) Cost Benefits of No-Clean?**

- Elimination of the costs associated with cleaning equipment, materials and process steps.
- Improve factory throughput by eliminating the cleaning process step and process times.
- Recover expensive manufacturing floor space.
- Ability to use cheaper components which do not have to be robust enough to survive cleaning processes.

##### **3.4.5 What are the No-Clean Cost Drivers?**

- Qualification program to choose and preferably standardize no- clean flux and paste.
- Qualification program to choose and standardize on rework and repair flux and paste.
- Qualification program to choose board and component suppliers that are in compliance with user cleanliness testing and standards for no- clean flux and paste processes.
- Optimize all soldering processes to leave a minimum of flux residues so that it does not interfere with in-circuit testing and conformal coating adhesion.
- Recalibrate automated optical inspection machines, standards, protocols plus all workmanship and inspection standards and institute new training and inspection programs. (Note: Flux residues change visual appearance.)
- Qualify new process with current customers and modify contracts accordingly.
- Review compliance with all existing and anticipated environmental air, water and solid waste regulations. Review compliance with all waste disposal regulations.
- Determine compatibility with present and future designs, especially if high frequency or optical fiber circuits are included or anticipated.
- OEMs must assure proper training and documentation of assemblies manufactured by contract assemblers or at multiple sites in current or future plans. Can alternative sites comply with main factory requirements?
- Are the circuits designed for best performance or to overcome possible problems, such as cleaning, soldering (J-STD-002 solderability), or dielectric oil cleanliness where the industry may not have sufficient information to guarantee process success?
- Determine process window limits through statistical testing.
- Requirement or verification of incoming parts to meet initial cleanliness requirements.
- Handling of no-clean products through manufacturing operations.

### 3.5 What are the Costs of Cleaning?

#### 3.5.1 Cost per Cleaned Part

Cost assessment includes many more factors than just the cost per gallon or liter of a particular cleaning agent. A complete cleaning cost analysis should take into account the following items:

- Equipment cost.
- Fixturing costs.
- Capital cost to purchase the equipment vs. investing the funds.
- Non-Recurring Engineering (NRE) cost for development and validation of the cleaning process.
- Depreciation.
- Floor space.
- Ventilation.
- Installation, equipment validation, and commissioning costs including testing materials and lab analysis including compatibility analysis for other assembly process materials and components which may have sensitivity issues related to the new process.
- Operator training costs.
- Operator labor costs.
- Water costs (if water used for cooling the cleaning system).
- Water filtration and treatment costs for associated cleaning process rinsing (ion beds, plumbing, neutralization or treatment depending on local regulations).
- Maintenance costs (labor, filling, draining, replacement equipment parts as necessary).
- Cleaning agent costs (including water if used as the cleaning agent. If water is used, as or with the cleaning agent, and discharged, include the variable sewer use cost.)
- Process performance monitoring costs including concentration measurement, ROSE equipment, and/or Ion Chromatography analysis costs as well as associated labor to perform those tasks.
- Costs associated with post-clean board assembly baking to ensure moisture level appropriate for downstream assembly processes like conformal coating, etc.
- Costs associated with cleaning agent selection and qualification per J-STD-001.
- Wastewater permit cost if spent cleaning agent is discharged to public sewer system.
- Cleaning agent recycle costs.
- Cleaning agent disposal costs (including evaporation costs, if evaporators are used).
- Cleaning agent storage costs and transportation (labor) to the equipment.
- Total electrical costs to operate cleaner, provide ventilation, added heating or cooling, recycle, and disposal equipment.
- Labor costs and fees associated with filing and maintaining required environmental reports.
- Labor costs associated with inspection, rework, repair, documentation.
- Production volume or throughput.
- Air emissions permit if cleaning agent contains a volatile organic compound (VOC) and emissions are above permit threshold for air district.
- Capital and operating costs for air emissions control device if required to meet air permit requirements.
- Industrial hygiene costs to determine baseline employee exposures to cleaning agent (if other than water) and to confirm ongoing compliance with worker hygienic standards.
- Calibration, testing, and maintenance of process control equipment per contract requirements.

### 3.5.2 Cost Modeling

| Cleaning Cost Modeling                                        |                                                                                                                                                                 |
|---------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cleaning Machine                                              | Parameter                                                                                                                                                       |
| Cleaning Machine                                              | Cost in Dollars                                                                                                                                                 |
| Shipping and Integration                                      | Cost in Dollars                                                                                                                                                 |
| Cleaning Solvent Process Control System                       | Cost in Dollars                                                                                                                                                 |
| DI Water Close Loop System                                    | Cost in Dollars                                                                                                                                                 |
| Service and Maintenance                                       | Dollars per year                                                                                                                                                |
| Spare Parts                                                   | Dollars per year                                                                                                                                                |
| Ionic Contamination Tester                                    | Cost in Dollars                                                                                                                                                 |
| Cleaning Equipment Cost before Depreciation                   | Cost in Dollars                                                                                                                                                 |
| Use of Baskets or Hold Down Mechanism                         | Cost in Dollars                                                                                                                                                 |
| Cleaning Material                                             | Parameter                                                                                                                                                       |
| Working Concentration                                         | % Cleaning Solvent Concentration                                                                                                                                |
| Cost Per Gallon                                               | \$/gallon                                                                                                                                                       |
| Cost Per Gallon of Cleaning Solvent in Working Solution       | % Cleaning Solvent Concentration * \$/gallon                                                                                                                    |
| Wash Bath Volume (Gallons)                                    | Gallons                                                                                                                                                         |
| Cost to Change Wash Bath with Cleaning Solvent                | % Concentration * Wash Bath Volume * cleaning solvent \$/gallon                                                                                                 |
| Cost to Charge Wash Bath with DI Water                        | % Concentration * Wash Bath Volume * DI water \$/gallon                                                                                                         |
| Frequency of Bath Change outs (Weeks)                         | # of weeks                                                                                                                                                      |
| Working Weeks per Year                                        | # of weeks                                                                                                                                                      |
| Gallons of Concentrate for Change outs per Year               | [# of weeks per year - # of weeks per bath change out] * [% Cleaning Solvent Concentration * Wash Bath Volume]                                                  |
| Gallons of DI Water for Change outs per Year                  | [# of weeks per year - # of weeks per bath change out] * [% DI water Concentration * Wash Bath Volume]                                                          |
| Annual Cost of Cleaning Solvent from Wash Bath Change outs    | [# of weeks per year - # of weeks per bath change out] * [% Cleaning Solvent Concentration * Wash Bath Volume * \$/gallon]                                      |
| Annual Cost of DI Water from Wash Bath Change outs            | [# of weeks per year - # of weeks per bath change out] * [% DI Water Concentration * Wash Bath Volume * \$/gallon]                                              |
| Wash Batch Operating Temperature                              | °C/°F                                                                                                                                                           |
| Average Exhaust Loss of Water                                 | gallons/hour                                                                                                                                                    |
| Average Exhaust Loss of Cleaning Fluid                        | gallons/hour                                                                                                                                                    |
| Average Total Exhaust Loss (water plus cleaning fluid)        | gallons/hour                                                                                                                                                    |
| Machine Operational Hours per Day                             | # of hours per day with the machine in operation                                                                                                                |
| Annual DI Water Lost from Exhaust                             | Exhaust loss of DI water in gallons/hour * Machine operational hours per day * Operational days per year                                                        |
| Annual Cleaning Solvent Lost from Exhaust                     | Exhaust loss of cleaning fluid in gallons/hour * Machine operational hours per day * Operational days per year                                                  |
| Annual Cost of Chemical Loss Due to Exhaust                   | Cleaning Solvent replacement from exhaust per hour * Machine operational hours per day * Operational days per year * Cleaning Solvent cost per gallon           |
| Annual Cost of DI Loss Due to Exhaust                         | DI water replacement from exhaust * Machine operational hours per day * Operational days per year * DI cost per gallon                                          |
| Average Dragout of the Wash Solution to Rinse                 | Gallons/hour                                                                                                                                                    |
| Average annual DI Water lost from Wash Dragout                | Average drag out of the wash * % of DI water in the wash * # of operational hours per day * # of days per year                                                  |
| Average annual Cleaning Solvent Lost from Wash Dragout        | Average drag out of wash * % of cleaning solvent in the wash * # of operational hours per day * # of days per year                                              |
| Operational Days per Year                                     | # of days                                                                                                                                                       |
| Annual Cost of Cleaning Solvent Lost from Exhaust and Dragout | Cleaning Solvent lost from exhaust per day + Cleaning Solvent lost from drag out per day * # of operational days per year * Cost of cleaning solvent per gallon |

| Cleaning Cost Modeling                                                         |                                                                                                                                         |
|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| Cleaning Machine (cont.)                                                       | Parameter (cont.)                                                                                                                       |
| Annual Cost of DI Water Lost from Exhaust and Dragout                          | DI Water lost from exhaust per day + DI water lost from drag out per day * # of operational days per year * cost of DI water per gallon |
| Total Annual Cost of Exhaust and Dragout per Year                              | Annual cost of cleaning fluid lost from exhaust and dragout + Annual cost of DI water lost from exhaust and dragout                     |
| Total DI Water Cost per Year                                                   | Annual cost of DI from Wash Bath Change outs + Annual Cost of DI water lost from exhaust and drag out                                   |
| Total Cleaning Solvent Cost per Year                                           | Annual cost of Cleaning Solvent from Wash Bath Change outs + Annual Cost of Cleaning Solvent lost from exhaust and dragout              |
| Total Cost of DI Water and Cleaning Solvent from the Wash per Year             | Total DI-water cost per year + Total Cleaning Solvent Cost per year                                                                     |
| DI Water                                                                       | Parameter                                                                                                                               |
| Annual DI Water Consumption from Wash                                          | Gallons per year                                                                                                                        |
| DI Water/hour into Final Rinse                                                 | Gallons per hour                                                                                                                        |
| Annual Rinse DI Water Consumption                                              | Gallons per hour * # of operational hours per day * # days of operation per year                                                        |
| Total Annual DI-Water Needed                                                   | Annual DI water consumption form wash + annual rinse DI water consumption                                                               |
| Cost to Treat One Gallon of DI Water                                           | \$/gallon                                                                                                                               |
| Total Cost of DI water                                                         | Cost to treat one gallon of DI water * Total annual DI water needed                                                                     |
| Replenishment/Replacement of Ion Exchange Columns                              | Hidden Costs to generate DI Water                                                                                                       |
| Energy                                                                         | Parameter                                                                                                                               |
| Pumps                                                                          | KW/Hr.                                                                                                                                  |
| Heaters                                                                        | KW/Hr.                                                                                                                                  |
| Dryers                                                                         | KW/Hr.                                                                                                                                  |
| Exhaust                                                                        | KW/Hr.                                                                                                                                  |
| Air Conditioning                                                               | KW/Hr                                                                                                                                   |
| Annual Cost of Electricity                                                     | Total KW/Hr. * # operational hours per day * # of operational days per year                                                             |
| External Sump Pumps to Push Water Pre-treatment                                | KW/Hr                                                                                                                                   |
| Waste Disposal                                                                 | Parameter                                                                                                                               |
| Rinse water to drain                                                           | Gallons/day                                                                                                                             |
| Solvent from Dragout to Drain                                                  | Gallons/day                                                                                                                             |
| Total Annual Cost to Dispose Water and Solvent to Drain                        | (Rinse water to drain + Solvent to drain) * # of operational hours per day * # of operational days per year                             |
| Pretreatment of Water and/or Chemistry Prior to Disposal including Evaporation | Cost/Gallon*KW/Hr\$ per month/quarter/year                                                                                              |
| Containerization and Transportation                                            | Cost/Gallon*mileage \$ per month/quarter/year                                                                                           |
| Other Disposal Costs                                                           | Cost/Gallon                                                                                                                             |
| Wastewater Permit Fees and Permit Monitoring                                   | \$/permit and capital investment, consumables, training, education                                                                      |
| Total Annual Cost of Disposal                                                  | \$                                                                                                                                      |
| Air Emissions                                                                  | Parameter                                                                                                                               |
| VOCs Emitter per Year                                                          | Grams per liter of cleaning solvent * 3.78 liters/gallon * gallons of cleaning solvent lost to exhaust                                  |
| Air Emissions Permit                                                           | \$/permit                                                                                                                               |
| Air Emission Control Device                                                    | \$ for water if water scrubbed; media replacement if absorbed, or fuel is thermal oxidizer                                              |
| Total Annual Cost per Ton of VOCs Emitted                                      | Grams of cleaning solvent emitted per year/454 grams per pound/ 2000 pounds/ton                                                         |
| Air Emission Controls                                                          | Capital investment, consumables, training, education                                                                                    |

| Cleaning Cost Modeling                                 |                                                                                 |
|--------------------------------------------------------|---------------------------------------------------------------------------------|
| Footprint                                              | Parameter                                                                       |
| Total Equipment Length                                 | Meters (Feet)                                                                   |
| Total Equipment Width                                  | Meters (Feet)                                                                   |
| Total Equipment Height                                 | Meters (Feet)                                                                   |
| Total Square Foot of Manufacturing Area                | Square Meters (Square Feet)                                                     |
| Cost per Square Foot of Manufacturing Area             |                                                                                 |
| Through-Put                                            | Parameter                                                                       |
| Cleaning Machine                                       | Inline or Batch                                                                 |
| Cleaning Cycle Time                                    | Meters (Feet) per minute or Minutes per batch                                   |
| Production Need                                        | Quantity of boards per day                                                      |
| Cycle Time                                             | Belt Speed or Minutes in Wash                                                   |
| Cleaning Machine Capacity                              | Boards per Day at Machine Parameters                                            |
| Required Cleaning Equipment                            | # of Cleaning Machines                                                          |
| Total Operating Costs                                  | Parameter                                                                       |
| Total Annual Cost of Cleaning Chemistry                | Cost in Dollars                                                                 |
| Total Annual Cost for Industrial Hygiene Services      | Cost in Dollars                                                                 |
| Total Annual Cost of DI Water                          | Cost in Dollars                                                                 |
| Total Annual Cost of Energy                            | Cost in Dollars                                                                 |
| Total Annual Cost of Waste Disposal                    | Cost in Dollars                                                                 |
| Total Annual Cost of Air Emissions                     | Cost in Dollars                                                                 |
| Total Annual Cost of WW Discharge                      | Cost in Dollars                                                                 |
| Total Annual Depreciation                              | Cost in Dollars                                                                 |
| Total Cost of Cleaning Operation                       | Cost in Dollars                                                                 |
| Return on Investment                                   | Net Operating Income from Cleaning/Average operating assets                     |
| Labor, Hours Required + Overhead per Day               | Cost in Dollars                                                                 |
| Other Considerations                                   | Parameter                                                                       |
| Noise Abatement                                        | Decibels of environmental noise                                                 |
| Specialized Conveyors or Hoists                        | Materials handling                                                              |
| Specialized Sump Pumps for pretreatment                | Materials handling                                                              |
| Benefit of Recycled DI Water                           | Positive Benefit of recirculated DI water vs. water to drain or new water needs |
| Cost for Cleaning Agent Qualification and Optimization | Boards, SIR Testing, J-STD-001                                                  |

**3.5.2.1 Cost Model History** Cost models have been generated by equipment or cleaning agent suppliers but they are usually incomplete, i.e., including only the supplier's favored process and most significant competitor, instead of all possible options. Often such models were used only to justify the purchase of new equipment, not to optimize economics of manufacturing operations.

The first interactive model published was generated by Hollis Engineering and included cleaning with saponifiers, pure water, or Type I semi-aqueous agents.<sup>30</sup> It was later modified by DuPont using actual semi-aqueous cleaning data gathered from field experience. Neither model included solvent cleaning data or no-clean data.

**3.5.2.2 Cost Model Value** While these models attempted to allow manufacturers to choose the optimum process based first on post-soldering cleanliness testing and secondly on the cost per cleaned part, they generally did not provide a comprehensive model that included all the major cleaning options. Further, the interactive nature of the models would allow assemblers to "plug in" utility and labor costs at each factory location to decide on the optimum overall cleaning process.

**3.5.2.3 Future Work** Industry accepted interactive cost models need to be generated that includes all the post-soldering cleaning processes in use today. The goal would be to strengthen our industry members by ensuring that they remain cost-competitive in the global marketplace. Such interactive models are not to be used as sales or marketing tools against other suppliers.

**3.6 What are the Costs of Ignoring Cleanliness?** High reliability electronic products require performance on demand and miniaturization accelerating the need for thinner and highly dense circuitry.<sup>8</sup> A common threat to the production of highly dense electronic assemblies is the growth of dendrites and intermetallics that ultimately cause short circuits. Literature on reliability risks of electronic circuit assemblies reports that this phenomenon appears to occur more frequently with lead-free electronics.<sup>9</sup>

The speed of electronic interconnection innovations outpace testing, regulatory, and standards bodies serving the industry.<sup>10</sup> Miniaturization is constantly imposing new criteria and challenges on the soldering materials.<sup>11</sup> With decreasing size of pad, through-hole, microvia, 3D manufacturing (multilayer chips and package on package) and pitch, the makeup of substrates and components becomes more delicate, which increases the vulnerability of solder joints.<sup>12</sup>

Increased functionality and smaller devices represent significant drivers in innovative circuit designs<sup>7</sup>. Manufacturing complexity increases with the continuous drive for smaller, lighter and more advanced features. In order to pack more circuits into a smaller device, everything within the device has to shrink in size.<sup>11</sup> As packages continue to shrink, while at the same time package size and I/O counts increases, the convergence of circuit board and advanced packaging drive designers and component engineers to develop board level features that improve reliability. The costs of avoiding cleaning could result in loss of life on the far end of the spectrum and costs associated with product performance.

**3.6.1 Lead Free Soldering** Lead-free is a disruptive change that requires manufacturing process change in a fundamental element of an electronics assembly - the connections between components.<sup>13</sup> Higher I/O counts, progressive miniaturization, more reliable performance, and other demands are being impeded by circuit board cleanliness effects.<sup>27</sup> The relevance of clean lead-free assemblies must be considered to mitigate stray leakage and electrochemical migration reliability risks.<sup>14</sup>

The change to lead-free manufacturing urges tighter process control.<sup>9</sup> The higher soldering temperatures necessary for lead free alloys creates additional cleaning challenges. Whereas previously an engineer could tune the process by increasing flux activity, changing conveyor speed, or increasing preheat ad hoc, high-tin/high melting point alloys are a different matter. Slight changes from a well-defined tin-lead process can result in an increase level of board failures.

A tightened lead-free SAC process window increases cleaning relevance. With increased soldering temperatures, and decreased component stand-offs, use of a no-clean process may no longer be tolerated.<sup>9</sup> If the flux oxidizes or chars during the soldering process, the board will experience high levels of ionic contaminants. During high lead-free processing temperatures, the board laminate expands with the risk of absorption of contaminants in the mask. Such risks can and do cause electrochemical reactions and reliability problems.

**3.6.2 Miniaturization** Miniaturization imposes a great challenge on the chemistry of fluxes, due to the increasing amount of oxides and requirements for no-clean lead-free applications.<sup>9</sup> The size of the component and the conductor spacing generates more heat during operation.<sup>15</sup> Problems arise from boards with greater design density resulting in ionic interference, metal migration, and reduction of surface insulation resistance.

Miniaturization often results in reduced wetting.<sup>11</sup> The oxide thickness does not decrease in proportion to pad size, thus consequently results in poorer wetting. A reduced joint size is also more prone to void formation, mainly due to a greater difficulty in wetting, resulting in an increase in vulnerability toward tombstoning or skewing. (See 3.6.3 Flux Changes.)

It stands to reason that a smaller solder joint will be depleted by corrosion sooner than a larger joint.<sup>11</sup> Oxidation of fine solder powder increases with reduced particle size due to the increasing exposure surface area of powder. Changing from SnPb solders to lead-free solders further worsens the problem since lead-free solders have higher melting points and less wetting than SnPb solders.

The ability to prevent materials that can cause corrosion is reduced as package standoffs decrease.<sup>16 & 28</sup> Condensation of water and contaminants onto the surface of an IC package occurs because of surface tension when the temperature passes through the dew point.<sup>16 & 28</sup> In a humid environment and in the presence of electrical bias, excessive ionic contaminants on an assembly can cause problems. At 60% relative humidity, a layer of water two to four molecules thick can form. Along with the water are contaminants, which increase the risk of other chemical reactions. When the relative humidity reaches 80%, the water layer is from five to 20 molecules thick and ions can flow freely on the surface. At this point moisture and organic acids can form a corrosive cell. The issue is increased from tight board traces, board density, and higher voltage.<sup>28</sup> At constant voltage, the electrical field between the conductors rises inversely with the conductor spacing.<sup>12</sup> As a result, electrochemical migration and the formation of dendrites are more susceptible from narrow conductor spacing. The tolerance of electronic products toward dendrite formation diminishes rapidly.<sup>11</sup> Shorts between traces are due to electrolytic dendrite growth, erosion of conductors, or loss of insulation resistance.<sup>9</sup>

**3.6.3 Flux Changes** Compatibility of lead-free alloys with a variety of flux chemistries is considered essential, and is determined for performance in handling ability, shelf life, and soldering capability, such as solder balling, wetting, and solder joint appearance.<sup>17</sup> In general, SAC lead-free alloys exhibit a poor wetting ability. More aggressive flux chemistries are needed in order to achieve wetting comparable with eutectic tin-lead alloys.<sup>18</sup> More aggressive flux chemistries can lead to more corrosive flux residues, thus requiring more use of effective cleaning processes to meet design reliability requirements.

Lee<sup>3</sup> cited desirable characteristics of lead-free no-clean flux compositions.<sup>11</sup> With a no-clean process the objective is for the residue to form a hard barrier that seals the circuit from exposed ionic contamination. However, as soldering temperatures rise, the flux materials undergo changes in their physical and chemical properties such as the evaporation of volatile fractions, surface energy, and melt viscosity.<sup>19</sup> While manufacturers did not want to clean assemblies, they couldn't risk exceeding the prescribed contamination threshold. Such systems will impart more residues, reduced SIR, and an increased need to clean.

The science of flux compositions for eutectic SnPb is well understood and mastered.<sup>19</sup> At higher soldering temperatures required for lead-free SAC alloys the organic solvent must be thermally stable to reduce the level of activator needed to solder the component. One critical problem is the lack of thermal stability, thus requiring more active flux compositions. This leaves a residue that no longer fits the no-clean categorization.

**3.6.4 Electrical Failure Mechanisms** Electronic assemblers use surface insulation resistance (SIR) testing when adapting to changes in processes, materials, and manufacturing equipment. SIR is defined as electrical resistance between two electrical conductors.<sup>20</sup> SIR can be thought of as a systems ability to resist surface shorting of leads or traces. Performance of SIR test samples are directly related to cleanliness.

SIR measures an aggregate of different resistance of both contaminated and non-contaminated values in parallel.<sup>2</sup> The growth of dendrites or the presence of conductive solutions between the conductors of the patterns affects the resistance between them. Higher SIR values are the result of cleaner boards that do not form dendrites. Lower values are a result of the presence of conductive dendrites or salts.<sup>20</sup>

**3.6.5 Electrochemical Migration** Electrochemical migration is an occurrence of a conductive metal bridge forming between conductors when they are subjected to a DC voltage bias.<sup>10</sup> Metal conductors grow from a positively charged conductor (cathode) to a negatively charged adjacent conductor (anode) creating a short circuit between the conductors. Electrochemical migration consists of metals plating in reverse.<sup>21</sup> An ionic contaminant combines with water, generally forming a localized source of acid, which dissolves metal ions. Under the influence of the electrical potential, the metal ions move across the intervening space, plating out on the laminate as it goes, forming a metal filament. A more contaminated assembly has greater risk than a clean assembly.

Electrochemical migration provides a measure of contaminants and their effect on assembly reliability.<sup>2</sup> Metallic salts and conducting ions, such as chloride and bromide commonly found in fluxes and PCB substrates, can create shorts across the leads or traces. These ions within the electrolyte may derive from corrosion or the metal conductors or from improperly cleaned circuit board substrates. Contamination may derive from the manufacturing of the bare PCB, subsequent handling, or from the application of corrosive fluxes without adequate cleaning. Studies have determined that failure due to electrochemical migration and corrosion is based primarily on the cleanliness of the parts.<sup>10</sup> Ionic residues surrounding metal leads will begin electrochemical migration when voltage is applied to the circuit in the presence of moisture.<sup>21</sup> Even before metal leads are corroded through, corrosion alters its conductivity.

**3.6.6 Reliability Risks** High risk of reliability problems can occur, especially in high-reliability end-use environments. Loss of process control within the facility in a no-clean environment increases risk especially when process control adjustments can be made in real time. No-clean implementation moves the cleaning and associated process controls out to multiple lowest bidder suppliers. Potential reliability issues are corrected prior to final tests and shipment to the customer. This is especially important if the assemblies are conformally coated.

When processing no-clean assemblies, both equipment and manpower are needed to perform testing and analyses needed to ensure cleanliness of incoming components and boards. Qualification of all suppliers manufacturing processes to ensure incoming parts meet manufacturing process standards. This problem becomes more cumbersome as the number of suppliers and supplier manufacturing sites increases. OEMs require Supplier/User/Customer agreements on existing industry performance and test method documents; or generation of any such documents that do not presently exist.

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## 4 DESIGNING ASSEMBLIES FOR CLEANING

**4.1 Design of Assemblies for Effective Cleaning** Designing printed circuit assemblies for cleanability has become an extremely challenging task, due to the miniaturization as well as the complexity of leading-edge products.<sup>1</sup> Design for manufacturability (DFM) includes a set of techniques to modify and improve printed circuit and cleaning process designs in order to match the cleaning process to the substrate, contaminant, and available cleaning methods. The desire to make electronic products smaller and lighter drives designers toward highly dense assemblies with reduced spacing between components. The objective of this section is to provide design rule methodologies for cleaning leading edge printed circuit designs.

Technology advances, use of smaller components, high density layouts, material changes, and environmental conditions renew heightened importance of circuit board cleanliness.<sup>3</sup> Designing printed circuit assemblies for ease of manufacture needs to begin with the CAD designer's awareness of the manufacturing process and its limitations. As a general rule, through-hole assemblies offer fewer problems than surface mount assemblies do and, in particular, those on high-density interconnection structure (HDI) substrates. The problem is that the driving force toward smaller components increases the complexity of component features and functions.<sup>2</sup> This complexity makes effective removal of residues more difficult.

In some cases, there may be a conflict between the requirements for a good electrical design, a good layout for soldering and a good layout for cleaning. In these cases, the designer should attempt to find an adequate compromise. As with all process changes, cleaning processes must be evaluated relative to the proposed design. The selected cleaning process must be validated prior to production of the new assembly. Designers, engineers, quality control personnel, shop floor personnel, safety/environmental advisors, and other key personnel should be involved in the cleaning process evaluation. The cleaning process includes the cleaning agent, the cleaning equipment, and the cleaning protocol. The cleaning process should be acceptable to show personnel; otherwise, the new process is less likely to be successful.

Team meetings, including key personnel are often helpful in educating the designer; this approach may be the most expeditious approach to DFM. When cleaning high-density surface mount assemblies, the CAD system should be tuned to ensure that every opportunity is taken to enhance the ability to clean. This may mean that components should be oriented in a specific direction and, in order to achieve this, it may be necessary to have one or more extra signal layers. If this is undesirable for economic reasons, then it may be necessary to insert signal conductors in voltage or ground plane layers. In the case of HDI circuits with micro-vias, it is usual to have the vias in the soldering pads. This eliminates the need of component fan-out (dog bones), permitting much higher component densities, which may seriously compromise the cleaning process with the present state of technology.

**4.2 Design for Cleaning** Printed circuit board design, assembly, and quality control follow defined industry standards. To mitigate risks of product failure due to contamination, the cleaning process must provide a defined process window that is repeatable across a wide range of variables encountered in the assembly process. To achieve a high yield cleaning process, many factors influence the cleaning process window: substrate, contaminant, available cleaning technologies, cleaning equipment, and environmental factors.

**4.2.1 Substrate** The first step in designing the cleaning process is a thorough review of PWB Layout to identify PTH holes, aspect ratios of the holes, any applicable plugging or tenting of the vias, and solder mask material selection. Part composition, size, and geometry can create low clearances and sandwiched components with little egress resulting in residues that are very difficult to remove. Small and light weight parts increase the need to fixture assemblies as they track through the cleaning process. Cleaning process design first starts with consideration of board surface, metallization, and compatibility constraints. Part unique restrictions may limit some components from being subjected to the cleaning process.

**4.2.1.1 Bare Board Cleaning Requirements** After plating and chemical etching processes, ionic contaminants leave an electrically conductive residue remaining on the PCB surface. Conductive ions are derived from metal cleaners, etchants, plating chemicals, fusing and leveling fluids, processing equipment, and human contact. Fluxes used in the HASL process may become entrapped in the spaces between the pads and solder mask or in tented vias. For incoming bare boards, consideration of the design for areas of tight mask-to-metal spacing and tented vias have little influence on the ability to clean. Bare boards often have unacceptable process residues from the fabrication process. IPC-5704 states: As received, single or double-sided and multilayer printed boards shall conform to the stated ionic cleanliness requirements listed for the respective surface finish in Table 4-1, when tested in accordance with IPC-TM-650, Method 2.3.28.2. Unsuitable design and layout of assemblies often cause difficulties in cleaning. Incompletely cured solder mask and/or legend inks can also negatively affect post-soldering and cleaning appearance.

**Table 4-1 Bare Printed Board Ionic Contamination Maximum Limits ( $\mu\text{g}/\text{cm}^2$ )**

| Ions                        | Non-OSP | OSP  |
|-----------------------------|---------|------|
| Chloride (Cl)               | 0.75    | 0.75 |
| Bromide (Br)                | 1.0     | 1.0  |
| Sodium (Na) + Potassium (K) | 2.0     | 4.0  |
| Total Inorganic             | 3.8     | 5.9  |

**4.2.2 Assembly Components** The drivers to make electronic products smaller and lighter are component miniaturization, the reduction of spacing between components, increased complexity of features and functions<sup>2</sup>. Highly dense assemblies use low feature (Z-height) components that occupy a significant area on the PCB. Examples of these components are Package-on-Package, Chip Capacitors, QFN, CSPs, etc. Reducing the component size and spacing increases cleaning difficulty on both component terminations and under the components.

The use of miniature components, such as resistors and capacitors pose increased cleaning challenges. The 01005 resistor is extremely small in size with dimensions of 0.4 x 0.2 mm [0.016 in x 0.008 in]. During the soldering process, surface tension of flux fills the underside of the component. The component stand-off height is less than 0.001 mm [0.00004 in] from the surface of the PCB. Products built with these small components report the need for all residues to be removed from under the component for the circuit boards to function properly.<sup>6</sup>

Component packages with high pin counts also present highly difficult cleaning challenges, in particular, cleaning under ball grid arrays (BGAs) and chip scale packages (CSPs). With pin counts of several hundred to more than one thousand, an understanding of the flux options, heat gradients, cleaning materials, and mechanical delivery of the cleaning materials (i.e., spray nozzles) is necessary.

Flip chip packages and packages like DFN, QFN, and land grid arrays (LGAs) are being used in greater numbers in manufacture of high volume electronics. In these cases, the designer should be warned that every effort must be made to ensure that cleaning is not impeded. Formation of designer-assembler teams to maximize electronic performance with high yield manufacture is critical to success. Designer assembler teams should validate the ability to clean under parts with small Z-axis clearances.

Multi-module advanced packages create a different set of challenges. Vented caps are used on some packages to protect flip chip die and passive components. The small vent hole allows cleaning fluid to permeate and potentially be entrapped under the protective cap. Assemblers are concerned that cleaning fluid entrapped under the protective cap may dry as an ionic residue and potentially cause a reliability concern. As devices increase in complexity, such as the flip chip example illustrates, component designers, assemblers, and materials suppliers must develop creative approaches to addressing this concern. Designer assembler teams should validate the ability to clean under parts with small Z-axis clearances. New lid designs were introduced at the 2010 IPC/SMTA Cleaning & Coating Conference. The paper referencing this development is available from either IPC or SMTA (Vuono, Bill, 2010, Cleaning Fluid Entrapment under Vented Flip Chip Packages, IPC/SMTA Cleaning and Coating Conference).

(Refer to Section 5 for a discussion on sensitive components.)

**4.2.3 Assembly Contaminants** With a clear understanding of the unique part consideration and restrictions, the next step in the design for manufacturability considers the effects of contamination left on the circuit board after the assembly (typically soldering) process. To understand the risk of contamination, designers consider the flux residue composition, physical properties, and quantity, the ability of the cleaning material to remove the soldering residues. Interaction of the soldering materials, i.e., the flux with the thermal processes associated with assembly and the dwell time between the thermal processes and the cleaning process have an effect on the resulting cleanliness of the assembly. Subsequent processing steps may also influence product cleanliness.

Solder flux performs a number of important functions simultaneously:<sup>7</sup>

- Removes surface oxidation.
- Prevents re-oxidation - Keeps the resulting surface oxide-free.
- Promotes generation of a metallurgical and mechanically strong joint.
- Reduces surface tension to eliminate bridges and shorts.
- Flux also promotes thermal stability during the metal jointing process.

- Flux reactions occur through acid-base and oxidation-reduction reactions with the metal/metal oxide/electrolyte solution interface. As component features decrease, greater activator levels and thermal stability become paramount. An additional factor impacting the electronics industry is the switch to low solids solders.<sup>2</sup> High tin alloys exhibit poor wetting properties and higher melting points that require flux compositions with higher levels of activation and increased thermal stability, which increases the level of flux residue.
- The size and pitch of the component with regards to the conductor spacing could increase the risk of electro-migration and corrosion.<sup>8</sup> The DFM metric for metal to metal spacing becomes more sensitive with the transition to lead-free soldering. Smaller solder joints are depleted by corrosion sooner than a larger joint.<sup>9</sup> Oxidation of fine solder powder increases with reduced particle size due to the increased surface area of the powder. Changing from tin-lead solders to *lead-free* solders further worsens the problem, since *lead-free* solders are more prone to oxidization than tin-lead solders.<sup>9</sup> Problems arise from boards with greater levels of ionic flux residues, which increase the risk of electrochemical reactions, metal migration, and reduction of surface resistance, thus creating the need to clean post soldering.<sup>8</sup> For more information reference IPC-5702.
- Solder pastes, paste fluxes, and wave fluxes influence the level and difficulty of residue removal after the soldering process. Flux residues clean at different rates based on the flux make-up, time after reflow, and reflow temperature. All of these reflow factors must be considered for each board design with the importance of following reflow parameters. Solvation involves different types of intermolecular interaction: hydrogen bonding, ion-dipole, and dipole-dipole attractions. As flux residues change, the cleaning rate also varies. For all cleaning activities, the cleaning agent and the cleaning system - including time, temperature, and force influence cleaning efficacy.

**4.2.4 Thermal Gradients** The soldering reflow profile is one of the most important factors in the soldering process.<sup>7</sup> Density of component distribution on the PCB greatly affects the reflow profile. Heavy or large components should be equally distributed on the PCB. Cleanability issues may occur due to the need to set the reflow profile based on the highest thermal need component on the assembly.

Designers and Process Engineers are challenged to develop and follow a reflow profile across the assembly in all directions to maximize soldering efficiency while not overheating or charring, and/or oxidizing flux residue to an un-cleanable state. The reflow profile represents an important factor in defect rates in the form of component cracking, tombstoning, wicking, solder balling, bridging, solder beading, cold joints, and intermetallic formation. Considering cleaning and the number of reflow process conditions before cleaning will influence the ease of cleaning flux residues.

The time above liquidus exposes the flux constituents to oxidation-reduction reactions needed to facilitate the joining process.<sup>11</sup> The time above the peak temperature has a significant influence on the cleanability of the flux residue. At the peak temperature, the flux flows away from the solder joint. As the flux flows away from the solder, the residue thins to its lowest point, from which the flux residue can oxidize or char from overheating. These thin flux films create an extremely difficult cleaning challenge.

**4.2.4.1 Multiple Process Cycles** In an effort to create one piece flow in the production of double sided surface mount and through hole mixed technology circuit assemblies, the board may see multiple soldering and therefore thermal cycles before the cleaning process. Each additional thermal cycle hardens the flux residue by degassing lower molecular solutes from the resin structure thus increasing the cleaning challenge. Additionally, some of the higher molecular weight resins may undergo thermal oxidation rendering a much different residue (polymerizing or cross-linking) set to clean.

Flux technology used with eutectic tin-lead solders, cleaning chemistry, and mechanical equipment innovations have opened the process window to a point where flux residue is still cleanable. With the trend of high density population, low standoff components, and *low solids* soldering, the difficulty of cleaning flux residues exposed to multiple reflow cycles may require aggressive cleaning conditions that may affect board compatibility and its assembled components.

**4.2.4.2 Lead-Free Soldering** Lead-Free soldering creates a new challenge from a cleanability perspective. High tin *lead-free* alloys exhibit poorer wetting properties, higher melting points, and higher molecular weight flux compositions to improve thermal stability. The deficiency in alloy wetting has to be compensated with a flux that facilitates improved wetting. This results in flux compositions with lower surface tension by increasing flux activation and synthetic polymers.<sup>12</sup> To reduce voiding, the reflow profile requires longer soak time to dry out volatiles, which requires a flux composition with higher oxidation resistance, oxygen barrier capability, high thermal stability, and low volatility.<sup>12</sup> These effects translate into a greater level of high molecular weight flux residue that is harder to clean.

When designing *lead-free processes*, a pre-existing cleaning process designed for tin-lead materials may not be sufficient for removing *lead-free* flux residues. Cleaning materials may require new or combinations of solvating materials and processes.

dissolution of high molecular weight polymers. Cleaning materials may require increased levels of reactive saponifying agents, which can create and exacerbate compatibility concerns. Some cleaning machines for such processes may be modified to increase mechanical action and the length of the wash sections may be increased to facilitate longer exposure time to the cleaning agent. These design related factors require an increased responsibility on the part of the assembler to validate that these changes still meet the desired result.

**4.3 Cleaning Agent Design Options** Electronic assembly cleaning material design options cover three classes that include solvent, semi-aqueous, and aqueous compositions. During the pre-ozone depletion era, CFC-113 and rosin-based flux compositions were the standard. Currently, the cleaning agent of choice is selected based on the soil to be cleaned, through-put, readily available cleaning equipment, compatibility with materials of construction, cost, and environmental regulations. All cleaning material types comprise strengths and weaknesses. In most cases, the application drives the cleaning material type.

Certain flux materials are not designed to be cleaned. Some of the no-clean flux products are classified as cleanable no-cleans. On the design side, the soldering material selected by the assembler needs to consider a product that is cleanable. Clients should inquire about the cleaning properties with their soldering materials supplier.

**4.3.1 Solvent Cleaning Materials** Solvent cleaning materials use one to three of the four building blocks: solvency, minor ingredients, and wetting. Several classes of solvents have been identified as alternatives for ozone depleting chemicals. A key property of solvent cleaning is the composition's evaporation after use, when cleaning the circuit assembly or advanced package. Heat of vaporization transforms the solvent into a vapor state from the liquid phase. Some solvent cleaners are mixtures that form azeotrope or azeotrope-like constant boiling properties. Compositions that exhibit low heat of vaporization, dispersive, and polar properties are desirable printed wiring board vapor degreasing candidates. They may be self-rinsing and have low residue. Volatility and ease of vaporization can be drawbacks that include containment, flammability, toxicity, and local regulations on emissions. It is necessary to balance the positive and negative aspects of the cleaning agent.

Solvent cleaning materials are commonly used on parts that cannot tolerate water during the cleaning process or where better wetting is required. The contaminant (flux residue) requiring removal must disperse and dissolve in the cleaning solvent mixture. As flux evolved from rosin-based materials, the properties of water soluble, low residue and synthetic compositions may or may not disperse and dissolve into the solvent cleaner. Solder paste and wave flux must be selected on the basis of solvent dissolution.

**4.3.2 Semi-Aqueous Cleaning Materials** Semi-Aqueous is the process of solvent washing/water rinsing. Semi-Aqueous products use three of the building blocks-solvency, wetting, and minor ingredients-in the formulation design. The objective is to solvate the soils from the surface of the assembly or component. Once the wash step is completed, the parts go through a series of DI water rinse steps to remove wash chemistry, spot mask and ionic residues. The parts are dried free of water and typically have contamination levels that are undetectable.

A broad array of product choices exists when choosing a semi-aqueous cleaning solvent. Each uses organic solvent mixtures but with different chemical structures. Most are a combination of low vapor pressure solvents, wetting agents and inhibitors. They are designed to remove both polar (flux, ionic salts) and non-polar (light oils, fingerprints, dust) soils. Semi-Aqueous cleaning agents have a typical bath life from two months to one year due to their stable structures and tendency to hold high levels of soil. Application temperatures are between 24° and 71°C [75° and 160°F], depending on the solvent's activity level versus temperature and the solvent's flash point. Semi-aqueous chemistries have good compatibility with most components used in electronic assembly.

**4.3.3 Aqueous Cleaning Materials** Aqueous cleaning materials are engineered concentrated fluids that dissolve with water. Aqueous cleaning materials are non-flammable and commonly processed in high energy machines (Table 4-2). High energy machines deliver the cleaning agent with velocity, pressure, spray channels, and flow. Aqueous concentrated products work based on the "*Cleaning Rate Theorem*" that holds: The static cleaning rate (rate at which the cleaning material dissolves the flux residue at its temperature and concentration in the absence of impingement energy) plus the dynamic rate (energy and time in the cleaning machine) equals the process cleaning rate.<sup>13</sup>

Table 4-2 Electronic Assembly Cleaning Agent Design Options

| Cleaning Agent Design                 | Organic Solvency Capability (Dissolution) | Reactant Saponifying Agents | Wetting | Minor Ingredients | Polar (Water Soluble)                                   | Non-polar (Water Insoluble)                          | Process Application    |
|---------------------------------------|-------------------------------------------|-----------------------------|---------|-------------------|---------------------------------------------------------|------------------------------------------------------|------------------------|
| Organic-based Solvent Cleaning Agents | High                                      | None                        | Yes     | Yes               | Some are water soluble and others are not water soluble | Some are non-polar and others may be partially polar | Bench Top Cleaning     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Under Stencil Wipe     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Stencil Cleaning       |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Pallet Finger Cleaning |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Wafer Level Pkg.       |
| Solvent Vapor Degreasing              | High                                      | None                        | Yes     | Yes               | Poor                                                    | Good                                                 | PCB Defluxing          |
| Semi-Aqueous Water-Insoluble          | High                                      | None                        | Yes     | Yes               | Poor                                                    | Good                                                 | PCB Defluxing          |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Advanced Packaging     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Wafer Level Pkg.       |
| Semi-Aqueous Water-Soluble            | High                                      | Low                         | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | PCB Defluxing          |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Advanced Packaging     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Wafer Level Pkg.       |
| Aqueous Solvent Blend                 | High                                      | None                        | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | Stencil Cleaning       |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Uncured Solder Paste   |
|                                       |                                           |                             |         |                   |                                                         |                                                      | SMT Adhesives          |
| Aqueous High Saponification           | Low                                       | High                        | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | PCB Defluxing          |
| Aqueous Medium Saponification         | Medium                                    | Medium                      | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | PCB Defluxing          |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Advanced Packaging     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Stencil/Misprint       |
| Aqueous Low Saponification            | High                                      | Low                         | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | PCB Defluxing          |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Advanced Packaging     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Stencil/Misprint       |
| Aqueous Neutral No Saponification     | High                                      | None - Low                  | Yes     | Yes               | Good cleaning performance on polar soils                | Good cleaning performance on non-polar soils         | PCB Defluxing          |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Advanced Packaging     |
|                                       |                                           |                             |         |                   |                                                         |                                                      | Stencil/Misprint       |

**4.3.4 Cleaning Equipment Design Options** Cleaning equipment designs are categorized into two classifications: batch and inline. The cleaning industry is constantly challenged to improve cleaning processes, staying ahead of the ever-advancing technology curve as it applies to increasingly new fields of application.<sup>13</sup> Processes are commonly represented as mechanical and chemical energy, temperature and time. Increased complexity of board and component geometry coupled with more difficult solder paste and flux formulations and cost of ownership concerns increased the demand on both static and mechanical driving forces. As a result, mechanical and chemical energy must make up for reduced temperatures and shorter process times.

To achieve a high production rate and an optimized process requires an accurate model to predict performance.<sup>13</sup> It has been suggested that most cleaning systems are governed by two fundamental principles: the solubility/reactivity rate of the residue in the cleaning solution and the physical energy available in the cleaning system. Equation 1 describes this relationship.

**Equation 1:** Process cleaning rate equation<sup>13</sup>:  $R_p \sim R_s + R_d$

Where;

Process cleaning rate =  $R_p$

Static cleaning rate =  $R_s$

Dynamic cleaning rate =  $R_d$

In equation 1,  $R_p$ ,  $R_s$  and  $R_d$  are the rates of removal of contaminate per unit of time.<sup>13</sup> Units will vary depending on the residues being cleaned. Rates for cleaning flux residue, rinsing wash chemistry, or drying water from a circuit assembly can be expressed as thickness or mass removed/second, volume flushed/second or mass removed/second. If solder balls or other particles were in the soil, then balls/second or particles/second would be appropriate units. When comparing rates of different cleaning processes, it may be appropriate to specify rates at the same temperature since rates are temperature dependent.<sup>13</sup>

An EMS company is contracted to build a lead-free assembly using SAC 205 no-clean solder paste. The high density device is populated with numerous leadless components. The OEM requires that all flux residues be removed from under component gaps. Static testing provides insight into the cleaning properties of all soils used to assemble the device. With this knowledge, the assembler gains an understanding of the difficulties that may be encountered when cleaning production assemblies. The next step is to select cleaning equipment that provides kinetic and thermal dynamic driving forces for delivering the cleaning agent to the soil. The process cleaning rate, which is the time required to clean the part, is a sum of the static and dynamic rates.

**4.3.5 Defining “An Optimized System”** The objective of mechanical cleaning systems is to reduce time by maximizing the physical energy delivered at the surface to be cleaned.<sup>13</sup> An optimized cleaning system is not overpowered or oversized. An optimized cleaning system delivers the necessary chemistry and energy to clean the most difficult or sensitive areas, at a rate that will meet the process time requirement using minimal chemical, energy and floor space consumption. In this definition of an optimized spray in air or batch cleaning system, it is important to note that the system should be designed to clean the toughest or most electrically sensitive areas of the parts to be manufactured. Minimum gap (space between assembly surface and bottom side of component), largest, or most complex components usually leads the way to identifying these areas.<sup>13</sup>

**4.4 The  $R_s + R_d$  Balance** Understanding the balance of  $R_s$  and  $R_d$  is key in predicting and optimizing process performance at each step of the washing, rinsing, and drying process.<sup>13</sup> Suppose for a minute that we washed our clothes by throwing them in a bucket of soapy water overnight. The water would dissolve the salts and sugars thoroughly and rapidly because of the high solubility rate ( $R_s$ ). The oils and greases would disappear slower and perhaps incompletely due to marginal solubility and low dissolution rates. Earth's persistent gravity (9.8m/sec) would be the only energy available to the static bucket cleaner to remove insoluble dirt and other adherent soils and some of it might drop off, but most would remain behind. Understanding the nature of the soil and the chemical and physical needs for removing it, allow us to select the bucket for a silk blouse with a coke stain or the heavy-duty cycle on our washing machine for kids' play clothes.<sup>1</sup>

The static cleaning rate is a function of the cleaning agents solubility at the defined operating temperature and concentration. The dynamic cleaning rate is a function of the kinetic energy forces used to deliver the cleaning agent, penetrate minimum gap areas (space between assembly surface and bottom side of component), high component density (distance between components in X and Y directions), the surface area under the component, and the solubility characteristics of the soil being removed. Spray-in-air cleaning machines deliver direct impingement using nozzle flow, angles, and pressure.

Static immersion in the absence of dynamic energy relies totally on the cleaning agent. Dishwasher style cleaning machines provide high flow, directional forces, and pressure. Planarized batch machines track the spray manifold over a stationary surface designed to hold parts. Inline spray-in-air machines track the boards on a moving conveyor with spray manifolds impinging the surface through-out the process. (Table 4-3)

**Table 4-3 Static versus Dynamic Design Options**  
(data findings are supported by several research studies)

| Static/Dynamic Design Options |                 |                   |                 |                   |             |                   |
|-------------------------------|-----------------|-------------------|-----------------|-------------------|-------------|-------------------|
| System Design                 | Wash            |                   | Rinse           |                   | Dry         |                   |
| Driver                        | Static Rate     | Dynamic Rate      | Static Rate     | Dynamic Rate      | Static Rate | Dynamic Rate      |
|                               | Chemical Forces | Mechanical Forces | Chemical Forces | Mechanical Forces | Convection  | Mechanical Forces |
| Static Immersion              | 100%            | 0%                | 100%            | 0%                | 100%        | 0%                |
| Ultrasonic Immersion          | 50%             | 50%               | 70%             | 30%               | 70%         | 30%               |
| Spray Under Immersion         | 80%             | 20%               | 50%             | 50%               | 50%         | 50%               |
| Dishwasher Style              | 60%             | 40%               | 70%             | 30%               | 70%         | 30%               |
| Planarized Batch              | 50%             | 50%               | 40%             | 60%               | 40%         | 60%               |

Normally,  $R_s$  or  $R_d$  dominates a given cleaning process step. Inline “air spray” cleaners and planarized batch cleaners are examples of cleaning processes dominated by high mechanical energy. Dip tanks, “spray under immersion,” “dishwasher style” batch “air spray” cleaners and vapor degreasers are examples of cleaning processes dominated by high chemical forces. There is the potential for any application of force to damage components or substrates. High pressure spray is not always safe for the assembly. Ultrasonic action is not always detrimental.

#### 4.5 Environmental Factors

Environmental laws must be incorporated with Designing for Manufacturing.

The following questions need to be considered when selecting a cleaning agent:

- Will air emissions require permitting (federal/state/local)?
- Will cleaning agent result in a waste water discharge that require permitting (generally Local requirement)?
- Will cleaning agent generate a “new” hazardous waste stream that must be registered and profiled?
- Will the cleaning agent require annual release reporting (air/water/off-site waste) under EPA Toxic Release Program?
- Are the substances of the cleaning agent “acceptable” to customers?
- Will the manufacturing process (no-clean processing) leave a residue that must be considered under REACH or RoHS directives?

Section 9 of this document provides a comprehensive overview of Environmental Considerations.

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## 5 MATERIALS COMPATIBILITY

Engineers responsible for the cleaning process must be aware of possible material compatibility problems. The information contained in this section seeks to provide the process engineer with awareness of the material compatibility risks when cleaning electronic hardware. Factors of concern are circuit board laminates, surface finishes, components, metal alloys, adhesive bond strength, part markings, plastics, the mix and configuration of materials in the assembly and the impact of entrapped contaminants. Other factors must also be considered, such as the chemical characteristics of the cleaning material, cleaning temperature, impingement energy, and exposure time to the cleaning process, including rework cycles. The possible interactions of all these factors are especially challenging today with the much wider availability of board and component lead finishes, as well as joining metals. The difficulty of locating data on each and every possible combination of factors associated with this issue creates a high level of complexity.

**5.1 Material Compatibility Considerations** Critical material compatibility considerations when designing the cleaning process are components, assembly materials, cleaning agents, impingement energy applied during the cleaning process, anticipated process time, temperature and equipment design. Cleaning factors that may impact the effectiveness of the cleaning process include the cleaning agent, wash bath concentration, flux loading, cleaning equipment, spray pressures, fluid flow, speed, and process temperatures. These same factors may influence materials compatibility. Consideration also may be given to interactions that occur as a function of cleaning bath lifetime due to contaminants from potentially incompatible materials built up in the bath.

**5.1.1 Cleaning Process Effectiveness** Design and material factors that impact the effectiveness of the cleaning process include circuit density, component standoff height, flux residue compositions, reflow temperatures, and number of thermal exposures before the cleaning process. Assembly materials that may be materially affected by the cleaning process include board laminates, surface finishes, plastics, components, labels, part markings, metallic alloys, coatings, non-hermetic sealed components, and adhesives. Process chemicals (including cleaning and surface preparation processes) used in preparation of the components and materials of construction may be materially affected during assembly cleaning process. Process chemistries that may impact the effectiveness of the cleaning process include SMT solder paste, SMT solder flux, wave solder bar, wave solder flux, rework solder wire, rework solder flux or any other material that must be removed during the cleaning process.

**5.2 Reliability Considerations** Factors important to ensuring the reliability of PCB assemblies requires an understanding of the raw material properties and characteristics from which electronic components and assemblies are made. An appreciation of potential negative impacts of the cleaning process on the surface qualities and even on overall component structure is fundamental for successful design engineering when selecting fluxes, paste, adhesives, substrates, cleaning materials, conformal coatings, and other common interconnect materials. The actual behavior of a material can vary from the theoretical or expected performance in various situations. Material properties vary from batch to batch and may impact material compatibility. Factors that affect the material behavior such as cleaning agent, cleaning time, cleaning temperature, number of exposures to the cleaning process, and impingement energy should be tested to understand material interactions.

**5.3 Material Compatibility Testing** Compatibility testing procedures to assure the printed wiring assembly materials of construction are compatible with the cleaning process are necessary during the process design phase. All chemicals have the potential to adversely affect substrates, components and equipment.

Compatibility testing is usually carried out for two time periods. The short test is the anticipated cleaning cycle time, which is often equipment or operator dependent. The time for the long test should be determined by the assembler/manufacture. For example, the long exposure test could mimic the exposure time to the cleaning agent if the assembly fell off the conveyor belt or out of the basket and remained in the sump during the entire shift. Long term testing is also needed to determine the influence of the cleaning agent with the cleaning equipment. Thus these test times could vary from 5 to 10 minutes up to 8 hours. To simulate rework, multiple exposures need to be performed.

It is suggested that both Standards and controls be used. Because defluxing processes are always a balance between optimizing removal of soil and avoiding materials damage, it is important to evaluate new processes with an eye to achievable reality. In this regard, if the materials compatibility attributes of a new defluxing process are being evaluated, it is prudent to, at the same time, test the existing process as a control or benchmark using the same performance and compatibility standards as are used for the new process. It is not uncommon to find that existing chemicals and processes that have been successfully used for years do not pass the long-term materials compatibility requirements that a manufacturer has set. Using controls as well as setting compatibility standards helps to avoid situations where it is erroneously determined that 'nothing works.'

**5.3.1 Compatibility and Functionality** Any cleaning or manufacturing process has the potential to result in materials compatibility issues. In some cases, there may be subtle surface changes. Such changes may be beneficial or benign. The definition of an acceptable surface depends in part on the end-use requirement of the assembly. The definition of compatibility also depends on the specific application.

While there are many standard tests for compatibility, and while such standards should be cited where appropriate, compatibility testing must be customized. There are many variables to consider. For this reason, while compatibility tables offered by suppliers and vendors provide a good starting point, testing must be tailored to the application in question.

**5.3.2 Selecting Materials to be Tested for Compatibility** Material compatibility testing using standard test vehicles and exposed product hardware is critically important when considering a process change. Compatibility studies during the design phase are helpful in selecting the best cleaning agent choices, process temperatures, times, and impingement energy when exposing product hardware to the cleaning process while not materially affecting the printed circuit assembly.

**5.3.2.1 Assembly Materials** All materials included in the assembly process, including flux residue and cleaning agents, should be tested for compatibility. Designing compatibility tests requires judgment. To address these concerns, short term exposure tests are recommended on the materials of construction used to build the printed wiring assembly. Short term means a reasonable "stress test" of expected process conditions. Some examples include a reasonably anticipated increase in temperature (somewhat beyond the expected process range), higher mechanical forces, and an increase in process time.

**5.3.2.2 Fixturing, Tooling, and Process Adjuncts** Longer term testing from 2-weeks to 3-months may be appropriate for materials of construction typically found in cleaning systems such as tanks, fixtures, plumbing, filtration, water treatment, ventilation, etc.

Some factors to consider in determining equipment compatibilities include:

- Temperature.
- Solvency.
- Plastics or metals used for plumbing and long term exposure.
- O-rings, pumps, ball valves, etc.

In addition, the adverse impact of swelling, cracking and aging on fixtures must be considered, because such fixtures may not perform properly and may recontaminate the product. Equipment vendors should be able to assist with general equipment compatibility. In evaluating equipment, be sure to clearly communicate expected process conditions.

**5.3.2.3 Evidence of Incompatibility** Typical parameters used are weight gain or loss, elongation after exposure and recovery of original dimensions, dimensional changes, change in color or texture of the component, and change in color or opacity of the surrounding process fluid. In addition, surface finish, contact angle, and/or surface analysis may be deemed appropriate.

If the product is to be used for medical applications, proximal to or within a living host, it may be prudent to consider the impact of surface change or product changes on the host, referring to the appropriate ASTM, AAMI, and ISO standards (especially the ISO-10993 series). This is important where the texture of the surface is crucial to functionality and where leaching or outgassing of residue from the component could cause a problem.

**5.3.2.4 Test Design** It is generally preferable to conduct compatibility testing using the combination of materials for a given assembly rather than to test each individual material separately. This may seem counterintuitive in that in an academic sense it would be preferable to test each material separately; however, given the complexity of interaction among materials, the impact of a given cleaning agent or cleaning process on a single material of construction does not reliably predict the behavior when an entire assembly is exposed to the same cleaning agent or process.

In addition to determining process compatibility, dynamic compatibility is more likely to yield practical information than is determining compatibility by exposure to the chemistry under static conditions.

**5.3.2.4.1 Controls** If the fluxing or defluxing process is to be changed but the product and/or product requirements remain the same, and if processes exist that have been historically deemed acceptable, it is instructive and prudent to use the current process as a control or benchmark during new process development.

**5.3.3 Test Methods: Examples** Standard test methods can be used for components and product hardware. Examples are provided below; they are not meant to be exclusive or exhaustive. The test methods may not be adequate for all end-use requirements. The appropriate method should be selected by the manufacturer.

#### **5.3.3.1 Example: Material Compatibility on Non-Metallic Materials and Components**

**Scope:** To measure the effect exposure to a chemical has on non-metallic substrates after 2 hours (short-term) and/or 168 hours (long-term), based on hardness and volume.

**Reference:** Pratt & Whitney Specification: PWA 36604 Revision B Revised 06-08-98; Compatibility with Non-Metallic Materials.

**Terminology:**

- Density Change: Difference between Density after exposure minus Density before exposure.
- Hardness Change: Durometer B minus Durometer A.
- % Volume Change: Final mass less initial mass divided by initial mass X 100.

**Summary of Method:** This procedure records the a) density change, b) volume change and c) hardness changes of a non-metallic substrate when exposed to a chemical for 2 hours (Short-term exposure) and 168 hours (long-term exposure).

**Apparatus:**

- Balance; capable of measurement to the nearest 0.1 mg.
- Durometer.
- Beaker or jar large enough to hold sample specimens.

**Reagents and Materials:**

- Test solution at specified concentration and temperature.
- DI water.

**Procedure:**

- Measure the hardness of sample substrate and record as Durometer "A."
- Weigh sample in air and record as "a."
- Weigh sample in DI water and record as "b."
- Expose sample substrate to the solution to be tested for 2 hours (short-term) or 168 hours (long-term) at room temperature unless otherwise specified.
- Rinse thoroughly with DI water.
- Weigh sample substrate in DI water and record as "c."
- Dry and measure hardness of tested substrate and record as Durometer "B."

• Calculate:

$$\text{Initial Density: } \frac{\text{wgt in air}}{\text{wgt in air} - \text{wgt in water a-b}} = a$$

$$\text{Density after exposure: } \frac{\text{wgt in air}}{\text{wgt in air} - \text{wgt in DI after exposure a-c}} = a$$

Density Change: Density after exposure minus density before exposure.

Hardness Change: Durometer B minus Durometer A.

$$\% \text{ Volume Change: } \frac{(M_3 - M_4) - (M_1 - M_2)}{(M_1 - M_2)} \times 100$$

Where:  $M_1$  = Mass of sample in air (grams) initial

$M_2$  = Mass of sample in water (grams) initial

$M_3$  = Mass of sample in air (grams) final

$M_4$  = Mass of sample in water (grams) final

**Notes and Comments:** For long-term compatibility, expose the sample substrate to the chemical for 168 hours before taking final readings. Use separate specimens if both short-term and long-term compatibility is required.

**Additional Considerations:** In the case of porous samples it is essential to completely dry the sample prior to weighing to eliminate all moisture.

### 5.3.3.2 Example: Material Compatibility on Metallic Alloys

**Scope:** To measure the effect exposure a chemical has on metallic substrates after 24 hours (Short-term) and/or 168 hours (Long-term), based on weight change and visual observations.

**Reference:** ASTM F-483; Standard Test Method for Total Immersion Corrosion.

**Terminology:**

- Discoloration: A lightening, darkening or color change of the substrate versus a control.
- Etching: A roughening or change in the morphology of the specimen surface.
- Pitting: Holes or gouges on the substrate surface.

**Summary of Method:** This procedure measures the weight change and visual differences of metallic specimens after exposure to specified chemicals.

**Apparatus:**

- Balance; capable of measurement to the nearest 0.1mg.
- Beaker or jar large enough to hold sample specimen. Use a separate jar for each metal substrate tested.

**Reagents and Materials:**

- Test solution at specified concentration and temperature.
- DI water.
- Acetone.
- Approximately 1 inch X 2 inch metal coupons, 2 each per alloy to be tested.
- Non-metallic abrasive pads. (Mike B to check spec)

**Calculations:** Report weight loss as mg/cm<sup>2</sup>/24 hours.

**Procedure:**

- Coupon preparation:
  - Using a wet 3M abrasive pad, lightly scrub both surfaces of the metal coupon.
  - Rinse with warm tap water followed by a rinse in DI water.
  - Using a wash bottle, rinse with a stream of acetone.

- Oven dry at 120°C [248°F], then desiccate until cooled to ambient temperature.
- Weigh one of two specimens of each alloy to the nearest 0.1 mg. (Use the second specimen as a visual control.)
- Immerse the weighed specimen of each alloy in the test solution (use a separate jar for each substrate tested), at room temperature unless otherwise specified, for 24 hours.
- Remove the test specimen and rinse with warm tap water followed by a rinse in DI water.
- Using a wash bottle, rinse with a stream of acetone.
- Oven dry at 120°C [248°F]; then desiccate until cooled to ambient temperature.
- Weigh and record.
- Calculate weight loss as mg/cm<sup>2</sup>/24hrs. (Short-term corrosion)
- Examine for and record the following visible changes in comparison to the unexposed control.
  - Discoloration and dulling
  - Etching
  - Pitting or localized attack
- For Long-term corrosion, immerse the same coupons in the same test solution for a further 144 hours.
- Repeat steps c, d, e, f and g.
- Calculations: Report weight loss as mg/cm<sup>2</sup>/24hrs. (Long-term corrosion).

**Notes and Comments:**

- It is not necessary to remove specimens after 24 hours if only long-term corrosion is needed.
- In general for non-catalytic reactions the reaction rate doubles for every 10°C [50°F] temperature rise.

**5.3.3.3 Product Hardware per J-STD-001** The protocols defined in the IPC Joint Industry Standard, J-STD-001 Appendix, Material and Process Compatibility Testing applies for:

- Validation of all flux material changes regardless of the J-STD type designation.
- When cleaning agents are changed.
- When changes to qualified processes are proposed that include major equipment or method changes. Examples of these types of changes include:
  - Cleaning equipment changes
  - Fluxing Methods
  - Reflow Processes

**5.3.3.3.1 Material Compatibility on Test Vehicles** Test vehicles used in the material compatibility evaluation shall meet the requirements defined in J-STD-001 Appendix, Material and Process Compatibility Testing, section titled, “Test Assembly.”

- Test Vehicles\* selected shall provide for assessment of various component technologies and packages with both through-hole and surface mounted components, including fine pitch and BGA devices. To facilitate testing the test vehicles shall include “Y” and Comb patterns defined by IPC and Telcordia Technologies specifications. Test vehicles shall be fabricated with the same type substrate, metallization, and solder-resist that represent the actual product.
- Manufacturing of the test samples shall represent the proposed production processes. Samples built with an isolated process may not adequately represent the true production environment. Residues from other process steps may cause interactions that must be considered in the total test.
- Minimum sample size for each material/process combination tested shall be 10 vehicles, consistent with J-STD-001 Appendix section titled, “Sample Size,” unless otherwise agreed to between the assembler and OEM.
- Testing shall include substrate materials and finishes per IPC-SMA-840. To establish baseline data, at least one bare board for each substrate and/or mask type shall be tested.

**\*Note:** In the context of compatibility studies Test Vehicles can mean any material, alloy, or component that may be used on your assembly.