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ALTERNATIVES TO CFC-SOLVENT BASED CLEANING FOR PCBS: WHICH OPTIONS ARE INDUSTRY PARTICIPANTS CHOOSING?

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ABSTRACT

Electronic equipment manufacturers and contract manufacturers, struggling to comply with environmental regulatory requirements by the year 2000, are searching for the best replacement for their chlorofluorocarbon (CFC) solvent-based printed-circuit-board (PCB) cleaning systems. Unfortunately, CFC solvents are difficult to replace because they are an effective cleaner for rosin-based fluxes: they are stable, have low toxicity, are nonflammable, are high in purity, evaporate quickly, and can be recovered for reuse. Yet they deplete the ozone layer, and therefore, must be replaced in electronics manufacturing operations. Aqueous cleaning was the most popular alternative for cleaning PCBs in 1991. Although demand for semi-aqueous and other chemical CFC-alternatives was still quite small in 1991, solvent improvements and the availability of new solvents could increase the demand for these alternatives by 1994. Approximately 15% of the overall market assembling PCBs has gone to no-clean fluxes in 1991 and this trend to use no-cleans will increase dramatically. The growth rate is highly dependent, however, on the products currently being developed by suppliers. Technology Forecasters has studied user demand in the PCB cleaning market and will present information on users' concerns, available alternatives, and

a market analysis of the alternatives by electronic industry group. The time has come to select and begin using alternatives to CFC solvents.

1. INTRODUCTION

The analysts at Technology Forecasters interviewed engineers from 30 electronics companies regarding their use of solder pastes, fluxes, and printed circuit board (PCB) cleaning processes in 1991. We wanted to find out how these engineers planned to cope with the required elimination of CFC solvents from PCB cleaning. Respondents represented the computer, communication, industrial and instrumentation, consumer and auto, and contract manufacturing industries. We also interviewed 20 companies that supply the electronics industry with cleaning equipment, solder pastes, and fluxes to understand how they planned to cope with their customers' decreasing use of CFC solvents.

2. REGULATORY IMPETUS TO CHANGE

In 1987, when the Montreal Protocol Conference called for the elimination of CFC production by the end of the century, almost all PCBs were being cleaned with CFC-113. Since then the U.S. government has ratified the Montreal Protocol, revised the Clean Air Act to mandate the elimination of CFC production and other chemicals that erode the ozone, placed a substantial progressive tax on all ozone-depleting materials, and mandated that products manufactured by using any CFCs must be so labeled starting in 1993. Some local governments have completely outlawed the use of ozone depleting compounds in any process, and in Europe the European Foundation for Quality Management now bases their Quality Award partially on a company's environmental protection practices.

By next year U.S. regulations mandate that CFC production represent only 80% of 1986 levels. Fortunately, many companies are already working on this CFC phase-out, as part of emerging "cradle-to-grave" environmental values in the electronics industry. And this phase-out is happening none

too soon: the Environmental Protection Agency's Chief, William Riley, recently stated that the decline in stratospheric ozone is occurring more than twice as fast as expected.

3. AVAILABLE ALTERNATIVES

In many cases, company management (whether eager to comply with environmental regulations, project a "good citizen" image to their clientele, or avoid excessive taxation on CFC solvents) has delegated responsibility to quickly eliminate CFC solvents from their PCB cleaning processes to the engineering and operations people. The challenge is to find a highly reliable cleaning alternative that meets the demands of increasingly complex PCB designs, while maintaining cost effectiveness, worker safety, and protection of the environment. Currently, 20% of U.S. electronics companies assembling PCBs have completely eliminated CFC solvents from their operations, and 25% to 30% still use CFC solvents exclusively. The others are testing, experimenting, using alternatives for selected applications, and phasing alternatives in gradually as they climb the learning curve. CFC cleaners are difficult to replace, because each of the alternative processes has noteworthy disadvantages.

In 1991, the most popular CFC alternative is an aqueous cleaning system. These washers require less costly consumables, are non-toxic to employees, and can be used on traditional fluxes or water soluble fluxes. But they require approximately 20 feet of floor space, large amounts of water which is prohibitive in water-conscious states such as California, a long drying time, saponifiers for high reliability boards using traditional fluxes, expensive waste-water treatment systems, restricted use of components that are not water-tolerant, and usually offer less-efficient cleaning compared to CFC solvents (especially in the removal of hydrophobic organic contaminants).

Alternative solvents such as hydrochlorofluorocarbons (HCFCs) or hydrocarbon blends are being promoted as an

interim cleaning solution—despite their ozone depletion potential. HCFCs could essentially be a drop-in solution to be used with modified equipment that originally used CFC solvents. Results of a study conducted by the Program for Alternative Fluorocarbon Toxicity Testing industry group, however, indicate that exposure to HCFC-123 produces non-malignant tumors in male rats. Based on this information, and the fact that this type of toxicity research takes five to seven years to complete, users will approach the use of HCFCs cautiously.

Semi-aqueous solutions such as the terpenes or alcohol-based solvents provide other alternatives. These substances require an additional rinse cycle after cleaning, and they can be highly flammable, destructive to conformal coatings, expensive, or toxic. Water and waste management are required for these systems. Semi-aqueous solvents contain hydrocarbons and thus are subject to strict state regulations based on their classification as volatile organic compounds (VOCs).

Ultrasonics, previously prohibited by the Department of Defense for cleaning military PCBs, has been reevaluated and deemed an acceptable cleaner for some military applications. It is currently used only in combination with a solvent or water-based cleaning system.

New methods of cleaning PCBs, such as use of carbon dioxide snow guns, liquid CO_2, and gaseous CO_2, and even lemon juice, are emerging quickly as suppliers seek to solve the cleaning problem for the industry. Hughes Aircraft Company recently developed a non-toxic aqueous-system solvent that passed testing by the Institute for Interconnecting and Packaging Electronic Circuits (IPC) with results superior to CFC-113 cleaning. Hughes calls the system RADS for reactive aqueous defluxing system.

No-clean fluxes allow users the opportunity to eliminate the entire cleaning process from the assembly line. With no-clean fluxes, large capital expenditures for cleaning equipment can be avoided and production time can be

decreased once processing is perfected. No-clean fluxes have the additional advantage of allowing users to escape cleaning-solvent and cleaning-waste regulation. Unfortunately, no-clean flux technology has not progressed to the point where the reliability of its boards is comparable to the reliability of a CFC-cleaned board; and it requires reflow in an inert atmosphere, leaves visible residue, interferes with test probes, needs precise application of the flux to the PCB, and requires considerable employee training for operational changes.

4. CURRENT AND FORECAST CLEANING PRACTICES

Since 1986 the use of CFC solvents in the United States for PCB cleaning had dropped by half. Which alternatives are currently being used by the other half of the electronics industry?

Approximately 25% of all PCBs assembled in the United States are cleaned with aqueous cleaners, 10% are cleaned with semi-aqueous solutions, and 12% to 15% are assembled with no-clean fluxes. The breakdown is not as straightforward as it sounds: (1) aqueous users may or may not use water-soluble fluxes and they only use saponifiers when necessary for certain applications owing to waste water disposal problems, (2) semi-aqueous use is unpredictable because results of ongoing toxicity studies may prove some unsuitable, and (3) many users are not changing their cleaning operations because they are waiting for breakthroughs in no-clean flux technology.

By 1994, most electronics companies will have made the changeover from CFC solvents to alternatives. At this time, CFC solvents will be used on only 20% to 25% of boards assembled. We expect that no-clean fluxes will be the predominant alternative in 1994 with 35% of the board volume, that aqueous cleaners will be used on 30% of the boards assembled, and that use of semi-aqueous and other HCFC alternatives will garner 10% to 15% of the board volume. The percent of no-clean flux users might change dramatically, if a supplier develops a no-clean flux that

provides board reliability equal to that of a CFC-solvent cleaned board.

5. CLEANING PRACTICES BY INDUSTRY

Those industries still holding on tenaciously to the CFC solvents are those whose products require high reliability cleaning such as companies producing computer, telecommunications, and military products.

The majority of those in the computer industry are still using CFC solvents for reliability reasons, and choosing aqueous cleaners as their first step toward the elimination of CFC solvents from their operations. Some of the computer industry respondents we interviewed indicated they are evaluating the no-cleans, but are continuing to use CFC solvents and aqueous cleaners for the most part at this time. Their biggest concerns with the aqueous systems is managing the lead content of the waste water and obtaining high reliability cleaning.

Companies in the communications industry are also reluctant to stop using the CFC solvents, but they have moved into alternative cleaning operations more quickly than the computer industry has. Many telecommunications companies have been using aqueous cleaners for some time, and they are currently investigating no-clean fluxes for their future operations. Some firms have already made the switch to no-clean operations exclusively. One of the main concerns indicated by telecommunication respondents is finding a workable flux that can be easily removed from 0.020" lead-spacing.

Military and aerospace companies, owing to their high reliability requirements, are mostly using CFC solvents in 1991. Some of these companies, though, have begun to move toward semi-aqueous solutions as the most reliable alternative. It is also the most expensive alternative.

Industrial and instrumentation companies do not show a concrete trend toward any one CFC-solvent alternative due to

their great diversity of products and markets. Some use no-cleans exclusively while others, searching for the best high-reliability alternative, have installed extensive semi-aqueous systems.

Although most consumer and automotive companies are using no-clean fluxes, few are using them exclusively. Respondents in these industries are using no-cleans when possible and CFC solvents otherwise. Reliability seems to be the determining factor as to which process is used for each different application. One respondent complained that the no-cleans are not as simple to use as he had originally thought. He says the through-put for aqueous cleaners is much faster than for no-cleans owing to the flexibility of the aqueous process.

Contract manufacturers must satisfy their customers demands for cleanliness, so many contractors use more than one type of cleaning process to meet each customers' specific needs. Respondents from our study typically employ at least three different types of PCB cleaning processes. The most popular combination is aqueous cleaning systems, CFC solvents, and no-cleans. Most contractors interviewed for our study intend to purchase additional aqueous cleaning equipment within the next two years.

6. INDUSTRY ANECDOTES

Most of the large electronic equipment manufacturers have been especially active about tracking down workable CFC-solvent alternatives for PCB cleaning. What have they found that works?

AT&T uses aqueous cleaners for much of its PCBs, although for some high-reliability boards, the aqueous systems were not cleaning efficiently enough. Gregory Munie at AT&T Bell Laboratories and Courtney Dodd of AT&T Network Systems together developed a water soluble flux to increase the efficiency of their totally aqueous systems. They modified the fluxes to prevent absorption of glycols and to increase the hydrophobicity. Some AT&T plants are using a low-solids

flux for wave soldering in an inert atmosphere which eliminates the need for PCB cleaning altogether. For this no-clean approach AT&T Bell Labs has developed a low-solids fluxer (LSF) that can apply fluxes on PCBs reliably and so accurately that little residue is left. AT&T conducted an extensive evaluation of terpene solvents for PCB cleaning as well. The company is determined to phase-out all CFC solvent emissions from its plants by 1994, and will not even use packaging materials that have been manufactured using CFCs. Last year, the AT&T Engineering Research Center in Princeton, NJ, was presented with the Governor's Award for Outstanding Achievement in Pollution Prevention.

Intel Corporation has switched to water-soluble solder pastes that can be cleaned with only water, and they switched to a no-clean flux for any soldering that is required in final assembly. Intel estimates that these simplified cleaning and no-cleaning processes will save them more than $1M this year. Intel intends to be CFC-free by the end of this year.

Some large companies, such as Motorola and Raytheon employ semi-aqueous cleaning systems for their high-reliability and rosin-based flux requirements. Motorola's Paging and Teleprint Communications Division manufacturing plant in Florida is using terpenes and a water rinse to clean PCBs. This system allows the company to continue using rosin-based fluxes and solder pastes that they are accustomed to processing. Motorola also installed closed-loop water recycling units with the semi-aqueous cleaners to prevent any discharge of lead-contaminated wastewater, even though they are allowed to do so by local regulations.

The Ford Motor Company is moving toward using more no-clean fluxes to eliminate the entire cleaning process. According to the respondent from Ford, board cleaning is a non-value added step and the best assembly method involves no cleaning at all.

Digital Equipment Corporation cleans PCBs, including SMT boards, with a water solution that the company developed two

years ago. Compaq Computer Corporation has converted to no-clean fluxes on selected products, and has set a goal of eliminating CFCs completely by 1995. The respondent from Compaq stated that no-cleans are the way of the future, and that if companies are truly concerned about the environment they must move to a clean-free system.

7. LOOKING FORWARD TO COMPLETE CFC ELIMINATION

The engineering or operations manager who is responsible for changing the manufacturing process to accommodate the elimination of CFCs must consider a wide variety of constraints and factors. Costs are difficult to assess because each system involves different capital expenditures, training, processing, and operational changes. For example, an aqueous system requires more floor space, a semi-aqueous system requires the added time and training for a two-step process, and other solvent alternatives such as HCFCs may require a closed-loop system to control toxicity. Although no-clean fluxes and solder pastes require no substantial capital expenditure, the required training, operational changes, or new processing controls may be extensive.

All of this means that managers coordinating the change-over from CFC-solvent use should set a reasonable timetable for this change. It will not be easy. Several management teams have mandated the elimination of CFCs without allowing sufficient time to evaluate alternatives and set up an appropriate environment for a successful transition.

Many companies are making this transition, however, and several have found that the alternatives are actually saving them money and time. Most importantly, though, these companies that have eliminated CFC solvents from their operations are contributing to the preservation of a safe worldwide environment.

8. BIOGRAPHY

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