

# A Clean Break from CFCs

By Kevin Borek

In 1988 Northern Telecom, a global manufacturer of digital telecommunications equipment, committed to eliminating the use of CFC-113 in all of its manufacturing plants by the end of 1991. This measure was a response to the growing body of evidence that CFCs are directly responsible for the reduction of ozone in the upper atmosphere.

CFC-113-based cleaning solvents were being employed to clean PCBs used in Northern Telecom's *Meridian 1* private branch exchange. In 1989 the Private Networks Group (Santa Clara, CA) began an analysis of alternatives to CFC-based cleaning processes. Factors considered in the analysis included product/process compatibility, process yield, ease of use, operating cost and environmental impact.

## Alternatives Evaluated

Products manufactured in the high-volume Santa Clara facility include high-density double-sided fine-pitch SMT, high-density conventional SMT, conventional double-sided through-hole and single-sided products. Several process alternatives were evaluated. Of primary interest was the selection of a process that would yield product reliability equivalent to that of CFC-based cleaning without narrowing the process window. The following alternatives were considered.

**Cleaning Process Elimination.** No-clean soldering processes were the first to be considered at the facility. They had been successfully implemented in other manufacturing plants and required less capital equipment. However, the characteristics that make these materials benign enough to leave on the assembly (i.e., low molecular weight and low flux activity) also impacted soldering yields. This effect was particularly prevalent on boards with dry-film solder mask, higher thermal mass or less-than-optimal solderability.

Flux residues also interfere with downstream processes, such as in-circuit test. In addition, there was no way to remove mechanical contaminants, such as router dust, glass fibers and solder balls.

**Drop-in CFC Replacements.** These alternative organic solvents can be used as substitutes for CFC-113 in existing equipment. These materials were briefly evaluated and rejected for various reasons, including concerns about operator exposure, the status of these solvents under the provisions of the Montreal Protocol and their impact on the environment.

**Aqueous Cleaning.** Aqueous cleaning comprises three categories: semiaqueous with hydrocarbon/surfactant blends, aqueous with saponified water and 100%-

aqueous cleaning with deionized water.

Both semiaqueous processing and cleaning with water and saponifiers are compatible with rosin-based fluxes, which meet military, IPC and Bellcore corrosivity specifications.

Our analysis showed that there are significant advantages to using 100%-aqueous cleaning processes in comparison to semiaqueous and saponified water-based systems. It also indicated that an equivalent or superior product can be produced. The following factors are critical in evaluating the process.

- It costs less to purchase, operate and maintain a 100%-aqueous cleaning system due to the less complex nature of the equipment.
- The flux residues are easier to remove because they are completely water soluble.
- Soldering process yields are improved, and solder wetting characteristics are superior due to the higher relative activity of water-soluble fluxes.
- It is easier to recycle the process effluent.

## Process Selection and Qualification

After careful analysis of the available options, 100%-aqueous cleaning was selected. A series of qualification tests was initiated to verify product/process compatibility and to serve as a basis for equipment and soldering materials selections. A key factor in process design was the decision not to discharge wastewater to the sanitary sewer. All soldering materials had to be compatible with a waste treatment system.

The evaluations were grouped as follows.

**Preliminary Process Trials and Verification.** The concern most often mentioned relative to water-soluble

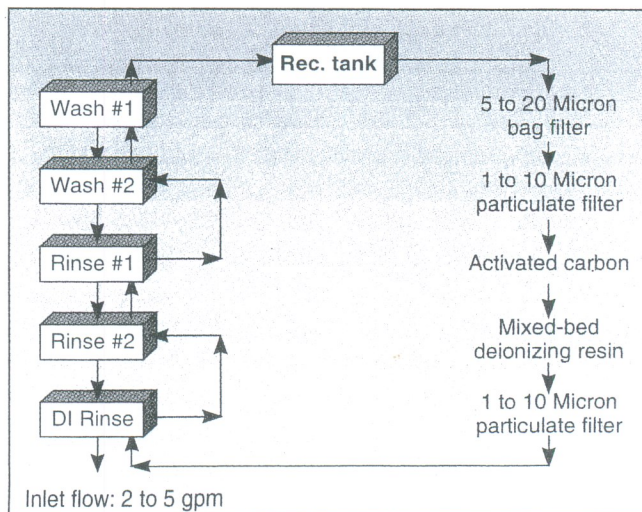


FIGURE 1: Diagram of the selected cleaning system.



CFC-based system	#Used	Cost/Item	Total
<b>Materials</b>			
Filter elements	6	12.27	73.62
Dessicant beads (lbs.)	1.5		
Freon TMS (lbs.)	3554	3.0021	10669.46
Electric power			650
<b>Facilities</b>			
Water (gal.)	3,675	0.0017	6.2475
Waste disposal (drums)	0.12	600	72
<b>Equipment maintenance</b>			
Manpower (hrs)			162.5
<b>Total cost per machine per month</b>			<b>11,633.83</b>
Aqueous-based system	#Used	Cost/Item	Total
<b>Materials</b>			
Bag filter elements	5	23	115
Cartridge filter elements	5	12.27	61.35
Resin (drums)	0.666	1,390	925.74
Carbon (drums)	0.333	11	39.294
<b>Facilities</b>			
Electric power		1,500	1,500
Water (gal.)	5,760	0.0017	9.792
Waste disposal (drums)	1.2	600	720
<b>Equipment maintenance</b>			
Manpower (hrs)	6.5	25	162.5
<b>Total cost per machine per month</b>			<b>3,533.66</b>

**TABLE 1: A cost comparison between the CFC-based systems and aqueous cleaning systems in the Santa Clara, CA, facility.**

fluxes is that they do not meet established corrosivity requirements. If not completely removed, they can cause corrosion and electromigration. The argument is that water has a high surface energy in comparison to CFC 113. Thus, when used as a solvent, water-soluble fluxes are difficult to remove from the small spaces beneath SMDs.

Preliminary evaluations, showed that aqueous flux solubility is high in heated deionized water, and most cleaning system manufacturers offer enough spray/air knife capacity to completely remove the residues. The selected system is shown in Figure 1. Destructive analysis and surface insulation resistance (SIR)/electromi-

gration testing were used to verify complete removal of flux residue.

The second concern was whether the cleaning equipment had the drying capacity to remove residual moisture from connectors and other water-trapping components in a high-volume environment. The greatest disparity in cleaner performance was drying capacity. The system in Figure 1 was selected based on drying efficiency and the inclusion of air knives between successive wash sumps to help remove flux residues from beneath components.

**Product/Component Compatibility.** A preliminary flux/solder paste combination was selected based on the process evaluations. Products were assembled using these materials and cleaned using equipment from various suppliers. A preliminary process specification was then documented. It included material data sheets as well as reflow process and cleaning profiles.

This document, along with a cover letter describing our intention to convert to the new process, was distributed to all of our component suppliers. They were asked to review the process information and provide a written statement of material compatibility. More than 95% of our component portfolio had already been qualified for aqueous cleaning. We ultimately subjected all of these materials to product-related reliability testing but were able to concentrate our efforts on evaluating the balance of unqualified components.

Components under evaluation included wire-wound devices from internal suppliers, mechanical switches and relays—all through-hole components. Approximately 3% were available in an aqueous-cleanable form. The remaining 2% were ultimately moved to postwave assembly stations, where they are assembled using no-clean fluxes.

**Product Reliability Testing.** The primary product failure mechanisms expected in a conversion to aqueous cleaning are metal corrosion, electromigration and SIR breakdown. It is easy to obtain comparative short-term reliability data on these mechanisms at an accelerated rate by increasing operating environment temperature and humidity.

In this analysis, multiple product samples were assembled, including

control and variable samples. (The latter are assembled using the proposed process and cleaned in various materials.) The samples were electrically tested, subjected to environmental preconditioning at temperature and humidity, and installed in functioning systems in environmental chambers. The products were functionally exercised at temperature and humidity while system per-

formance was datalogged. In other cases, individual samples were removed from the chamber on a weekly basis and parametrically tested. Failed components were replaced and saved for analysis. The systems were removed from the chambers after about 10 weeks of conditioning, and selected control and variable samples were identified for destructive analysis. Failed compo-

nents were also analyzed.

Samples were analyzed using traditional techniques, such as visual inspection, scanning electron microscopy, energy-dispersive X-ray analysis and metallurgical cross-sections.

SIR and electromigration testing are acceptable as quick, comparative determinants of PCB and flux compatibility. But we were concerned that the conventional IPC and Bellcore test procedures did not meet our application's requirements.

Our product typically includes 0.03"-pitch SMT devices, with some components as low as 0.02" pitch. Most operating voltages are under 15 VDC. In order to more effectively represent the product, an interdigitated test coupon was developed using daisy-chained 0.02"-pitch 208-pin SMDs. Nine components were assembled per board, and comparative SIR and electromigration data were gathered using traditional techniques. The only exceptions were that a 10-VDC bias was used as a soak voltage, and the test period was increased to 1,000 hours.

The results were positive (Table 1). There was no evidence of electromigration or SIR value reduction relative to CFC-113-cleaned control samples to 1,000 hours of testing.

The aqueous-cleaned samples performed as well as their CFC-cleaned counterparts.

*Wastewater Treatment Compatibility.* A key factor in the process design was the decision to recycle the discharged water from the cleaner for environmental and economic reasons. Although some companies had been recycling water from through-hole cleaning, no one had tried to recycle effluent bearing the high organic solids content associated with solder paste. Thus, it was necessary to carefully evaluate soldering materials in combination with our recycling equipment.

The recycling system we selected was manufactured by Separation Technologists Inc. (Methuen, MA). The discharge water is mechanically filtered, passed through activated carbon, deionized and then returned to the cleaning equipment. System performance is directly influenced by soldering materials and reflow profile. Solder pastes and fluxes with too high an organic load will foul mechanical filters and reduce the operating efficiency and life of the



## SEPARATION TECHNOLOGISTS

Separation Technologists, Inc.



deionizing beds. Flux chemistries that are too active will have the same effect, consuming deionizing resin at an accelerated rate. Obviously, the operating costs and cleaning efficiency of such a system are directly related to the frequency of filter and resin replacement. We found that the selection of fluxes and solder pastes can impact system operating costs by as much as 50%. Process consistency and cost are of the utmost importance in high-volume manufacturing operations, and these factors must be carefully considered prior to process installation.

Discussing our application with solder paste and flux vendors enabled us to establish the approximate composition of the effluent, identify the means of removal (e.g., mechanical, carbon or resin) and thereby estimate resin and carbon life expectancies.

### Process Implementation

The entire plant was converted to closed-loop aqueous cleaning over three months. Our first system, installed in August 1990, was used on a two-shift-per-day basis. One of the first relationships that had to be established after installation was that between water quality and PCB cleanliness at production volumes.

Product cleanliness is traditionally expressed in terms of volume resistivity and SIR measurements. Factors within the cleaning system that directly impact product cleanliness are water quality, sump spray pressure and volume, air knife efficiency and position relative to the conveyor belt, and conveyor speed. It is not possible to identify a specific level of water quality necessary for an application without considering cleaning equipment efficiency.

In the evaluations, most product qualification testing had been done with final rinsewater measuring above 0.5 m $\Omega$ /sq.cm and below 20 ppm total oxidizable carbon (TOC) content (a measure of organic content in the water). For this reason, 0.5 m $\Omega$ /sq.cm was arbitrarily selected as the resin changeout target. Water quality varies from over 18 to 0.5 m $\Omega$ /sq.cm and approximately 2 to 20 ppm TOC over a typical consumption cycle in the recycling unit. Although the water's organic content is monitored, we have not yet established a correlation between this

factor and product cleanliness.

Water with a TOC of 0.5 m $\Omega$ /sq.cm is very high in quality compared to tap water. We are evaluating whether our systems can run at lower levels of water quality and achieve acceptable cleanliness levels. None of the metal concentrations exceeds 5 ppb—a good indication of water quality.

The system's operating cost has been low compared to that of the CFC-113 systems. Table 1 provides a cost analysis based on one year of production experience. Not including equipment depreciation, the new cleaning system's operating costs are approximately 35% of the older CFC-based machines' operating costs. Most of these savings are taxes that are applied to CFC-based solvents.

An additional benefit of process conversion is that product soldering yields have improved approximately 50%. In addition, defect rates are typically below 100 ppm due to the improved wetting performance of aqueous flux chemistries.

### Future Work

We are seeking to improve the operating costs and performance of our cleaning systems. In the past, we have disposed of the activated carbon and deionizing resins as hazardous waste, which increases costs.

By adjusting deionizing bed composition, it is possible to selectively concentrate the heavy metals in one small bed and regenerate the balance of the system. The cost of regenerating deionizing resin is less than 20% of replacement costs (not including waste disposal costs). Regeneration is also favorable from an environmental standpoint because it will further reduce waste generation. We are also experimenting with different-sized mechanical filter elements to reduce resin bed fouling and extend the working life of the carbon and resin.

Other activities include defining a correlation between product SIR values and resistivity/TOC measurements at lower levels of water quality and developing a multipurpose test vehicle for aqueous process development. □

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*Kevin Borek is with Northern Telecom, Santa Clara, CA.*