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SUCCESSFUL IMPLEMENTATION of CLOSED LOOP SEMI-AQUEOUS CLEANING

by

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Abstract:

Following extensive materials and process testing, and equipment develop-ment, a Closed Loop spray cleaning cell utilizing the Semi-Aqueous, Terpene hydro-carbon BioAct ® EC7R, has been installed at the Motorola Inc., Communications Manufacturing Facility, at Plantation, Florida. This cleaning cell, which represents the present best viable alternative to CFC cleaning, is now being used to clean and to remove post reflow solder paste residues from soldered surface mount PCBs used in portable communications equipment. This paper will report the system development, production implementation and use history to date, review the terpene technology equipment developments to date, explain the environmental non-impact of system, outline the cleaning cell process philosophy and construction, and overall cleaning experience to date.

The Issues:

The concern about possible depletion of the ozone layer from CFCs, first proposed in 1974 (1,2), has now become universally accepted by the scientific and world government communities. As a result, an international treaty, named the Montreal Protocol, intended to control the production and consumption of stratosphere ozone depleting chemicals, became effective in January of 1989, and has been ratified by all major CFC producing nations of the world. As it now stands, the amended treaty controls all halogenated CFCs and halons, and requires a 50% reduction in production by 1995, with complete elimination by the year 2000.(3,4,5) In support of this treaty, the Omnibus Budget Reconciliation Act of 1989 placed an excise tax on the sale of chemicals which deplete the ozone layer and on products which contain such chemicals. Individual corporations through out the world have established their own individual corporate goals for compliance to the protocol. Some of the major corporate CFC elimination goals are published elsewhere (3), with Motorola Corporate goals shown graphically in Figure 1. With encouragement from our Chairman of the Board, Motorola has adopted an aggressive posture in this issue, and adopted a corporate policy on CFC elimination that reads:

> *" Motorola Inc., endorses the goal to eliminate by the end of 1992, the emission of chlorofluorocarbon chemicals (CFCs), that deplete the protective ozone shield. Motorola promotes and encourages the technology to develop CFC substitutes, since it is our policy worldwide to conduct all operations in an environmentally sound manner, as well as promote safety and avoid risk to our employees and neighbors."*

In addition to this, Motorola and eight other major US Corporations formed an Industry Cooperative for Ozone Layer Protection (ICOLP), with the EPA (3). The intent of this cooperative is that the parties will work together, and share information on new CFC alternatives with world wide industry, and help developing nations to do the same.

The Alternatives:

A number of alternative cleaning methods have been evaluated at Motorola and in the electronics industry with varying degrees of effectiveness. (6 to 14) These include: 1) Not cleaning at all, or using "low solids" wave fluxes and leaving the soldering residues on the assemblies (15); 2) Hydrochlorofluoro-carbon (HCFC) blends (16,17,18); 3) Alcohols, like isopropanol or pentafluroproponol (19); 4) Aqueous based processes, with or without saponifiers (20 to 24); 5) Controlled soldering atmospheres, both reducing and inert (25 to 28); and 6) Semi-Aqueous cleaning processes, which combine washing with hydrocarbon surfactant blends, and a subsequent water rinse to remove residual washing media (29 to 44).

The Semi-Aquaeous process which uses a terpene hydrocarbon, plus water rinse has been, to date, the most effective and implementable alternative, at Motorola.

The Chemistry:

At the present time, a number of hydrocarbons are available commercially for use in semi-aqueous cleaning applications. The most common and widely known hydrocarbons used for cleaning applications are called "TERPENES". They have a distinct advantage over other hydrocarbons in that they are natural products, are non-Ozone depleting, are used in foods and consumer products, are biodegradable, and are generally regarded as safe because of their low toxicity (45,46).

The terpene sold specifically for semi-aqueous cleaning applications in the electronics industry is called "BioAct® EC-7R", produced by Petroferm Inc., Fernandina Beach, Fla., and marketed world wide by Alpha Metals (47). The BioAct® EC-7R is made primarily of d-limonene, an orange rind extract. It has a slight orange odor, is a clear liquid with a specific gravity of 0.85, a vapor pressure of 1.6 mm Hg at room temperature, and a Closed Cup flash point of 120°F. The BioAct EC-7R is easily separated from it's rinse water, which will allow for the capture and reuse of both the rinse water and the terpenes lost through process dragout.

Although there are many terpene chemistries available, (i.e. "BioT®" by Coors, and "Citrikleen" by Penetone Corp.), none are sold specifically for PCB cleaning, as Petroferms position is patent protected (48 to 51). Alternate non-terpene semi-aqueous hydrocarbon blends are produced by DuPont, under the name "Axarel 38" (52).

The System:

The Semi-Aqueous (terpene) cleaning alternative to CFCs is defined as a wash with a terpene hydrocarbon-surfactant blend, and a subsequent water wash/rinse. The water wash/rinse step is necessary because the terpene hydrocarbons used in the cleaning operation have relatively low vapor pressures, don't easily evaporate, and therefore must subsequently be washed off. In order to conserve and recycle the rinse water effluent from the terpene washing equipment, a "Water/Terpene Separator" and a "Water Purification" unit are also needed. Figure 2 shows a block diagram of the system. The complete closed loop system consists of four distinct functions or pieces (47):

1) a Terpene Wash Unit,
2) a Water wash, Rinse, & Dry Unit,
3) a Terpene / Water Separation Unit, and
4) a Water De-Ionization Purification Unit.

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The Semi- Aqueous Equipment:

A number of equipment vendors are now producing cleaning machines that are compatible with the terpene semi-aqueous cleaning concept. Batch type cleaners are available from both ACCEL and ECD. Inline production equipment is manufactured by: Corpane, Detrex, Electrovert, and Vitronics.

A Vitronics Model SA-2150 Semi-aqueous Terpene system was purchased and installed into one of the Motorola Portable Radio assembly lines, in order to evaluate the Semi-Aquaeous concept. At the time of purchase, a one to one comparison of the available inline equipment indicated that the Vitronics unit was smaller and less expensive than the other vendors' offerings. In addition, Vitronics had units presently operational in the field, whereas we were unable to verify the successful production application of Semi-Aqueous equipment for any other vendor at that time. The two module Vitronics system is small, compact, and occupies nearly the same footprint as the CFC defluxing system that it replaced.

The Terpene Cleaning module consists of a vented recirculating terpene spray chamber, with an air knife to minimize terpene dragout. The system has onboard fire detection and suppression systems.

The Water Wash module has two recirculating spray rinses, followed by a hot DI rinse from the water purification unit, an air knife to accelerate the removal of the water rinse, and a final IR assisted recirculating hot air heater to complete the drying of the cleaned assemblies.

Water Separation & Purification Equipment

A number of equipment vendors have been supplying the Aqueous cleaning industry with water purification equipment, to clean, purify, and sometimes reuse their process waste water effluent (53 to 56). Within the last six months, a few vendors began producing "Water Separation and Purification" machines that are compatible with the Terpene Semi-Aqueous cleaning chemistries. Separation Technologists, Reading, Ma., at our request and direction, built and installed, the system required to treat, heat and reuse all process rinse and wash water (57).

The theory of operation of the system, is that the rinse water from the Semi-Aqueous rinse module will first drain via gravity to a holding sump, and subsequently will be mechanically pumped (through filters) to a terpene gravity separation holding tank. Here the floating terpene layer that accumulates on the water surface, is decanted for future reconstitution. The remaining separated water layer is then pumped through activated carbon (to remove low concen-trations of dissolved organics), and mixed ion exchange resin beds. The purified water is then reheated and returned to the water rinse module for reuse. This water separation/purification equipment was coupled to the Semi-Aqueous equipment described above, to complete the "Closed Loop" Semi-Aqueous System.

Other sources of Terpene compatible water separation/ purification recently identified, but as yet not evaluated, are: 1) Alpha Metals of Japan; and 2) Waste Treatment Systems of Santa Clara, California (58).

Equipment Installation & Startup:

The Closed Loop Semi-Aqueous System was installed into the factory in two stages. The Semi-Aqueous Terpene system was installed first, with it's waste rinse water discharge routed through the campus waste water treatment system. Once the Semi-Aqueous system was proven operational, the Terpene Separation Water Purification Loop was installed, and coupled together to make the installation completely closed loop, with zero waste discharge from the system.

The Terpene Cleaning Machine, (Vitronics), was installed into one of the existing Portable Radio lines, on the weekend of June 17th, 1990. In the weeks prior to the actual installation, all necessary facilities for water, drain, electricity, and venting were installed to the new equipment location, to minimize factory down time during change over. At the end of the second shift, on Friday, June 15th, the old CFC equipment was drained, dis-connected and dismantled. On Saturday

June 16th, it was removed from it's location, the floor tiles stripped and replaced, and the new Semi-aqueous Machine dropped into it's place. Electrical, water, drain and vent connections were completed Monday June 18th. The equipment was filled with Terpene and production circuit boards began to pass through the machine on following day, June 19th.

Equipment tweaks and factory authorized control upgrades for air knife, venting, and spray pressure control, were installed the following week without interruption to production. The ease with which the equipment swap was implemented is an example of exceptional interdepartmental teamwork by facilities, engineering, production, and the vendor.

A few weeks later, the "Terpene Separator" and "Water Purification" equipment were spliced into the water drain/water feed loop to complete the closed loop system implementation.

Operating Performance: The First 6 Months !

The **NEW BENCHMARK** for cleaning has now been set with the implementation of TERPENE Semi-Aqueous Cleaning. The following cleanliness levels after cleaning, as measured on the Omegameter #600, are being reported:

Cleaner Type	ugms of NaCl/sq.in.
• CFC	5 to 9
• **TERPENE**	**0 to 3**

The **COST SAVINGS of using TERPENE** rather than CFC is 85%. After six months of production cleaning, the following monthly consumptions can be reported.

	Terpene	CFC
• Consumed	125 gal	6600#
• Total Cost	$4100	$28,160

The above Terpene consumption is greater than had been predicted, due to dragout and volitization losses. The current circuit boards, components and fixtures were not designed to minimize dragout. "Designing for Terpene Cleaning" in future products will reduce usage.

In an attempt to intentionally tax the cleaning capabilities of the system, no constraints were introduced on what product or materials would be cleaned in the initial startup. As a result, not only were surface mount PCBs cleaned in the equipment, but also solder paste misprints, dirty solder screens, wave solder pallets, experimental solder pastes, hand repaired boards (with paper tag ID), and various wave soldered products were all randomly cleaned, two shifts per day, six days per week. After eight weeks of running at this rate, the Terpene samples from the machine were analyzed to show:

	t=0	t=8 weeks
color	clear	turbid-red
sp. gravity	0.84	0.944
Viscosity(cps)	0.8	8.3
% Loading	0	56%
Surfactant	10%	20%
Evap. Residue	0	23%

As a result of the exceptionally heavy loading, the Terpene was removed for salvage and the system cleaned and recharged. The residues removed from the bottom of the Terpene sump during the cleanup contained a large quantity of cellulose fibers from paper tags , glass fibers and epoxy from routed PWBs, a few components, and in excess of 30+ pounds of solder powder from the washing of solder misprints and solder screen cleaning. As a result, we have significantly reduced the amount of raw solder paste presently cleaned in the system from misprinted boards and screens, and have correspondingly seen a significant decrease in Terpene loading. The recharged system, after four months of continuous operation, is now approximately 8.6% loaded.

It was determined during the first 8 weeks of continuous operation, that hot rinse water containing small quantities of terpene, severely degrades PVC pipes, specifically chlorinated PVC pipes and fittings. The problem manifested itself initially with a level switch failure, and subsequently with a sump pump failure. All potentially vulnerable plumbing has now been replaced with stainless steel components.

Water quality at system startup was factory RO water at approximately 800,000 ohm cm. Upon cm. After 8 weeks of continuous operation, the dissolved terpene loaded and penetrated the activated carbon filters, and they were recharged. Water quality at recharge was 500,000 ohm cm. After six more weeks, the water quality declined to 200,000 ohm cm, and the ion exchange resin filters were replaced. Water quality immediately returned to better than 2 Meg ohm cm.

<u>What Have We Learned?</u>

The system is operating as initially envisioned. We realize that for future conservation optimization, future circuits must be designed with Semi-Aqueous cleaning in mind, and minimize dragout.

Raw solder paste will prematurely overload the terpene solvent system, however, the system will still clean effectively when loaded to near 50% .

There is no identifiable component sensitivity or negative reliability impact attributable to Semi-aqueous terpene cleaning.

Hot terpene rinse water will attack PVC plumbing.

And finally, we have learned that the Semi-Aqueous Closed Loop system cleans better than our former CFC cleaner, while reducing the cost of cleaning by approximately 85%.

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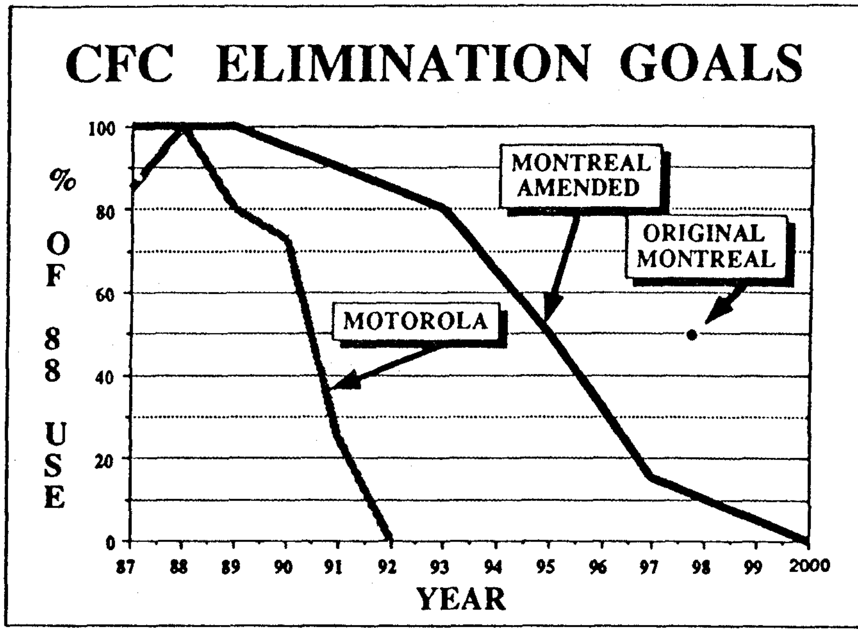

Figure 1.

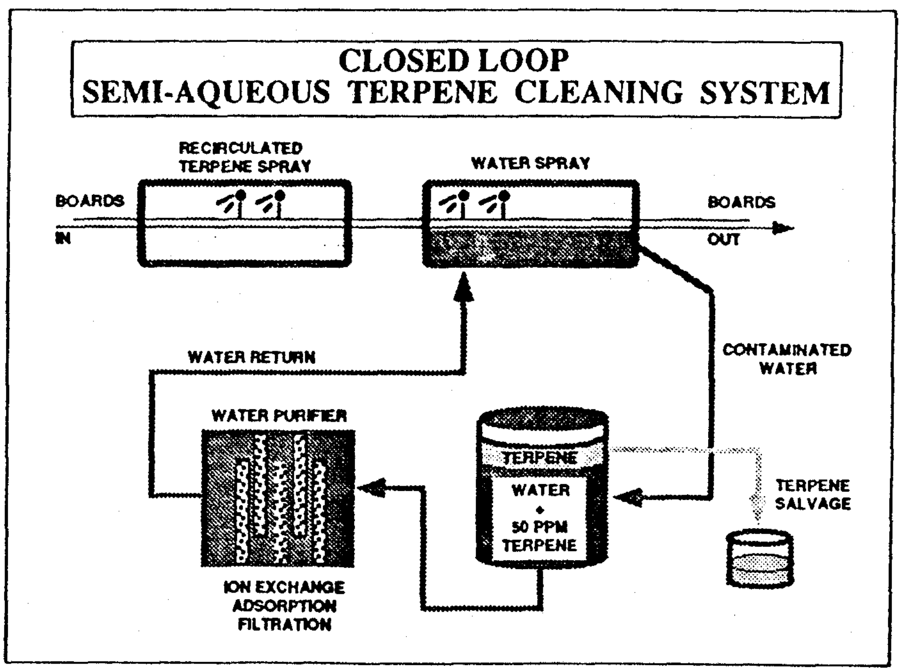

Figure 2.