

# Micro Joining and Assembly Technology

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## Section 6 Cleaning Chemicals

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### 6.1 Stencil Cleaner

#### Introduction

Application of solder paste in electronics packaging can be divided into dispensing, stencil printing, and pin transfer.<sup>1</sup> Stencil printing is the most popularly used among them because of its highly productive efficiency. Recent trend of high-density packaging with finer pitches of circuit patterns and downsizing electronic components, namely the installation of 0603 chip or 0402 chip, places new demands that stencil openings in printing process become ever thinner and smaller. Cases increased with this trend in which residual solder paste and small solder balls on the aperture edges cause trouble in printing or packaging process, once again highlighting the importance of stencil cleaning.

In the first half, we will describe requirements for stencil cleaner and features of their each existing type. In the latter half, we will move on to explain cleaning methods that are commonly used in stencil cleaning.

#### 6.1.1 Object

Object of cleaning is solder paste residue on repeatedly used stencils. Stencils must be cleaned not only after everyday operation but also after certain times they go through the printing process, removing the solder paste accumulated on the openings thus to maintain the quality in printing and of the stencils themselves (fig. 6.1.1).

The solder paste in use has improved its performance; its thixotropic agent shifted to that of higher melting point in order to prevent heat slump as it goes lead-free, and its activator demonstrating better wettability and stability in reflow process. Moreover, even better in their performance and increased in the amount, the thixo agent and activator adjusted to the recent stream of halogen-free and finer stencil pitches in often cases make cleaning much more difficult. Therefore one should reexamine the performance of the cleaner when switched to the newer types of solder paste even if no trouble has occurred in removing the residue in the conventional way.

#### 6.1.2 Purpose

The purpose of removing solder paste from stencils is to avoid the following problems that

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<sup>1</sup> Micro-Soldering Education Division, Japan Welding Engineering Society, *Standard Micro-Soldering Technology 3<sup>rd</sup> ed.* (Business and Technology Daily News, 2011), 114.

may occur during the printing process;

i. Inappropriate application of solder paste

Clogged apertures due to dried out solder paste cause insufficient application or of too much with dried paste being mixed into, making it unable to apply the proper amount of solder paste.

ii. Unnecessary application of solder paste

Clogged solder paste attached underneath the stencil (exposed to the substrate) may spread to end up causing soldering defects such as bridging.

iii. Contamination of lead into lead-free solder paste

If not properly cleaned, residual lead may contaminate lead-free solder paste even after the lead-free kind is installed.

### 6.1.3 Requirements

In order to prevent the above listed problems, stencil cleaner should meet the following requirements and conditions;

i. High dissolvability of solder paste

Some manufacturers hand-wipe clean the stencils using brushes and rags with Isopropyl alcohol (hereafter IPA). In such cases stencils are seemingly cleaned because of the physical impact of hand wiping, even though IPA has low dissolvability of solder paste. However, with finer and smaller stencil apertures, the physical force becomes inadequate for covering the low dissolvability of the cleaner, causing inconsistent cleaning performance namely the solder paste residue on stencil openings.

The same can be said in cases when cleaned in cleaning equipment. Low soluble cleaner may deteriorate the cleaning performance or take longer cleaning time than necessary.

ii. Low impact on components

Stencil is a stainless or nickel plated metal tightly taped with a metal frame made of aluminum and such via combination.<sup>2</sup> Except when the stencils are washed in cleaning equipment where only the openings are exposed to the cleaner, the cleaner is supposed to meet the contradictory conditions of high dissolubility and low impact on the combination or on the adhesive layer between frame and fixing tape. When the cleaner affects the adhesive layer between frame and fixing tape, deteriorated adhesiveness causes separation of the stencil or

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<sup>2</sup> Japan Institute of Electronics Packaging, *Dictionary of Electronics Packaging Technology* (Kogyo Chosakai Publishing Co., Ltd., 2009), 609.

printing defects with lowered tension of the stencil.

iii. Human and environmental friendliness

As cleaner should be human- and eco-friendly as possible while satisfying the above-mentioned conditions, each chemical composing the cleaner other than water has a smell unique to its own. Although in general the working environment prefers cleaning chemicals with no or less smell, they may not necessarily be better for human or the environment. One should reconsider using especially those with no smell in terms of safety.

iv. Inapplicability to the related laws

Concerned parties shall adhere to the related laws including Ordinance on Prevention of Organic Solvent Poisoning in accordance with the Enforcement Order of the Industrial Safety and Health Law (hereinafter the Ordinance) and Law concerning Pollutant Release and Transfer Register (hereinafter PRTR Law) when applicable. The Ordinance requirements such as installation of local exhaust ventilation put additional costs to that of cleaning itself. Thus non-applicable cleaners are better in terms of cost effectiveness.

v. Total cost effectiveness

Total cost should be evaluated based on the liquid exchange frequency and recyclability considering the lifetime of the cleaner, determined by lower dissovability due to contamination, in addition to the price of the cleaner.

#### 6.1.4 Classification<sup>3</sup>

Stencil cleaner can be classified into following categories;

i. Glycol ether-based

Most widely used is glycol ether based stencil cleaner.

Fig 6.1.2 shows the structural formula of glycol and glycol ethers. These chemicals contain both lipophilic alkyl, lipotropic ether structure and hydroxyl group in their molecules. They have appropriate dissolvability in both nonpolar (lipophilic) compounds including rosin in soldering flux and polar (lipotropic) compounds of activator etc.

Generally speaking, ethylene glycol is widely used because of its lesser smell among others. However, some kinds of ethylene glycol with a low boiling point are strictly controlled in terms of their allowable concentration or under PRTR Law due to their possible reproductive

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<sup>3</sup> Japan Industrial Conference on Cleaning, *Industrial Cleaning Checklist 2009 ed.* (Japan Industrial Conference, 2009)

toxicity and teratogenicity in metabolism<sup>4</sup> (table 6.1.1). Propylene glycol has increased demands from the market despite of its slightly stronger smell, for its lesser reproductive toxicity and teratogenicity compared to ethylene glycol. Dialkyl glycol acts as solubilizer in spite of its higher dissolvability among the three and low smell, since it is rather expensive.<sup>5</sup>

Primarily the Fire Services Act categorizes glycol ether-based cleaners as hazardous because of their having a flash point, yet those with a certain ratio of water canceling the flash point can be classified as nonhazardous.

Many of those classified as hazardous dry relatively fast with the boiling point of 120-170 °C (248-338 °F) and can be used solely.

The nonhazardous cleaners that have no flash point because of the added water have a larger proportion of chemicals with a high boiling point, making them dry at a slower rate. Therefore they require adequate rinsing in order to dry out. Cleaning chemicals compounds with a high boiling point remains without volatilization in an adhesive layer of the stencil frame, undermining the adhesiveness to cause separation of the frame. Although some cleaners with chemicals with a low boiling point do not require rinsing, they have less dissolvability since they contain a good deal of water to set off the flash point. It is important to control the water concentration of the cleaners as even the nonhazardous may be classified as hazardous under the Fire Services Act once the water vaporizes to uncanceled the flash point.<sup>6</sup>

ii. Alcohol-based

Lower alcohol such as ethanol or IPA is popular in hand-wipe cleaning. Despite its less dissolvability compared to glycol ether cleaners, it is cost effective in terms of its price and also its recyclability meaning contamination can be removed by distillation. It requires, however, safety measures regarding its flammability with the low flashing point, since it falls under the category of the fourth group alcohol stated in the Fire Services Act. (Flash point of IPA: 11.7°C (53.1°F) measured by Continuous Closed Cup Flash Point measurement method)

In addition, IPA asks for measurements including concentration control in the working environment and local exhaust since it falls under Type 2 Organic Solvent under the Ordinance.

iii. Hydrocarbon-based

Hydrocarbon-based cleaners can be divided into paraffins, naphthenes, and aromatics from their chemical structures. Aromatic hydrocarbons have the strongest dissolvability of

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<sup>4</sup> Kasuke Nagano et al, "Testicular Atrophy of Mice Induced by Ethylene Glycol Mono Alkyl Ethers," *Journal of Occupational Health* (1979), 21. 29-35

<sup>5</sup> Shigeo Hori, *Ready-to-Use Cleaning Technology* (Kogyo Chosakai Publishing Co., Ltd., 2001), 273.

<sup>6</sup> Nahoko Imori, *Fabricated Materials for Electronic Components April ed.* (2000), 105.

solder paste followed by naphthenes and paraffins. They also have a stronger smell than naphthenes, which smell relatively less than paraffins. The molecular weight and the boiling point range determine how fast they dry. Hydrocarbon-based may not demonstrate enough dissolubility depending on the type of solder paste while it is less expensive than glycol ether-based cleaners. It also requires measurements on explosion due to static electricity since it has a flash point and moreover, even those with a higher flash point can be easily electrified. Its impact on adhesive on the frame is larger than that of glycol ether or of alcohol, in proportion to the dissolvability of aromatics the highest, followed by naphthenes and paraffins.

Many of the highly soluble aromatic hydrocarbons have been subject to PRTR Law such as Toluene, Xylene and 1, 3, 5-Trimethylbenzene (Mesitylene). Under the amended PRTR Law enforced from Oct. 2010, most of them are now regulated including newly added Cumene and 1, 2, 4-Trimethylbenzene (Pseudocumene).

iv. Ketone-based and Ester-based

Ketone-based such as Acetone, Methyl ethyl ketone (MEK) and Cyclohexanone, and ester-based chemicals as in Ethyl acetate, Butyl acetate, and Ethyl lactate, solely or several components combined, are popular for hand-wipe cleaning because of their high dissolvability of synthetic resin. They have peculiar smell, however, are also highly volatile and extremely flammable. They largely impact adhesive on the frame as well.

Many of them are subject to PRTR Law and Type 2 Organic Solvent under the Ordinance or Fire Services Act, which demand appropriate usage and control in accordance with the laws.

v. Bromides-based

1-Bromopropane (*n*-Propyl bromide) is the principal component of bromides-based cleaners currently in the market. 2-Bromopropane (Isopropyl bromide), its structural isomer which was previously popular, disappeared from the market owing to the arisen social problem that it may cause reproductive dysfunction. 1-Bromopropane-based cleaner is a colorless clear liquid heavier than water, nonflammable similarly to 1, 1, 1-Trichloroethane (chlorinated chemicals), and recyclable. Meanwhile, it requires considerate usage control below the working environment concentration control standard, for being classified as Type 1 Designated Chemical under PRTR Law.

vi. Water-based

Water-based cleaners include that of surfactant- and alkali agent-added-water and functional water of electrolyzed water and such.

While they have advantages of having no flash point, no volatile organic compounds, nor

smell, they may need physical force assistance such as ultrasonic irradiation and high-pressure injection of the cleaner in order to maintain adequate cleaning performance, because in most cases they are less soluble to certain kinds of solder paste when compared to other chemical-based cleaners.

Alkali cleaners containing inorganic alkali of Sodium hydroxide and Potassium hydroxide demand safety measurements to prevent them from hurting human eyes and skin. When cleaning electrolyzed, deposited, or resin-treated stencils which the purpose of those to provide better printing with smoother release of solder paste and such, it should be noted that alkali in the cleaner may harm the coating. Meanwhile, when inadequately rinsed and exposed to PCBs, residual alkali on the stencil surface would cause metal corrosion or degrade the circuit characteristics.

#### 6.1.5 Cleaning Method

Stencils can be cleaned hand-wiped with highly volatile cleaners such as IPA or with manual or automated cleaning equipment near printing process of packaging line.

Although hand wiping is inexpensive and easy to be done, it is highly problematic both in terms of cleaning performance and working environmental safety.

As for the cleaning performance, it is hard to completely clean spots namely micro aperture edges by hand, resulting in quality discrepancy largely depending on who to clean them. Moreover, hand-wiping may damage the shape of apertures or the stencil surface. Besides, it may cause working environmental problems since workers must operate in the chemical-filled atmosphere.

Some users who want cleaning performance without bringing in gigantic cleaners adopt cleaning spray, which cleans the stencils with chemical dissolvability and pressure of the spray, or small-sized handy ultrasonic cleaners (fig 6.1.3)<sup>7</sup>.

As for the cleaning equipment, the market has several kinds depending on the cleaning methods; shower, soak into the cleaner and irradiate ultrasonic, and directly irradiate ultrasonic. Cleaning equipment must be able to provide a high cleaning performance while being eco-friendly and cost effective. The less cleaner the better since it cannot fulfill these conditions if a large amount of cleaner is necessary. Also the longer cleaning time causes more volatilization of the cleaner and harsher impacts on the frame due to longer exposure to the cleaning product.

Thus cleaning equipment must be designed to enable fast cleaning with a little amount of cleaner.

The mechanism of cleaning differentiates in each method. The most suitable cleaner must be

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<sup>7</sup> Akio Inoue, *Basics and Application of Electronics High Quality Screen Printing* (CMC Publishing, 2011), 175.

chosen for the particular cleaning equipment. Followings are the representative cleaning methods;

i. Showering

Showering method uses an impinging force and dissolvability of the fluid by jetting cleaner to the object from nozzles. Concerns are that when cleaner covers the entire stencil the frame tape may come off, and when sprayed with high pressure the stencil may deform. Besides, the cleaning equipment should have suitable spray nozzles and a transporter of the nozzles or the stencils in order to prevent uneven spraying.

ii. Immerseble ultrasonic cleaning

This is a method to soak the entire stencil into the cleaner and irradiate ultrasonic, where cavitation occurs when ultrasonic is irradiated into the cleaner. Although it varies on the size of the stencil, the more initial volume of cleaner in the tank, the closer attention is required on designated volume control of the hazardous cleaners. Oscillation of the stencils is necessary to make up the difference in cavitation impacts in the cleaning tanks in order to maintain consistent cleaning performance. Another possible concern is that the ultrasonic is likely to impact parts that do not require cleaning, including aluminum frame, aluminum tape and adhesive.

iii. Non-immersible ultrasonic cleaning (fig 6.1.4)<sup>7</sup>

In this method cleaner acts as a liquid membrane as applied on the front and back of the stencils, transmitting ultrasonic onto the stencils. The amount of cleaner can be much less for it is only necessary for covering the stencil surface. This method of direct irradiation offsets the influence of distance on ultrasonic that its effectiveness weakens in inverse proportion to distance. Thus less than half the electricity brings about the same effect as in the immerseble ultrasonic cleaning. Moreover, it has other advantages including less impact on the stencils, less consumption of the cleaner and electricity, and less running costs.

#### 6.1.6 Drying Method

Air blowing is popular in drying after cleaning or rinsing. Emission volume of volatile organic compounds is of the issue since much of the stencil cleaner compounds have the boiling point below 200°C while emissions are released via local exhaust. Cleaners should curtail volatile organic compounds, along with their emission control regarding the equipment.

#### Conclusion

Stencil cleaning asks for inclusive consideration not only on the cleaning performance of the subjected solder paste but also on the impacts on the stencils as well as the environment, and stencil

quality after cleaning. It is not hard to imagine that higher cleaning performance along with finer pitches and less environmental burden will be in greater demand. One should considerably choose appropriate cleaner and cleaning equipment in order to meet these requirements.

## 6.2 Deflux Chemicals

### Introduction

Soldering in electronics packaging uses flux in most cases. This use of flux evokes following demands: **a.** cleaning of flux residue on PCBs after soldering, **b.** cleaning of resin deposited in reflow furnace, **c.** cleaning of flux branded on solder pallets, and **d.** cleaning of flux attached on peripheral devices of fluxer, tools and jigs. In this article we specifically define the chemicals for **a.** cleaning of flux residue on PCBs after soldering, which requires the most sophisticated cleaning technology of all, as “deflux chemicals.” Meanwhile, we omit the general arguments and classifications on flux cleaning materials since a number of books have discussed about them already.

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Current situation questions the significance of deflux, where joining technology plays an important role in electronics packaging, and increasingly stricter chemical substance regulations regarding the packaging scene calls for mitigation of energy and environmental burden. Moreover, ever higher density and speed of the circuits asks for even more sophisticated cleaning technology in order to lessen the disturbing impact of flux residue on circuit characteristics.

Therefore, this article explains the history, purpose and significance of deflux in the first half, and goes on to the latter half on existing technology and future issues concerning glycol ether based chemicals, the most popularly used deflux chemicals in the packaging scene.

### 6.2.1 History

Flux in early times comprising Hydrochloric acid demanded immediate water rinsing and drying because of its strong corrosiveness. Birth of rosin-based flux in 1960s improved the reliability after soldering, bringing us the concept of non-cleaning. In the late 1970s, however, when surface packaging became the mainstream with rapidly downsizing electronics, demands on deflux reincreased with higher aspiration for reliability on PCBs. This is when Du Pont introduced CFC-113, one of its industrialized fluorine compounds to the Japanese market as “magical liquid” for it being nonflammable, fast-drying, insulative, chemically stable and safe for precision cleaning.

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<sup>1</sup> Tadashi Kubota, *Reliable Post-Freon Technology on PCBs* (Triceps, 1993)

<sup>2</sup> Kogyo Chosakai Publishing, *Ready-to-use Cleaning Technology* (Kogyo Chosakai Publishing Co., Ltd., 2001)

<sup>3</sup> Japan Industrial Conference on Cleaning, *Industrial Cleaning Checklist 2009 ed.* (Japan Industrial Conference, 2009)

This liquid is the so-called “Freon,” which became the standard for flux cleaning for about 20 years and established the status of flux cleaning in electronics packaging process until it was banned at the end of the year 1995 after being accused of causing the ozone depletion.

In the meantime, neither the necessity of deflux nor post-deflux circuit performance attracted much attention for the following reasons: Freon became reasonable as it spread in the market; the characteristic of Freon did not require the cleaning equipment furnish state-of-the-art technology but it be compact and inexpensive; and the whole Japanese market of electronics at the time was experiencing a rapid growth and expansion.

It was the phasing out of Freon and collapse of the Japanese bubble economy that triggered the rise of deflux business. Together with Freon, Trichloroethane, the chlorine solvent mainly used for metal cleaning, was banned to create a new market for cleaning of approximately 0.3 million tons per year. About 300 companies, mostly chemical manufacturers, entered this newly created market from 1988 to 1995.

Many veered to introduce the non-cleaning process during this warlike period, thanks to soldering manufacturers who have developed non-cleaning flux while the packaging industries once again giving serious consideration on the necessity and performance evaluation of deflux. Yet cleaning process is of the importance regarding in-vehicle equipment and high frequency parts that need to have high reliability, and high-density semiconductor packaging.

### 6.2.2 Purpose

Companies that introduce deflux often aim to avoid the following residual flux-related problems:

#### (1) Bonding defect

When doing wire bonding or flip chip bonding in assembly and testing process, mere organic coating of flux residue on electrodes e.g. gold-plated pads is likely to cause bonding defect by weakening the bonding strength. Thus cleaning is important to remove the flux residue entirely. One thing to keep note is that wrong cleaning methods can result in chemicals residue compounds or flux reattachment, worsening the bonding defect.

#### (2) Resin

Flux residue can create void when applying underfill or mold resin on the soldering surface in assembly and testing process; for example, its metal soaps and wax undermine wettability of resin or cause resin cure failure due to its amine compounds.

#### (3) Solder ball

Besides flux residue, solder ball generated from slump and spatter in printing or preheating process should be removed to avoid electrical failure including leakage and short circuit. Solder ball is generated from rapid heating of solder when solvent gas in flux expands to spatter the flux and solder.

(4) Insulation discredit

Since most kinds of current flux are able to provide high insulation reliability in terms of flux residue after soldering, rare cases demand cleaning to avoid insulation discredit. However, residue of water soluble flux, which is partially used, cannot offer insulation reliability unless immediately washed away with hot water and dried out because of its hygroscopicity and corrosiveness. Some water soluble flux requires cleaning with appropriate deflux chemicals since its post-soldering residue remains even after the hot water cleaning. Such cases are expected to increase with the trend of VOC elimination.

(5) Contact failure

Flux residue, containing insulator of rosin, may attach to contacts such as connector to cause contact failure. Yet cleaning may not be effective or brings even worse results for U-shaped contacts of connector if the cleaning method is inappropriate.

(6) Inspection inaccuracy

Surface inspection to find blow holes, one of soldering defects, or to identify gloss of solder and fillet shape becomes difficult to carry out if the junction is covered with flux residue. Residual flux on fixture pins for in-circuit test or function test also diminishes the efficiency of electrical inspection by hindering connection.

### 6.2.3 Significance

Although deflux is introduced for the above-listed reasons, packaging sites have always discussed the option of non-cleaning method by reviewing packaging process and soldering conditions, or by improving the flux itself in order to achieve a better working environment and cost efficiency.

However, flux is a highly active material that plays the role to accelerate wettability with solder and alloy formation by chemically reacting with oxide, hydroxide, and carbonate on the surface of joined metal, turning them into fusible and soluble compounds e.g. metal oxide, metal complex, and organic acid metal soaps to add fluidity. Additionally, resins, including rosin to prevent exposed metal surface re-oxidation, react fiercely in soldering process and generate flux residue while being exposed to intense heat for organic materials of over 200°C (392°F). It is hard

to imagine that stable electronic characteristic and circuit constant aimed by the circuit designer can be maintained with residual flux remained on PCBs. Moreover, the following reasons make it difficult for all the flux components to react completely: the level of joined metal surface oxidation varies on parts and materials; various shapes of resin parts with low thermal conductivity surround the junction; and heated condition differs when soldered. Soldering temperature rise due to recent inclination toward lead-free, too, has pressed the need to elevate flux activity in order to maintain its effectivity. Besides, halogen-free stream lead to more organic acids, being less active than halogen compounds which act vigorously with a little amount, added in the activator, making it almost impossible to maintain as good electrical characteristic as flux residue for PCB insulation materials.

Flux residue after soldering is a compound of various dielectric components with many contact surfaces, with flux being composed of resin including modified rosin which has relatively low polarity and high permittivity and of activator with high polarity and high permittivity (fig 6.2.1). In addition, with lower dielectric PCB materials adjusting to the recent trend of high frequency and high speed, residual flux as dielectric exists as stray capacitance between fine pitch circuits on the low permittivity boards to invoke interfacial polarization when put in an AC electric field.<sup>1</sup>

Appropriate cleaning to remove flux residue is necessary to maintain primary circuit characteristics since electric characteristic of flux residue cannot follow that of PCBs as density, speed and frequency go higher onward.

#### 6.2.4 Design Requirements

Deflux chemicals design is one of the most difficult in the field of designing industrial cleaners, since it has to fulfill a number of contradictory requirements and conditions listed as follows;

- (1) Consistent PCB electrical characteristic before and after the cleaning process
- (2) Extensive dissolvability of residual flux, the mixed compounds of largely varied polarities and solubility parameters (fig 6.2.2)
- (3) Little impact on PCB parts including electrical parts to be packaged
- (4) Human/environmental safety in an appropriate working environment
- (5) Inapplicability of concerned laws with strict use control
- (6) Long life of cleaning with low agent deterioration
- (7) Recyclability
- (8) Sustainable supply with introducible costs

Among them, especially (2) is incompatible with (3) and (5) which makes it technically difficult to go together. Acceptable design is limited considering that the stricter chemical related laws constraint usable chemical materials and the influence on various parts on PCBs should be as

little as possible. On the other hand, lead-free and halogen-free of soldering decreases residual flux dissolubility, demanding higher dissolvability of deflux chemicals. Generally high soluble materials are chemically active and likely to impact creatures, environment and electronic components.

Residual flux between fine pitches, under the electronic components for example, may swell due to high soluble deflux chemicals to unable cleaning, filling the space under the parts with a sticky liquid. Given these cases, adding a low soluble assistant should be considered in order to decrease the viscosity of the whole system. Deflux chemicals design must meet the contradictory requirements such as dissolvability of residual flux and low impacts on PCB electronic components, by using such technologies to mix several cleaning compounds. Combination with appropriate cleaning equipment is the key to match the ever more complicated needs of deflux for the packaging process, by maximizing the advantages of deflux chemicals and covering their disadvantages.

#### 6.2.5 Glycol Ether-based Chemicals

A variety of alternatives to Freon were considered after its disuse. Major deflux chemicals currently on the packaging market include *Pine Alpha* (Arakawa Chemical Industries, Ltd.), *Cleanthrough* (Kao Chemicals), and *Microclean* (Kaken Tech Co., Ltd.), all being glycol ether based chemicals.

Glycol ether, aforementioned in **6.1 Stencil Cleaners**, consists of ethylene oxide (EO) or propylene oxide (PO) in addition to alcohol, butanol for instance which etherifies one or both of hydroxyl group of glycol, the dihydric alcohol. Table 6.2.1 shows some of glycol ethers produced for industrial use.

Glycol ether has both polar and nonpolar characteristics in its molecule. Mixing different glycol ethers enables a design that has the most suitable dissolvability of flux residue with an extensive solubility parameter. While glycol ether itself has a flash point and may be classified as hazardous under the Fire Services Act, with a proper chemicals design it can get away as nonhazardous by adding a certain amount of water. Water dissolved glycol ether becomes insoluble in water at a certain point called a cloud point as the temperature rises. Oil/water separating cleaning chemicals take the advantage of this characteristic to recycle water by isolating and removing the cleaning compounds from the rinse water.

Oxidative decomposition is problem glycol ether may fall into under a heated environment especially when used for deflux chemicals; it accelerates together with organic acids in flux to compose more organic acids including formic acid (fig 6.2.3), promoting the phenomenon even more.<sup>4</sup> Also since organic acids undermine the material quality with PCB corrosion, electro

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<sup>4</sup> Shigeo Hori, *Ready-to-Use Cleaning Technology* (Kogyo Chosakai Publishing Co., Ltd., 2001) p273.

chemical migration and such, glycol ether needs an appropriate antioxidant to prevent oxidative decomposition in an ordinary usage environment.

#### 6.2.6 Adequate Design for Rinse

Glycol ether based cleaning chemicals are hard to dry out because of their compounds holding a high flash point and boiling point for safety reasons. Thus drying process is common with fast drying rinse chemicals replacing the deflux chemicals. Water or water content alcohol is the most suitable for rinsing glycol ether based deflux chemicals; in order to thoroughly remove ionic substances that PCBs are the least durable of them remaining on the surface.

Although water is the safest and the most ecological material for rinse, it comes in second in replacing chemicals in narrow gaps, under the electronic components for instance, due to its high surface tension. In addition, much of the residual flux compounds do not dissolve in water that those once solute in deflux chemicals precipitate again, reattaching to the cleaned materials when they contact the rinsing water. These issues can be solved by adding surfactants to deflux chemicals, yet some surfactants may cause rinsing water to bubble, barring its performance. Also, surfactants, easily remained on PCBs, may cause dielectric loss for its hygroscopicity.<sup>5</sup> Besides, water has other issues including microbial contamination and high corrosiveness on metal surfaces e.g. circuits and electrical parts. Designing proper deflux chemicals requires thorough and comprehensive consideration on all such features.

Industrially used water content alcohol consists of mainly ethanol for safety and environmental reasons and a little more than 40 weight percent of water, being nonhazardous under the Fire Services Act. It has such advantages over water as: **a.** better rinse property with a less surface tension compared to glycol ether based chemicals, **b.** lesser reattachment of precipitated flux residue, **c.** consistent circuit characteristics before and after the cleaning process since adding surfactants to deflux chemicals is unnecessary, **d.** dry faster than water, equivalent to IPA, **e.** mere metal corrosiveness, **f.** less risk on microbial contamination because of its bactericidal effect. Meanwhile, despite of the fact that it is nonhazardous under the Fire Services Act, water content alcohol can only be used in safely designed cleaning equipment because it is flammable similarly to drinkable alcohol such as whisky.<sup>6</sup>

#### 6.2.7 Future Issues

Improved, smaller electrical circuits or parts such as multichip modules will demand even better performances of deflux chemicals in order to secure the characteristics and reliability of

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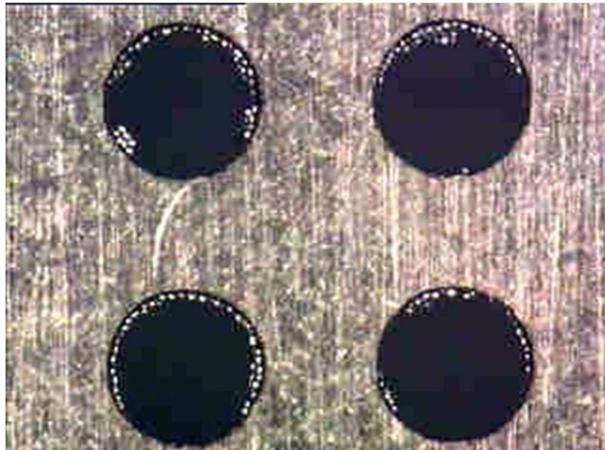
<sup>5</sup> Seiho Terasawa, *Reliable Post-Freon Technology on PCBs* (Triceps, 1993)

<sup>6</sup> Shigeo Hori, *Ready-to-use Cleaning Technology* (Kogyo Chosakai Publishing Co., Ltd., 2001) p335.

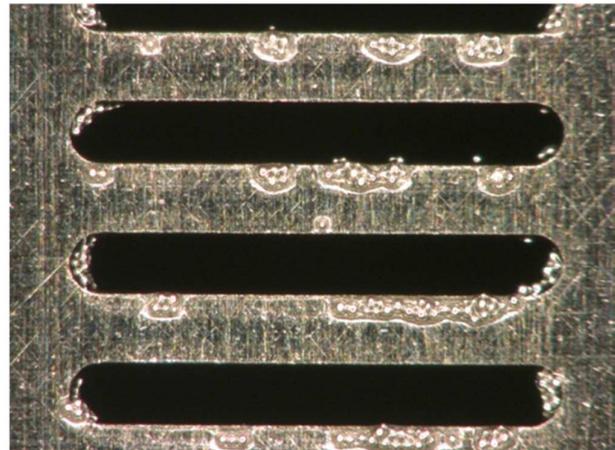
high-density circuits, by completely removing flux residue and other foreign materials. At the same time, eco-friendliness will have a higher profile in terms of mitigating the energy and environmental burdens.

Establishing the effective deflux system as a whole, by combining chemicals with practical cleaning methods and cleaning equipment, is essential to meet the above-mentioned requirements.

Fig.6.1.1 Solder Paste on Stencil Apertures



CSP Opening Diameter: 100um

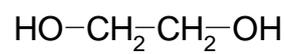


QFP 0.4mm pitch

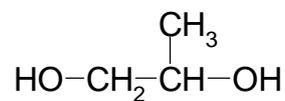
Fig. 6.1.2 Structural Formula of Glycols and Glycol Ethers

Common Glycol (Dihydric Alcohol)

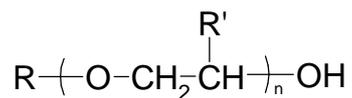
Ethylene Glycol



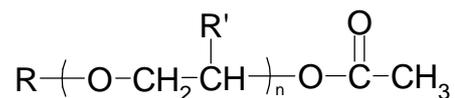
Propylene Glycol



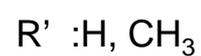
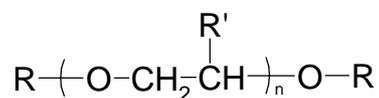
Glycol Ether (General Formula)



Glycol Ether Acetate (General Formula)



Dialkyl Glycol Ether (General Formula)



**Table 6.1.1**  
**Glycol Ether Based Solvents with Strict Concentration in the Working Environment**

Chemical & Structural Formula	Alias	Allowable Concentration stated by Japan Industrial Association (2010 Ed.)	TWA* (2010 Ed.)	PRTR Law	Ordinance
Ethylene glycol monomethyl ether $\text{CH}_3\text{-O-CH}_2\text{-CH}_2\text{-OH}$	2-Methoxyethanol, Methyl cellosolve	0.1 ppm	0.1 ppm	Type 1 Designated Chemical Compounds	Type 2 Organic Solvent
Ethylene glycol monoethyl ether $\text{C}_2\text{H}_5\text{-O-CH}_2\text{-CH}_2\text{-OH}$	2-Ethoxyethanol, Cellosolve	5 ppm	5 ppm	Type 1 Designated Chemical Compounds	Type 2 Organic Solvent
Ethylene glycol monomethyl ether acetate $\text{CH}_3\text{-O-CH}_2\text{-CH}_2\text{-O-CO-CH}_3$	2-Methoxy ethyl acetate, Methyl glycol acetate	0.1 ppm	0.1 ppm	Type 1 Designated Chemical Compounds	N/A
Ethylene glycol monoethyl ether acetate $\text{C}_2\text{H}_5\text{-O-CH}_2\text{-CH}_2\text{-O-CO-CH}_3$	2-Ethoxy ethyl acetate, Cellosolve acetate	5 ppm	5 ppm	Type 1 Designated Chemical Compounds	Type 2 Organic Solvent
Ethylene glycol monobutyl ether $\text{C}_4\text{H}_9\text{-O-CH}_2\text{-CH}_2\text{-OH}$	2-Butoxy ethanol, Butyl cellosolve	N/A	20 ppm	N/A	Type 2 Organic Solvent

\*8-hour Time Weighted Averages (TWA) are an average value of exposure over the course of an 8 hour work shift.  
 A worker may be exposed to a level higher than the TWA for part of the day as long as he is exposed to levels below the TWA for the rest of the day.  
 (Recommended by The American Conference of Governmental Industrial Hygienists)

**Fig.6.1.3 Small-sized Handy Ultrasonic Cleaning Equipment**

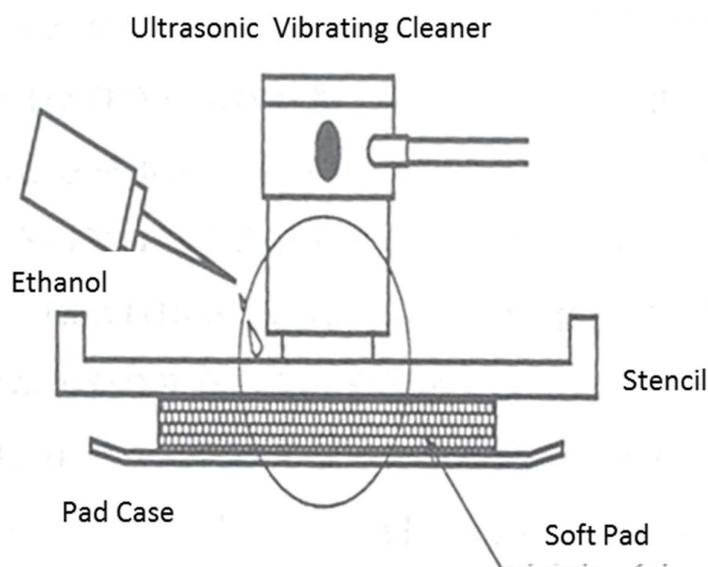


Fig.6.1.4 Non-immersible Ultrasonic Cleaning Method

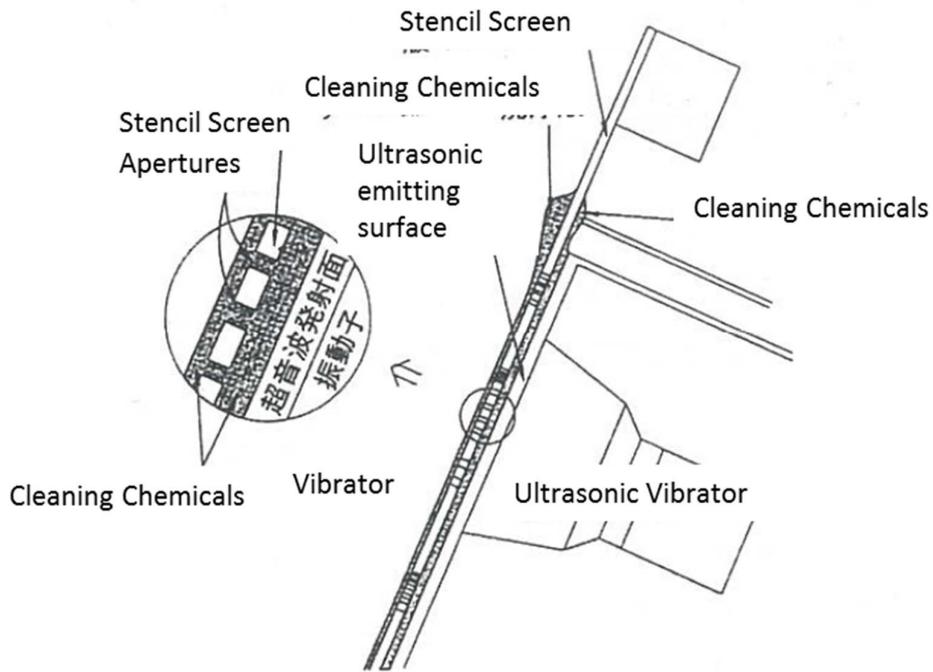
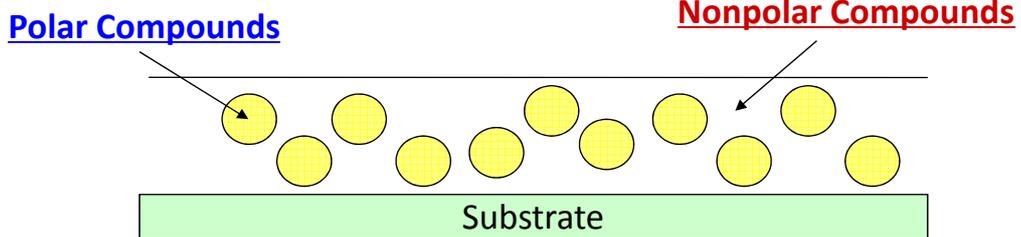


Fig. 6.2.1 Flux Residue Compounds after Soldering

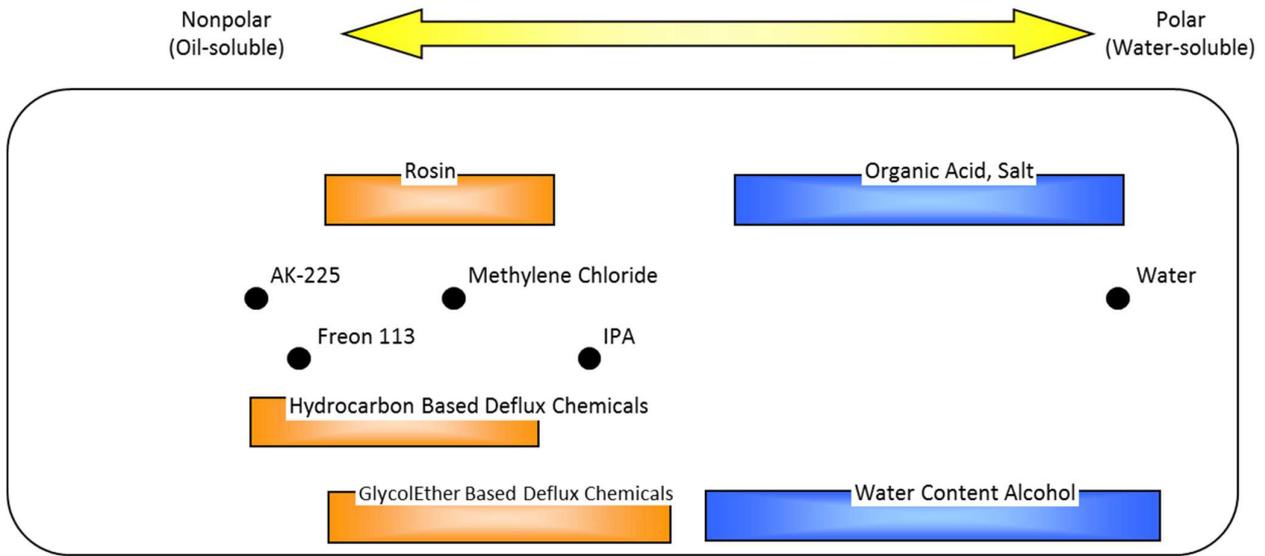
-Flux Residue Model



-Flux Residue Compounds

<u>Polar Compounds</u>	<u>Nonpolar Compounds</u>
Organic Acid	Rosin Resins
Organic Acid Metal Soap	Modified Rosin
Amine Hydrohalide	Various Resin Acid Derivative
Amine Salt of Organic Acids	Fats and Oils
Amine Metal Complex	Wax
Various Metal Halide	

Fig.6.2.2 SP Value of Flux Residue



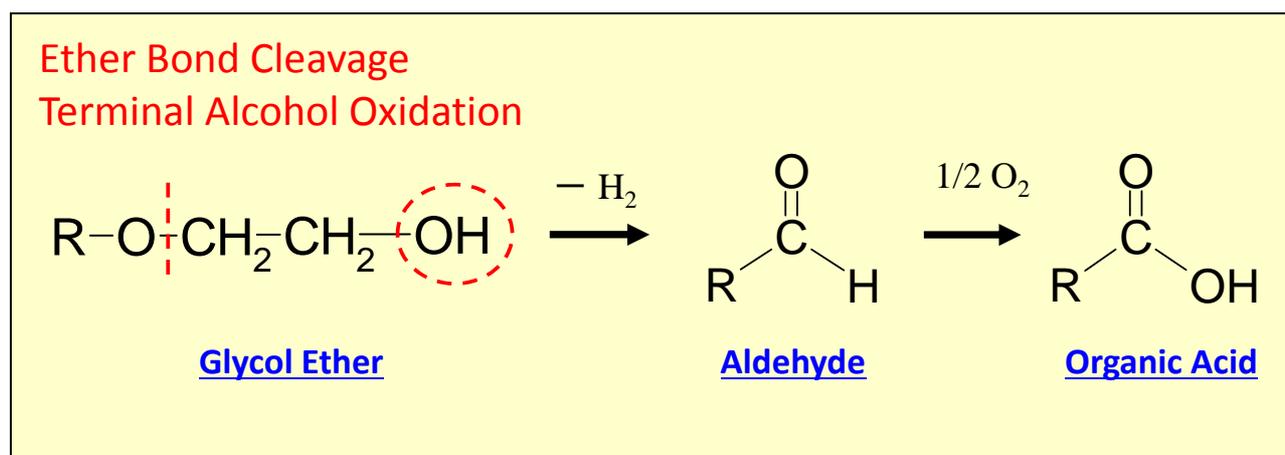
SP: Solubility Parameter, index to show solubility of substance.  
 It enables evaluation of solvents on their mixability, wettability, and solubility to polymer or biopolymer liquid.  
 Since substances of similar parameters tend to blend easily, SP can demonstrate the mixability of solute and solvent.

Table 6.2.1 Some of Glycol Ethers Produced for Industrial Use

	Chemical Name	Abbr.	Boiling Point 1013hPa(C)	Flash Point (C)
Ethylene Oxide	Diethylene glycol monobutyl ether	BDG	230.6	120
	Triethylene glycol monobutyl ether	BTG	271.2	156
	Ethylene glycol monoisobutyl ether	iBG	160.5	56.5
	Ethylene glycol monohexyl ether	HeG	208.0	102
	Diethylene glycol monohexyl ether	HeDG	259.1	141
Propylene Oxide	Propylene glycol monomethyl ether	PGM	121.0	32
	Diethylene glycol monomethyl ether	MFDG	187.2	76.5
	Propylene glycol monopropyl ether	PFG	149.8	48.5
	Dipropylene glycol monopropyl ether	PFDG	212.0	108
	Propylene glycol monobutyl ether	BFG	170.2	61.5
	Dipropylene glycol monobutyl ether	BFDG	230.6	117
	Propylene glycol monomethyl ether acetate	PMA	146.0	48
Dialkyl Glycol Ether	Diethylene glycol dimethyl ether	DMDG	162.0	56
	Triethylene glycol dimethyl ether	DMTG	216.0	113
	Diethylene glycol diethyl ether	DEDG	188.9	70.8
	Diethylene glycol dibutyl ether	DBDG	254.6	122
Others	3-Methoxy-3-methyl-1-butanol	MMB	174.0	68
	3-Methoxy-3-methyl-1-butyl acetate	MMB-Ac	188.0	75.5

\*Boiling Point and Flash Point varies according to the manufacturers of the chemicals.

Fig. 6.2.3 Oxidative Degradation of Glycol Ethers



## Section 2 PCB Packaging Equipment

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### 2.8 Cleaning equipment

#### Introduction

Cleaning is an operation to separate and remove the unnecessary—object to be cleaned including stain and tarnish—attached on the targeted product to the level where the product is able to express and maintain its original characteristics and quality. Although dry washing methods of not using liquid also exist, here we refer to wet cleaning methods using cleaning chemicals as “cleaning” in this article.

Besides, cleaning equipment in production line is a machine that realizes the most appropriately designed cleaning process by effectively bringing out physical chemistry functions of cleaning chemicals including wetting, infiltrating, dissolving, peeling, diffusing, and removing, to the object in order to achieve the sufficient quality of the product and enable smooth production.

Therefore, designing or introducing cleaning equipment must be carried out based on the clear understanding about the quality requirements with thorough research on the property of the object, product and cleaning chemicals as well as on the state of the object and the characteristics of the targeted product. Especially PCBs with high quality standards call for the individual design of cleaning process. Many cases indicate that hastily introducing generally designed cleaning equipment, even used with proven cleaning chemicals, usually ends up in failure in securing the necessary quality. Although some may misunderstand with these cases that “cleaning process rather causes quality deterioration,” it all comes down to underestimating the significance of cleaning process design.

The first half explains the basics in designing deflux process and the latter half demonstrates the proven cleaning system in packaging line and gives existing examples of cleaning quality control.

#### 2.8.1 Design for Cleaning Process

This article opts out the descriptions of flux residue, the target of cleaning, and deflux chemicals introduced in Section 6.2, Chapter 3. Instead, the following will explain the cleaning process given that the most suitable cleaning chemicals are chosen.

Cleaning process is a process to efficiently separate flux residue from the product by wetting, infiltrating, dissolving, peeling or diffusing with cleaning chemicals.

Although simply soaking the product in cleaning chemicals could separate flux residue, it takes too much time to complete the separation, thus failing to suit the production aim. The first

step of cleaning process design is to shorten the cleaning time with the raised cleaning chemicals temperature or with the physical functions such as liquid flow or ultrasonic. Also, equipment design is essential in accordance with the packaging structure of the product to equalize the cleaning quality, based on the clear understanding on controlling factors of cleaning process.

Cleaning speed has an impact on the solving rate and diffusion velocity of flux residue solved in cleaning chemicals. The dissolvability of residual flux highly depends on the cleaning chemicals. Increasing diffusion velocity is the key to maintain the dissolubility of cleaning chemicals and to accelerate the cleaning speed.

Below is the Fick's first law, the principle on diffusion;

$$dm/dt = -D*A*dc/dx$$

$D$ : Diffusion coefficient

(Minus: Diffusion happens toward lower concentration.)

Fick's first law states that  $dm$ , material mass that diffuses toward direction  $x$  across square measure  $A$  in the time period of  $dt$ , goes in proportion to  $dc/dx$ , the concentration gradient on the two-dimension.<sup>1</sup>

In other words,

Diffusion velocity = Diffusion coefficient \* Concentration gradient,

and since diffusion velocity reflects the value of concentration gradient, promoting liquid replacement on the contact surface maintains the high concentration gradient to accelerate the cleaning speed.

Cleaning equipment has two methods to replace the liquid on the contact surface with liquid flow in a short period of time in order to increase the diffusion velocity: one is the circulating jet method that circulates the liquid in the cleaning tanks with pumps and the other is the direct path cleaning method that cleaning chemicals, forced from one direction, directly flushes through the gap between products, utilizing the entire energy of discharge and intake from the pumps.

Direct path cleaning method improves the cleaning efficiency between gaps by gathering the products to narrow the space the liquid can go through, resulting in flow speed acceleration.<sup>2</sup> Substrates that require narrow gap cleaning, for Flip Chip packaging being one, or those that are relatively flat prefer this method. On the other hand, for PCBs with intricate surfaces mounted with various components, methods in which turbulence from many directions creates a surface flow, such as the circulating jet method, are preferable to level the cleaning performance. Also, the direct path

<sup>1</sup> D.J.SHAW, translated by Fumio Kitahara and Koichiro Aoki, *Chemistry on Colloid and Surface* (Hirokawa Bookstore, 1978), 21.

<sup>2</sup> Junichi Maeno, *Production Technology Application Manual* (Kogyo Chosakai Publishing, 2000), 865.

cleaning method demands several special baskets that suit the shape of each product to be cleaned when cleaning high variety low-volume products.

In the circulating jet method turbulence enhances the cleaning efficiency, yet the tipping point in cleaning effect appears far above the critical Reynolds number, where  $Re =$  more than 26,000. (Fig. 2.8.1) Circulation amount and speed need to be determined to satisfy the appropriate Reynolds number range to get the turbulence effect.

The essence of deflux is the removal of flux residue on the surface, ionic residue, and residual flux under the electronic components that are difficult to conduct visual inspection. As recent Flip Chip packaging represents, those with gaps of less than 50 $\mu$ m under the components have been produced and the gaps will be even narrower considering the trend. Deflux is becoming more difficult because of smaller apertures where cleaning chemicals contact flux residue under the electronic components. Cleaning difficulty varies depending on the size and shapes of the components granting the same solder paste and under the same conditions of reflowed flux residue. Deflux of PCBs that have complex surfaces mounted with various components requires the most suitable condition setting for the packaging component with the longest cleaning time. Especially the space under the components needs higher performance settings since the cleaning quality cannot be verified unless post-cleaning destructive inspection is conducted. For such settings to be determined precise evaluation on quality discrepancy becomes necessary based on the quantitative assessment on cleaning speed.

While aforementioned diffusion velocity largely influences conventional deflux of circuit surfaces, for under electronic components it is dissolution speed that has a large impact. Although diffusion velocity and dissolution speed have different mechanisms, the following form similar to Arrhenius equation can describe both  $D$  the diffusion coefficient and  $k$  the rate constant for dissolution kinetics equation;<sup>3</sup>

$$D = A \exp(-E/RT)$$

$$k = A \exp(-E/RT)$$

$D$ : diffusion coefficient

$A$ : temperature irrelevant constant (frequency factor)

$E$ : activation energy (Arrhenius parameter)

$R$ : gas constant

$T$ : absolute temperature

As the above equation shows, the higher the cleaning temperature becomes, the shorter the

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<sup>3</sup> Gordon M. Barrow, translated by Ryoichi Fujishiro, *Physical Chemistry* (Tokyo Chemistry Doujin Publishing, 1981) 644.

cleaning time due to proportionately higher  $D$  and  $k$ . Additionally, when dissolving solid flux residue the raised temperature softens the residue giving the surface fluid effect.

Fig. 2.8.2 shows the relation between cleaning temperature and dissolving time of flux residue for lead-free solder paste. Cleaning time assessment enables calculation on cleaning speed given the same physical/mechanical conditions.

Deflux process requires the system design based on cleaning method thermodynamics, as well as the choice of highly dissolvable cleaning chemicals. As shown in table 2.8.1 listing features/advantages and disadvantages<sup>4</sup> of common deflux methods, choosing appropriate cleaning chemicals and methods are essential in securing the precision cleaning quality.

### 2.8.2 Design for Rinse Process

Many of deflux chemicals used in packaging process have the boiling point of over 200 °C, unrealistic to dry out on their own. There comes in the rinse process where fresh rinse chemicals, such as water that has the high capability to dry and remove ionic substances or water content alcohol, dissolve and diffuse cleaning chemicals with a high boiling point and high flux density, ultimately replacing the cleaning chemicals.

In the rinse process of mass cleaning, problems including rinse property deterioration, flux residue reattachment to the product, drying failure or the remained object after drying process may arise because of the increasing concentration of cleaning chemicals and flux residue in rinse chemicals constantly brought in from cleaning tanks. Therefore rinse process in precision cleaning such as for PCBs usually has several tanks, gradually rinsing off the cleaning chemicals and flux residue. Despite the cleaning process succeeds in residual flux removal, cleaning performance will deteriorate if contamination concentration is not controlled properly in the finishing rinse process. Thus it is important to control and operate the system by always monitoring the contamination concentration of the finishing rinse tank that it remains below the set limit based on the required quality of the product.

The following lists the necessary control conditions in rinse process;

#### (1) Conductivity

Conductivity is commonly used as a control standard for the finishing rinse tank since flux residue contains a large amount of ionic substances came from the activator such as amine halide salt and organic acid. The more ionic substances contained, the higher the conductivity becomes. Thus rinse chemicals contamination can be controlled by monitoring the conductivity transition in water or water content alcohol.

Generally water with the conductivity of 20uS/cm or higher may cause metal discolor or

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<sup>4</sup> Yutaka Hiratsuka, *Ready-to-use Cleaning Technology* (Kogyo Chosakai Publishing, 2001) 33.

corrosion because of the electric chemical reaction. Also, it accelerates ionic surfactant precipitation, causing reattachment of unsolved or slightly solved flux residue compounds solubilized or spread in water because of ionic surfactant.<sup>5</sup>

Water content alcohol, on the other hand, has mere possibility of metal rust or corrosion because alcohol molecules form a cluster structure surrounding water molecules in alcohol without generating H<sup>+</sup> ion that accounts for metal rust and corrosion. In addition, unsolved or slightly solved flux residue is less likely to reattach for it is soluble to alcohol.<sup>6</sup>

Yet the most important in post-precision cleaning quality is to maintain the circuit characteristics as well as to prevent corrosion or reattachment on the surface, asking for the conductivity setting appropriate for required cleaning quality.

## (2) Liquid temperature

When rinsing with water, conductivity increases to cause metal corrosion as water resistivity decreases in inverse proportion to water temperature rise.

Water content alcohol that contains water of 40 weight percent or more, though nonhazardous under the Fire Services Act, has a flash point as to drinkable alcohol such as whisky, requiring chillers in order to maintain the liquid temperature below its flash point.

## (3) Concentration of cleaning chemicals and flux residue

Either with water or water content alcohol, quality discrepancy such as drying failure and post-cleaning object arises as the concentration of cleaning chemicals and flux residue increases in the finishing rinse tank. Accordingly designing the most suitable equipment for long-term operation including the recycle and retrieval process is of the essence, based on the trial calculation of material balance in cleaning at the upper limit of contamination concentration for long-term use.

## (4) Water concentration

Water content alcohol as rinse calls for water concentration control. Under ordinary use water concentration increases as alcohol with a low boiling point volatilizes. Higher concentration may cause degradation in rinse and drying properties. Refractometer enables water concentration control.

### 2.8.3 Design for Drying Process

Properties and shapes of the products largely influence the drying process in wet cleaning,

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<sup>5</sup> Junichi Maeno, *Industrial Cleaning No. 5* (2010), 12.

<sup>6</sup> Shigeo Hori, *Ready-to-use Cleaning Technology* (Kogyo Chosakai Publishing, 2001) 335.

which prefers higher vapor pressure to vaporize rinse chemicals attached to the product.

Drying methods consist of sole or a combination of below-listed physical methods;

- (1) To accelerate vaporization by replacing the rinse vapor containing gas around the products with fresh gas, lowering the rinse vapor concentration. E.g. air circulation and blowing
- (2) To promote vaporization by heating rinse chemicals attached to the product and elevating vapor pressure of rinse chemicals. E.g. air circulation
- (3) To separate rinse chemicals from the product by physical force. E.g. suction dry, spin dry
- (4) To accelerate vaporization by depressurizing the atmosphere around the product lower than the vapor pressure of rinse chemicals. E.g. vacuum dry
- (5) To dry the product in saturated vapor, using solvents with low vaporization heat to replace and dry. E.g. vapor dry

In PCB deflux, heat transfer speed of the product often determines the drying process since attached amount of rinse chemicals is relatively little compared to the size of the product. PCBs contain a large amount of resin materials as insulator including epoxy resin, polyimide resin and Tefron resin, requiring an equipment design that enhances the heat transfer speed of these substances.

Fourier's law, the principle of heat transfer, can be written as follows in the same form as aforementioned Fick's first law, in which  $dq/dt$ , the amount of heat transfer per unit time, proportions to  $A$ , square measure of the material vertical to the heat direction, and  $dT/dx$ , the temperature gradient of the heat direction;<sup>7</sup>

$$dq/dt = - \lambda * A * dT/dx$$

$\lambda$  : thermal conductivity

As table 2.8.2 of thermal conductivity of each material shows, the thermal conductivity of resin materials including epoxy resin is less than one percent compared to that of metals. Hence, heat transfer speed escalation with forced convection of air as a medium for heat transfer is necessary in PCB drying process. Air circulation drying needs the most appropriate value setting on wind speed and wind amount based on the experiments. Vacuum drying requires measures to increase heat transfer speed by utilizing heat transfer of radiation and conduction since air convection will not occur.

#### 2.8.4 Design for Retrieval and Purification Process

Cleaning equipment must operate where the contamination concentration of cleaning

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<sup>7</sup> Shigefumi Fujita, *Chemical Engineering I* (Iwanami Publishing, 1977) 50.

chemicals and rinse chemicals is always below the control standards given the control standards on the cleaning equipment. Since flux residue and foreign materials contaminate the next process by reattaching to the product surfaces, consistent cleaning performance in long-term continuous use realizes only with a process to retrieve the contamination and purify the cleaning and rinse chemicals. The retrieval and purification process plays an important role in the cleaning system, greatly influencing the running costs and environmental burdens as well as the cleaning performance.

Common retrieval and purification methods are as follows;

(1) Contamination retrieval by filtering

This method is to collect solid foreign materials by filtering, including solder balls, separated compounds of flux residue and substrate scrap mixed in cleaning and rinse chemicals, or to retrieve ionic substances and organic compounds solubilized or spread in rinse chemicals by adsorption.

Non-woven filters made of resin collect solid foreign materials such as solder balls, with apertures based on the size of collecting products. Filtering has two ways: one is dead end filtration installed in the circulation line of equipment and the other is by-pass filtration. While the former can filter the entire amount of liquid, depending on the aperture size and collectability it may degrade the performance of pumps and the cleaning system by clogging the liquid flow with greater pressure loss. The latter, though such concern is less likely to apply, requires the eligible choice of pumps considering the liquid residence time.

Also, some filters adsorb ionic substances solubilized or spread in rinse chemicals with ion exchange resins and others adsorb organic compounds with activated carbons. As mentioned above, especially the water for rinse is apt to cause metal corrosion or reattachment of flux residue due to high conductivity caused by the elevated ionic substances concentration. Organic compounds, too, if mixed a large amount trigger drying failure or cleaning failure. Filtering prevent these problems, contributing to the longer lifetime of rinse chemicals.

However, filters need to be changed periodically because they have a limit in absorption.

(2) Cleaning chemicals retrieval by oil/water separation

When using water for rinse, settled or mechanical separation in a different tank from the rinse tank can separate and retrieve the oil compounds of cleaning chemicals and of flux residue from the rinse water. The oil removed water, recycled as pre-rinse water, can mitigate the burden of water waste on the cleaning system. However, some kinds of cleaning chemicals preclude oil/water separation.

(3) Distillation of cleaning chemicals

Distillation is common for cleaning chemicals purification in the one liquid cleaning system

such as hydrocarbon based cleaning chemicals. It secures a consistent cleaning performance by retrieving nonvolatile flux residue to maintain the low concentration of flux residue in cleaning chemicals. Conventionally, cleaning chemicals applicable to continuous distillation supposedly consist of a single compound or azeotrope, while mixed solvents with several different boiling points have been distilled per batch. Moreover, only non-water containing solvents have been considered for distillation since water may cause explosive boil due to boiling point difference and imbalance of vapor-liquid equilibrium in distillation.

Most of deflux chemicals suitable for removing flux residue, the mixture of compounds with various polarities, do not fit into these categories for continuous distillation. However recently the newly suggested cleaning system has solved this issue with a continuous distillation structure for deflux chemicals such as non-azeotropy solvents and water content solvents.<sup>8</sup>

#### (4) Distillation of rinse chemicals

In a certain cleaning system where water content alcohol acts as rinse, continuous distillation retrieves nonvolatile flux residue and cleaning chemicals with a high boiling point. Distillation maintains the consistent rinse property and high purity of liquid in the finishing rinse tank. Since water content alcohol is non azeotropy which water and alcohol have different vapor pressure, knowhow of the equipment manufacturers is necessary to install continuous distillation with a component ratio consistency based on thorough understandings on vapor-liquid equilibrium.

### 2.8.5 Common Cleaning System

The followings are the commonly used deflux systems in packaging line (Fig. 2.8.3);

#### (1) Semi-aqueous cleaning system

The system with cleaning chemicals mainly composed of glycol ether in addition to surfactant and water, and rinse water. The basic tank structure has four tanks for cleaning, pre-rinsing, rinsing and drying (the number of cleaning or rinse tank may increase if necessary). Attached are the granular activated carbon and ion exchange facilities to maintain the purity of rinse water, and ultraviolet disinfection equipment to prevent microbe contamination of various germs. The cleaning equipment itself is often large-scale and water waste treatment facilities are also necessary. Though not all cleaning chemicals apply, oil/water separation facilities can mitigate the burden of water waste on the cleaning system. VOC contained in cleaning chemicals will not be brought in to volatilize in the drying process since rinse water replaces the cleaning chemicals beforehand.

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<sup>8</sup> Yuki Akamatsu, *Electronic Materials, July edition, supplement* (2009) 90.

(2) Water content alcohol rinse cleaning system

The system with cleaning chemicals mainly composed of glycol ether or higher alcohol, and water content alcohol for rinse. The basic tank structure is the same as that of semi-aqueous cleaning system. The difference is the great amount of reduction in waste liquid because rinse chemicals regenerate through continuous distillation. Cleaning performance remains consistent because of clean rinse chemicals in the finishing rinse tank, where distillation and ion exchange resins cut the contamination. The sterilization of water content alcohol and distillation together eliminate the necessity of microbe disinfection and waste water treatment facilities, realizing smaller cleaning equipment with lesser supplement facilities compared to semi-aqueous cleaning system.

(3) Hydrocarbon based cleaning system

Either the system with hydrocarbon based cleaning chemicals and IPA rinsing in order to secure ionic substance removability, or the one liquid cleaning system with hydrocarbon and glycol ether mixed.

The latter is more popularly used with the basic structure of three tanks: pre-cleaning, cleaning and drying, many attached with a distiller. Cleaning chemicals with a relatively low boiling point suitable for the one liquid cleaning system requires adequate safety measurements such as explosion-proof facilities.

(4) Co-solvent cleaning system

The system with cleaning chemicals mainly composed of hydrocarbon or glycol ether based solvents, and fast-drying, nonflammable fluorine solvents for rinse. Although this system uses less heat in drying, the VOC consisting 100% of cleaning chemicals largely impact the environment in an open system and fluorine solvents are expensive. Therefore closed system is popular to reduce atmospheric exhaust.

#### 2.8.6 Cleaning Quality Control of Deflux Cleaner<sup>910</sup>

Here describes the examples of cleaning quality control on deflux equipment capable of continuously distilling rinse chemicals (Fig.2.8.4) using glycol ether based cleaning chemicals and water content alcoholic rinse chemicals as follows;

Purity control standard of rinse chemicals in the finishing rinse tank is determined based on dielectric loss ( $\tan\delta$ ) between wirings of JIS 2 type wiring board of the comb-pattern. In other

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<sup>9</sup> Shigeo Hori, Hisakazu Takahashi, *Surface Mount Technology, Sep. edition*, (1983), 30.

<sup>10</sup> Hisakazu Takahashi, *Production Technology Application Manual* (Kogyo Chosakai Publishing, 2000) 859.

words, the control standard is the allowable concentration of the rinse chemicals set according to the correlation between the concentration of contamination in the rinse chemicals, flux residue and such, and  $\tan\delta$  between wirings (Fig 2.8.5). Also it is designed for packaging sites to be able to manage the contamination concentration in rinse chemicals with a conductivity meter based on the correlation of contaminating flux residue concentration and conductivity (Fig.2.8.6).

Mass cleaning, which constantly cleans a great deal of work, prioritizes the most appropriate equipment design including the concentration control of the finishing rinse tank and recycling, with calculations on the material balance of cleaning at the upper limit of the object concentration in long-term use.

As Fig 2.8.7, the flow of deflux cleaning, shows, clarification of control standards on the cleaning performance enables optimization of each process.

#### Future Prospect

Ideal deflux equipment realizes high cleaning performance, high production efficiency and low environmental impacts. Additionally, it must respond to requests from the packaging scene including downsizing of the equipment and costs, efficient cleaning methods with lesser amount of cleaning chemicals, recycling system and closed system of entire equipment.

To satisfy these requests, building and designing a cleaning system is of the essence with which post-cleaning reliability evaluation technology, cleaning chemicals design technology and cleaning equipment design technology all combined and collaborated.

Fig. 2.8.1 Relationship between Reynolds Number and Cleaning Effect

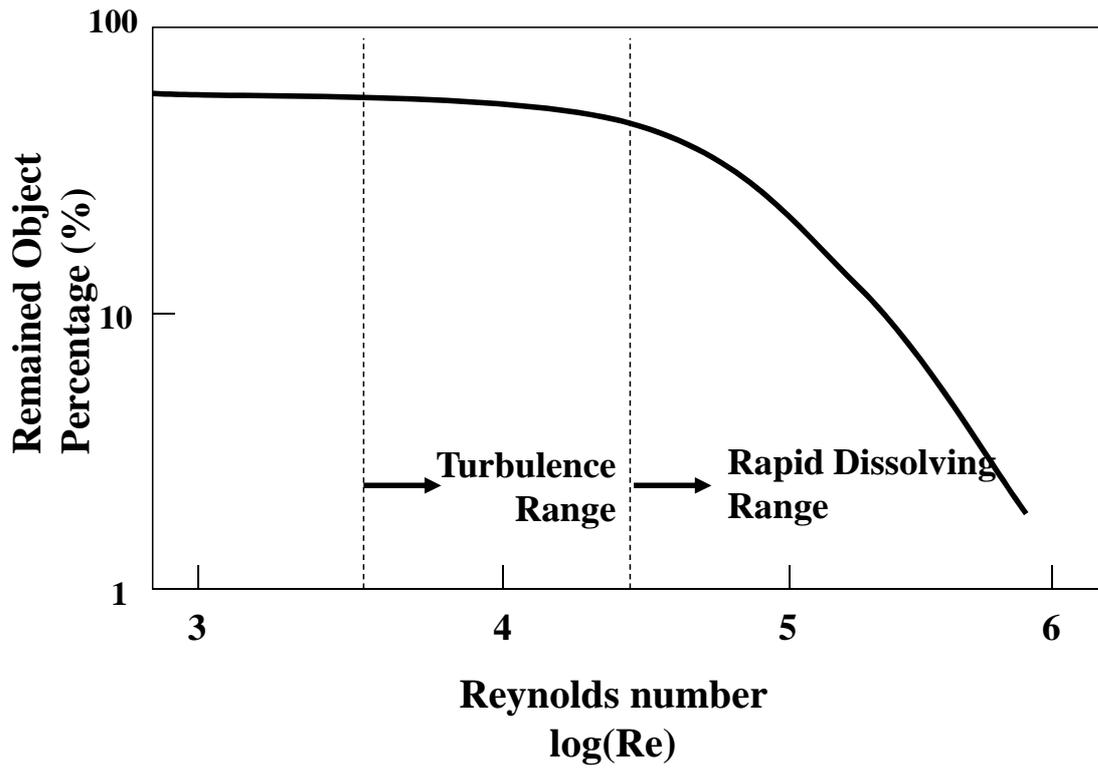


Fig.2.8.2 Relationship between Cleaning Temperature and Solving Time of Flux Residue of Lead-free Solder Paste

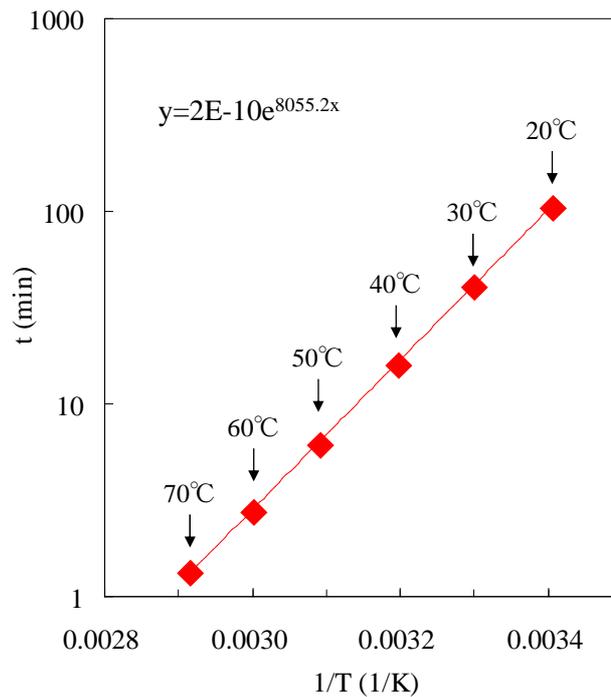


Table.2.8.1 Advantage/Disadvantage of Commonly-used Deflux Methods

Classification	Name	Features/Advantages	Disadvantages
<b>Immersible Cleaning</b>	Jet Circulation Cleaning	Liquid circulates in cleaning tanks with pumps, diffusing the object. Changing the liquid transfer pressure of the pump or the shape of outlet can improve the cleaning performance. Less physical impact on the products.	Cleaning performance may be inconsistent depending on the fixed position of the products in tanks. Lower cleaning performance in narrow gaps.
	Direct Path Cleaning	The method to directly pass a large amount of cleaning chemicals through the products by reducing the gap with products or jigs. Suitable for cleaning gaps because it can efficiently send the suction/discharge energy of pumps to the products.	It may not be effective depending on the product shape, for that the products must be gathered in cleaning baskets. Basket alteration is also necessary. Unsuitable for high-variety low-volume product cleaning. Mostly large-scale.
	Ultrasonic Cleaning	Cleaning with the cavitation function occurring from ultrasonic radiated in cleaning chemicals. It promotes peeling and diffusing the object from the products. Suitable for cleaning narrow gaps and removing solder balls and small particles.	To secure the cleaning performance consistency, oscillation of products is necessary to equalize the cavitation effect in cleaning tanks. Since ultrasonic has a property of going straightforward, its effect weakens on lapped products. Some components are not applicable because soft materials such as aluminum may cause erosion. Cleaning performance improves with deaerated cleaning chemicals.
	Vacuum Cleaning (Depressurizing Cleaning)	Depressurizing the inside of confined containers, containing the products soaked in cleaning chemicals, lead cleaning chemicals to enter between deaerated gaps of the products. Suitable for cleaning complicated shaped products. Better performance with ultrasonic cleaning.	Facility costs relatively expensive. Longer cleaning time due to repeating the state with an ambient pressure and that of depressurized. Cleaning performance depends on the confinement state.
<b>Non-Immersible Cleaning</b>	Showering Cleaning	The method to clean a wide range with a small amount of cleaning chemicals by showering the chemicals with a low pressure from nozzles. Either line several nozzles or move them around to cover wider area of cleaning.	Unsuitable for cleaning chemicals with high formability or high flammability. Showering must thoroughly cover the entire area to gain a satisfactory effect.
	Jet Spraying Cleaning	This method is to remove the object attached on the product surface by jet spraying the cleaning chemicals from nozzles with a higher pressure than showering, utilizing the collision force of liquid.	Unsuitable for cleaning chemicals with high formability or high flammability. Spraying must thoroughly cover the entire area to gain a satisfactory effect.
	Vapor Cleaning	This method is to remove the object attached on the product surface with vaporated cleaning chemicals condensed on the surface. Same effect as to rinse with purified distilled liquid. Used for finishing cleaning. Can also dry if the product taken out when its surface temperature equals to the vapor temperature.	Explosion-proof facilities are necessary when using cleaning chemicals with a low flash point. Cooling pipes in the upper area of cleaning tanks are also necessary to prevent solvent vapor loss. Unsuitable for objects with low heat capacity.

Table.2.8.2 Thermal Conductivity k

Substance	$\kappa$ (W/m°C)
Silver	420
Copper	398
Gold	320
Aluminum	236
Steel	86
Tin	65
Lead	35
Alumina	21
Stainless Steel	18
Lead Glass	0.6
Teflon	0.5
Polyethylene	0.4
Silicon Rubber	0.2
Epoxy Resin (Bisphenol A)	0.2

Fig.2.8.3 General Tank Structure of Each Cleaning System

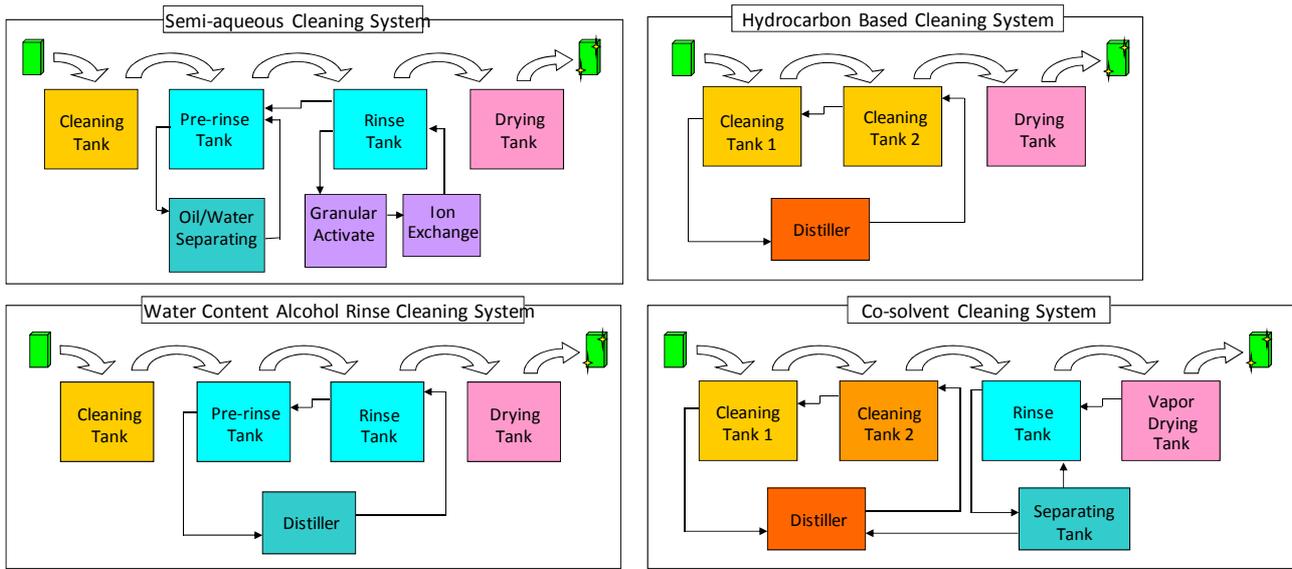


Fig.2.8.4 Appearance of Deflux Tool



Fig. 2.8.5 Relationship between Cleaning Chemicals Concentration in Rinse Chemicals (including 10wt% of Flux Concentration) and  $\Delta D$ , Increased Amount of Dielectric Loss Tangent due to Post-Cleaning Moisturized Substrates

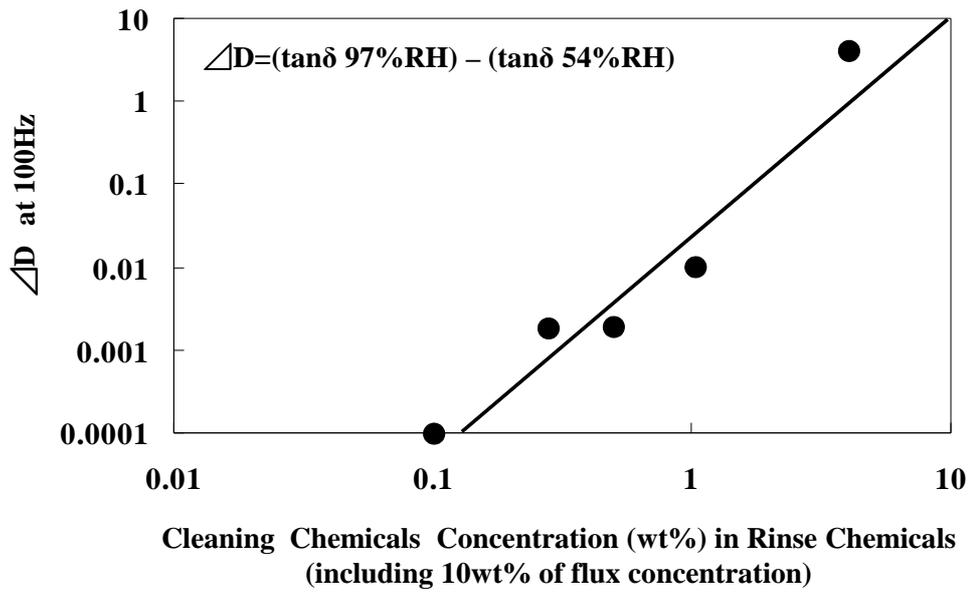


Fig.2.8.6 Relationship between Cleaning Chemicals Concentration (including 10wt% of Flux Concentration) and Conductivity

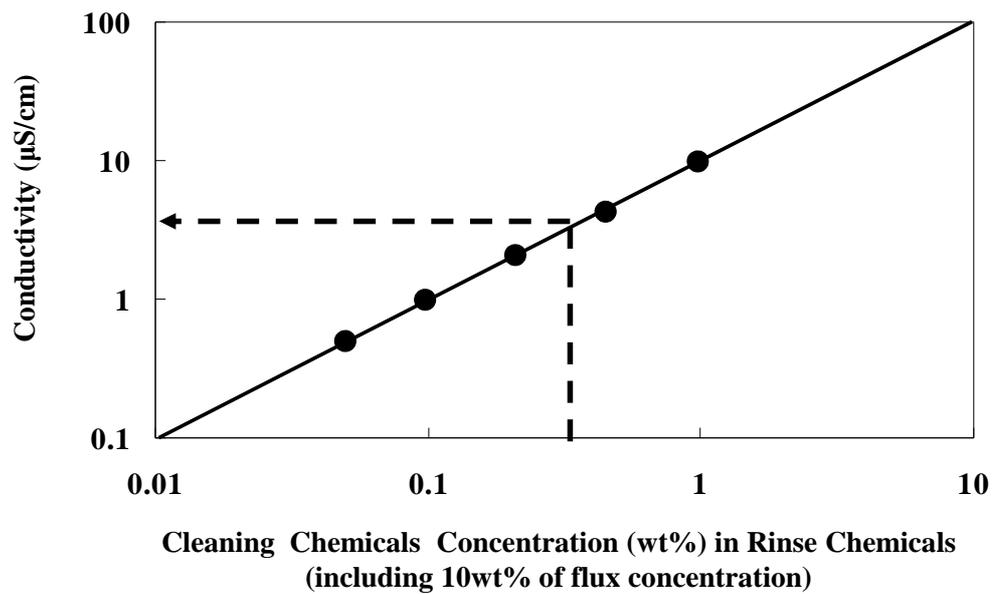


Fig.2.8.7 Flow of Deflux Tool (example)

