As originally published in the IPC APEX EXPO Proceedings.

Meeting the Challenge of Removing Flux Residues from Electronic Circuitry Utilizing Low Standoff Heights

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Abstract

Our insatiable desire for smaller, faster and highly functional electronic devices presents numerous challenges for package designers and manufacturers. Current day popular approaches include stacked components and boards, high I/O density, and short interconnection distances. Unfortunately, these solutions make flux residue removal from underneath components increasingly difficult. Adding to the challenges are the changing global environmental and safety regulations which make the cleaning task even more challenging. The objectives of this study are to 1) evaluate cleaning effectiveness of several currently available cleaning chemistries/processes in removing flux residues from underneath low standoff height components, 2) determine differences in the effectiveness of these individual cleaning processes on Sn/Pb and Pb-free solder paste residues, and 3) evaluate inherent advantages or limitations for each type of cleaning chemistry and process.

Introduction

With demand increasing for smaller and high-performance consumer electronic devices and appliances, manufacturers are relying more on high density and miniaturized circuitry. Miniaturization is requiring the use of smaller components with finer and finer pitch with low standoff heights. The standoff heights in the newer fine-pitch electronic circuitry are typically only a few mils, thus making the act of cleaning post-soldering flux residues from underneath components a very difficult task. Even though the use of No-Clean flux for such low standoff devices is increasing, manufacturers of products for high-reliability and military applications are forced to include a cleaning process in the manufacturing cycle because of concerns of long-term reliability. Electronic assembly manufacturers are now faced with the challenge of finding suitable cleaning processes and chemistries to address the flux residue removal from low standoff devices.

While a number of cleaning processes[1, 2] have been successfully used over the years to remove the flux residues, the use of newer pastes/fluxes coupled with denser and tighter spaces is making the task of cleaning a challenging job. While cleaning was relatively easy in boards using components such as BGA’s with typical standoff heights of 18-35 mil, the task has become increasingly challenging with the use of fine pitch components such as micro BGA’s and Quad Flat No-leads (QFN’)s with typical standoff heights in the range of 1-5 mil.

This study was undertaken to evaluate the effectiveness of various currently available cleaning processes/chemistries in removing flux residues from underneath low standoff components. The specific objectives of this study are to:

1) evaluate cleaning effectiveness of several cleaning chemistries/processes in removing flux residues from underneath low standoff height components,
2) determine differences in the effectiveness of these individual cleaning processes on Sn/Pb and Pb-free solder paste residues, and
3) evaluate inherent advantages or limitations for each type of cleaning chemistry and process.

Cleaning Processes

While a number of processes are currently available for cleaning, some of the most widely used processes have been evaluated in this study. They are:

1) Aqueous Inline Spray-in-Air
2) Aqueous Batch Ultrasonic
3) Monosolvent Vapor Degreasing
4) Cosolvent Vapor Degreasing

Description of Cleaning Processes

AQUEOUS INLINE SPRAY-IN-AIR

A typical Aqueous Inline Spray-in-Air process uses a pre-wash, wash, chemical isolation (chem-iso) section, two rinses and a drying section. The pre-wash and wash sections typically use a chemical concentration of 10-25% cleaning chemistry operating at 140-165°F. The cleaner is usually a saponifier mixed with other ingredients to improve performance, inhibit corrosion, and reduce foaming. The chem-iso section is used to prevent contamination of the rinse sections by reducing the amount of drag out of the wash solution into the rinse sections as the boards travel through the machine. The rinse section of the machine uses deionized water usually heated to 140-165°F. The rinse water is either sent to drain or to a water treatment system for recycling. The drying section is typically either heated or unheated forced air. Inline systems have the highest throughput capacity.

AQUEOUS BATCH ULTRASONIC

Aqueous Batch Ultrasonic systems have multiple tanks for washing and rinsing steps. They are relatively inexpensive, have low energy requirements, and higher throughput. Cleaning and rinsing are performed with the boards immersed in the clean/rinse stage utilizing ultrasonic agitation. Process temperatures are usually set 30ºF below the flash points of the cleaning materials in order to avoid the need for additional fire prevention controls. After the wash tank, parts are typically moved through multiple rinse tanks and are finally dried. The use of ultrasonics for electronics cleaning was a concern in the past, but the technique has gained acceptance in recent years as the probability of damage to electronic components has been minimized using newer high-frequency (40 KHz and higher) units with variable frequency capabilities.

MONOSOLVENT VAPOR DEGREASING

Conventional Monosolvent Vapor Degreasing systems are equipped with either one or more sumps employing a single solvent, referred to as monosolvent, functioning as both the washing and rinsing agents. A typical vapor degreasing monosolvent is a relatively low boiling, high vapor pressure, non-flammable material that can be either a single component or an azeotrope. As the monosolvent boils, it forms a blanket of vapor which is contained within the equipment by cooling coils. In a one sump degreaser, the part to be cleaned is typically immersed in the vapor phase; the cleaner condenses on the part, cleaning it and carrying the soil away. In vapor degreasers with two or more sumps, the part to be cleaned may be first submerged in the boiling sump to loosen very tough soils, though this is not common and then only if the degreaser is equipped with a still. The part is then (or initially) submerged into the rinse sump or sumps, which are constantly being replenished with clean monosolvent condensed on the cooling coils. The rinse sump or sumps continually overflow into the wash sump, where the contaminants are concentrated. The part is raised in to the vapor zone where the vapor condenses on the part which acts as the final rinse.

COSOLVENT VAPOR DEGREASING

The patented Cosolvent Vapor Degreasing process[3] is similar to a conventional vapor degreasing process and requires a two-sump vapor degreaser. The process uses a high boiling solvent blend or Solvating Agent (SA) that is mixed with a relatively low boiling, high vapor pressure, non-flammable solvent or Rinse Agent (RA). The boil sump consists of both the SA and the RA, while the rinse sump consists exclusively of RA. The operating temperature and aggressiveness of the cleaning is determined by the ratio of SA to RA in the boil sump. The RA boils in the boil sump creating a vapor blanket. Cleaning only takes place in the boiling sump where the parts are exposed to the SA, so the parts must be lowered into the boil sump to remove the soil. The parts are immersed in the rinse sump to remove the dissolved soil and SA, and finally raised into the vapor zone where the RA condenses on the parts for a final rinse.

Experimental Procedure

In order to easily determine cleanliness under components visually, specially designed FR-4 test boards with glass slides acting as components were utilized to simulate low standoff circuitry. The standoff height was controlled by using standard shims of 1 mil thickness as spacers between the glass slides and the FR-4 board. The glass slides were attached to the boards using an epoxy. The circuit boards were 4.125” x 3.625” with various size solder pads in a repeating design. The glass slides used were 1” x 3”. Figure 1 shows a picture of the test board used. Each test board had three sections. Glass slides were attached to the two outer sections of the board to simulate components with 1 mil and 5 mil clearances respectively; the middle section was left open to simulate unobstructed areas without any components.

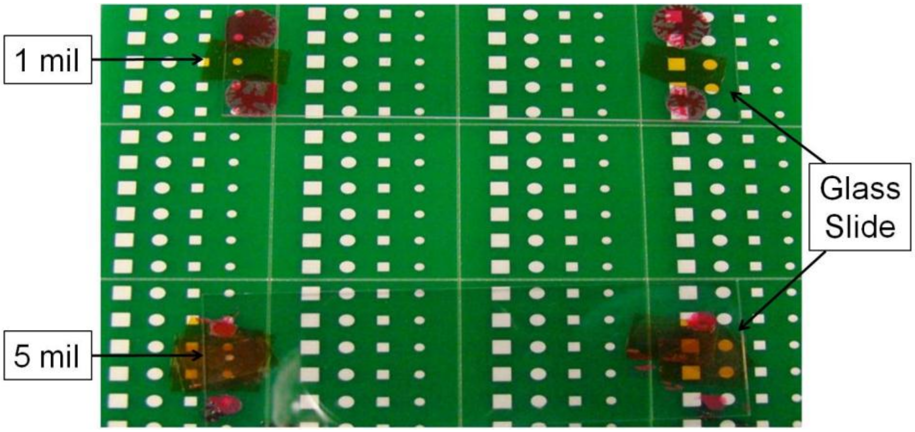

Figure 1 - Picture of the experimental test vehicle

The test boards were reflowed in a nitrogen atmosphere using the manufacturer specified reflow profile for each solder paste. The slides were clamped onto the circuit boards during reflow to maintain the desired spacing. The reflowed boards were allowed to sit for 24 hours before cleaning to simulate the "worst case" scenario. After cleaning, the boards were evaluated for any remaining residues. Cleanliness evaluation was performed by observing the cleaned glass slides at 50X magnification using a HIROX digital microscope. Based on the amount of residue around all solder joints on the board and underneath the glass slides, the boards were rated for cleanliness as "+", "0" and "-". Boards that were totally clean without any residue underneath the glass slides were rated as "+". Boards that were partially clean, with slight flux residues still visible were rated as "0". Boards with considerable flux residues remaining were rated as "-". Figure 2 illustrates typical examples of flux removal ratings of "+", "0" and "-".

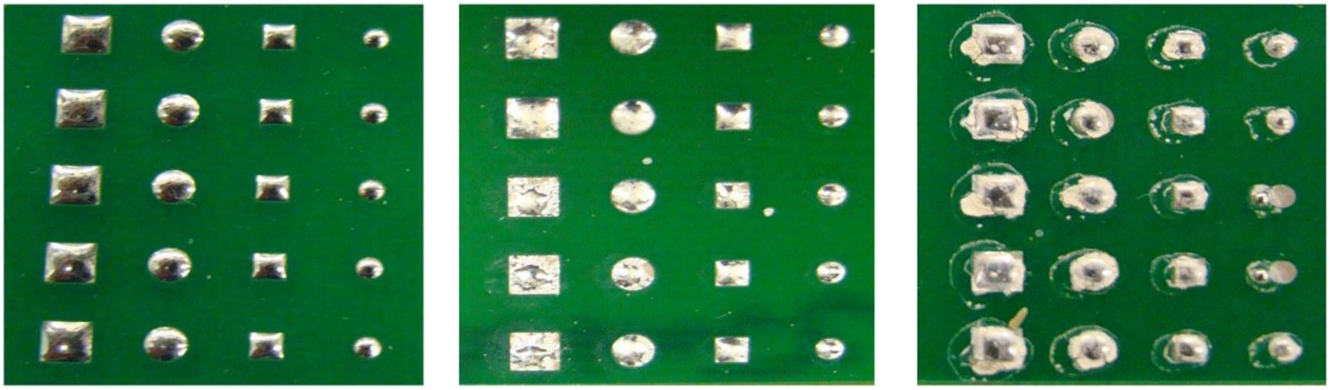

Figure 2 – Flux removal ratings of "+", "0" and "-" respectively

SOLDER PASTES TESTED

A variety of popular solder pastes, both Sn/Pb and Pb-free, were used in determining the cleaning ability by each process. The pastes are listed below in Table 1. Sn/Pb solder pastes included one each of Rosin Mildly Activated (RMA), No-Clean and Water-Soluble (WS) pastes. Pb-free solder pastes included one each of No-Clean and Water-Soluble pastes. For ease of recognition, the Sn/Pb pastes are represented in blue while the Pb-free pastes are represented in green in each of the tables below.

Table 1 - List of solder pastes tested in this study

Type	RMA	No-Clean	Water-Soluble
Sn/Pb	Paste 1	Paste 2	Paste 3
Pb-free	-	Paste 4	Paste 5

PROCESSES TESTED

Each of the above solder pastes were cleaned by each of the following processes (described above):

1) Aqueous Inline Spray-in-Air
2) Aqueous Batch Ultrasonic
3) Monosolvent Vapor Degreasing
4) Cosolvent Vapor Degreasing

OPERATING PARAMETERS

Aqueous Inline Spray-in-Air process test conditions were as follows:

Chemical:	Aqueous saponifier
Chemical concentration:	20%
Wash Temperature:	150°F
Wash Pressure:	45 psi
Rinse Temperature:	150°F
Rinse Pressure:	25 psi
Dry Temperature:	80°F
Belt Speed:	1 ft/min

Aqueous Batch Ultrasonic process parameters were as follows:
Chemical: Aqueous-based cleaner
Chemical concentration: 20%
Wash Temperature: 150°F
Wash time: 25 minutes with ultrasonics
Rinse temperature: 150°F
Rinse time: 20 minutes with ultrasonics

Monosolvent Vapor Degreasing process test conditions were as follows:
Chemical: n-propyl Bromide/IPA azeotrope
Wash Temperature: 148°F
Wash time: 10 minutes
Rinse temperature: 146°F
Rinse time: 10 minutes
Vapor temperature: 148°F
Vapor time: 1 minute

Cosolvent Vapor Degreasing process parameters used were as follows:
Chemical: Hydrocarbon/Fluorinated solvent blend
Wash Temperature: 200°F
Wash time: 10 minutes
Rinse temperature: 120°F
Rinse time: 10 minutes
Vapor temperature: 142°F
Vapor time: 1 minute

Results and Discussion

Three sets of observations were made on each board cleaned by a particular process/chemistry. The observations included 1) flux removal from the solder pads in the open areas (without any glass slides) which represented the baseline unobstructed cleanliness, 2) flux removal from underneath 5 mil spacing, and 3) flux removal from underneath 1 mil spacing.

Figure 3 and Table 2 show the results of relative flux removal ability of various processes/chemistries in the absence of any components, representing the baseline cleaning ability without the limitations of tight spaces. In Figure 3 and subsequent figures a cleanliness rating of 100 is equivalent to "+".

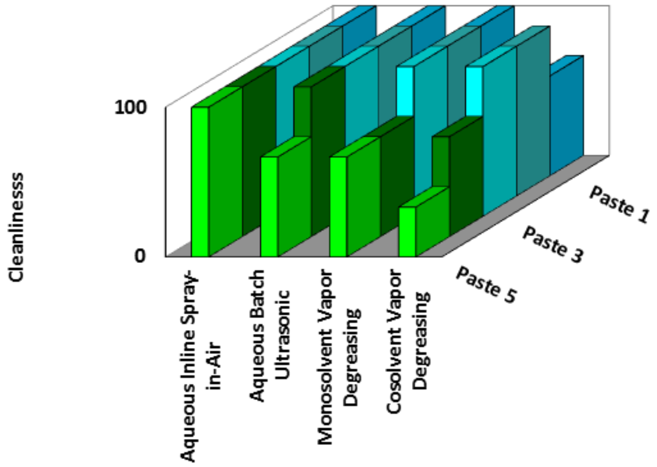

Figure 3 - Clean-ability of the pastes by various processes

Table 2 - Baseline cleaning ability of various processes

Solder Paste	Aqueous Inline Spray-in-Air	Aqueous Batch Ultrasonic	Monosolvent Vapor Degreasing	Cosolvent Vapor Degreasing
Paste 1	+	+	+	0
Paste 2	+	+	+	+
Paste 3	+	+	+	+
Paste 4	+	+	0	0
Paste 5	+	0	0	-

The Aqueous Inline Spray-in-Air process was the best in removing all types of flux residues, followed by the Aqueous Batch Ultrasonic process. Monosolvent Vapor Degreasing was very effective in removing Sn/Pb flux residues, but was only partially successful in removing Pb-free flux residues. Cosolvent Vapor Degreasing was effective on certain types of Sn/Pb flux residues, but it too had limited success with the Pb-free flux residues tested in this study.

Table 3 shows the results of cleaning ability of various processes in removing flux residues from underneath 5 mil spacing. Aqueous Batch Ultrasonic and Monosolvent Vapor Degreasing processes were very effective in removing Sn/Pb residues from underneath 5 mil spacing, but fell short in removing Pb-free residues. The Aqueous Inline Spray-in-Air process was able to completely clean two of the three Sn/Pb pastes, but had limited success with Pb-free pastes.

Table 3 - Cleaning underneath 5 mil spacing

Solder Paste	Aqueous Inline Spray-in-Air	Aqueous Batch Ultrasonic	Monosolvent Vapor Degreasing	Cosolvent Vapor Degreasing
Paste 1	-	+	+	-
Paste 2	+	+	+	0
Paste 3	+	+	+	0
Paste 4	-	-	-	0
Paste 5	0	-	-	-

Table 4 shows the results of cleanliness underneath 1 mil spacing by various processes. As expected, the results demonstrate the difficulty in cleaning underneath such low standoff heights. None of the processes were able to clean all the pastes. Only a few processes were successful in the removal of Sn/Pb residues, while none of the processes were successful in the removal of any Pb-free residues.

Table 4 - Cleaning underneath 1 mil spacing

Solder Paste	Aqueous Inline Spray-in-Air	Aqueous Batch Ultrasonic	Monosolvent Vapor Degreasing	Cosolvent Vapor Degreasing
Paste 1	-	+	0	-
Paste 2	+	0	+	0
Paste 3	0	+	-	-
Paste 4	-	0	-	-
Paste 5	0	-	-	-

For each of the four processes, the clean-ability of each of the pastes under different standoff heights is shown in Figures 4-7. The difficulty in cleaning increased as the standoff height decreased for all processes.

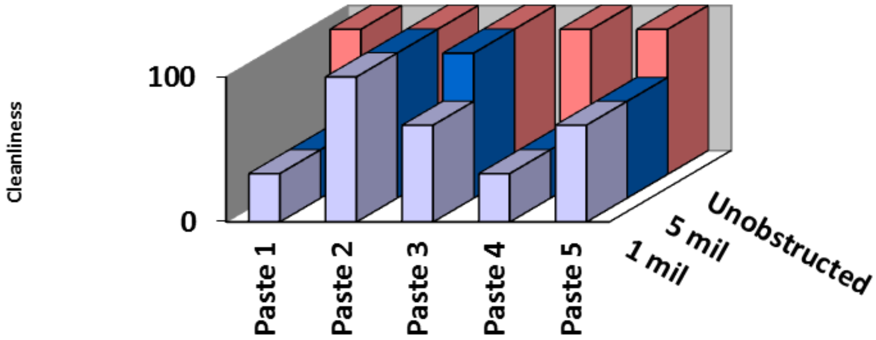

Figure 4 - Clean-ability of 5 pastes under various standoff heights by Aqueous Inline Spray-in-Air process

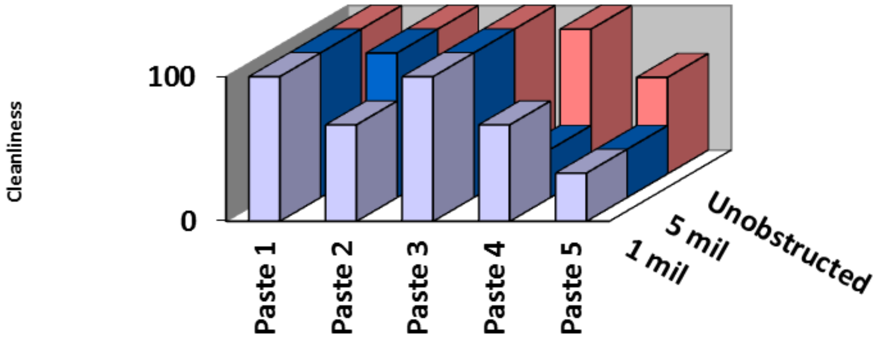

Figure 5 - Clean-ability of 5 pastes under various standoff heights by Aqueous Batch Ultrasonic process

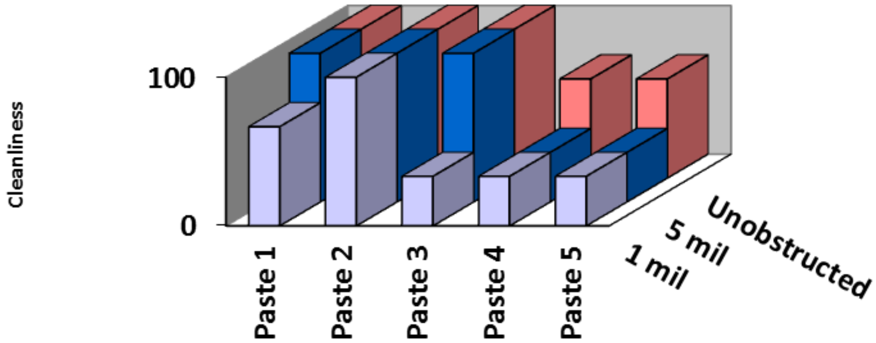

Figure 6 - Clean-ability of 5 pastes under various standoff heights by Monosolvent Vapor Degreasing process

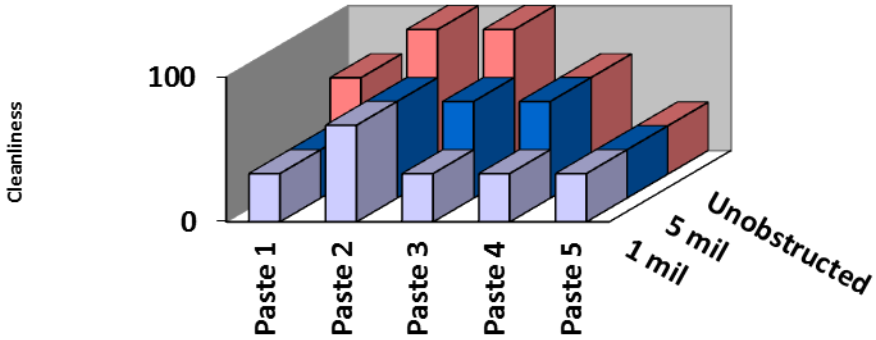

Figure 7 - Clean-ability of 5 pastes under various standoff heights by Cosolvent Vapor Degreasing process

Since the ability of cleaning is directly dependent upon the cleaning agent's effectiveness in penetrating the tight spaces, observations were also made at the edge of the glass slides and compared to those in the center of the glass slide, as shown in Figure 8.

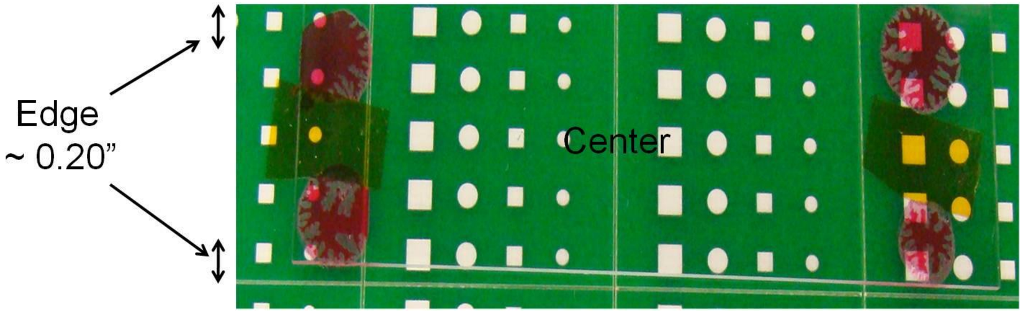

Figure 8 - Picture showing the edges and center of the glass slides where flux removal effectiveness was rated

Table 5 shows the cleaning results at the edges and the center of the glass slide for Aqueous Inline Spray-in-Air process at different standoff heights. As can be seen from Table 5, the unobstructed area was cleaned effectively demonstrating that the cleaner is able to remove the residues in these conditions. For 5 mil spacing, most of the pastes had similar results at the edge as in the center. However, as the standoff height is reduced to 1 mil, most of the pastes showed worse results at the center than at the edge of the glass slides. Since the surface tension of the aqueous cleaner is high, its ability to penetrate underneath tight spaces is limited. Moreover, since the spray jets are positioned perpendicular to the boards, using higher spray pressures generally does not improve the ability to penetrate tight spaces. Even if the cleaner is able to penetrate the tight spaces, rinsing from underneath is more difficult due to the higher surface tension of the rinse water as compared to the cleaning agent.

Table 5 - Cleaning results for Aqueous Inline Spray-in-Air process at different standoff heights

Solder Paste	Unobstructed	5 mil spacing		1 mil spacing	
		Edge	Center	Edge	Center
Paste 1	+	0	0	0	-
Paste 2	+	+	+	+	+
Paste 3	+	+	+	+	0
Paste 4	+	-	-	-	-
Paste 5	+	+	0	+	0

Table 6 illustrates the results for Aqueous Batch Ultrasonic process underneath different standoff heights. Again, as in Aqueous Spray-in-Air process, better results were noticed underneath 5 mil spacing than underneath 1 mil spacing. For Paste 4, the results under 1 mil spacing were better than the results under 5 mil spacing, which may be due to a variety of factors including preparation of the sample board, thickness of the paste applied, variations in ultrasonic energy in the cleaning bath, etc. However in general, the use of ultrasonics improved flux removal under tight spots when compared to Spray-in-Air.

Table 6 - Cleaning results for Aqueous Batch Ultrasonic process at different standoff heights

Solder Paste	Unobstructed	5 mil spacing		1 mil spacing	
		Edge	Center	Edge	Center
Paste 1	+	+	+	+	+
Paste 2	+	+	+	+	0
Paste 3	+	+	+	+	+
Paste 4	+	0	-	+	0
Paste 5	0	0	-	-	-

The cleaning results for Monosolvent Vapor Degreasing process are illustrated in Table 7. At 5 mil spacing the results at the center were comparable to those at the edges for Sn/Pb pastes. However, for 1 mil spacing, the results were slightly better at the edges than at the center. Even though the vapor is able to penetrate tight spaces, if the residence time is insufficient in the wash cycle, the vapor condensing on the board in the rinse stage will not be able to remove the residues from underneath. The results for Pb-free pastes show only partial cleaning even in unobstructed situations, showing the limitation of the Monosolvent process where the wash temperatures are limited to less than 150°F.

Table 7 - Cleaning results for Monosolvent Vapor Degreasing process at different standoff heights

Solder Paste	Unobstructed	5 mil spacing		1 mil spacing	
		Edge	Center	Edge	Center
Paste 1	+	+	+	+	0
Paste 2	+	+	+	+	+
Paste 3	+	+	+	+	-
Paste 4	0	0	-	-	-
Paste 5	0	0	-	0	-

Table 8 shows the results for Cosolvent Vapor Degreasing process at two different standoff heights for various pastes. A variety of combinations of Solvating Agents/Rinse Agents with different solvency are available in the Cosolvent process. While higher temperatures were achievable when compared to the Monosolvent Vapor Degreasing Process, the combination chosen was not optimal. Matching the flux to be cleaned with the right combination of Solvating Agents/Rinse Agents is critical for the success of the Cosolvent Vapor Degreasing process.

Table 8 - Cleaning results for Cosolvent Vapor Degreasing process at different standoff heights

Solder Paste	Unobstructed	5 mil spacing		1 mil spacing	
		Edge	Center	Edge	Center
Paste 1	0	0	-	-	-
Paste 2	+	+	0	+	0
Paste 3	+	+	0	0	-
Paste 4	0	0	0	0	-
Paste 5	-	-	-	-	-

Summary

With the increased use of high density and miniature components in modern electronic devices, the electronics assembly industry continues to deal with the challenge of finding the right cleaning process for removing residues from low standoff components. The advent of new flux chemistries along with the changing environmental regulations add to the complexity of finding the right cleaning process. Moreover, economic considerations, waste disposal and space requirements also play an important role in choosing a cleaning process. In this study, four different cleaning processes were evaluated for their performance in removing flux residues from underneath 5 mil and 1 mil clearances. The processes included Aqueous Inline Spray-in-Air, Aqueous Batch Ultrasonic, Monosolvent Vapor Degreasing and Cosolvent Vapor Degreasing. Three Sn/Pb and two Pb-free solder pastes were tested in each of the four processes.

Each process demonstrated the increased difficulty in cleaning as the standoff height was reduced. While some reduction in cleaning efficiency was observed under 5 mil spacing as compared to cleaning in unobstructed areas, complete cleaning is achievable under 5 mil spacing with the selection of the right chemistry/process and optimization of process parameters. However, cleaning underneath 1 mil spacing remains very difficult as evidenced in this study. While none of the processes tested were able to clean all of the paste residues underneath 1 mil spacing; the Aqueous Batch Ultrasonic process was most successful. This can be attributed to the apparent reduction in the surface tension of the aqueous cleaner due to the ultrasonic energy introduced into the system. The results of this study also demonstrate that under similar operating conditions, Pb-free pastes continue to be more difficult to clean than Sn/Pb pastes. This suggests that solder paste manufacturers should consider the need for cleaning when designing Pb-free and Sn/Pb solder pastes for low standoff height applications. Additionally, novel approaches may be required to meet the cleaning needs as new manufacturing trends continue.

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3. Co-solvent Vapor Degreasing Patents include: 2,111,337 (Canada); 588,978 (Great Britain and Italy); 182,549 (Mexico); 48,238 (Singapore); 5,679,175 (United States); 6,187,729B1 (United Sates) and 5,716,457 (United Sates).