Optimizing Cleaning Strategies for Advanced Packaging Technologies with Low Standoff Components

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ABSTRACT

As computing chips evolve to offer enhanced functionalities, packages like SiP, fcBGA, PoP, and 2.5D have become more intricate, incorporating larger die sizes, increased bump counts, and lower standoff heights. These advancements have posed challenges in achieving effective cleaning.

The interconnects in these packages commonly use solder. Post-soldering, flux residues create significant cleaning hurdles, particularly beneath low-profile components. With standoff heights decreasing to less than 50µm, outgassing during reflow diminishes, further complicating flux residue removal. Components such as QFNs and LGAs with large thermal pads add to these challenges, risking reliability issues including electrochemical migration and electrical leakage.

Understanding the nuances of cleaning processes, especially in conveyorized spray-in-air inline systems is critical for overcoming these challenges. This study will focus on optimizing cleaning parameters to ensure reliable performance and durability under harsh conditions. From analyzing the arrangement and orientation of spray bars to controlling pressure and spray nozzle distance from the belt of wash and rinse modules, optimizing these parameters is essential to balance cleaning effectiveness while minimizing potential damage to delicate components.

The study will utilize various test vehicles with low standoff components, using both No-clean and Water-soluble solder formulations. Two aqueous-based cleaning agents will be evaluated, and cleanliness assessed through visual inspection, SIR, and IC testing following IPC standards. The results will provide insights into optimization advantages, helping manufacturers reduce risk of failures, improve efficiency, and ensure optimal cleaning consistency and repeatability.

Key words: Advanced Packaging, Electrochemical Migration, Electrical Leakage, Reliability, Solder Interconnects, Miniaturization, Reliability testing

INTRODUCTION

Advanced packaging technology has grown dramatically in the past few decades, and thousands of different semiconductor package types have been created. Nowadays, chip integration with additional functions to improve performance, processing challenges, storage, and networking have become a standard. This is especially true with the growing trends of IoT, 5G Technology, Automotive (ADAS, Infotainment, EVs), Medical Devices, Telecommunications, A&D, etc. which requires high reliability, miniaturization, and robust performance in harsh environments.

System-in-Package (SiP) is one of the Advanced Packaging technologies that plays a critical role in this aspect and it involves integrating multiple semiconductor dies, passive components, and interconnects within a single package. This approach enhances functionality, reduces form factor, and improves overall performance, making it essential for modern electronic devices.

In this context, the demand for 5G mobile phones is driving the adoption of system-in-package (SiP) technology, as seen in the growing number of 5G phone releases by companies like Apple, Samsung, Huawei, Xiaomi, OPPO and VIVO. SiP enables high-performance, space-saving integration of multiple components, which is crucial as consumers seek thinner phones with enhanced capabilities. Millimeter-wave 5G technology necessitates the use of complex radio frequency (RF) front-end modules, further increasing SiP usage. Companies like Qualcomm have commercialized solutions like AiP antenna modules and QSiP, which streamline mobile phone design and manufacturing. Additionally, Apple's wearables, such as the Apple Watch and AirPods Pro, actively leverage SiP technology to meet the demand for compact, high-functionality devices. As technology evolves, SiP is expected to integrate more components, further enhancing device performance while reducing size.

The use of 01005 and 008004 components in System-in-Package (SiP) substrates is driven by the need for miniaturization and high-density integration. These components are among the smallest available, allowing for more components to be placed within a limited space, which is essential in SiP technology where multiple ICs, passive elements, and other components are integrated into a single package. The small size of 01005 and 008004 components enables the design of compact, high-performance devices with increased functionality without expanding the footprint of the package. This is particularly important in applications like wearables, smartphones, and other IoT devices, where size, weight, and power efficiency are critical. Their use supports the ongoing trend towards smaller, more efficient, and powerful electronic systems.

Cleaning System-in-Package (SiP) technology is challenging due to its dense component layout and low standoff heights. The compact design and tightly packed elements make it difficult for cleaning agents to reach and remove flux residues, especially in shadowed areas or narrow gaps. Additionally, the multi-layered, complex packaging structures often found in SiP assemblies create further obstacles for flux residue removal, requiring cleaning solutions to navigate through intricate layers and spaces.

Flux residues can significantly impact the reliability and performance of SiP (System-in-Package) technology substrates. These residues, if not properly cleaned, can lead to various issues such as corrosion, dendritic growth, and electrical leakage. In the densely packed environment of SiP, where multiple components are integrated into a single package, even minimal contamination can cause malfunctions or reduce the lifespan of the device. Proper cleaning is critical to removing flux residues and other contaminants to ensure electrical integrity, prevent failures, and maintain the high performance expected from advanced SiP assemblies. Cleanliness is especially important given the growing complexity and miniaturization of SiP devices, where the margin for error is extremely small. Partially removed or untouched residues can lead to reliability failures as consequences of electrochemical migration and dendrite growth as well as electrical leakage currents.

Moreover, SiP technology involves sensitive materials and miniaturized components, which complicates the cleaning process. The use of diverse materials with varying chemical and thermal tolerances necessitates precise control to avoid damage while ensuring effective flux removal. If flux residues are not properly cleaned, they can become trapped under components or within the package, potentially leading to long-term issues like corrosion, signal interference, and reduced device reliability.

With advanced solder paste formulation, cleaning techniques using precision spray nozzles and specially formulated cleaning chemistries, are often necessary to ensure that all residues are thoroughly removed without compromising the integrity of the components. Proper cleaning is critical to prevent issues like electrical shorts, corrosion, or signal integrity problems, which can be more pronounced in densely packed SiP assemblies.

The key to a successful cleaning study is providing a recommendation that removes the soil and is the most optimal for that application. When employing a cleaning process, four major influencing factors need to be considered to have an efficient cleaning process. Described as 'T.A.C.T.,' these are Time (chemical exposure), Action (mechanical impingement offered by equipment), Chemical Energy (offered by cleaning agent), and Thermal Energy (wash temperature). [1]

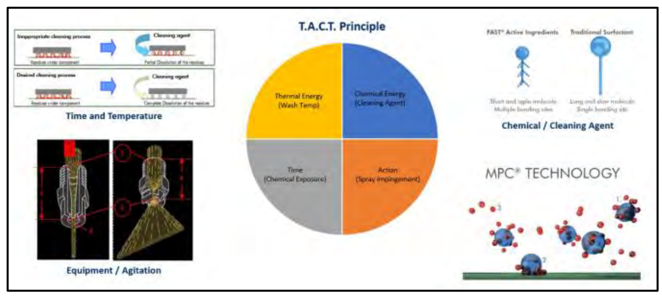

Figure 1. T.A.C.T Principle

MAIN RESEARCH

As part of this study, one of the variables that was investigated was the use of Adjustable Height Manifold. In a typical inline cleaner, the spray manifold is at a fixed height above the conveyor belt. For this research, the authors chose to explore the 'Action' impact the spray manifold may have on cleaning effectiveness and especially under extremely low standoff components. The study was conducted to compare the cleaning performance at different height increments, identify any correlations between the height of the spray nozzles and the cleaning process effectiveness and determine the optimal height for the most efficient and effective cleaning based on the 8-spray bar intermix.

HYPOTHESES:

1. Lowering the manifold-to-conveyor spacing height will improve cleaning efficiency and expand the process window.

2. Smaller component types are easier to clean thoroughly compared to larger components.

SOLDER PASTE FORMULATION:

Solder powder is classified by type according to IPC J-STD-005A. For SMT applications, Types 3-5 are commonly used, while SiP applications typically require Types 6 and 7, with future applications expected to use Type 8. Relevant powder types for SMT and SiP are shown in Table 1.

Table 1. Powder Sizes

Powder Type	Powder Size (um)	Minimum Stencil Aperture (um)	Approximate Surface Area Ratio
3	25-45	270	1.0
4	20-38	230	1.2
5	15-25	150	1.9
6	5-15	90	3.7
7	2-11	66	5.6

The two solder pastes selected for this study are commonly used in fine-feature soldering applications. Paste A is a water-soluble paste, chosen for its widespread use in high-volume manufacturing and its ability to be fully dissolved in water, a feature not all water-soluble pastes offer. Paste B is a no-clean paste, selected for its specific formulation.

While water-soluble pastes are often preferred for fine-feature applications, manufacturers sometimes add low-concentration cleaning agents or semi-aqueous solutions to DI water to reduce surface tension, making it easier to clean under low standoff components. Paste B has been tested in HVM environments and is completely cleanable with this specific chemistry. This paste can also be used as a standard no-clean which can be cleaned using a typical solvent, the value being the ease of cleaning with harsher chemistries.

In this study, a 40µm-thick stencil was used, with print parameters based on previously established settings for the solder paste. The test vehicle featured both ENIG and Cu-OSP surface finishes. The reflow profile, optimized for Indium's test vehicle, is shown below.

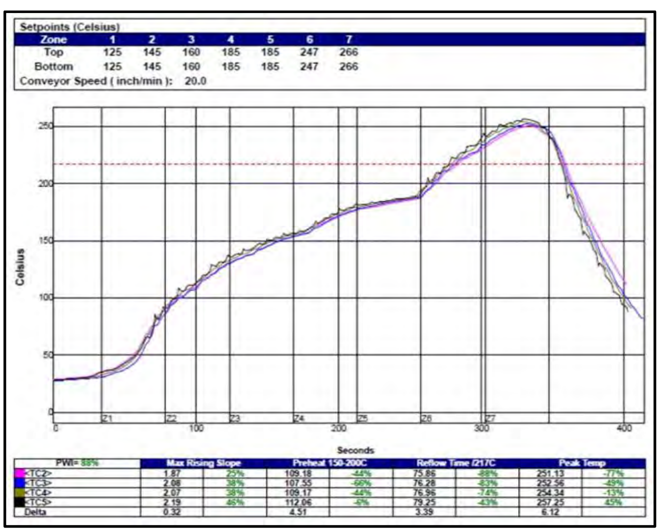

Figure 2. Soldering profile used in this study

SPRAY MANIFOLD DETAILS

As stated in the hypotheses, Adjustable Height Manifold may be a useful tool for improving cleaning process efficiency and effectiveness for cleaning hard-to-clean PCBAs, particularly in industry segments where high precision and cleanliness are critical.

For the purpose of this study, the Adjustable Height Manifold is set at 4", 3" and 2" as measured from the top of the conveyor belt to the bottom of the spray nozzles. Nozzle setup is standard for all scenarios.

TESTING AT DIFFERENT HEIGHTS:

- **Four Inches:**
  - Adjustable Height Manifold positioned at 4" from the top of the belt to the bottom of the spray nozzles.
  - Run the cleaning process and monitor the effectiveness.
  - Record cleaning performance metrics such as residue removal, uniformity, and any signs of damage or inefficiency.

- **Three Inches:**
  - Adjustable Height Manifold positioned at 3" from the top of the belt to the bottom of the spray nozzles and repeat the cleaning process.
    - Collect and analyze the same metrics.

- **Two Inches:**
  - Adjustable Height Manifold positioned at 3" from the top of the belt to the bottom of the spray nozzles and repeat the cleaning process.
  - Collect and analyze the same metrics.

The images below illustrate the pressure at the board level. As shown, the pressure significantly increases as the manifold is lowered closer to the board, with the most notable change resulting from the fan spray nozzles. Each image compares the effect of a coherent nozzle versus a fan spray nozzle, highlighting the differences in pressure distribution.

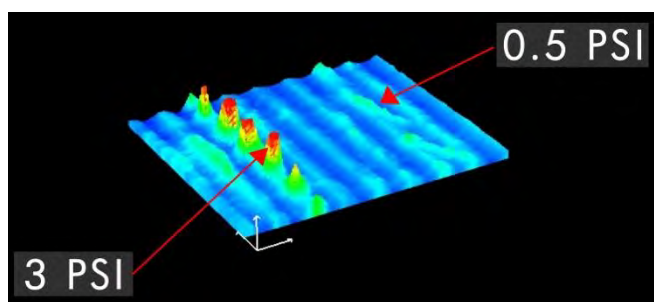

Figure 3. Adjustable Height Manifold at 4"

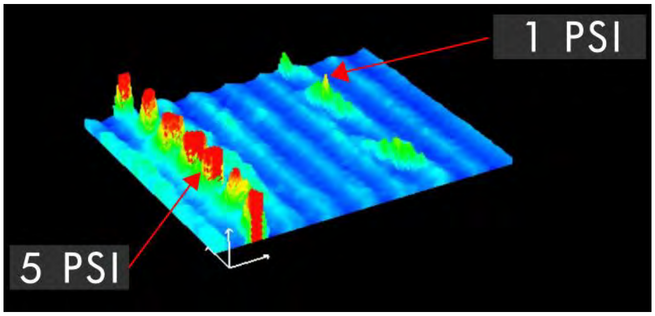

Figure 4. Adjustable Height Manifold at 3”

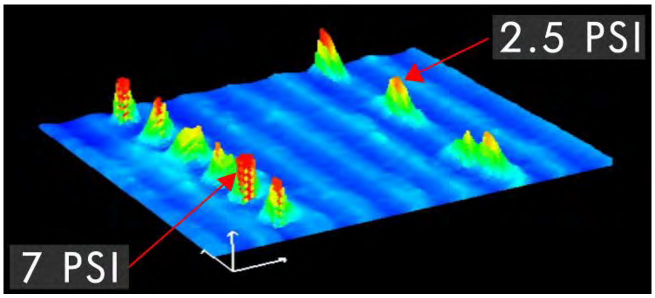

Figure 5. Adjustable Height Manifold at 2”

As seen from Figure 3-5, reducing the distance of the Adjustable Height Manifold to the conveyor belt enhances both mechanical and thermal energy transfer during the cleaning process. To fully optimize cleaning, it is crucial to reduce the atomization of particles while preserving adequate velocity and coverage. By positioning the nozzles closer to the surface, we can limit the dispersion of the spray in the air and more effectively direct the mechanical and thermal energy toward the product being cleaned. This advanced nozzle technology provides superior performance, particularly in handling the most demanding cleaning applications.

The adjustability of the manifold significantly enhances cleaning performance by optimizing spray patterns and improving energy transfer, which leads to more effective cleaning. Its design ensures precise and repeatable alignment of spray patterns in both the wash and rinse stages, contributing to greater uniformity in the cleaning process.

CLEANING AGENT USED

Two (2) recently developed aqueous-based cleaning agents identified as Cleaning Agent ‘A’ and Cleaning Agent ‘B’ were evaluated. Each cleaning agent was formulated specifically targeting semiconductor segment in the field of advanced substrates including 2.xD/3D, BGAs and SiPs. They offer optimal surface conditions for subsequent processes such as underfill, wire bonding, and molding. They also offer a high level of material compatibility with sensitive metals and is recommended for use in spray-in-air system processes.

TEST VEHICLE USED

The test vehicle used in this study is an Advanced Packaging Test Vehicle with a wide variety of components. The focus was on specific miniature components commonly found in complex front-end modules (FEMs), which pose unique cleaning challenges due to their compact size and dense assembly. The area highlighted in red indicates the components that were populated for this study.

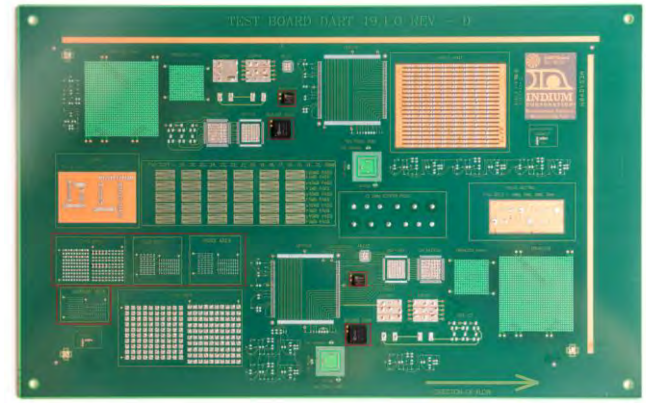
Figure 6. Representative pictures of components on the test vehicle

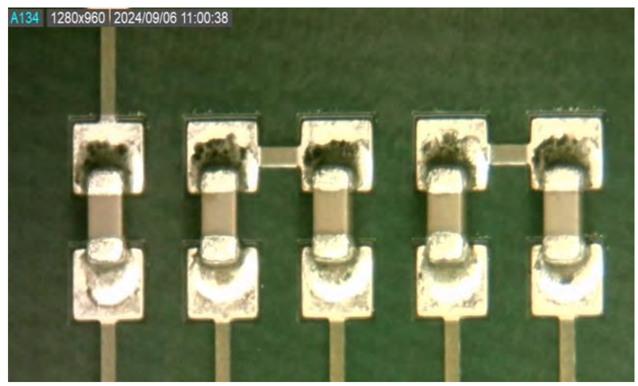

Figure 7. 0402 Component Before Cleaning

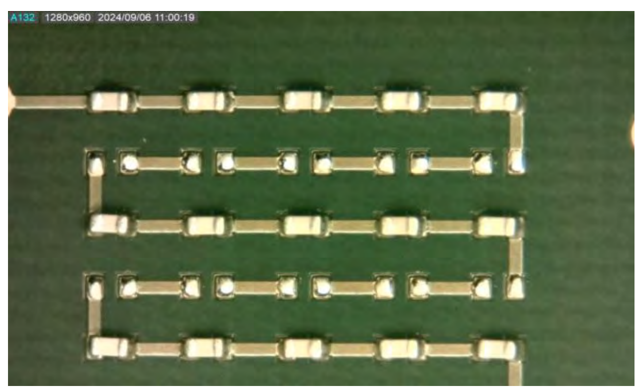

Figure 8. 0201 Component Before Cleaning

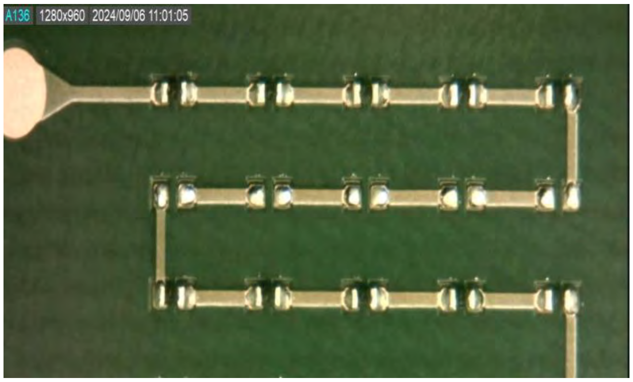

Figure 9. 01005 Component Before Cleaning

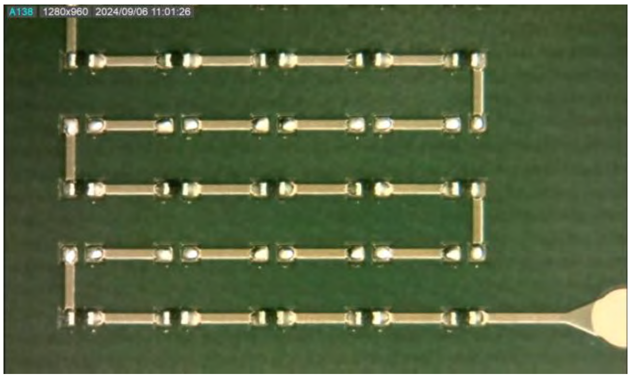

Figure 10. 008004 Component Before Cleaning

Figure 11. BGA368 Component Before Cleaning

Figure 12. BGA97 Component Before Cleaning

EXPERIMENT PERFORMED

Chemical supplier worked closely with the equipment and solder paste supplier in identifying the most commonly used pastes for this application as well as procuring specific spray manifolds for this study. After mutually agreeing to the experiment plan, it was decided to initiate the trials.

A conveyorized spray-in-air inline cleaner was employed in this study. This study maintained uniformity in temperature and pressure settings in all the sections of the inline cleaner, as process optimization was not the objective. However, two different concentrations and belt speeds along with varying manifold heights were used.

Employing both Cleaning Agents ‘A’ and ‘B’, the test plan was executed utilizing the parameters as detailed on Table 2.

Table 2. Test plan for the study

Solder Paste	Concentration (%)	Height (")	Belt Speed (fpm)
Water-soluble paste	5%	4"	1.5 fpm
			3.0 fpm
		3"	1.5 fpm
			3.0 fpm
		2"	1.5 fpm
			3.0 fpm
	10%	4"	1.5 fpm
			3.0 fpm
		3"	1.5 fpm
			3.0 fpm
		2"	1.5 fpm
			3.0 fpm
No-clean paste	10%	4"	0.7 fpm
			1.5 fpm
		3"	0.7 fpm
			1.5 fpm
		2"	0.7 fpm
			1.5 fpm
	15%	4"	0.7 fpm
			1.5 fpm
		3"	0.7 fpm
			1.5 fpm
		2"	0.7 fpm
			1.5 fpm

The process settings used in the spray-in-air inline cleaner are detailed in Table 3.

Table 3. Inline cleaner process parameters

Wash Stage	
Equipment	ITW AS200C Inline Cleaner
Cleaning Agent (Concentration)	Cleaning Agent ‘A’ & ‘B’
Manifold Distance Spacing to Conveyor Belt (inches)	***Refer to earlier table***
Conveyor Belt Speed	
Wash Spray Configuration	Top: 8-spray intermix manifold Bottom: 8-spray manifold
Wash Pressure (Top/Bottom)	50 PSI / 30 PSI
Wash Pressure (Top/Bottom)	70 PSI / 20 PSI
Wash Hurricane Pressure (Top/Bottom)	40 PSI / 40 PSI
Wash Temperature	150°F
Chemical Isolation Pressure (Top/Bottom)	25 PSI / 25 PSI
Rinsing Stage	
Rinsing Agent	DI water
Wash Spray Configuration	Top: 8-spray intermix manifold Bottom: 4-spray manifold
Rinse Pressure (Top/Bottom)	70 PSI / 20 PSI
Rinse Hurricane Pressure (Top/Bottom)	40 PSI / 20 PSI
Rinse Temperature	150ºF
Final Rinse Pressure (Top/Bottom)	25 PSI / 25 PSI
Final Rinse Temperature	Room Temperature
Drying Stage	
Drying Method	Hot Circulated Air
Drying Temperature (D1)	180°F
Drying Temperature (D2)	210°F
Drying Temperature (D3)	210°F

Cleanliness assessment was conducted per IPC-A-610 Rev H standards, focusing on both test vehicle surface and under-component cleanliness. Visual inspections were conducted utilizing a 40X microscope magnification supported by a polarized filter to enhance contrast.

Under-component cleanliness evaluation involved mechanically shearing all components from the test vehicles and categorizing visual inspection ratings into “fully cleaned” or “not cleaned” [2]

For each component type, the cleanliness assessment was independently carried out by multiple Application Engineers and the results aggregated, averaged, and expressed as a percentage of under-component cleanliness using the formula:

$$Average\ Cleanliness\ Level = \frac{Number\ of\ fully\ cleaned\ components}{Total\ number\ of\ components\ on\ test\ vehicle}$$

RESULTS:

The comprehensive cleanliness assessments are detailed in Figures 13-18.

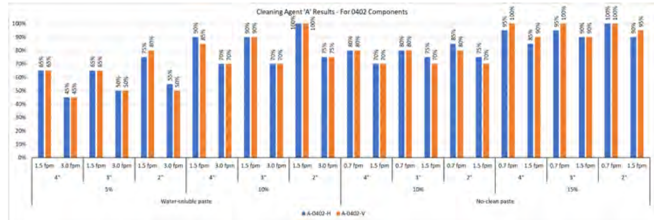

Figure 13. Cleaning Agent ‘A’: Cleanliness rating under 0402 components

As observed in Fig. 13., the cleaning efficacy is significantly influenced by the manifold-to-conveyor spacing, belt speed and concentration. For water-soluble paste, the optimal conditions for achieving 100% cleanliness were found at a 2" spacing height with a 1.5 fpm belt speed and a 10% concentration. Wider spacings (3" and 4") also showed high efficacy at this concentration. In contrast, no-clean paste consistently delivered higher efficacy across various conditions, particularly at slower belt speeds (0.7 fpm) and higher concentrations, with efficacy achieving 100% even at wider spacing heights. The results suggest that closer spacing and slower speeds generally improve cleaning performance with no-clean paste.

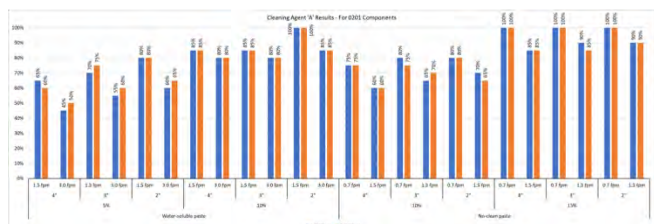

Figure 14. Cleaning Agent ‘A’: Cleanliness rating under 0201 components

Fig. 14 indicates that Cleaning Agent 'A' performs optimally with closer manifold-to-conveyor spacing and slower belt speeds. For water-soluble paste, the highest efficacy (100%) was achieved at a 2" spacing with a 1.5 fpm belt speed and 10% concentration. No-clean paste consistently delivered 100% cleaning efficacy across various spacing heights at 0.7 fpm and 15% concentration. Overall, no-clean paste showed more consistent performance, while water-soluble paste efficacy varied depending on spacing height and conveyor speed.

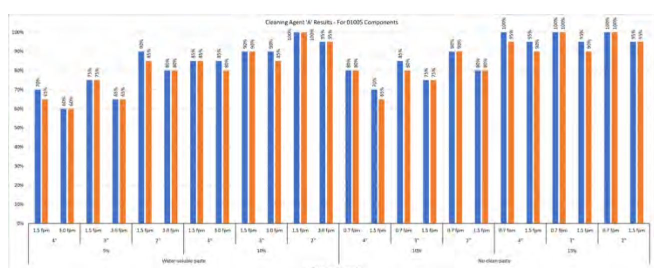

Figure 15. Cleaning Agent ‘A’: Cleanliness rating under 01005 components

Fig. 15 indicates that slower belt speeds generally result in slightly better cleaning efficacy for both water-soluble and no-clean pastes. Higher manifold to conveyor spacing (4" and 3") show consistently lower cleaning effectiveness to shorter spacing heights (2"), particularly with water-soluble and no-clean pastes at lower concentrations. The cleaning effectiveness of Cleaning Agent 'A' on 01005 components is relatively consistent across different orientations, with minor variations depending on the specific paste type and height.

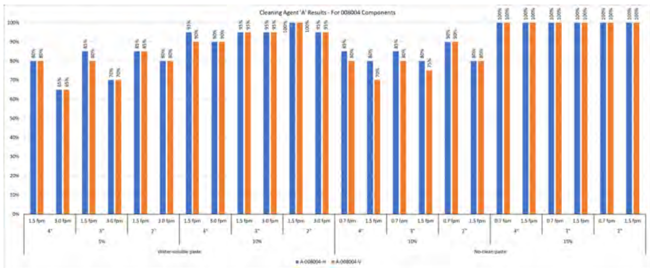

Figure 16. Cleaning Agent 'A': Cleanliness rating under 008004 components

Fig. 16 indicates that for water-soluble paste at 5% concentration and slower belt speed (1.5 fpm), not much changed from a cleanliness standpoint when correlated to the spacing heights. However, at faster belt speeds, significant improvement was observed with reduced spacing height.

For water-soluble paste at 10% concentration and slower belt speed (1.5 fpm), not much changed from cleanliness standpoint when compared to 4" & 3" spacing height. However, 100% cleanliness was observed at 2" spacing. At faster belt speeds, almost 95% cleanliness was achieved at both 3" and 2" spacing which is an improvement over 4" spacing.

For no-clean paste at 10% concentration and slower belt speed (0.7 fpm), slight improvement from cleanliness standpoint was observed when correlated to the spacing height (2" slightly better than 3" & 4"). Not much improvement was observed at faster belt speed.

For no-clean paste at 15% concentration, all the residues were completely removed under all process conditions and varying spacing height.

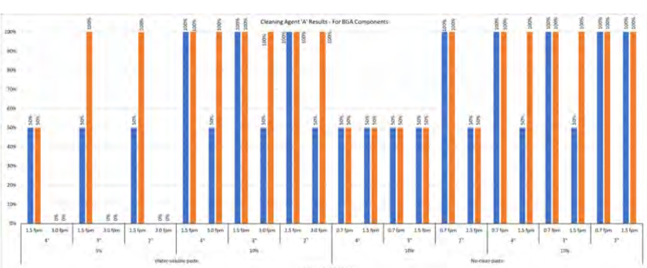

Figure 17. Cleaning Agent 'A': Cleanliness rating under BGA components

Fig. 17 indicates for water-soluble paste at 5% concentration and slower belt speed (1.5 fpm), BGA368 did not show any improvement at all spacing heights. However, at 2" and 3" spacing height, the BGA97 component was found to be fully clean compared to 4" height. At faster belt speed, none of the BGA components was clean.

For water-soluble paste at 10% concentration and slower belt speed (1.5 fpm), all the flux residues were fully removed at all spacing heights (4", 3" & 2") from both BGA368 and BGA97 components. At faster belt speed (3.0 fpm); it was observed that BGA368 component was partially cleaned whereas BGA97 component was fully clean at all spacing height.

For no-clean paste at 10% concentration and slower belt speed (0.7 fpm), there was improvement observed for both BGA368 and BGA97 components at 2" spacing height.
At 15% concentration and slower belt speed (0.7 fpm), all the flux residues were fully removed at all spacing heights (4", 3" & 2") from both BGA368 and BGA97 components. At faster belt speed, there was improvement observed at 2" spacing height for both component types.

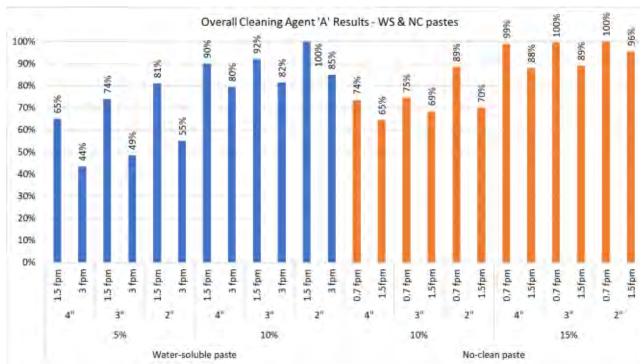

Figure 18. Cleaning Agent 'A': Overall cleanliness rating for both WS and NC pastes

Fig. 18 indicates that the No-clean solder paste residues were easier to clean (84%) when compared to Water-soluble pastes (75%) using Cleaning Agent 'A'.

After entering the obtained data in the Minitab® software, the interaction among the factors in respect to the cleaning results was investigated.

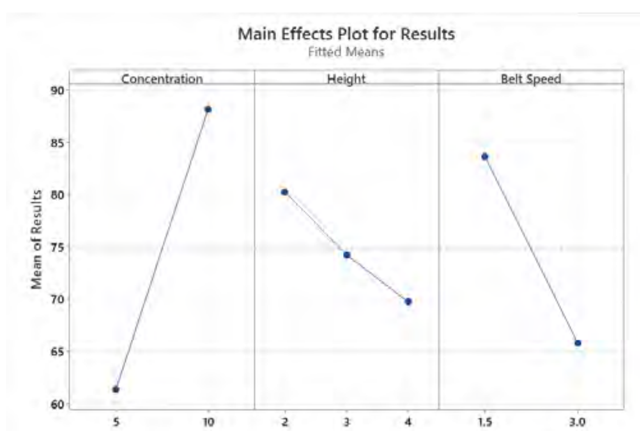

Figure 19. Cleaning Agent 'A' Main Effects Plot for Water-Soluble Paste

Fig. 19 Main Effect plot indicates that higher concentration (10%), lower manifold-to-conveyor spacing (2”) and slower belt speed (1.5 fpm) has most significant impact from cleaning standpoint.

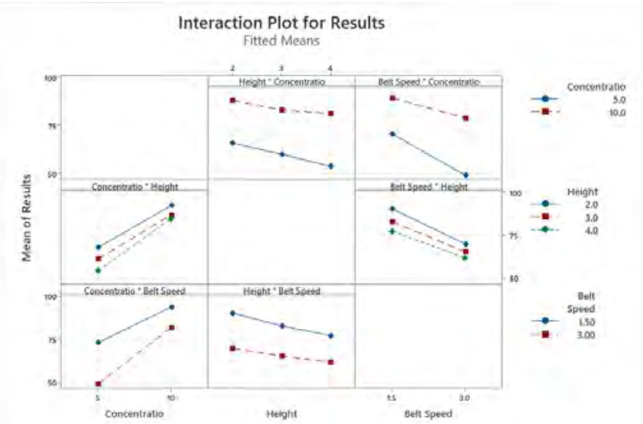

Figure 20. Cleaning Agent ‘A’ Interaction Plot for Water-soluble paste

The interaction between concentration and manifold-to-conveyor spacing shows that a 10% concentration with a 2-inch spacing height provides significantly better cleaning results compared to 3-inch and 4-inch spacings. This trend holds even at lower concentrations.

When examining the interaction between belt speed and concentration, reducing the belt speed to 1.5 fpm at lower concentrations leads to a noticeable improvement in cleaning performance, while higher concentrations result in only a slight improvement.

In terms of the interaction between belt speed and manifold-to-conveyor spacing, the 2-inch spacing demonstrates better results at slower belt speed (1.5 fpm), with a steeper improvement compared to larger spacings. At faster belt speeds, cleaning effectiveness decreases, but the 2-inch spacing still outperforms the 4-inch spacing.

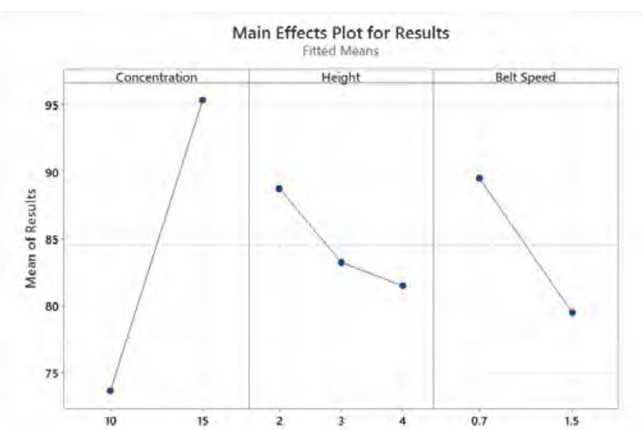

Figure 21. Cleaning Agent ‘A’ Main Effects Plot for No-Clean Paste

Fig. 21 Main Effect Plot indicates that higher concentration (15%), lower manifold-to-conveyor spacing (2”) and slower belt speed (0.7 fpm) has most significant impact from cleaning standpoint.

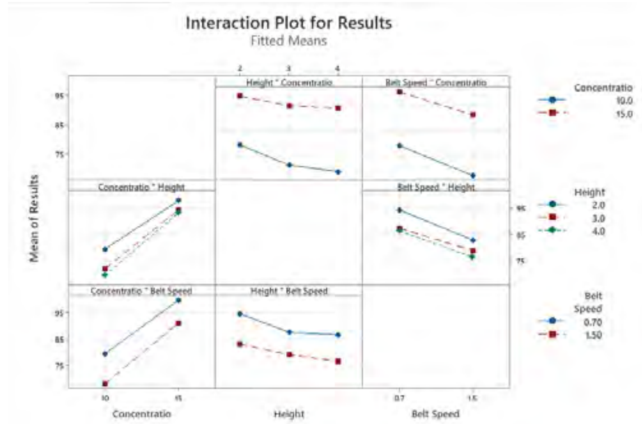

Figure 22. Cleaning Agent ‘A’ Interaction Plot for No-Clean paste

The interaction between concentration and manifold-to-conveyor spacing shows that a 10% concentration with a 2-inch spacing height results in significantly better cleaning compared to 3-inch and 4-inch spacings. This improvement is consistent even at lower concentrations.

For the interaction between belt speed and concentration, a noticeable improvement in cleaning is seen when the belt speed is reduced to 0.7 fpm at lower concentrations, while higher concentrations provide only a slight benefit.

Regarding the interaction between belt speed and manifold-to-conveyor spacing, the 2-inch spacing shows a steeper improvement in cleaning at all belt speeds. Although cleaning performance decreases at faster belt speeds, the 2-inch spacing still outperforms the 4-inch spacing.

The comprehensive cleanliness assessments for Cleaning Agent ‘B’ are detailed in Figures 23-28.

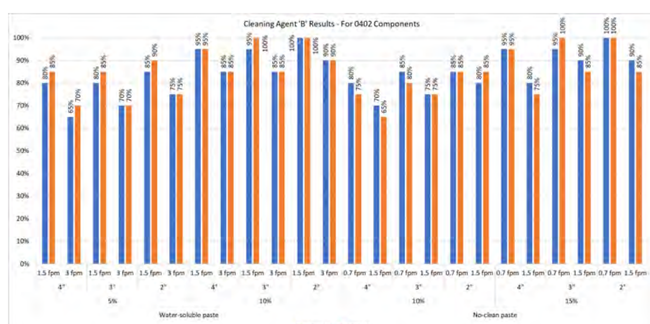

Figure 23. Cleaning Agent ‘B’: Cleanliness rating under 0402 components

As shown in Fig. 23, cleaning efficacy is strongly influenced by manifold-to-conveyor spacing, belt speed, and concentration. For water-soluble paste, 100% cleanliness was achieved at 1.5 fpm and 10% concentration, with spacing height having minimal impact. A similar trend was observed with no-clean paste, where the best results occurred at 15% concentration and slower belt speeds. Both 2-inch and 3-inch manifold spacings produced comparable outcomes.

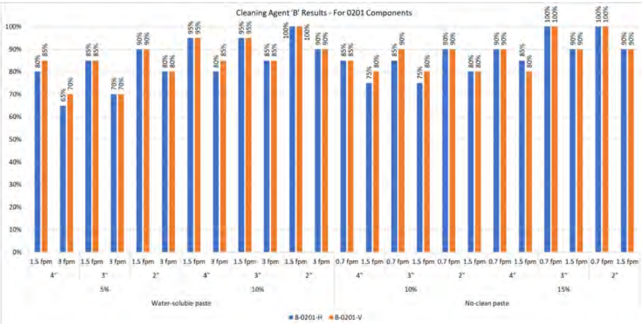

Figure 24. Cleaning Agent ‘B’: Cleanliness rating under 0201 components

Similar to the previous case, results show that Cleaning Agent 'B' performs best with closer manifold-to-conveyor spacing and slower belt speeds. For water-soluble paste, optimal cleaning (100%) was achieved at 1.5 fpm and 10% concentration, with 2-inch spacing outperforming 3-inch and 4-inch at lower concentrations. At higher concentrations, 2-inch spacing provided better results across all belt speeds. For no-clean paste, there was little difference at 10% concentration. However, at higher concentrations, both 2-inch and 3-inch spacings showed significantly better cleaning at the slower belt speed of 0.7 fpm.

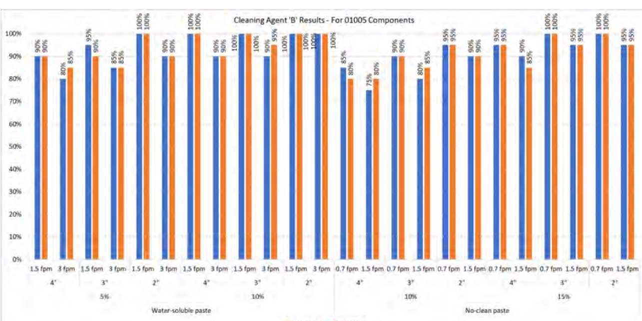

Figure 25. Cleaning Agent ‘B’: Cleanliness rating under 01005 components

For water-soluble paste at lower concentrations, the best results were achieved with a 2-inch spacing. At higher concentrations, improved cleaning was observed at 1.5 fpm, and complete cleaning was achieved even at 3.0 fpm with 2-inch spacing.

For no-clean paste, better results were seen at lower concentrations with a 2-inch spacing. At higher concentrations, similar outcomes were obtained with both 2-inch and 3-inch spacing, regardless of belt speed.

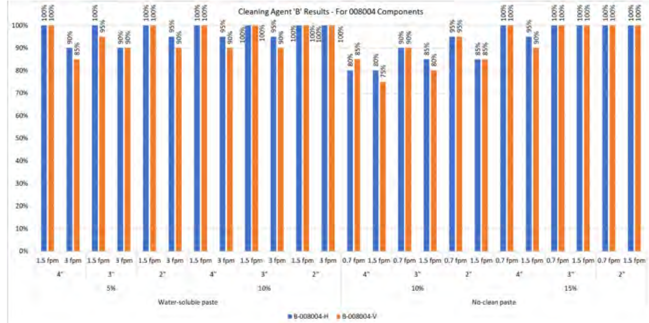

Figure 26. Cleaning Agent ‘B’: Cleanliness rating under 008004 components

For water-soluble paste at 5% concentration and a slower belt speed of 1.5 fpm, cleanliness remained consistent across all spacing heights, though faster belt speeds showed gradual improvement with reduced spacing. At 10% concentration and 1.5 fpm, flux residues were fully removed at all spacing heights (4", 3", and 2"), with 100% cleanliness achieved even at faster belt speeds with 2-inch spacing.

For no-clean paste at 10% concentration and 0.7 fpm, a slight improvement in cleanliness was seen with 2-inch spacing compared to 3-inch and 4-inch. No significant improvement was noted at higher belt speeds. At 15% concentration, all residues were completely removed under slower speeds, while at faster speeds, complete removal was observed with both 3-inch and 2-inch spacing.

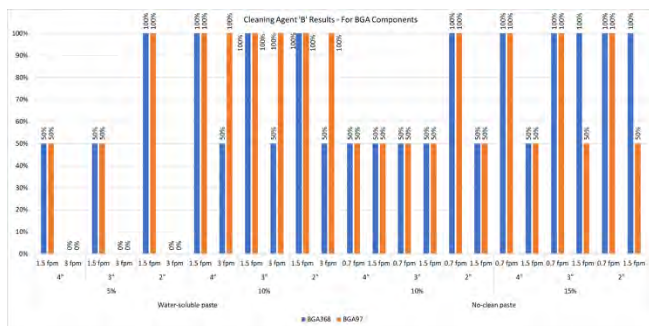

Figure 27. Cleaning Agent ‘B’: Cleanliness rating under BGA components

For water-soluble paste at 5% concentration and a slower belt speed (1.5 fpm), BGA368 showed no improvement at 4" and 3" spacing but was fully clean at 2" spacing, a result also seen with BGA97. At faster belt speeds, neither BGA component was fully cleaned.

At 10% concentration and 1.5 fpm, all flux residues were fully removed from both BGA368 and BGA97 at all spacing heights (4", 3", and 2"). At faster belt speeds (3.0 fpm), BGA368 did not show any improvements, while BGA97 was fully clean at all heights.

For no-clean paste at 10% concentration and 0.7 fpm, both components showed improvement at 2" spacing. At 15% concentration and 0.7 fpm, all residues were removed from both BGA368 and BGA97 at all spacing heights. At faster belt speeds, BGA368 improved at 2" and 3" spacing, while BGA97 showed little difference.

Figure 28. Cleaning Agent ‘B’: Overall cleanliness rating for both WS and NC pastes

Fig. 28 indicates that the both Water-soluble and No-Clean pastes were equally easier to clean (84% vs 85%).

After entering the obtained data in the Minitab® software, the interaction among the factors in respect to the cleaning results was investigated.

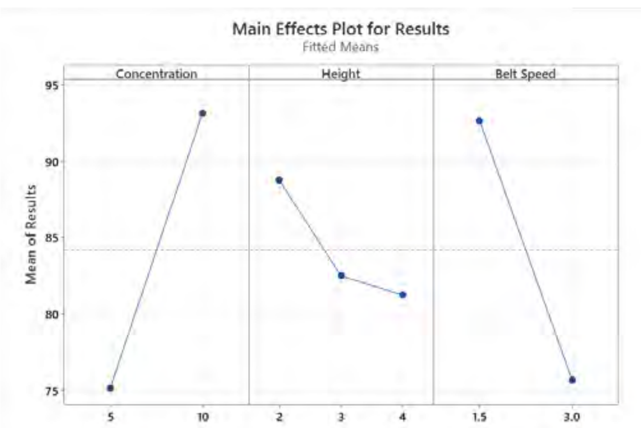

Figure 29. Cleaning Agent ‘B’ Main Effects Plot for Water-Soluble Paste

Fig. 29 Main Effects Plot indicates that higher concentration (10%), lower manifold-to-conveyor spacing (2"), and slower belt speed (1.5 fpm) have the most significant impact on cleaning performance. Only a slight improvement is observed when reducing the spacing from 4-inch to 3-inch.

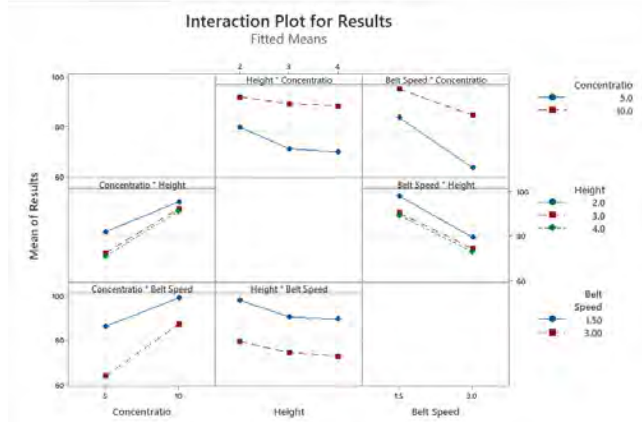

Figure 30. Cleaning Agent ‘B’: Main Effect & Interaction Plot Results for Water-soluble paste

The interaction between concentration and manifold-to-conveyor spacing shows that a 10% concentration with a 2-inch spacing offers better cleaning compared to 3-inch and 4-inch spacings. At lower concentrations, the 2-inch spacing shows significant improvement, while little difference is observed between 3-inch and 4-inch spacings.

When examining belt speed and concentration, a notable improvement is seen when the belt speed is reduced to 1.5 fpm at lower concentrations, with further improvement at higher concentrations.

For the interaction between belt speed and manifold-to-conveyor spacing, the 2-inch spacing shows better results at slower belt speeds (1.5 fpm), with cleaning performance declining at faster speeds but still outperforming the 4-inch spacing. Minimal difference is observed between the 3-inch and 4-inch spacings across different belt speeds.

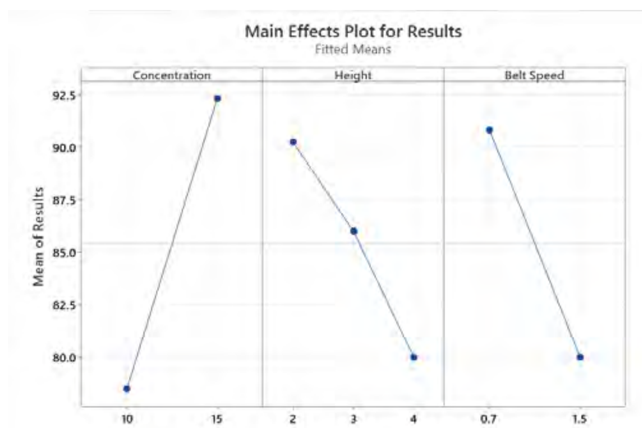

Figure 31. Cleaning Agent ‘B’ Main Effects Plot for No-Clean Paste

The results indicate that a higher concentration (15%), lower manifold-to-conveyor spacing (2-inch), and slower belt speed (0.7 fpm) have the most significant impact on cleaning performance.

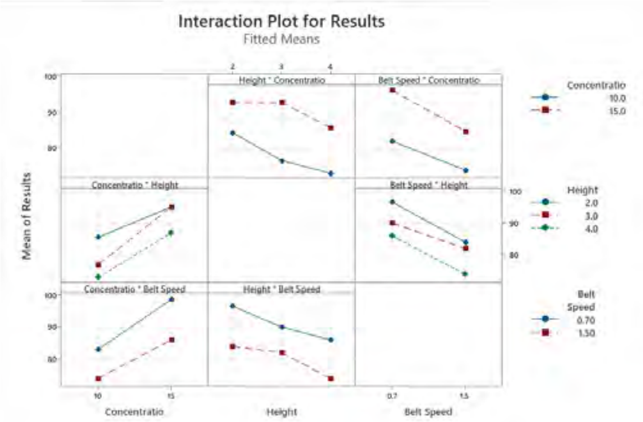

Figure 32. Cleaning Agent 'B': Main Effect & Interaction Plot Results for No-clean paste

In the interaction between concentration and manifold-to-conveyor spacing, at a 15% concentration, there is little difference between 2" and 3" spacings, both of which outperform the 4" spacing. At lower concentrations, the 2" spacing shows significantly better results compared to 3" and 4".

For the interaction between belt speed and concentration, a significant improvement is seen when the belt speed is reduced to 0.7 fpm at all concentration levels.

In the interaction between belt speed and manifold-to-conveyor spacing, the 2" spacing provides better cleaning results at all speeds. At higher belt speeds, both 2" and 3" spacings offer similar improvements compared to the 4" spacing.

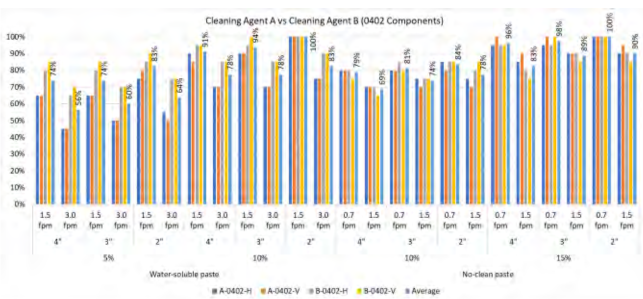

Figure 33. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under 0402 components

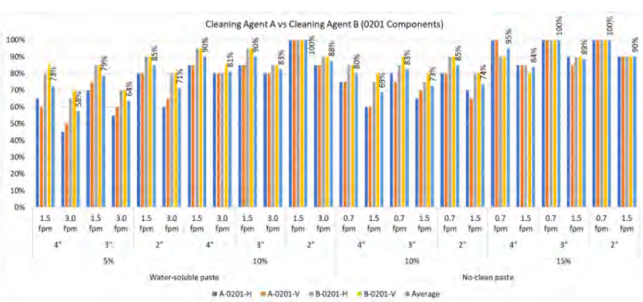

Figure 34. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under 0201 components

Figure 35. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under 01005 components

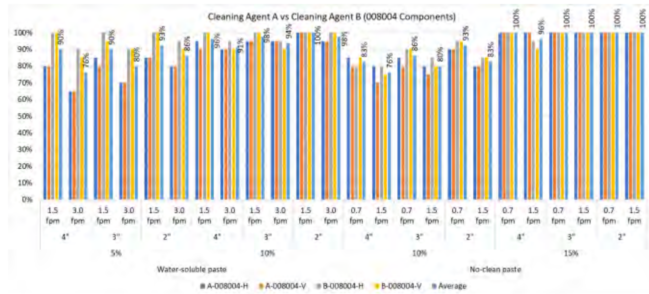

Figure 36. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under 008004 components

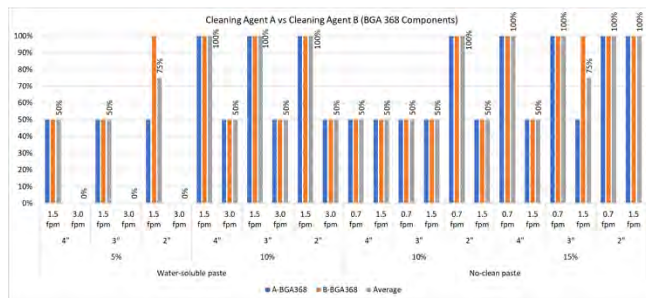

Figure 37. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under BGA 368 components

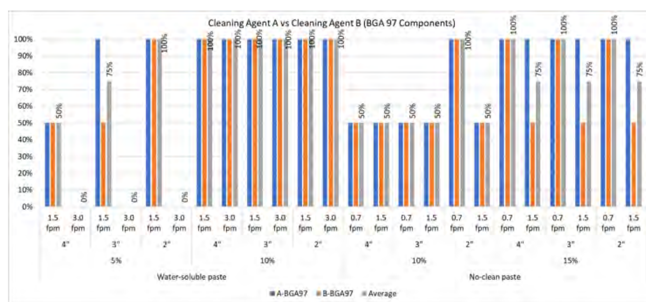

Figure 38. Cleaning Agent 'A' vs Cleaning Agent 'B': Cleanliness rating under BGA 97 components

Based on Figs. 33-38, Cleaning Agent 'B' performed slightly better than Cleaning Agent 'A' for 0402 components. This pattern continued for 0201, 01005, 008004, and BGA368 components. However, for BGA97 components, Cleaning Agent 'A' showed marginally better results.

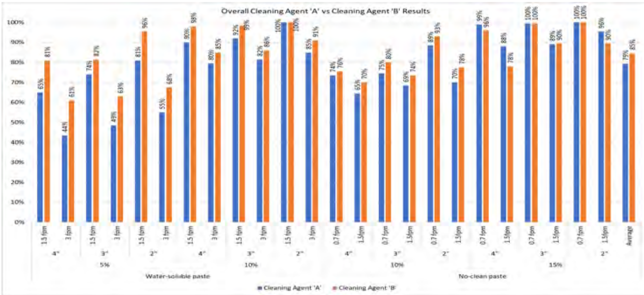

Figure 39. Overall Cleaning Agent ‘A’ vs Cleaning Agent ‘B’ Cleaning Results for both OA and NC pastes

Overall, Cleaning Agent ‘B’ outperformed Cleaning Agent ‘A’ (85% vs. 79%), but it should be noted these results are valid only for the selected paste types.

SIR & IC TESTING

Based on the study results, it was decided to conduct Ion Chromatography (IC) and Surface Insulation Resistance (SIR) testing in accordance with IPC standards. IC testing followed IPC-TM-650 Method 2.3.28 [3], and SIR testing adhered to IPC-TM-650 Method 2.6.3.7 [4]. The industry-approved IPC-B-52 test vehicles were cleaned using a spray-in-air inline cleaner under specified conditions shown below in Table 4.

Table 4. Test Vehicle Cleaning Process Operating Parameters

Chemical Formulation	Solder Paste Type	Best Case	Worst Case
Cleaning Agent ‘A’ and ‘B’	Water-soluble	10%, 2-inch spacing & 1.5 fpm	5%, 4-inch spacing & 3.0 fpm
	No-clean	15%, 2-inch spacing & 0.7 fpm	10%, 4-inch spacing & 1.5 fpm

All the vehicles successfully passed the IC and SIR testing.

Refer to Table 5-12 and Figures 40-64 in the Appendix for IC and SIR results for both cleaning agents ‘A’ and ‘B’.

CONCLUSION:

The study confirmed that lowering the manifold-to-conveyor spacing height improves cleaning results and broadens the process window. A 2-inch spacing height, in some cases, even allowed for increased conveyor belt speeds compared to 3-inch and 4-inch heights, validating Hypothesis 1.

Additionally, it was observed that smaller components were easier to clean than larger ones, likely due to differences in geometry, surface area, and standoff height. Smaller components, such as 008004 and 01005, have significantly reduced surface areas, limiting the accumulation of flux residue and making it easier for the cleaning solution to remove it. The smaller footprint and less migration of flux across the board allow capillary action to more effectively pull residues outward, enhancing cleaning efficiency.

In contrast, larger components like 0402 and 0201 present greater challenges due to their larger surface area, which allows more flux to accumulate. These components require stronger cleaning mechanisms as the flux spreads further, and capillary action is less effective at removing residue from underneath. This increases the difficulty in achieving complete residue removal.

In summary, smaller components (008004, 01005) are easier to clean due to their smaller surface areas, lower standoff heights, and better accessibility for cleaning solutions. Larger components (0402, 0201), with their greater surface area and flux retention, require more intensive cleaning. Hypothesis 2 was confirmed as valid.

FUTURE WORK

Based on the conclusions from the study, the following areas of future work has been identified and subsequent work has been initiated. The results will be presented at a later stage.

- **Cleaning Efficiency at Higher Belt Speeds:** Future work could explore the limits of cleaning efficiency at higher speeds, increasing throughput without compromising quality, especially for smaller components.
- **Mixed Assemblies:** Research should focus on optimizing cleaning for circuit boards with both small and large components, ensuring effective cleaning across all sizes.
- **Testing with Different Paste Types:** Future studies could expand to various solder pastes (e.g., lead-free, no-clean, water-soluble) to assess the universality of the conclusions.
- **Impact on Component Reliability:** Investigate how different cleaning techniques, spacing, and belt speeds affect long-term component reliability, including corrosion and electrical performance.

These areas offer valuable insights for optimizing cleaning processes, improving performance, and promoting sustainable practices in semiconductor manufacturing.

REFERENCES

[1] Critical Cleaning Requirements To Overcome Advanced Packaging Defluxing Challenges, Guan Tatt Yeoh, ZESTRON Precision Cleaning Sdn Bhd & Ravi Parthasarathy, M.S.Ch.E., ZESTRON Americas. Originally presented at IEMT Conference 2022, Putrajaya, Malaysia.

[2] Visual inspection according to IPC-A-610-REV. G – Acceptability of Electronic Assemblies

[3] IPC-TM-650 2.3.28 “Ionic Analysis of Circuit Boards, Ion Chromatography Method”

[4] IPC-TM-650 2.6.3.7 “Surface Insulation Resistance”

APPENDIX:
IPC-B-52 Test Vehicles – IC Test Results

Table 5. Ion Chromatography Test Results – 5% Cleaning Agent 'A' for Water-Soluble Paste

	Ionic Species	Acceptance Criteria	5% Cleaning Agent 'A' WS-1	5% Cleaning Agent 'A' WS-2	5% Cleaning Agent 'A' WS-3
ANIONS	Fluoride (F^-)	3	0.0159	0.0621	0.0200
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.0000	0.0000
	Formate (CHO_2^-)	3	0.0000	0.0000	0.0000
	Chloride (Cl)	3	0.0638	0.0617	0.0280
	Nitrite (NO_2^-)	3	0.0089	0.0106	0.0033
	Bromide (Br^-)	6	0.0020	0.0000	0.0286
	Nitrate (NO_3^-)	3	0.0000	0.0066	0.0646
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.5040	0.4476	0.7497
	WOA	25	0.0000	0.5359	0.4286
CATIONS	Lithium (Li^+)	3	0.0017	0.0010	0.0013
	Sodium (Na^+)	3	0.1955	0.1805	0.2056
	Ammonium (NH_4^+)	3	0.2100	0.2154	0.1973
	Potassium (K^+)	3	0.5953	0.5737	0.6099
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0337	0.0305	0.0316

Table 6. Ion Chromatography Test Results – 10% Cleaning Agent 'A' for Water-Soluble Paste

	Ionic Species	Acceptance Criteria	10% Cleaning Agent 'A' WS-1	10% Cleaning Agent 'A' WS-2	10% Cleaning Agent 'A' WS-3
ANIONS	Fluoride (F^-)	3	0.0109	0.0181	0.0305
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.0000	0.0000
	Formate (CHO_2^-)	3	0.0214	0.0000	0.0000
	Chloride (Cl)	3	0.0794	0.0351	0.0901
	Nitrite (NO_2^-)	3	0.0659	0.0080	0.0093
	Bromide (Br^-)	6	0.0000	0.0027	0.0053
	Nitrate (NO_3^-)	3	0.0893	0.0000	0.0000
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0388
	Sulfate (SO_4^{2-})	3	0.4806	0.6344	0.5287
	WOA	25	0.3696	0.3239	0.3866
CATIONS	Lithium (Li^+)	3	0.0007	0.0003	0.0007
	Sodium (Na^+)	3	0.1311	0.1481	0.1593
	Ammonium (NH_4^+)	3	0.1989	0.1992	0.2034
	Potassium (K^+)	3	0.4130	0.4295	0.4485
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0208	0.0227	0.0235

Table 7. Ion Chromatography Test Results – 10% Cleaning Agent 'A' for No-clean Paste

	Ionic Species	Acceptance Criteria	10% Cleaning Agent 'A' NC-1	10% Cleaning Agent 'A' NC-2	10% Cleaning Agent 'A' NC-3
ANIONS	Fluoride (F^-)	3	0.0346	0.0574	0.0314
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.0000	0.0000
	Formate (CHO_2^-)	3	0.0449	0.0000	0.0000
	Chloride (Cl)	3	0.0366	0.0694	0.7674
	Nitrite (NO_2^-)	3	0.0010	0.0180	0.0033
	Bromide (Br^-)	6	0.0186	0.0027	0.0185
	Nitrate (NO_3^-)	3	0.0113	0.0000	0.0000
	Phosphate (PO_4^{2-})	3	0.0575	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.0981	0.3862	0.3632
	WOA	25	0.7835	0.7100	0.6735
CATIONS	Lithium (Li^+)	3	0.0007	0.0010	0.0003
	Sodium (Na^+)	3	0.1040	0.1254	0.1153
	Ammonium (NH_4^+)	3	0.2510	0.2108	0.1956
	Potassium (K^+)	3	0.2114	0.3812	1.1729
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0246	0.0180	0.0172

Table 8. Ion Chromatography Test Results – 15% Cleaning Agent 'A' for No-clean Paste

	Ionic Species	Acceptance Criteria	15% Cleaning Agent 'A' NC-1	15% Cleaning Agent 'A' NC-2	15% Cleaning Agent 'A' NC-3
ANIONS	Fluoride (F^-)	3	0.1318	0.0719	0.0000
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.0000	0.2351
	Formate (CHO_2^-)	3	0.0000	0.0063	0.0000
	Chloride (Cl)	3	0.2277	0.0596	0.0287
	Nitrite (NO_2^-)	3	0.0171	0.0073	0.0157
	Bromide (Br^-)	6	0.0231	0.0120	0.0307
	Nitrate (NO_3^-)	3	0.0181	0.0513	1.7156
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.4514	0.3032	0.4135
	WOA	25	0.7741	0.6504	0.5615
CATIONS	Lithium (Li^+)	3	0.0010	0.0013	0.0020
	Sodium (Na^+)	3	0.1582	0.1078	0.1307
	Ammonium (NH_4^+)	3	0.1659	0.1714	0.0060
	Potassium (K^+)	3	0.5103	0.3488	0.4615
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	1.5586
	Calcium (Ca^{2+})	n/a	0.0244	0.0140	1.0784

Table 9. Ion Chromatography Test Results – 5% Cleaning Agent 'B' for Water-Soluble Paste

	Ionic Species	Acceptance Criteria	5% Cleaning Agent 'B' WS-1	5% Cleaning Agent 'B' WS-2	5% Cleaning Agent 'B' WS-3
ANIONS	Fluoride (F^-)	3	0.0292	0.0969	0.0577
	Acetate ($C_2H_3O_2^-$)	3	0.0000	1.1473	0.0000
	Formate (CHO_2^-)	3	0.0156	0.0000	0.0000
	Chloride (Cl)	3	0.0086	0.0226	0.0230
	Nitrite (NO_2^-)	3	0.0053	0.0027	0.0177
	Bromide (Br^-)	6	0.0070	0.0056	0.0017
	Nitrate (NO_3^-)	3	0.0000	0.0000	0.0000
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.4801	0.4080	0.4782
	WOA	25	0.4748	0.3522	0.4509
CATIONS	Lithium (Li^+)	3	0.0007	0.0000	0.0003
	Sodium (Na^+)	3	0.1289	0.0956	0.1477
	Ammonium (NH_4^+)	3	0.1874	0.0926	0.1788
	Potassium (K^+)	3	0.3280	0.2201	0.3605
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0156	0.0126	0.0157

Table 10. Ion Chromatography Test Results – 10% Cleaning Agent 'B' for Water-Soluble Paste

	Ionic Species	Acceptance Criteria	10% Cleaning Agent 'B' WS-1	10% Cleaning Agent 'B' WS-2	10% Cleaning Agent 'B' WS-3
ANIONS	Fluoride (F^-)	3	0.0056	0.0267	0.0000
	Acetate ($C_2H_3O_2^-$)	3	0.0000	1.5213	0.5276
	Formate (CHO_2^-)	3	0.0000	0.0000	0.0000
	Chloride (Cl)	3	0.0355	0.0174	0.0344
	Nitrite (NO_2^-)	3	0.0239	0.0064	0.0238
	Bromide (Br^-)	6	0.0282	0.0033	0.0089
	Nitrate (NO_3^-)	3	0.0076	0.0000	0.0000
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.3777	0.3129	0.3366
	WOA	25	0.7231	0.5886	0.5005
CATIONS	Lithium (Li^+)	3	0.0007	0.0000	0.0007
	Sodium (Na^+)	3	0.1097	0.0909	0.1047
	Ammonium (NH_4^+)	3	0.1926	0.1922	0.1860
	Potassium (K^+)	3	0.2596	0.2387	0.2732
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0123	0.0090	0.0122

Table 11. Ion Chromatography Test Results – 10% Cleaning Agent 'B' for No-clean Paste

	Ionic Species	Acceptance Criteria	10% Cleaning Agent 'B' NC-1	10% Cleaning Agent 'B' NC-2	10% Cleaning Agent 'B' NC-3
ANIONS	Fluoride (F^-)	3	0.0020	0.0739	0.0375
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.0000	1.0340
	Formate (CHO_2^-)	3	0.0778	0.0000	0.0000
	Chloride (Cl)	3	0.0020	0.0231	0.0143
	Nitrite (NO_2^-)	3	0.0221	0.0047	0.0136
	Bromide (Br^-)	6	0.0138	0.0117	0.0060
	Nitrate (NO_3^-)	3	0.0241	0.0358	0.0302
	Phosphate (PO_4^{2-})	3	0.0000	0.0097	0.0000
	Sulfate (SO_4^{2-})	3	0.0745	0.0863	0.1161
	WOA	25	0.7795	1.0570	0.8682
CATIONS	Lithium (Li^+)	3	0.0003	0.0003	0.0000
	Sodium (Na^+)	3	0.1058	0.1007	0.1125
	Ammonium (NH_4^+)	3	0.2320	0.2428	0.2266
	Potassium (K^+)	3	0.1744	0.1742	0.1466
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0145	0.0144	0.0060

Table 12. Ion Chromatography Test Results – 15% Cleaning Agent 'B' for No-clean Paste

	Ionic Species	Acceptance Criteria	15% Cleaning Agent 'B' NC-1	15% Cleaning Agent 'B' NC-2	15% Cleaning Agent 'B' NC-3
ANIONS	Fluoride (F^-)	3	0.0408	0.0313	0.1929
	Acetate ($C_2H_3O_2^-$)	3	0.0000	0.6406	0.0000
	Formate (CHO_2^-)	3	0.0000	0.0000	0.0000
	Chloride (Cl)	3	0.0070	0.8653	0.0269
	Nitrite (NO_2^-)	3	0.0050	0.0033	0.0030
	Bromide (Br^-)	6	0.0127	0.0118	0.0067
	Nitrate (NO_3^-)	3	0.0000	0.0586	0.0000
	Phosphate (PO_4^{2-})	3	0.0000	0.0000	0.0000
	Sulfate (SO_4^{2-})	3	0.0762	0.4494	0.2896
	WOA	25	0.9862	0.4665	0.4672
CATIONS	Lithium (Li^+)	3	0.0007	0.0000	0.0007
	Sodium (Na^+)	3	0.0842	0.0957	0.0565
	Ammonium (NH_4^+)	3	0.2684	0.2339	0.1998
	Potassium (K^+)	3	0.1293	1.2275	0.1377
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.0000
	Calcium (Ca^{2+})	n/a	0.0150	0.0092	0.0083

IPC-B-52 TEST VEHICLES – SIR TEST RESULTS FOR CLEANING AGENT ‘A’

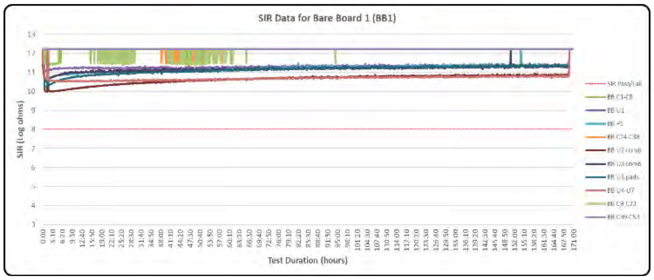

Figure 40. IPC-B-52 Vehicle – Bare Board – **Passed**

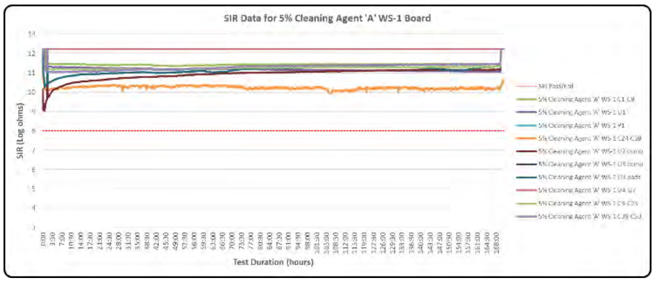

Figure 41. IPC-B-52 Vehicle – 5% Cleaning Agent ‘A’ WS-1 – **Passed**

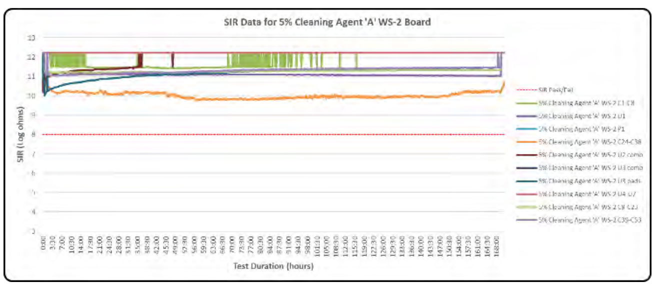

Figure 42. IPC-B-52 Vehicle – 5% Cleaning Agent ‘A’ WS-2 – **Passed**

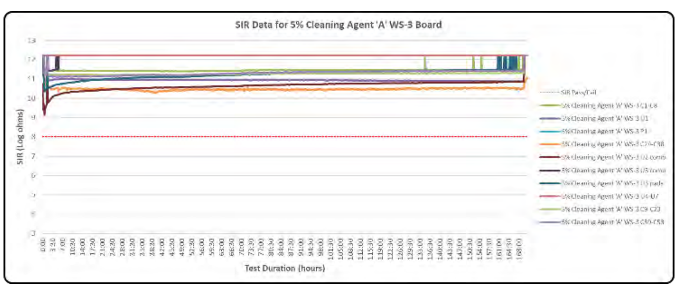

Figure 43. IPC-B-52 Vehicle – 5% Cleaning Agent ‘A’ WS-3 – **Passed**

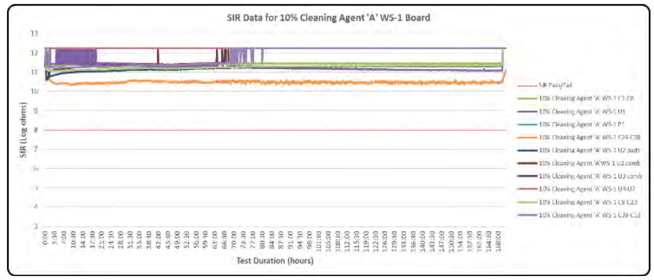

Figure 44. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ WS-1 – **Passed**

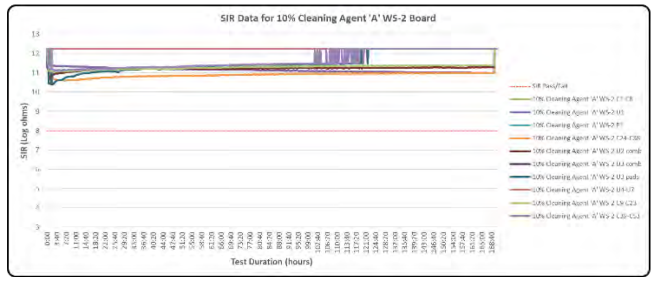

Figure 45. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ WS-2 – **Passed**

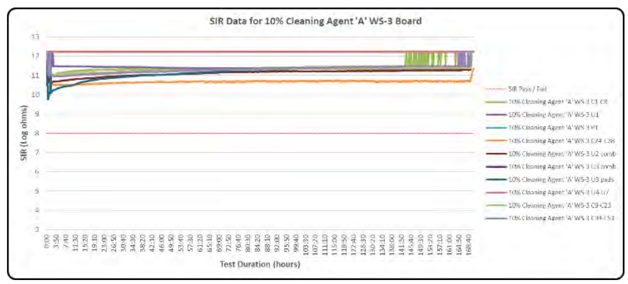

Figure 46. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ WS-3 – **Passed**

Figure 47. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ NC-1 – **Passed**

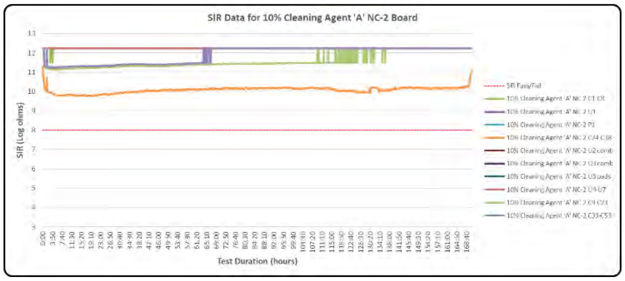

Figure 48. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ NC-2 - **Passed**

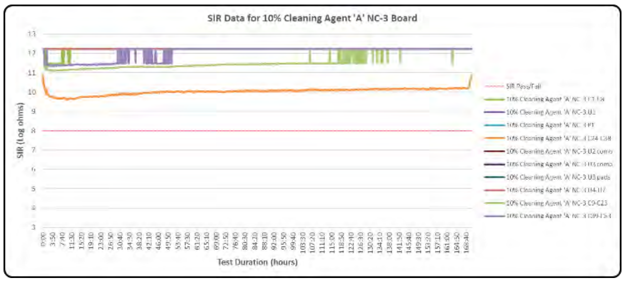

Figure 49. IPC-B-52 Vehicle – 10% Cleaning Agent ‘A’ NC-3 – **Passed**

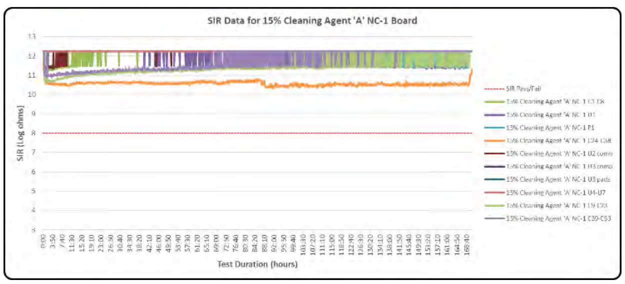

Figure 50. IPC-B-52 Vehicle – 15% Cleaning Agent ‘A’ NC-1 – **Passed**

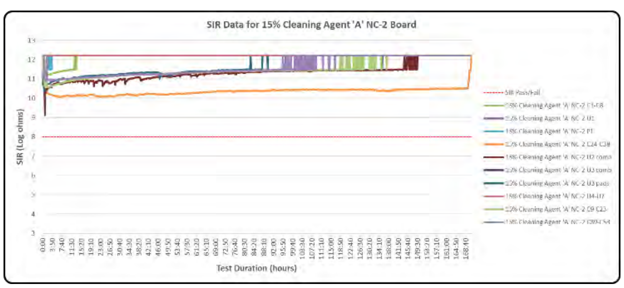

Figure 51. IPC-B-52 Vehicle – 15% Cleaning Agent ‘A’ NC-2 – **Passed**

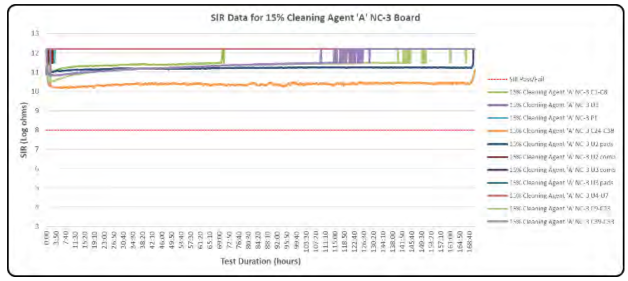

Figure 52. IPC-B-52 Vehicle – 15% Cleaning Agent ‘A’ NC-3 - **Passed**

IPC-B-52 TEST VEHICLES – SIR TEST RESULTS FOR CLEANING AGENT ‘B’

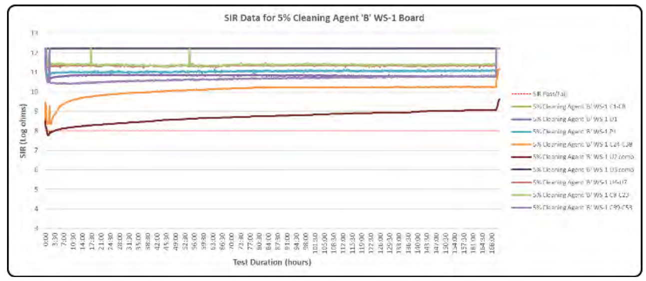

Figure 53. IPC-B-52 Vehicle – 5% Cleaning Agent ‘B’ WS-1 – **Passed**

Figure 54. IPC-B-52 Vehicle – 5% Cleaning Agent ‘B’ WS-2 – **Passed**

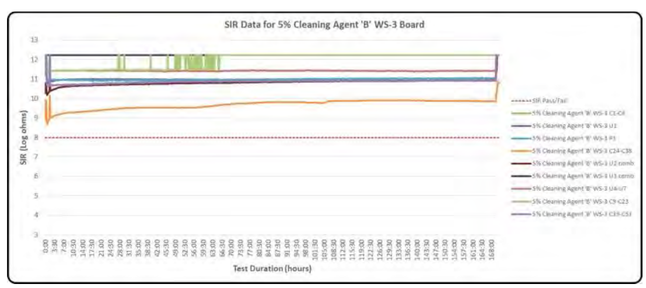

Figure 55. IPC-B-52 Vehicle – 5% Cleaning Agent ‘B’ WS-3 – **Passed**

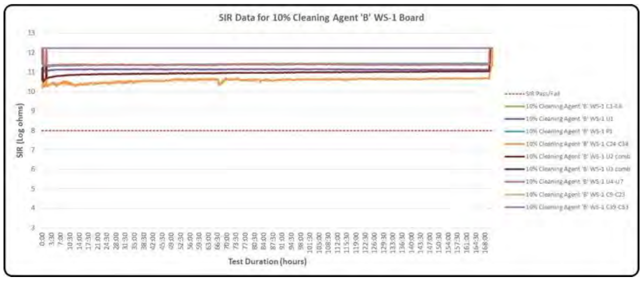

Figure 56. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' WS-1 – **Passed**

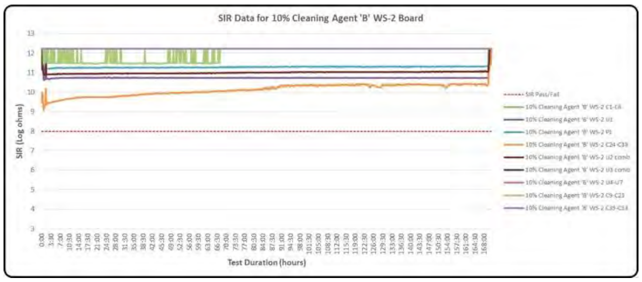

Figure 57. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' WS-2 – **Passed**

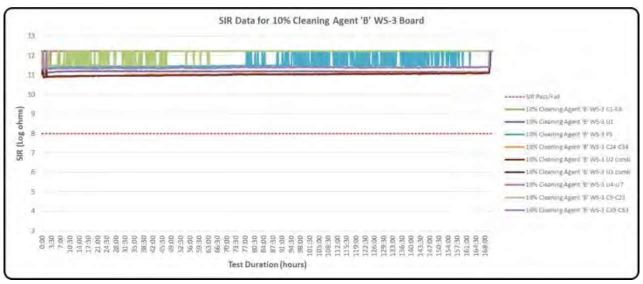

Figure 58. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' WS-3 – **Passed**

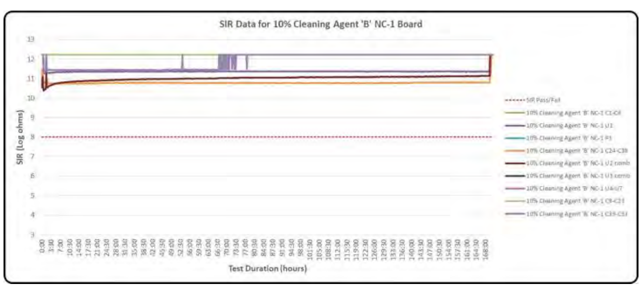

Figure 59. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' NC-1 – **Passed**

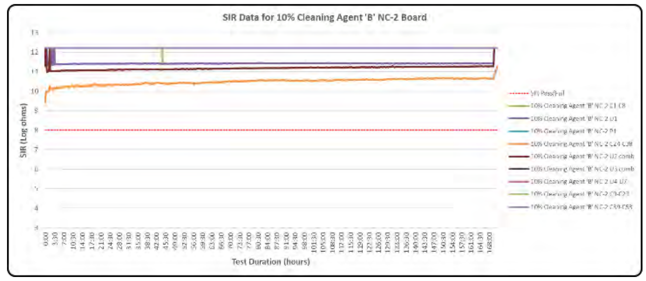

Figure 60. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' NC-2 – **Passed**

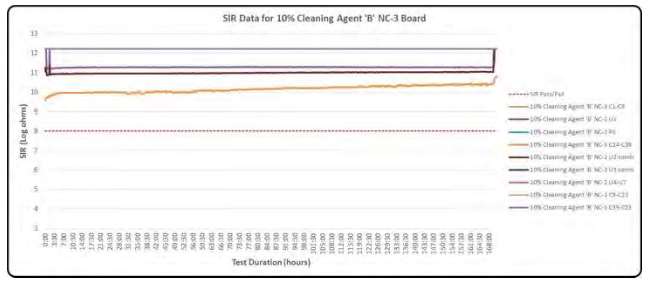

Figure 61. IPC-B-52 Vehicle – 10% Cleaning Agent 'B' NC-3 – **Passed**

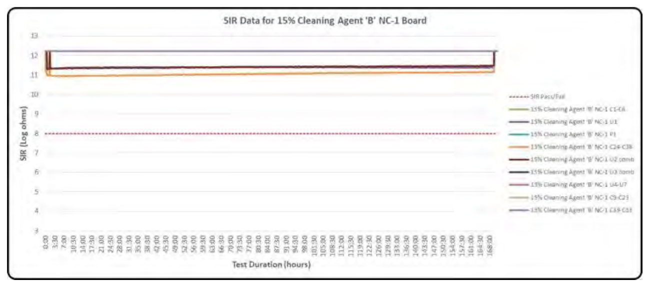

Figure 62. IPC-B-52 Vehicle – 15% Cleaning Agent 'B' NC-1 – **Passed**

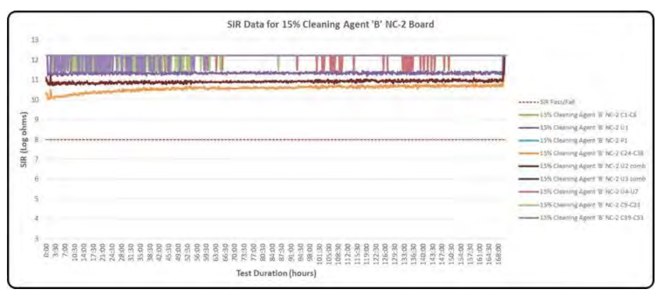

Figure 63. IPC-B-52 Vehicle – 15% Cleaning Agent 'B' NC-2 – **Passed**

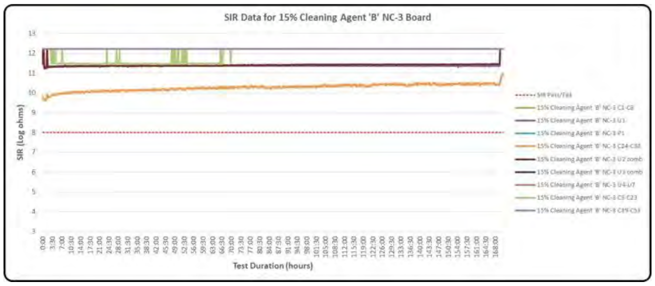

Figure 64. IPC-B-52 Vehicle – 15% Cleaning Agent ‘B’ NC-3 – **Passed**