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Case Study – "Limitations of DI-Water Cleaning Processes"

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ABSTRACT:

While most cleaning processes in the global electronics manufacturing industry still rely on cleaning with DI-water only (for OA flux removal), recent studies suggest that water is beginning to reach its cleaning limitation, favoring the use of chemically assisted cleaning processes. The increased use of water-soluble lead-free solder requires more activators and higher soldering temperatures, which result in more burnt-in fluxes and produce water insoluble contamination. DI-water alone has a limited to no ability to solubilize non-ionic residues on the board's surface.

These findings coincide with the use of smaller, more densely packed components which further limit the effectiveness of pure DI-water. Due to its high surface tension of over 70 dynes/cm, water cannot effectively penetrate underneath low standoff components. Chemistry assisted cleaning processes, however, can reduce the surface tension to 30 dynes/cm and below and therefore eliminate penetration problems.

This technical case study complements the authors' initial in-house findings by comparing them to actual production assemblies and conditions. The lead engineering team at a participating customer site designed this comprehensive blind study to determine removability with DI-water versus various chemistry supported systems. The findings revealed significant experimental data, which shed much needed light on this emerging industry challenge.

INTRODUCTION:

Upon examination of the electronics manufacturing industry in North America, a clear trend is apparent as many are shifting away from cleaning with pure DI-water to chemistry assisted cleaning processes.

A number of reasons can be cited supporting the recent trend toward cleaning with chemistry. First, there is the increased use of lead-free solder which requires higher soldering temperatures. This results in more burnt-in fluxes that are much more difficult to remove as they begin to produce water-insoluble contamination. [1] DI-water alone has a very limited to no ability to solubilize non-ionic residues on the board's surface.

Second, the cleaning of leaded and lead-free water-soluble fluxes (especially under low standoff components) has also become a lot more difficult since water with its high surface tension of over 70 dynes/cm cannot effectively penetrate under low standoff components. As standoff heights decrease and component densities increase, companies will have to improve their existing cleaning process. [1], [2]

	Solder paste 5		
	120°F	140°F	150°F
DI-water	2.2	1.7	1.9
Cleaning Agent 1 (3%)	5	4.8	4.8
Cleaning Agent 2 (3%)	3	3.8	5
Cleaning Agent 1 (5%)	5	5	5
Cleaning Agent 2 (5%)	3.8	3.4	5

The ranking of the results was defined as follows:

1. Contamination in all areas untouched
2. Contamination in most areas
3. Contamination in few areas
4. Some minute and specs or lines
5. Clean

Figure 1: Recent cleaning performance of DI-water when compared to chemistry assisted processes for solder paste 5. [1]

Chemistry assisted cleaning can reduce the surface tension to 30 dynes/cm and below. Interestingly, the industry so far has mostly reverted to adjusting the cleaning process to its respective limits. This entails, for example, an increase in operating temperature to above 150°F (in some cases up to 180°F), an increase in spray pressures and a lowering of belt speeds to improve and prolong the exposure time [3]. With pure water-soluble fluxes in a eutectic environment, such measures can provide sufficient cleaning results. Given the introduction of lead-free solder pastes, however, the solubility of residues in DI-water becomes limited. If non-ionic contamination is produced, water alone cannot chemically dissolve such contamination [4]. Another commonly overlooked consequence is that higher pressures might allow the water to penetrate low standoff components by forcing water underneath or into the capillary spaces. Unfortunately, the cleaning equipment will be challenged to remove dissolved contamination during the drying process, what leads to entrapment. It is of utmost importance to verify a dry and clean environment under components after cleaning, to limit the formation of electrochemical migration or leakage currents. Cleaning agents, on the other hand, can be easily rinsed and dried as the lower surface tension allows for quick removal.

During a recent, comprehensive in-house study the authors were able to validate a number of research hypotheses. The main objective was to determine the differences of cleaning water-soluble flux residues with DI-water versus using a chemistry assisted process. Test boards with 0603 chip capacitors and 20+ water-soluble, lead-free solder pastes were used. Figure 2 summarizes the results visually.

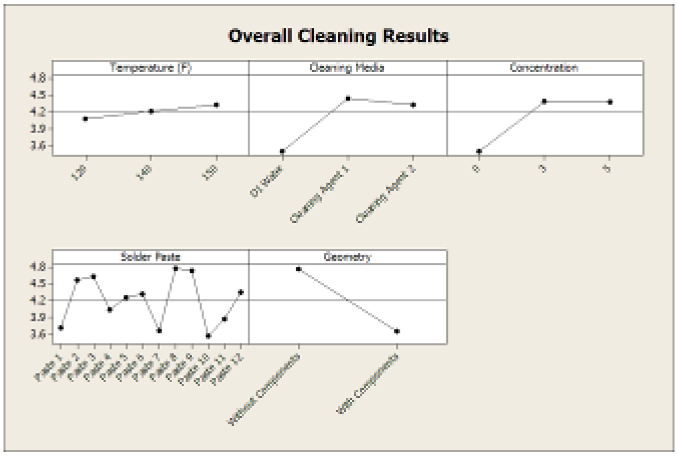

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Figure 2: Results highlighting effects of each variable through Minitab® Software, full factorial.

In summary, the following conclusions were reached:

- At lower wash temperatures, the tested cleaning agents demonstrated superiority over the pure DI-water cleaning process when cleaning water-soluble flux residues.
- At 3% concentration versus 5% concentration level, the cleaning results were comparable.
- Out of 12 pastes five were more responsive to an increase in wash temperature in terms of clean-ability.
- The use of a cleaning agent with a concentration level as low as 3% provided up to 111% better cleaning results underneath the low standoff components when compared to pure DI-water.

MAIN RESEARCH: As indicated above, DI-water applications have reached their respective cleaning limitations. The core objective of this paper is aimed at determining the latest status and potentially to alert current users of their process limitations through a representative customer case study. We hope that we can help facilitate this transition for many manufacturers, as they may not be completely aware of the current operating risk of using straight DI-water. Field failures due to insufficient cleanliness are expensive and can easily damage any company's reputation. Previous internal studies are now being validated by numerous customer case studies.

HYPOTHESES:

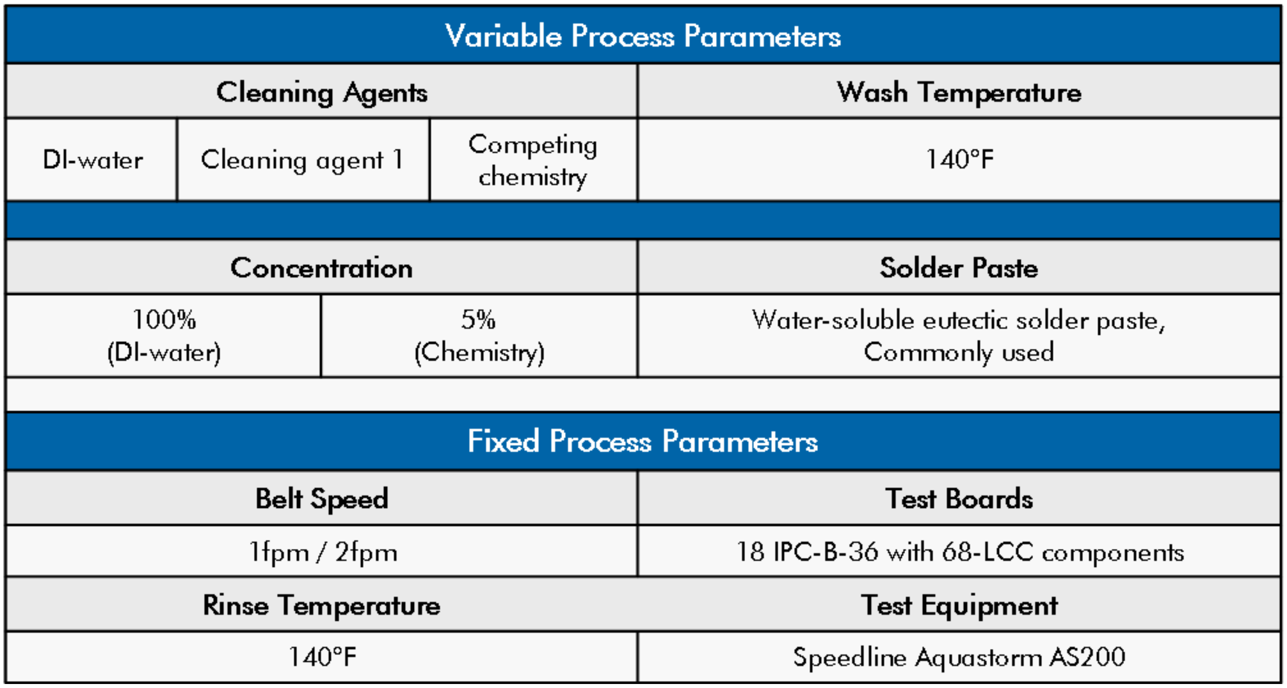
H_1: Water-soluble flux residues are becoming more difficult to remove completely with DI-water alone.

H_2: Low concentrations of chemistry can provide better cleaning results and widen the process window.

RESEARCH:

The research design compared three different cleaning media within identical cleaning equipment. Cleanliness was determined underneath four 68-LCC (Leadless Chip Components) components placed on an IPC-B-36 coupon. A commonly used water-soluble, eutectic solder paste was used for this study. All test assemblies were reflowed in a 10 stage state-of-the-art oven to simulate production conditions as closely as possible. A special arrangement of components (4 quads) on the test boards was found to be optimal based on prior experience gained through cleaning under low standoff components and customers' feedback. Six of the test boards were cleaned at the customer's site with the existing cleaning process as a benchmark. The remaining 12 boards were tested at ZESTRON's Technical Center. The table below shows the test parameters as they were used during this case study at both sites.

Table 1: Variable and fixed process parameters



Variable Process Parameters			
Cleaning Agents			Wash Temperature
DI-water	Cleaning agent 1	Competing chemistry	140°F
Concentration			Solder Paste
100% (DI-water)	5% (Chemistry)		Water-soluble eutectic solder paste, Commonly used
Fixed Process Parameters			
Belt Speed			Test Boards
1fpm / 2fpm			18 IPC-B-36 with 68-LCC components
Rinse Temperature			Test Equipment
140°F			Speedline Aquastorm AS200

METHODOLOGY

The paste was screened onto the test substrate. The components were applied and reflowed according to the guidelines supplied by the solder paste manufacturer. A standard IPC B-36 circuit board was used as test vehicle. Each sample was populated with four 68-LCC components as shown in Figure 3.

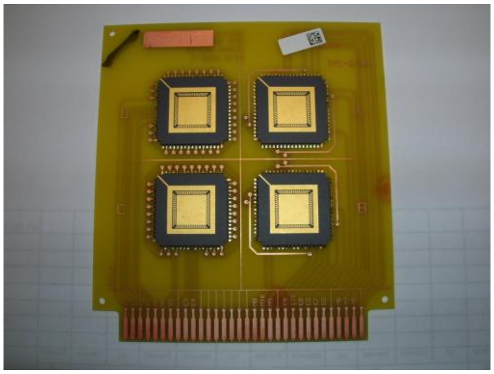


Figure 3: Test vehicle IPC-B-36 board with four 68-LCC components with <1 mil standoffs

Figure 4a: Fail - Flux residue detected at 40X

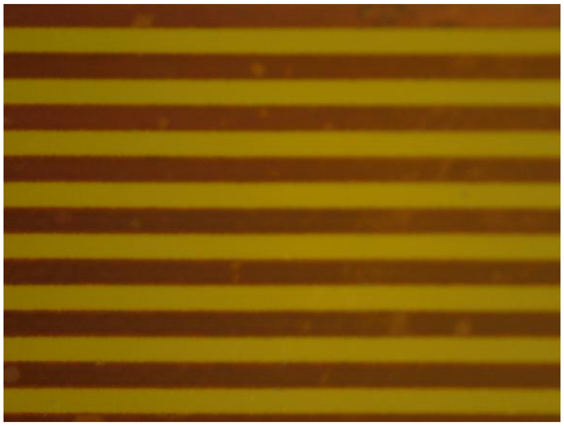


Figure 4b: Fail – Flux residue detected at 40X

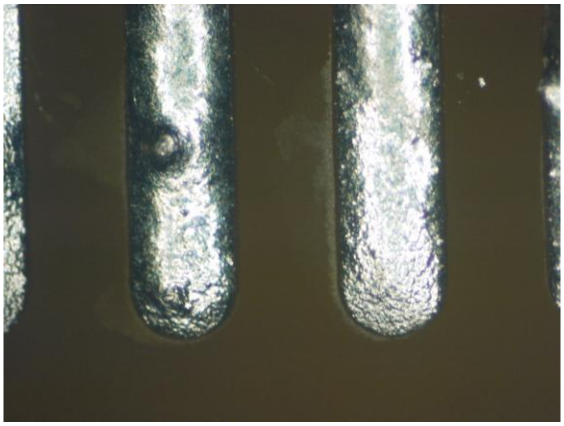


Figure 5a: Fail - Flux residue detected at 40X

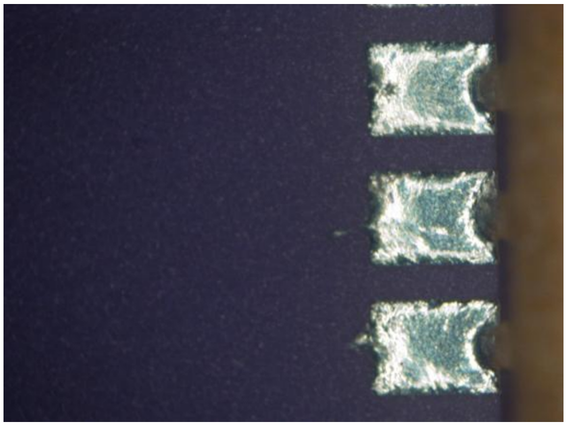


Figure 5b: Pass - No flux residue detected at 40X

All of the components were removed for visual analysis. Any residue detected under or around any of the four leadless components on the board constituted failure of the entire board.

DATA FINDINGS:

The visual inspection was performed by the customer and two process engineers. The results were averaged. Each cleaning experiment was repeated three times to establish reproducibility. Components were removed in one quad area given complete surface cleanliness. Other assemblies were not destructed to allow for subsequent analytical test procedures, i.e. SIR.

Table 2: Test results for cleaning agent 1 at 1 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Surface clean	- Surface clean - Wetness seen on component underside	Surface clean	Surface clean
2	Surface clean	Clean on surface & Underneath component	Surface clean	Surface clean
3	Surface clean	Clean on surface & Underneath component	Surface clean	Surface clean

The first set of trials was conducted with cleaning agent 1 and all four quads were inspected for cleanliness. Belt speed was maintained at 1 ft/min. Components were inspected with an optical microscope, before and after the full removal of the components. Interestingly, these settings provided the most optimal results. With one single exception, all quads were found to be completely flux free. In one isolated case, the inspection yielded a slight wetness on the underside of the component. Based on the obtained results, the belt speed was increased to 2 ft/min to determine the maximum belt speed required.

Table 3: Test results for cleaning agent 1 at 2 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Very minor residue	Very minor residue	Surface clean	Very minor residue
2	Very minor residue	Very minor residue	Very minor residue	Surface clean
3	Surface clean	Surface clean & under component	Surface clean	Surface clean

At elevated belt speed the trials with the same cleaning agent showed mixed results. The exposure time seemed essential for the full removal of all residues under all four quads. In the majority of the quads, residues (although only slight) were observed. For board #3, the surface was found fully cleaned, which was also confirmed underneath the component on quad B. Overall, the results establish that minor to no residues resulted from a decrease in exposure time. For this particular example, the authors conclude that belt speeds below 2 ft/min provide fully cleaned assemblies.

Table 4: Test results for DI-Water at 1 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Residue observed	Speck of residue on solder joints	Surface clean	Surface clean
2	Residue observed	Very minor residue	Residue observed	Residue observed
3	Residue observed	Residue observed	Surface clean	Surface clean

In comparison to cleaning agent 1, the authors evaluated the possibility of running straight DI-water as a benchmark. Having employed a water-soluble flux, the initial inclination would be to use water as the cleaning agent. As previously stated, the high surface tension and limited solubility of water insoluble residues could limit its use. This notion was confirmed as across all assemblies significant residues were detected during this experiment. The removal of the components was therefore deemed unnecessary. These results were obtained at the lowest belt speed of 1 ft/min. The authors confirmed the limitation of DI-water as a suitable cleaning agent according to hypothesis I.

Table 5: Test results for DI-Water at 2 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Surface clean	Some residue on board surface underneath the component	Surface clean	Surface clean
2	Very minor residue	Residue observed	Very minor residue	Very minor residue
3	Surface clean	Speck of residue after removal	Residue observed	Residue observed

The increase in belt speed provided similar cleaning results. More than 50% of the quads showed residues on the surface implying that residues also remained under the components. With a standoff height of less than 1 mil, leadless components are currently considered the most challenging substrates on the market. In previous studies, the authors used 0603 chip capacitors to provide a challenging cleaning environment. Compared to 1ft/min, the results remained unsatisfactory.

Table 6: Test results for current competitor cleaning agent at 1 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Surface clean	Slight speck of residue & also some wetness	Surface clean	Surface clean
2	Very minor residue	White residue on the joints	Residue observed	Surface clean
3	Surface clean	Surface clean & under components	Surface clean	Surface clean

Both, the DI-water and cleaning agent 1, were intended to provide a side by side comparison to the currently installed cleaning process. Given the limitations of DI-water and its insufficient cleaning results, alternatives were investigated. Results indicate that for belt speeds of 1 ft/min numerous quads still show residues after cleaning using the current process. Nevertheless, the results show a relative improvement over straight DI-water. Cleanliness under leadless components was also confirmed for board #3 under quad B.

Table 7: Test results for current competitor cleaning agent at 2 ft/min

Board #	Quad A	Quad B	Quad C	Quad D
1	Surface clean	Surface clean & Under component	Surface clean	Very minor residue
2	Very minor residue	Slight residue on joints	White residue on joints	Residue observed
3	Very minor residue	Residue observed	Surface clean	Residue observed

The final experiment included the use of the competing chemistry at a belt speed of 2 ft/min. Both, DI-water and cleaning agent 1 were intended by the customer as side by side comparisons to their currently installed cleaning process. Results indicate that most quads have remaining, post cleaning residues on their surface areas. Components were not removed due to insufficient surface cleanliness levels. This once again highlights the need for sufficient exposure times to achieve good cleaning results. Temperatures were kept constant during the experiments.

FUTURE EXPERIMENTS:

Based on the conducted customer case study, the customer collected data in line with the commonly accepted limitations of DI-water. This blind study helped this company determine the performance of newer, more advanced cleaning agents available today and included DI-water as a baseline. Future experiments will focus on experimental data obtained from numerous, ongoing case studies. Variables to be included are different paste formulations, pH-neutral cleaning agent technologies and overall cost comparative studies of chemistry assisted processes versus DI-water.

CONCLUSION:

Valuable experimental data was collected to further demonstrate the limitations of DI-water as a viable defluxing agent. To continue our ongoing market research on this topic, three cleaning media were tested for cleaning leadless components with low standoff of less than 1 mil. The most promising results were obtained with cleaning agent 1. Cleaning agent 1 showed full removability at a belt speed of 1ft/min across all surfaces and under all quad areas. Based on the results obtained, the authors were able to validate both hypotheses of this study. Given the findings, the authors encourage current DI-water users to take the time and closely investigate their current cleanliness levels, especially under low standoff components.

One previously highlighted advantage of using a chemistry assisted process is that users can operate at lower temperatures and with a wider process window and clean not only OA but also RMA and no-clean fluxes.

Despite all the valid arguments encouraging the use of chemistry assisted processes, the authors would like to caution interested users as well. Most machines currently dedicated strictly to DI-water are not properly equipped to use a closed looped chemistry. This means that they do not have the necessary chemical isolation section. The latter is an essential part not only to conserve chemistry but also to minimize cross contamination in the rinse tank. DI-water machines take advantage of cascading DI-water tanks from front to back. Employing a chemical product in the wash tank would lead to a continuous dilution of the recommended application concentration by DI-water. Companies that are strategically planning their capital purchases are therefore well advised to incorporate the mechanical option to run aqueous chemistries. A slightly higher investment will provide significantly more process flexibility in years to come, and might lead to additional savings.

AUTHORS:

This research paper is the 5th in a series written by ZESTRON on optimizing electronic cleaning processes and presented at the industry's known conferences IPC/APEX and SMTAI. Based on our findings, key market developments have been initiated and the current shortcomings observed in the industry are starting to be addressed.

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