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WHY SWITCH FROM PURE DI-WATER TO CHEMISTRY?

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ABSTRACT
It is noteworthy that while most cleaning processes in the North American and Asian markets rely on cleaning with DI-water only (for OA flux removal), recent market studies suggest that water is beginning to reach its cleaning limitation, favoring the use of chemistry assisted processes. Innovative cleaning solutions are already available to address this process limitation and, in some cases, are even more cost effective. The purpose of this DOE study is to report a timely direct comparison between a pure DI-water process and a chemically assisted application.

Key words: DI-water, chemistry, cleaning agent, limitations of DI-water, chemistry assisted cleaning.

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 processes.

A number of reasons can be cited supporting the recent trend toward cleaning with chemistry. For one, there is the increased use of lead-free solder which requires higher soldering temperatures. This results in more burnt in fluxes that are much harder 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 boards surface.

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

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, increase the spray pressures, lowering belt speed to improve and prolong the exposure time, respectively [3]. With pure water-soluble fluxes in an eutectic environment, such measures can provide sufficient cleaning results. Given the introduction of lead-free however, the solubility of residues in DI-water becomes the limiting aspect. If non-ionic contamination is produced, water alone cannot chemically dissolve such contamination [4]. Another often times 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 equipments are not capable of removing the water later on in the drying sections, which in turn traps contamination. It is of utmost importance to verify a dry and water and flux free 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.

ARTICLE SUMMARY

Main Research

As indicated above, DI-water applications are reaching their respective limit. The core study of this paper is aimed at determining the current status and potentially to alert current users of their process limitations. We hope that we can help facilitate this transition for many users, as they might not have realized the risk they are currently operating under. Field failures due to insufficient cleaning are expensive and can damage the reputations of companies easily. Internal studies were initially completed with test boards using 0603 chip capacitors and 20+ water-soluble, lead-free solder pastes. These findings are currently being validated by numerous customer case studies.

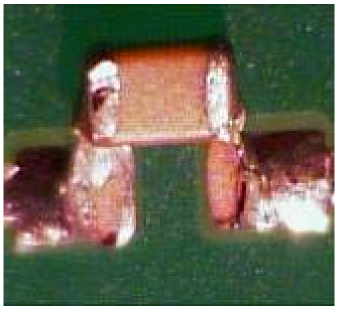


Figure 1a: Pass - No flux residue remains under component

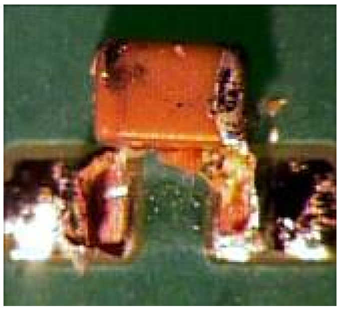


Figure 1b: Fail – Any Flux residue detected at 40X

HYPOTHESES

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

H_2: Components limit the penetration of DI-water

H_3: Low concentrations of chemistry can provide better cleaning results and widen the process window

METHODOLOGY

The research design compared 12 of the most used water-soluble, lead-free solder pastes. Cleanliness was determined on bare FR-4 areas as well as underneath 0603 chip cap components (Figure 2). The latter were listed by numerous customers as challenging components. All prepared assemblies were reflowed in a 10 stage state-of-the-art oven to simulate production conditions as closely as possible. The special arrangement of components on the test boards was found to be optimal based on prior experience gained with cleaning under low standoff components.

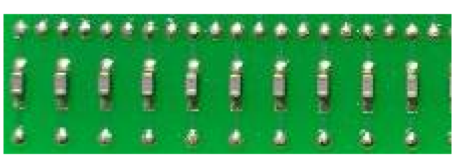


Figure 2: Test vehicle sequentially populated with 0603 capacitors

The table below shows variable as well as constant process settings as they were used during the test series.

Table 1: Process settings

Variable process parameters					
Cleaning agents			Temperature		
DI-water	Cleaning agent 1	Cleaning agent 2	120°F	140°F	150°F
Concentration			Solder pastes		
100% (DI-water)	5%	3%	12 lead-free water-soluble solder pastes		
Invariable process parameters					
Belt speed			Test boards		
2fpm			FR-4 with 0603 components		
Rinse temperature			Test equipment		
140°F			Speedline Aquastorm AS200		

For this Design of Experiment study the full factorial analysis evaluated the variables of wash temperature, cleaning agent technology, cleaning agent concentration, different brands of solder pastes used. No sump side additives were needed due to the uniquely engineered cleaning agents, including a pH-neutral defluxing technology. The baseline for evaluating relative cleanliness was DI-water and unpopulated assemblies with the same pastes, but without any components. State-of-the-art Inline equipment was used to perform all experiments. Visual inspection (40X) was performed by three (3) principal investigators respectively and data subsequently averaged.

DATA FINDINGS

Part 1: Cleaning w/o Components

The initial baseline was established with the use of DI-water and both cleaning agents at different concentrations without the use of any complex geometry (i.e. low standoff devices). The authors argued that this should show an initial comparison of cleaning effectiveness of each medium. For this set of experiments all 12 OA-LF pastes were tested, by being printed and reflowed according to their respective, recommended profile. Table 1 shows the test parameters as well as the solder pastes used during the test series with DI-water.

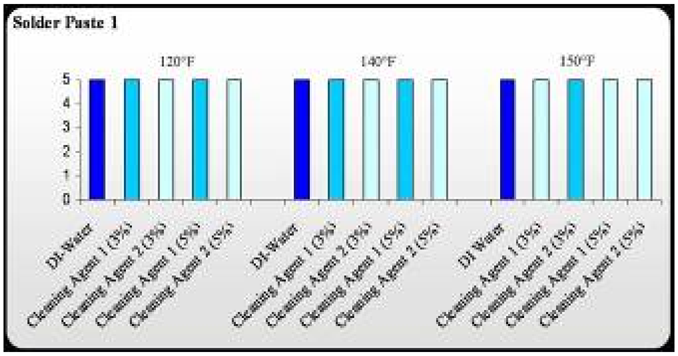
Table 2: Test conditions during the cleaning

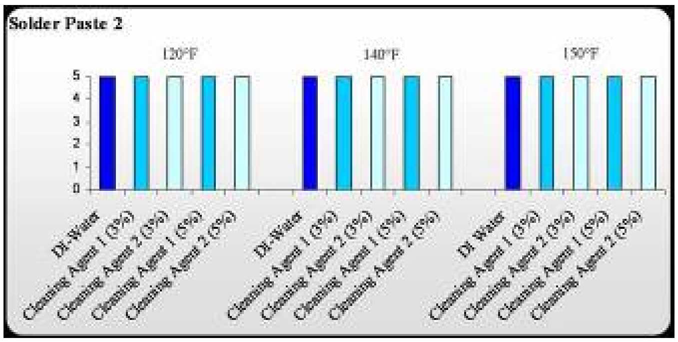
Contamination	Lead - free	Wash Temp.	Rinse Temp.	Belt Speed	Substrate
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				
[illegible]	[illegible]				

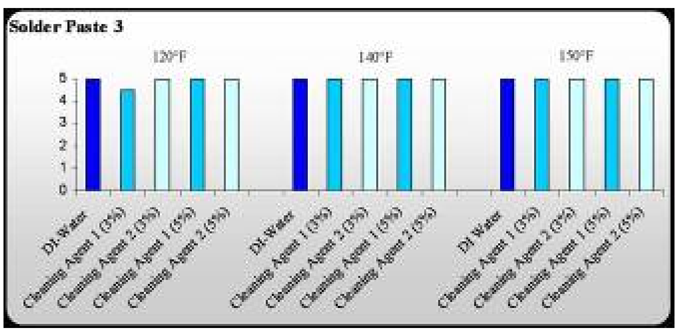
The ranking of the results was defined as follows:

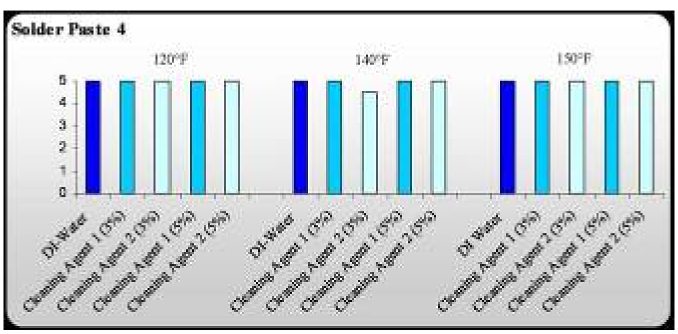
1. Contamination in all areas untouched
2. Contamination in most areas
3. Contamination in few areas
4. Some minute and specs or lines
5. Clean

The pictures below show the cleaning results for pastes 1-4:

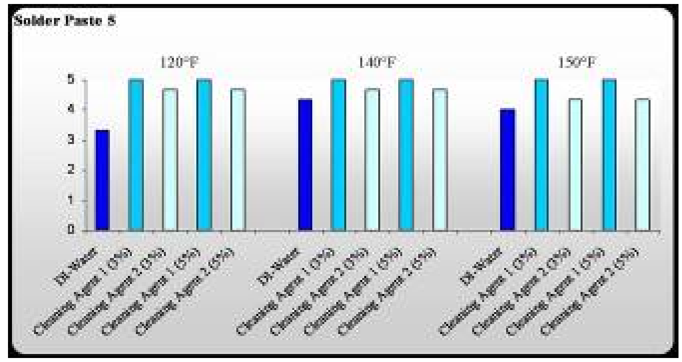




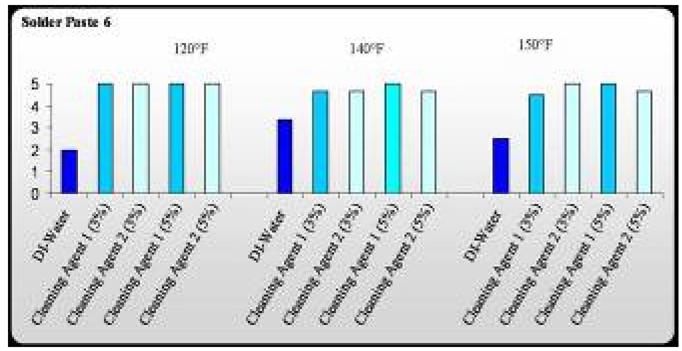




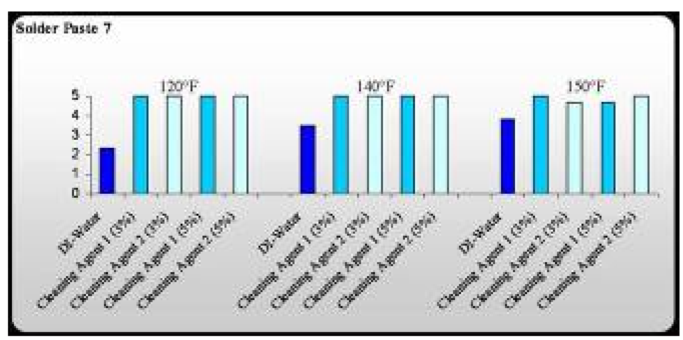
For pastes 1-4 very minimal differences were noticed. All results indicate that DI-water was just as effective as the chemistry supported cleaning process. This conclusion applies to all respective temperatures.



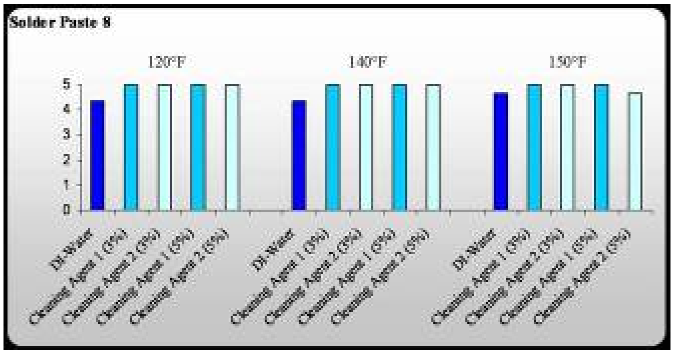
Cleaning agent 1 was able to fully clean at 3 and 5% at all temperatures. The cleaning results for DI-water alone remained between 3 and 4. Cleaning agent two did clean better than DI-water but was not able to completely remove all residues.



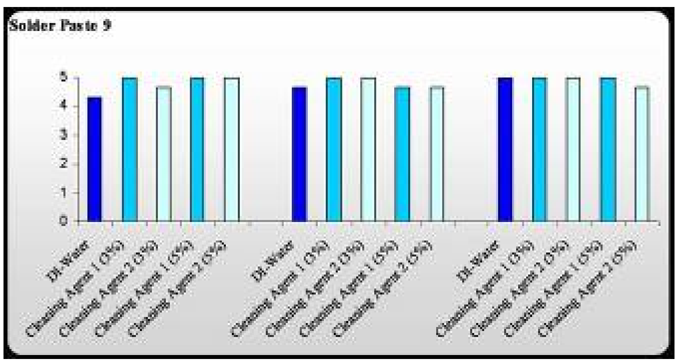
Best results for both cleaning agents were obtained at the lowest operating temperature of 120°F. DI-water alone at 120°F barely removed the residues, leading to a 2/5 (5 being fully cleaned) result. Surprisingly the cleaning agent 2 with a neutral pH-formulation was able to clean as well as its alkaline counterpart. Increasing the temperature did not improve the cleaning result further for any of the chemistries but DI-water did clean marginally better.



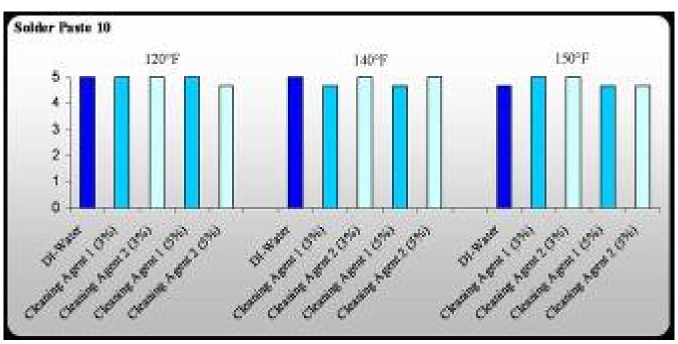
Similar as with paste 6, DI-water did not perform nearly as well as either one of the chemistries tested at 120°F for paste 7. All chemistries at both 3 and 5% respectively were able to fully clean at this temperature. A further increase in temperature did not provide better results. DI-water however improved from 2 to almost 4 through the increase from 120°F to 150°F.



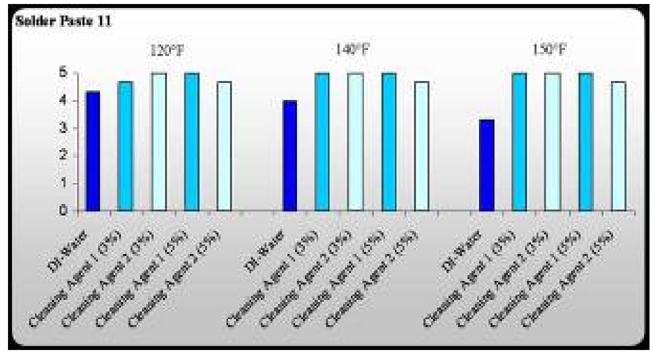
Paste 8 was seemingly easier to clean under constant process conditions. The cleaning results at 120°F were comparable to those at 150°F where DI-water almost reached 100% cleanliness. Interestingly for this paste, the cleaning chemistries were able to fully clean at concentrations as low as 3%!



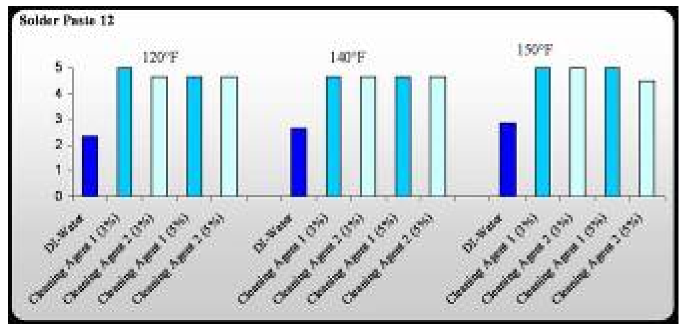
These cleaning trials support the author's hypothesis that temperature increases cleaning effectiveness. DI-water showed good cleaning results at 120°F, but an increase to 150°F demonstrated 100% clean-ability. Both chemistries at 3 and 5% also showed full removability.



For paste 10 all three cleaning agents delivered similar results at all three cleaning temperatures. Cleaning agent 1 though showed best cleaning results at 150°F at 3% concentration.



Paste 11 was almost completely removed at all temperatures. Only DI-water could not achieve 100% cleanliness at all temperatures.



Cleaning paste 12 was relatively easy as best cleaning results could already be achieved with cleaning agent 1 at 3% concentration at 120°F. Cleaning with DI-water showed better results at 150°F but left flux residues.

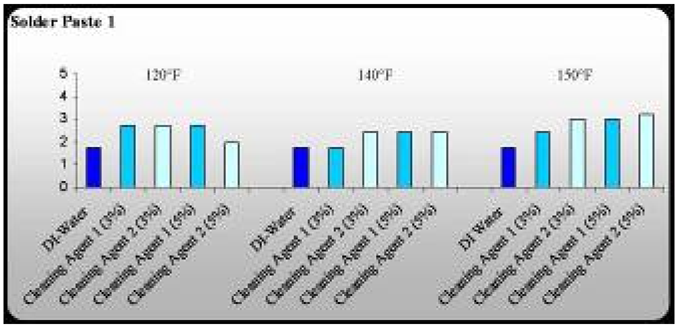
CONCLUSIONS

Part 1

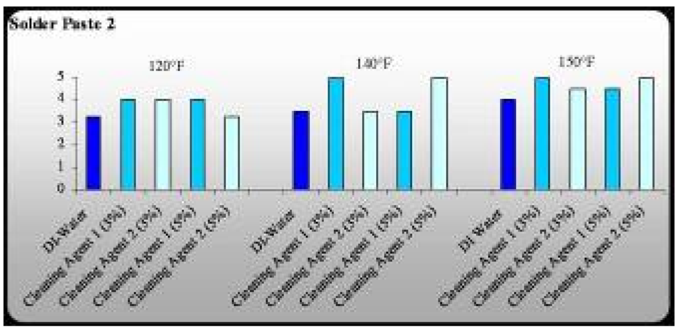
The cleaning results for all 12 water-soluble pastes tested showed quite significant differences in the cleaning results on bare, reflowed assemblies. It is noteworthy to state that the limitations of DI-water are already becoming quite evident when compared to a 3% and 5% chemically supported cleaning process. Temperature and concentration did factor into the cleaning results for DI-water mostly, but there was no significant difference noticeable for both chemistries between 3% and 5% active concentration. This is an important conclusion as it suggests that 3% is a feasible concentration and it points to potentially lower operating temperatures when using a cleaning agent other than DI-water. Hypothesis I is therefore validated.

Part 2: Cleaning Under 0603 Chip Capacitors

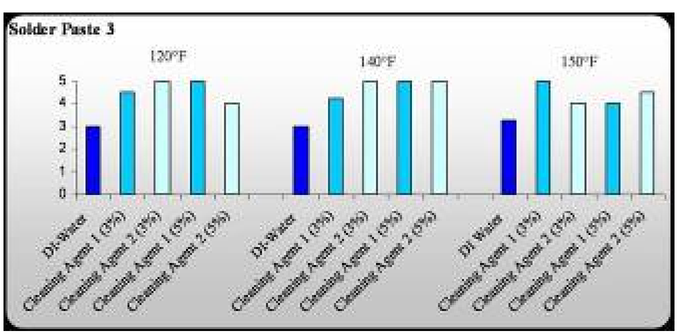
The second set of experiments was then conducted by introducing low standoff components on the test boards. These were sequentially populated 0603 chip capacitors using the same 12 water-soluble, lead free pastes. The objective was to assess the validity of hypothesis two and three, which stated the cleaning limitation of DI-water under components and favored the use of chemistry assisted cleaning process.



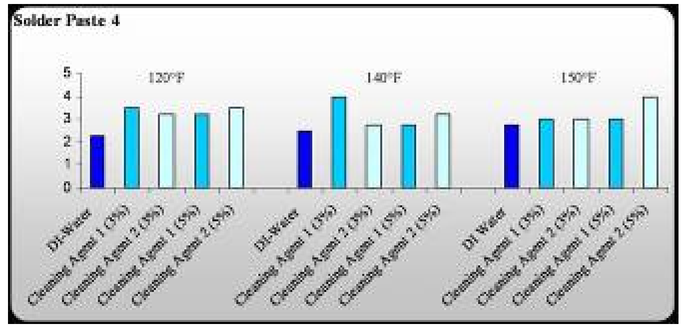
The removal of all flux residues with pure DI-water was found to be not feasible at all tested temperature levels. Despite the fact that none of the cleaning agent resulted in fully cleaned assemblies, the chemistry assisted processes showed a significantly better overall result. It is noteworthy that DI-water did not clean any differently between 120°F and 150°F. The neutral product formulation also showed a better cleaning result at 150°F level.



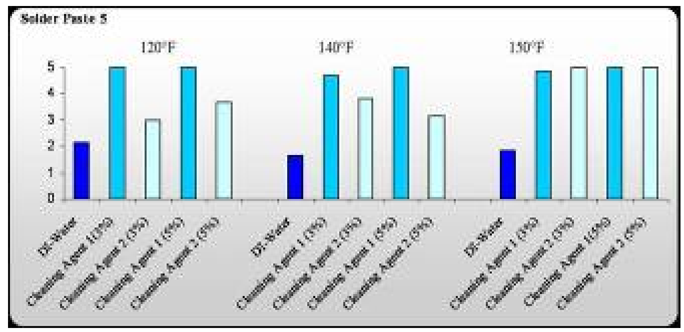
For paste 2 the results obtained favored the use of cleaning agents at both concentrations. Although DI-water did clean well, the best results were found at 3% for cleaning agent 1 and 5% for cleaning agent 2. In both cases all residues were successfully removed.



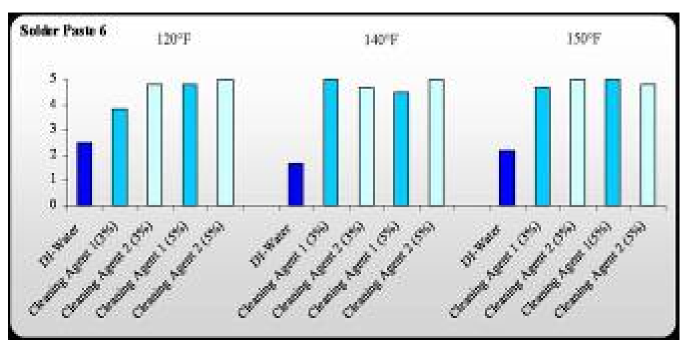
This cleaning trial demonstrated that a 3% concentration level can be even more effective in cleaning when compared to 5%. Very good results were achieved at temperatures as low as 120°F, while DI-water only achieved a 3/5 rating at all temperatures tested.



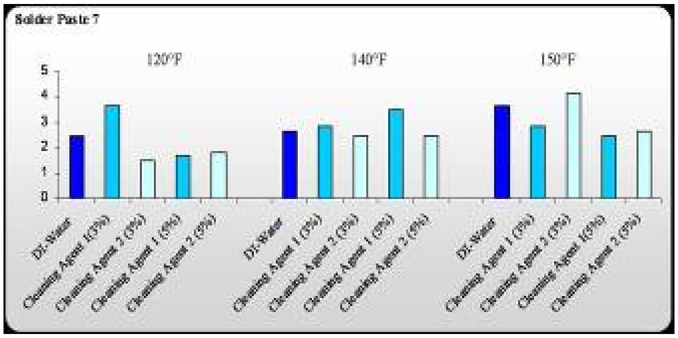
Surprisingly the pH-neutral cleaning agent 2 did overall achieve the best results. None of the tests showed complete flux removal under the components. The relative cleaning assessment illustrates the better cleaning results of chemistry over DI-water.



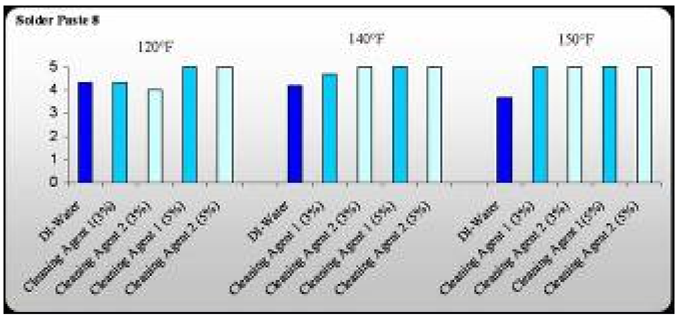
This water-soluble lead-free paste showed a direct relationship between cleaning temperature and cleaning result. Despite positive cleaning results with cleaning agent 1 at 3% and 5% at 120°F all other results at this temperature did not provide full flux removal. Increasing the temperature to 140°F and 150°F respectively elevated all cleaning results to 5/5. Only DI-water was not able to fully remove all fluxes underneath the 0603 chip capacitors at 150°F.



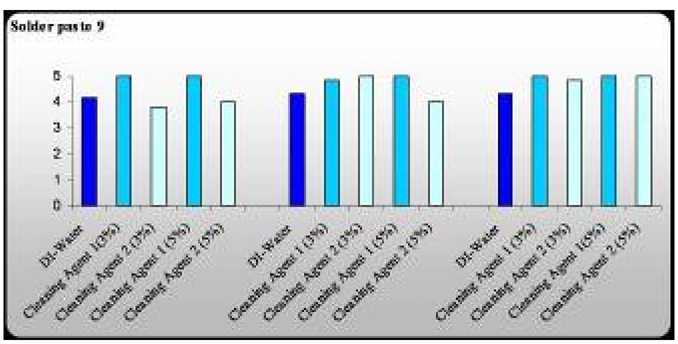
A similar result as with paste 5 was achieved with paste 6. The only difference being that the results at 120°F and 140°F were slightly better. At 150°F the results were almost identical.



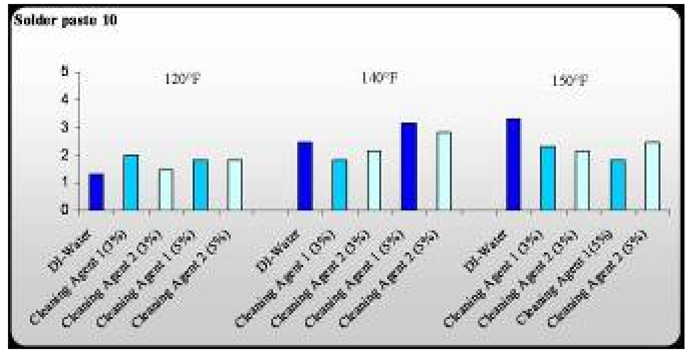
The results of this cleaning trial showed for the first time comparable cleaning results between DI-water and any of the chemistries used. No significant differences were detected at either concentrations and/or temperatures. Overall none of the liquids were able to show 100% cleaning under components.



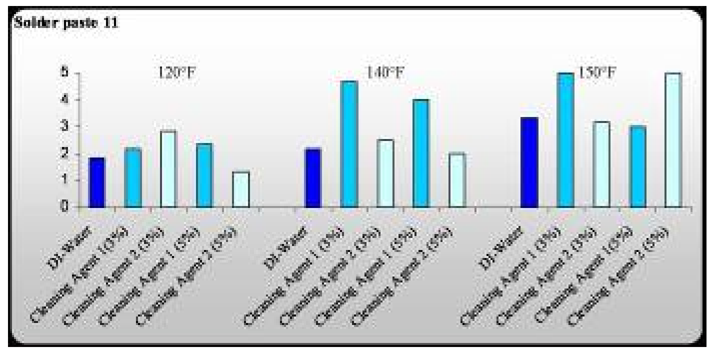
Paste 8 showed generally very good cleaning results across the board. Chemistry assisted processes accomplished full cleaning at 140°F and 150°F respectively. DI-water showed good cleaning but not complete results at either temperature.



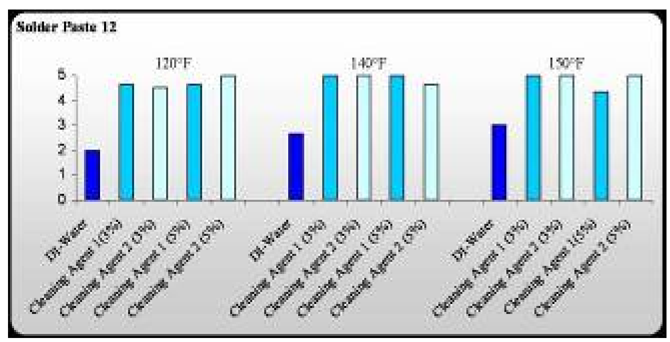
Cleaning agent 1 did the best at both 3 and 5% respectively. DI-water almost removed all residues and performed equally well when compared to the pH neutral cleaning agent 2.



The water-soluble paste 10 can be considered to produce hard to remove residues. Surprisingly DI-water cleaned the best at 150°F, while at lower temperatures the cleaning agents did outperform straight water. The best results were achieved by cleaning agent 1 at 140°F and 5% active concentration.



The main observations for these experiments centered on temperature and chemistry assisted cleaning. An increase in temperature to 150°F showed an overall increased cleaning performance. DI-water did perform better at 150°F.



Cleaning results at 120°F for this paste were 100% successful at temperatures of 120°F for cleaning agent 2 at 5% application concentration. An increase in temperature to 140°F increased the success rate. At 150°F the cleaning results remained consistent, with the exception of cleaning agent 2 which cleaned worse.

Tables below show visual results of the DI-water process as well as chemistry assisted cleaning processes at 3% and 5% concentration.

Table 3a: Visual results of DI-water cleaning process

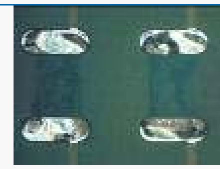
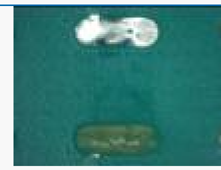
DI-water cleaning process				
	Solder paste 1	**Solder paste 2**	**Solder paste 3**	**Solder paste 4**
120°F	 Partially removed. Residues and dark stains	 Flux widely removed. Still dark flux traces	 Dark flux traces	 Dark flux traces
140°F	 Residues and dark stains.	 Not clean. Dark stains.	 Not clean.	 Dark flux traces
150°F	 Residues and dark stains visible	 Not clean. Flux traces.	 Partially clean.	 Partially clean

Table 3b: Visual results of chemistry assisted cleaning with cleaning agent 1 at 5%

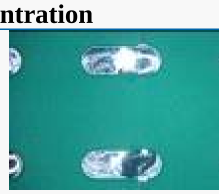
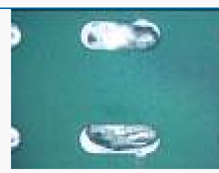
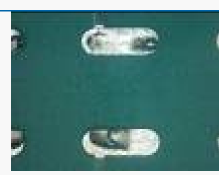
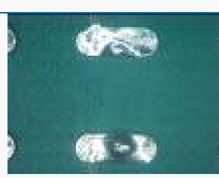
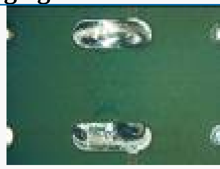
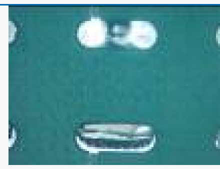
Cleaning agent 1 at 5% concentration				
120°F	 **Solder paste 1:** Partially clean with some residues	 **Solder paste 2:** Clean! No flux residues	 **Solder paste 3:** Clean	 **Solder paste 4:** Partially clean with residue trace
140°F	 **Solder paste 5:** Clean	 **Solder paste 6:** Clean	 **Solder paste 9:** Clean	 **Solder paste 12:** Clean
150°F	 **Solder paste 5**: Clean	 **Solder paste 6:** Clean	 **Solder paste 9:** Clean!	 **Solder paste 12:** Clean

Table 3c: Visual results of chemistry assisted cleaning with cleaning agent 2 at 3% concentration

Cleaning agent 2 at 3% concentration				
120°F	 **Solder paste 1:** Not clean	 **Solder paste 2:** Clean	 **Solder paste 3:** Clean	 **Solder paste 4:** Clean
140°F	 **Solder paste 6:** Clean	 **Solder paste 8:** Clean	 **Solder paste 9:** Clean	 **Solder paste 12:** Clean
150°F	 **Solder paste 1:** Clean	 **Solder paste 3:** Partially clean	 **Solder paste 9:** Clean	 **Solder paste 10:** Partially clean

Conclusions (Part 2)
With the exception of 2 cases, the chemistry assisted process outperformed straight DI-water usage. It was noticed that an increase in temperature generally supported slightly better results, but numerous cases indicated full flux removal at temperatures as low as 120°F. The relative concentration levels indicated that chemistry levels of 3% might be sufficient for a variety of pastes used currently in the industry. The minority of pastes was not cleanable, which indicates that the tested chemistries seem to be chemically capable of removing most commonly used flux residues. Hypothesis II and III are therefore confirmed as valid.

Overall Conclusions and Recommendations
After entering the obtained data in the Minitab® Software, the interaction among the factors in respect to the cleaning results was investigated. Figures 3 and 4 show the overall results. This lead to the following set of conclusions:

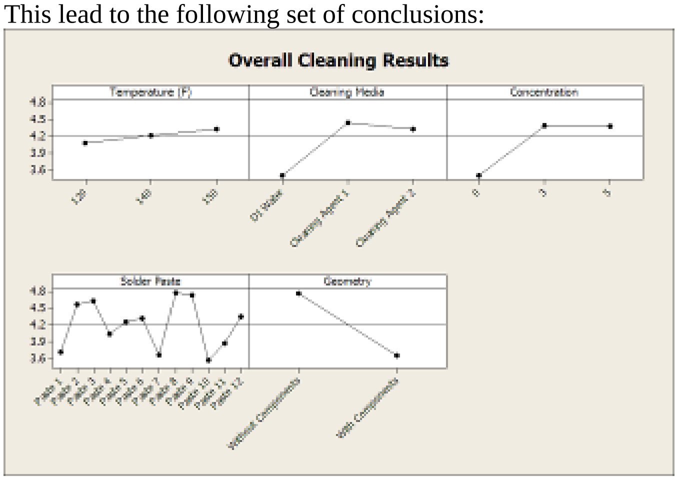


Figure 3: Individual Plot of Results

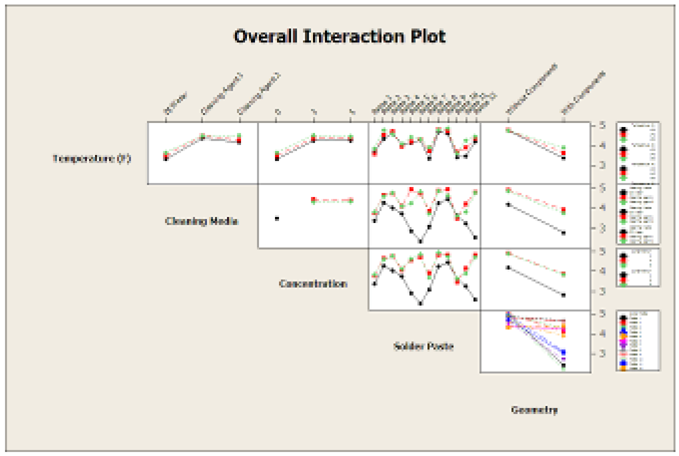


Figure 4: Overall Interaction Plot

One of the initial observations is an improvement in cleaning with an increase in the wash temperature. Secondly, at lower wash temperatures, the tested cleaning agents 1 & 2 demonstrated superiority over the pure DI-water cleaning process when cleaning water-soluble flux residues.

When the role of the concentration levels of the two cleaning agents was examined, it was found that the cleaning results were not that different from each other at 3% concentration versus 5% concentration level. Out of 12 pastes five (5) were more responsive to an increase in wash temperature in terms of clean-ability, and not the cleaning agent concentration levels of 3% and 5%. Here the authors conclude that the removability for the remaining 7 pastes has a correlation with the exposure time of the flux residues to the tested cleaning agents, in other words longer wash exposure times would assist in removing the flux residues to achieve 100%

cleanliness level. As expected, cleaning underneath low standoff components was more challenging (at least 25% or more) than cleaning around and top of the components.

As a conclusion of this study the use of cleaning agent 1 at a 3% concentration level, at 150°F wash temperature and 2.0 fpm belt speed would provide up to 111% better cleaning results (reaching 100% full cleanliness) underneath the low standoff components when compared to pure DI-water inline cleaning process!

The usage of chemistry in the long run seems to offer a number of previously unknown benefits. Despite the additional process cost of a cleaning agent, the “value added” benefits are sizable or should exceed the former.

They include but are not limited to better cleaning (i.e. lower ionic contamination), which in turn provides much higher product reliability. Recent studies have also demonstrated better bonding and coating after the introduction of chemistry assisted cleaning. To offset the added cost, users can operate at lower temperatures and with a wider process windows one clean not only OA but also RMA and no-clean fluxes. And that will become a requirement in the North American market as contract manufacturers are moving to lower volume, higher mix and a significantly more high reliability products. At the end, the introduction of a chemistry assisted cleaning process, will increase your cleaning process window and permit the de-fluxing of all production boards in a single cleaning process.

Despite all the valid arguments encouraging the use of aqueous processes, the authors would like to caution interested users as well. Most equipments currently using strict DI-water are not properly equipped to use a closed looped chemistry. This means that they do not have a chemical isolation section included. The latter is an essential part not only to conserve chemistry but also to minimize foaming for example. DI-water machines take advantage of cascading DI-water tanks from back to front. Employing a chemical product in the wash tank would lead to continuous dilution of the recommended application concentration by DI-water. Company’s 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 contracts.

OUTLOOK

Various customers are currently investigating our hypothesis in real-time. Results should be available shortly and will be presented at upcoming conferences.

AUTHORS

This research paper is the 4th in a series written by ZESTRON on optimizing electronic cleaning processes presented at the industry’s known conferences SMTAI and IPC/APEX. Based on our findings, key market developments have been initiated and began to address current shortcomings observed in the industry.

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