New Cleaning Agent Designs for Removing No-Clean Lead-Free Flux Residues

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Abstract
The process cleaning rate theorem holds that the static rate (chemical forces) plus the dynamic cleaning rate (mechanical forces) equals the process cleaning rate. New lead-free flux residues result from more demanding soldering drivers created by high soldering temperature, surface tension effects, and miniaturization. Lead-Free flux compositions require thermal stability, resistance against burn-off, oxidation resistance, oxygen barrier capability, low surface tension, high fluxing capacity, slow wetting, low moisture pickup, high hot viscosity, and halogen free. The static cleaning rate for lead-free flux residues is dramatically different from eutectic tin-lead flux residues. To clean lead-free soils, longer wash exposure time, high cleaning agent concentrations, and high levels of mechanical energy are needed. The purpose of this research paper is to measure the cleaning variability induced by lead-free flux residues and to compare the cleanability of lead-free flux residues to determine the viability of new cleaning agent designs.

Introduction
The distances between conductors, and the under clearance gaps from the board to the bottom of the components on printed circuit boards, are smaller due to miniaturization. Smaller spacing increases the probability that flux residues or surface contamination will be sufficient to bridge all or most of the under clearance gap between conductors. Flux bridging conductors opens the pathway to form a conductive cell between two points on the board assembly. As a result, higher density board designs increase reliability risks, which are commonly mitigated by cleaning all flux residues and ionic contamination on the surface and under components on the assembly.

Cleaning flux residues from under component gaps has become extremely challenging due to the nature of the flux residue, under component clearance from the board to the bottom of the component, time required for the cleaning agent to penetrate the gap, the cleaning agents ability to solvate and break the flux dam needed to create a flow channel, and the mechanical energy needed to deliver the cleaning agent to the flux residue. Flux residues that form a hard shell require longer wash times to dissolve in the cleaning agent, thus requiring increased time to clean these residues under the component gaps. The variability of flux residues from different solder paste manufacturer’s places increased importance on the cleaning agent design.

As a response to these cleaning challenges, new cleaning agent designs are needed to better dissolve advanced flux compositions. The most advanced flux technologies fit within the low residue no-clean flux category. For eutectic tin-lead, cleaning product to product variation was not an issue from a cleaning perspective. With the move toward highly dense miniaturized board assemblies and lead-free soldering, flux compositions require higher molecular weight flux vehicles with increased thermal stability. The flux residues from these higher molecular weight flux compositions have a greater degree of product to product variation, form hard resinous barriers, and increasingly difficult to clean.

To remove these hardened flux residues under low component gaps, increased wash time, wash temperature, wash concentration, and impingement energy are needed. One of the critical issues from using more aggressive cleaning parameters is material compatibility on board finishes, board laminates, solder joints, labels, and components. The challenge is the need for more effective cleaning agents with improved material compatibility. For aqueous cleaning agent designs, one formulation approach is to build cleaning agents that drive with both hydrophobic (resin loving) and hydrophilic (water loving) properties. A second design feature is to reduce alkaline saponification in an effort to improve compatibility on surface metallic alloys. The goal is a cleaning agent design balance that limits tradeoffs and maximizes performance benefits.

The purpose of this research paper is to measure cleaning variability induced by lead-free flux residues and to compare the cleanability of lead-free flux residues under low component gaps to determine the viability of new cleaning agent designs. Most of the leading cleaning agents designed to clean PCBs post soldering are effective at removing these higher molecular weight flux residues from the exposed surface solder leads and pads. This is not the case when it comes to removing flux residues under component gaps. If the cleaning agent is slow at dissolving the hardened flux shell, residue will remain under the component gap following the cleaning process. Therefore, the critical cleaning agent differentiator is the speed at which the cleaning agent dissolves the flux residue.

Cleaning agents that have a high affinity at dissolving the residue open the process window and relax critical process parameters of wash concentration, wash time, wash temperature and impingement energy.

Factor Affecting Printed Wiring Board Cleaning

Numerous assembly factors influence the cleaning properties of flux residue including the solder process, solder flux, soldering temperatures, post bake out before cleaning, under clearance from the board to the bottom of the component, static cleaning rate, and cleaning equipment. Variations in any of these factors can and does influence the cleaning rate.

Solder Process

Component advances in transistors, resistors, capacitors, diodes and integrated circuit packages provide increased functionality but require modifications to the soldering process to achieve high yields. The solder connection involves four basic elements: base metals, flux, solder, and heat.[1] Alloys which are commonly used for assembling electronic assemblies such as tin, lead, copper, silver, and their intermetallic's influence surface wetting and oxidation properties.

Surface oxidation on the solder alloy and board finish prevents good solderability. A second issue is that metals oxidize at an accelerated rate at elevated temperatures experienced during the soldering process. To address oxidation concerns, flux compositions are needed to remove surface oxidation, improve wetting of alloys, and to form an oxygen barrier to prevent oxidation of metals during the soldering process. The reflow environment (i.e. heat exposure and atmospheric oxygen level) and the compositions formulated into the flux component directly influence the cleanability of the flux residue.

The alloys most commonly used for building electronic assemblies consist of tin, lead, silver, and copper. The ratio of these alloys, and their eutectic properties, influence the temperatures at which the alloys reflow and wetting properties. Each alloy composition has unique properties such as melting point, hardness and solid to liquid transition phase. Poor wetting of the base metals results in a poor solder joint. To control the rate of oxidation, critical process variables such temperature control, soldering atmosphere, and flux compositions must be optimized. These factors also influence the cleanability of the flux residue post soldering.

The alloy selection influences cleaning due to liquidous temperature, heat exposure, rate of oxidation as a function of temperature, and thermal stability of flux vehicles. High lead solders reflow at temperatures in excess of 300°C, which requires thermally stable high solids flux vehicles. High tin solders used in many lead-free solders reflow at temperatures in excess of 230°C, which increased the need for thermal stability, oxidation resistance, and high oxygen barrier properties.[2] The problem is that higher soldering temperatures may result in flux thermal decomposition, flux side reactions, and oxidized flux residue. These properties results in a greater cleaning difficulties.

Solder Flux

Solder alloys rapidly oxidize upon exposure to air, moisture, and heat.[3] Oxidation is caused by exposure to oxygen in air, which results in a non-conductive and non-solderable metallic surface. Solder flux is a chemical cleaner that removes oxidation form metal surfaces, facilitates wetting, and improves metallurgical bonding. When flux is heated, low boiling constituents within the flux evaporate, flux activators remove surface oxidation, and oxygen barriers (rosin/resins) protect the alloys from reoxidation during the solder process. During the soldering process, heating and cooling ramp rates must be compatible with the assembly and components. The time of exposure to high temperatures must be defined and maintained.[4]

The soldering process can be affected by the mass of the associated component, proximity and mass of neighboring components, the size of the pads, and the amount of heat that travels through the tracks and boards.[4] These factors increase demands on the flux, which has a significant influence on quality and low defect soldering rates. This task becomes more difficult with highly dense miniaturized designs and lead-free soldering. To address these complexities, the flux must be stable to high temperatures; resist charring, oxidation and burning; and provide a resistant oxygen barrier.[2] These properties change the solubility and cleaning properties of flux residue post soldering.

Flux and cleaning agent advances of the past 20-years have kept pace with component and board assembly technology advances. Rosin, low-solids, no-clean, and water soluble flux technologies designed for eutectic tin-lead were readily cleanable even after multiple soldering processes. The same ***cannot*** be stated for lead-free soldering. Miniaturization and lead-free soldering require more active and stable flux compositions that remove oxidization with less flux, wet higher surface tension alloys, and protect the underlying metal from oxidation during the soldering process. The cleaning properties of lead-free flux compositions, including water soluble, have changed. The residues are harder and require more active cleaning agents and mechanical to remove the flux residues.

Soldering Temperatures

The reflow process heats the circuit board plus components held by solder paste through successively higher temperatures.[4] The solder profile progressively starts by evaporating flux volatiles, initiates flux activation, raises the components to be joined to a temperature which is sufficiently consistent for the solder to flow evenly onto all surfaces, and reflows the solder paste over board finishes to facilitate solder connections. Temperature excursions and the time exposed to liquidous solder temperatures influence cleaning properties.

Excessive exposure to the soak and liquidous stages can oxide (char), crosslink (polymerize) and harden flux residues. Figure 1 illustrates a lead-free solder profile using a soak process near liquidous. A long soak profile ensures that the solder paste is fully dried before hitting reflow temperatures. In this example, the heat generated from the flux activation zone cross-linked the flux residue. To clean this residue, an aggressive cleaning condition was needed to remove cross-linked residues. In some cases, the cleaning process window is so narrow, resulting in highly inconsistent cleaning.

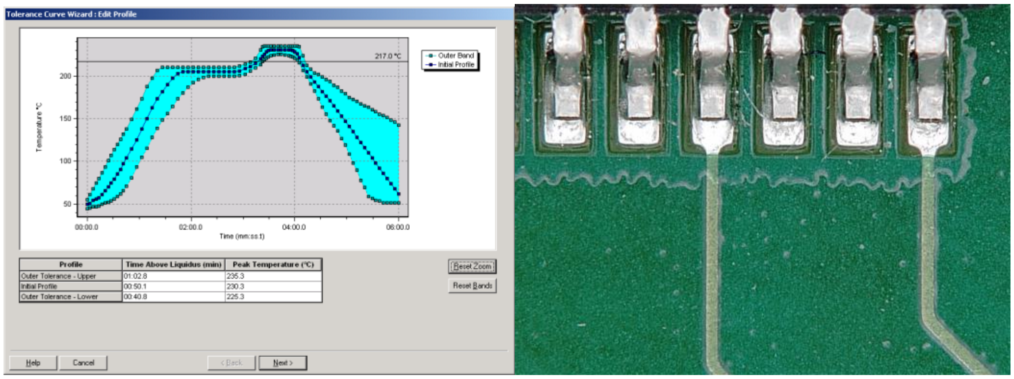

Figure 1: Lead-Free Soak Profile

Optimal soldering processes are hot enough to enable the solder to wet the board and components yet cool enough not to damage the items being soldered and a controlled cool down to ensure solder joints are sound.[4] Defining the exposure to high temperature requires heating and cooling ramp rates that are compatible with the solder paste, components, board finishes, and cleaning process. Figure 2 illustrates a ramp to spike lead-free solder profile using the same solder paste illustrated in Figure 1. Reduce heat exposure rendered a cleanable flux residue.

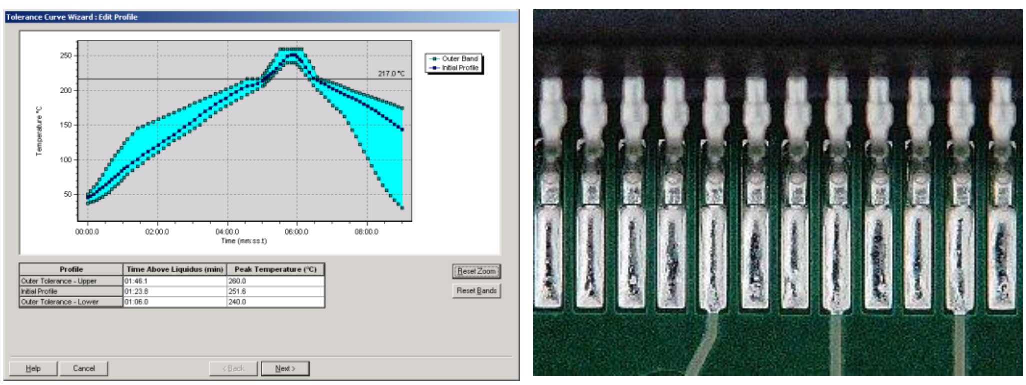

Figure 2: Lead-Free Ramp to Spike Profile

Post Bake Out Before Cleaning

Exposing flux residues to excessive heat over long periods of time can char, polymerize, oxidize and harden flux residues. In some cases the residues are not cleanable using production cleaning processes. The images illustrated in Figure 3 were from boards bake over the weekend at temperatures exceeding 120°C. The charred flux residues were not cleanable using the current production cleaning process. Changes to normal process procedures can change the nature of the flux residue. This change can render a residue that when processed under normal conditions is cleanable, but when exposed to long bake out cycles at elevated temperatures renders a residue that is not cleanable.

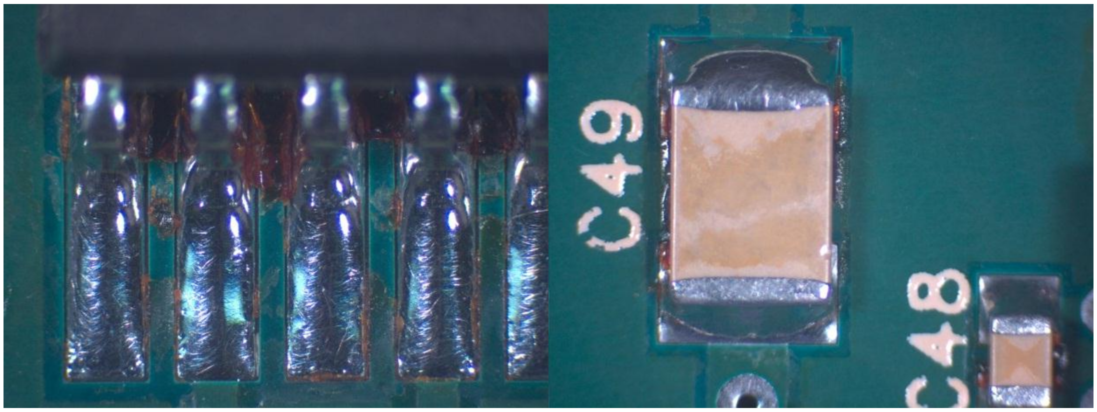

Figure 3: Charred Flux Residues

Under Clearance from the Board to the Bottom of the Component

Component miniaturization decreases the spacing between conductors. During solder reflow, flux under fills the bottom side of the component (Figure 4). The distance from the board surface to the bottom side of leadless components is consistently less than 2 mils. For cleaning to occur, the cleaning agent must first wet the residue. To sufficiently wet the residue, the cleaning process must break through the flux dam to create a flow channel.

Cleaning under low gap components is increasingly more difficult due to the higher molecular weight non-polar covalent resins being formulated into lead-free flux compositions. With clearance gaps under components of less than 2 mils, and for small chip caps, gaps less than 1 mil creates a highly difficult cleaning challenge (Figure 4). The higher molecular weight resins formulated in no-clean solder pastes require increased solubility and mechanical forces to enable the flux residue to dissolve into the cleaning agent. This force of attraction depends upon the nature of the cleaning agent and the nature of the flux residue. Penetrating low clearance gaps requires a cleaning agent that matches up with the flux residue, impinging forces that can deliver the cleaning agent to the residue, wash temperature and wash time.

On soft residues, such as the water soluble soils, flux residues are much easier to clean under low gap components. Penetrating the residue and creating a flow channel occurs rapidly. Conversely, for hard no-clean flux residues, the time to clean all residues under the component gap can be five to ten times greater than the time required for a soft residue.

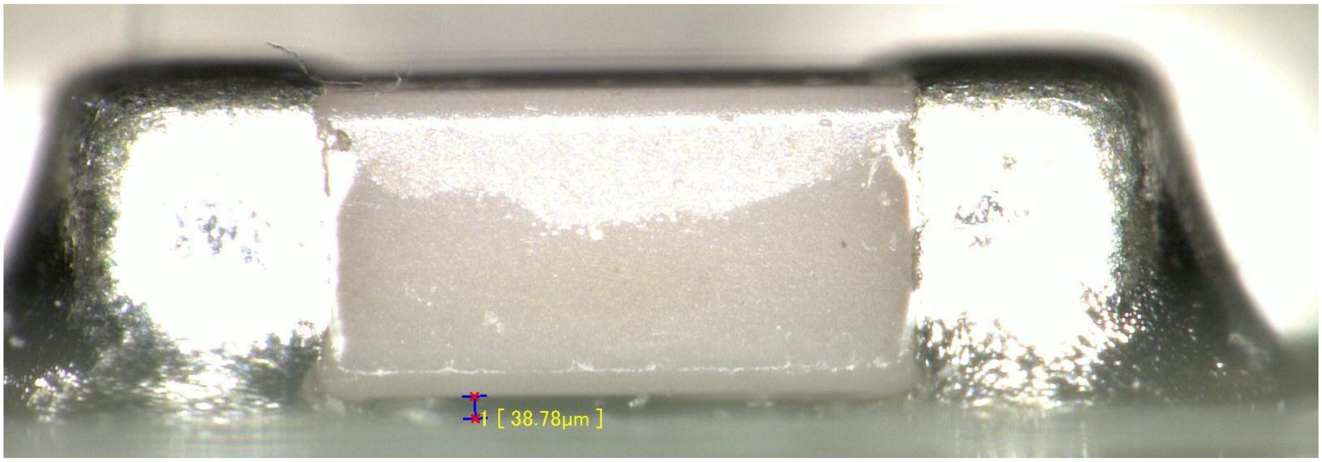

Figure 4: Flux Residue Fill the Gap

Static Cleaning Rate

The Static Cleaning rate is the cleaning agent's ability to dissolve the flux residue in the absence of impingement energy. Solubility testing provides insight into the properties of the flux residue and the chemical structures that dissolve the residue. The test methodology exposes the reflowed flux residue on test coupons to a series of solvents with known solubility parameters. The data findings provide insight into specific solvent families that exhibit a tendency to dissolve the residue. Using the analogy of "like dissolves like" a composite solubility parameter for the flux residue can be calculated. These forces of attraction help those schooled in the art design cleaning agents understand the driving forces that provide a strong affinity for the residue.

Engineered cleaning agents are designed with the desired forces of attraction for specific residue types. To determine the best matched cleaning agent, solubility testing can be used to study factors such as wash concentration and wash temperature in the absence of impingement energy. The static rates provide insight into the cleaning agent's match to the residue. Cleaning agents closely matched to the residue open the process window for penetrating and removing hidden flux residue under component gaps.

Dynamic Energy

Today's circuit assemblies are populated with smaller components, increased density and shorter spacing between conductors. Penetrating small gaps is dependent on the physical properties of the cleaning agent's solubility for the residue, surface tension, density and viscosity. Delivering the cleaning agent to the soil requires high energy fluid delivery in the form of fluid flow, impact velocity, and directional forces.

Lead-free flux residues require cleaning agents with high dispersive forces. Solvent based cleaning agents drive with high dispersive forces, and in some cases provide the best solubility match. Solvent cleaning agents require lower levels of dynamic energy in the form of spray under immersion, centrifugal and ultrasonic driving forces. Aqueous cleaning agents overcome the dilutive effects of water by engineering a broad array of properties that match up to the residue and deliver the cleaning using high fluid flow pressures and spray in air impingement.

Fluid flow delivered through high energy spray jets provides an effective mechanism for delivering the cleaning agent into and under component gaps. Conveyorized machines limit the amount of time for each of the process zones. Unlike batch immersion systems, inline cleaning machines must clean the part in less than five minutes residence time. The design of an optimal process requires the study and quantification of significant factors such as spray jets, directional forces, cleaning agent, fluid flow pressure, wash temperature and wash time.

Is There One Best Cleaning Agent Design?

The critical differentiator for removing higher molecular weight flux residues is the cleaning agent. The ideal cleaning agent is formulated with the greenest environmental properties within performance limitations; rapidly dissolves polar protic, dipolar aprotic and non-polar soils; and is easily rinsed leaving an ionic cleaned assembly. Since flux residues are a composition of rosin, resins, activators, rheological additives and reacted ionic salt forms, the cleaning agent requires a composition of materials that remove polar protic soils, dipolar aprotic soils, and non-polar resins. One of the lead-free flux residue differences is the increase in non-polar resins. To clean flux residues with high molecular resin structures, a greater level of solvency is required.

Aqueous engineered cleaning agents provide a viable approach toward meeting the requirements for cleaning lead-free flux residues. Two justifications for this statement are the ability to formulate materials that match to the wide range of materials found in flux residue and the ability to deliver these cleaning agents using high impinging forces.

The aqueous cleaning agent can be engineered with materials that target ionic, polar covalent and non-polar covalent materials found in the flux residue. In order to classify the materials that make up the cleaning agent, the concept of "like dissolves like" guides the formulators understanding of the forces needed to enable the flux residue to dissolve in the cleaning agent.

Research into many of the lead-free flux residue properties indicate a much broader range of resins used than what was previously applied to tin-lead solder paste formulations. With different solder paste suppliers using a wide range of resin/rosin materials, the attraction of the cleaning agent for the soils will be different. With this increased level of complexity, there will be a greater requirement for matching the cleaning agent to the soil.

The challenge in designing cleaning agents for lead-free soils is that residue properties are very different amongst solder material companies. Depending on the properties of the residue, some aqueous designs must be drive with stronger forces than needed for soft residues. Upstream factors, as discussed in this paper change the cleaning properties. So, to answer the question of "is there one best cleaning agent," the answer is no since the nature of the cleaning process today is far more inconsistent than years past. As such, cleaning agent designs must be match to the process need and nature of the soils being cleaned.

Methodology 1

The static cleaning rate for seven aqueous engineered cleaning agents was tested on 30 solder pastes. Ten of the solder pastes were tin-lead no-clean solder pastes, ten were lead-free no-clean solder pastes, and ten were lead-free water soluble solder pastes. The static cleaning rate measures the cleaning agent's affinity to dissolve the soil in the absence of mechanical forces. High static cleaning rates indicate a strong match for the soil in question.

The test exposes each engineered cleaning agent to test coupons from each solder paste reflowed using a soak profile. Each test coupon is placed into a small vial of the test solution. The factors tested were wash concentration and wash temperature. Time is fixed at 10 minutes. The test vials are rotated to assure that the cleaning agent is well mixed during the test. Figure 5 illustrates the grading scale used to score the test coupons. Table 1 provides a description of the cleaning results with the grading score representing the response variable. A score of 1 is reported when all residues are completely removed with scores beyond 1 showing greater levels of remaining flux residue.

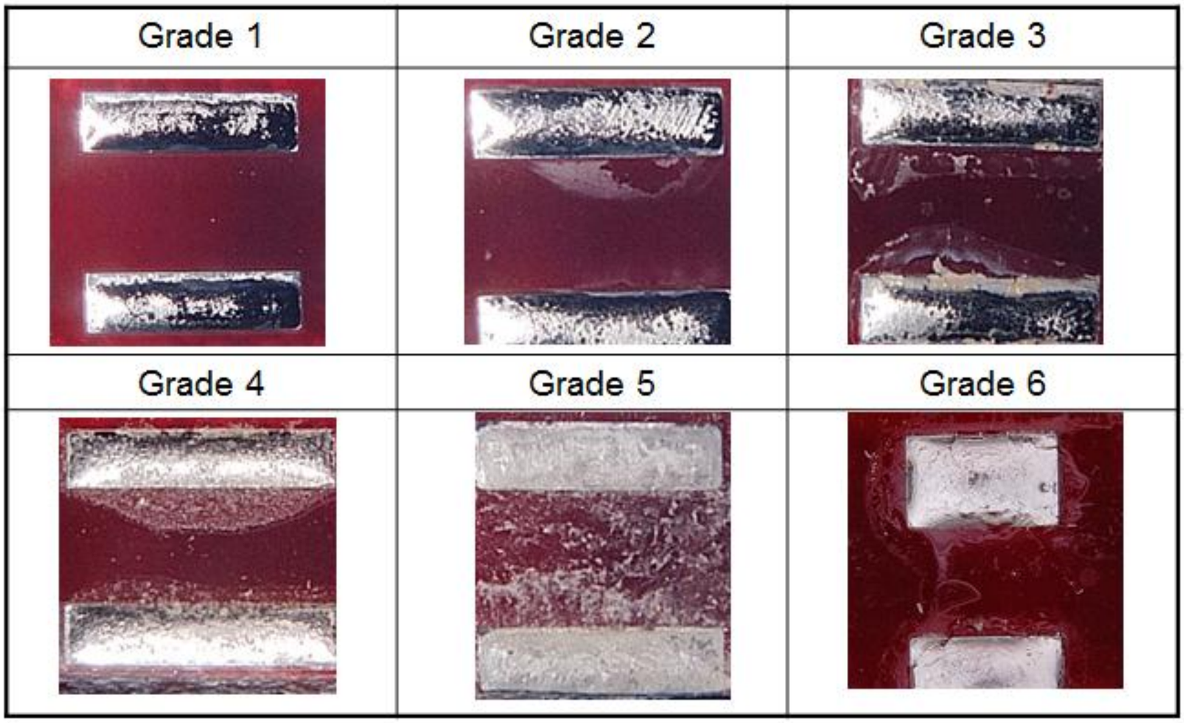

Figure 5: Grading Scale

Score	Description
1	Clean, no visible residue
2	Small level of residue remaining
3	Cleaning interaction present, but impingement energy needed
4	Marginal cleaning agent, boundary cleaning agent
5	Very little cleaning of the soil
6	No interaction with the cleaning agent

Table 1: Grading Scale

The number of data points in the static cleaning study accounted for in the Design of Experiment was1836. The data points were analyzed using Minitab statistical software. The main effect plots for each solder paste family is a plot of the means at each level of a factor. A main effect occurs when the mean response changes across the levels of a factor. The main effects plot compares the relative strength of the effects across factors.

The research measures cleaning variability induced by solder paste residues on tin-lead no-clean, lead-free no-clean and lead-free water soluble solder paste families. The research compares the cleanability of those flux residues solder paste families to seven commercially available aqueous cleaning products designed for cleaning post soldering residues from printed wiring assemblies. A description of the seven aqueous cleaning agents is as follows:

1. **HSLR1:** Aqueous cleaning agent formulated to clean with solvency combined with low reactivity and functional additives. The pH of this cleaning agent is 9.5.
2. **Low VOC:** Aqueous cleaning agent formulated to meet the low VOC air quality emissions such as those in the South Coast Air Quality Management District of the State of California. The pH of this cleaning agent is 10.3.
3. **MSMR1:** Aqueous cleaning agent formulated to clean with solvency combined with reactivity and functional additives. The pH of this cleaning agent is 10.4.

4. **MSMR2:** Aqueous cleaning agent formulated to clean with solvency combined with reactivity and functional additives. The pH of this cleaning agent is 10.6.
5. **MSMR3:** Aqueous cleaning agent formulated to clean with solvency combined with reactivity and functional additives. The pH of this cleaning agent is 10.3.
6. **Neutral 1:** Aqueous cleaning agent formulated to clean with solvency and functional additives. The pH of this cleaning agent is 7.1.
7. **Neutral 2:** Aqueous cleaning agent formulated to clean with solvency combined with low reactivity and functional additives. The pH of this cleaning agent is 8.5.

Data Findings

The main effect plot for the tin-lead no-clean solder pastes finds that all of the seven aqueous cleaning agents will clean the post reflowed flux residues from each of the 10 solder pastes tested. The cleaning agents that provided slightly better static cleaning rates were HSLR1, MSMR2, and Neutral2. Higher cleaning concentrations and wash temperatures improved cleaning performance. There was variability in the solder pastes tested with four of the solder pastes being significantly harder to clean.

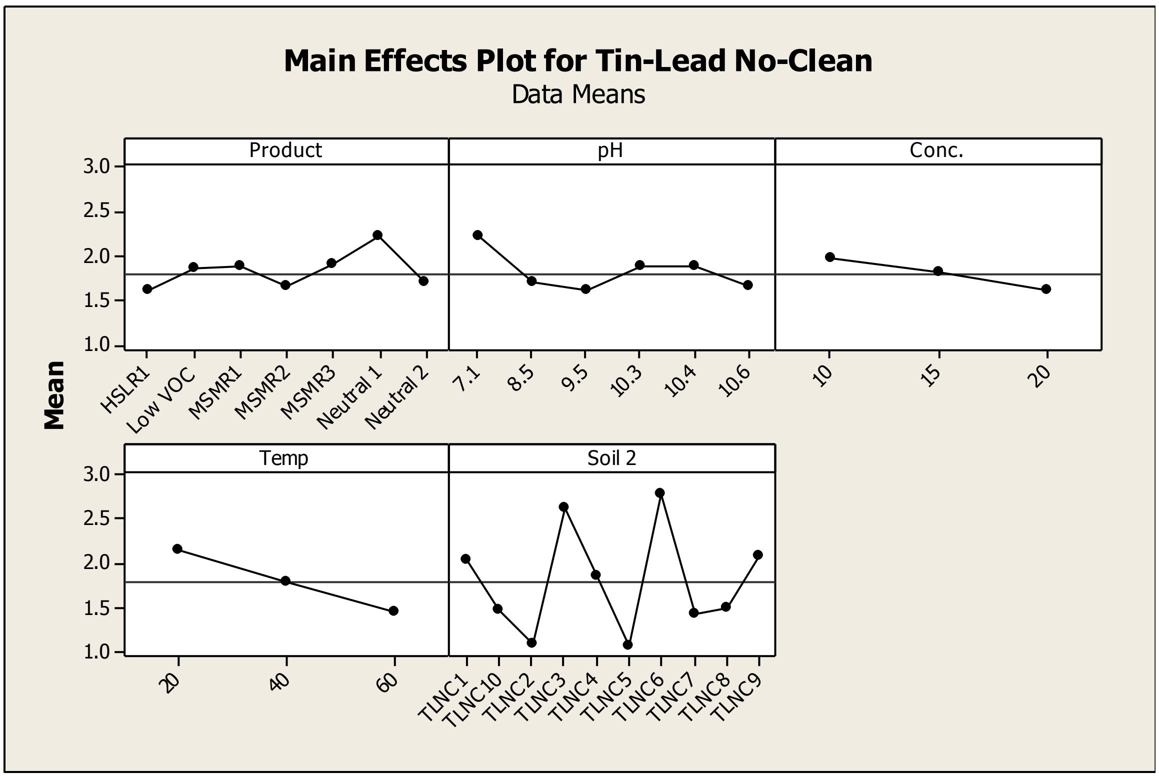

Figure 6: Main Effects Plot for Tin-Lead No Clean Solder Paste Flux Residues

The main effect plot for the lead-free no-clean solder pastes finds that the residues are significantly harder to clean than the tin-lead flux residues. The mean cleaning performance of 3.3 indicates that the cleaning agents are capable of cleaning the lead-free flux residues with the help of impinging forces. The cleaning agents that provided the best static cleaning rates were HSLR1 and MSMR1. Higher cleaning concentrations and wash temperatures improved cleaning performance. There was variability in the solder pastes tested with half of the solder pastes in the study being highly difficult to clean, four moderately difficult to clean and one of the solder pastes being easily cleaned.

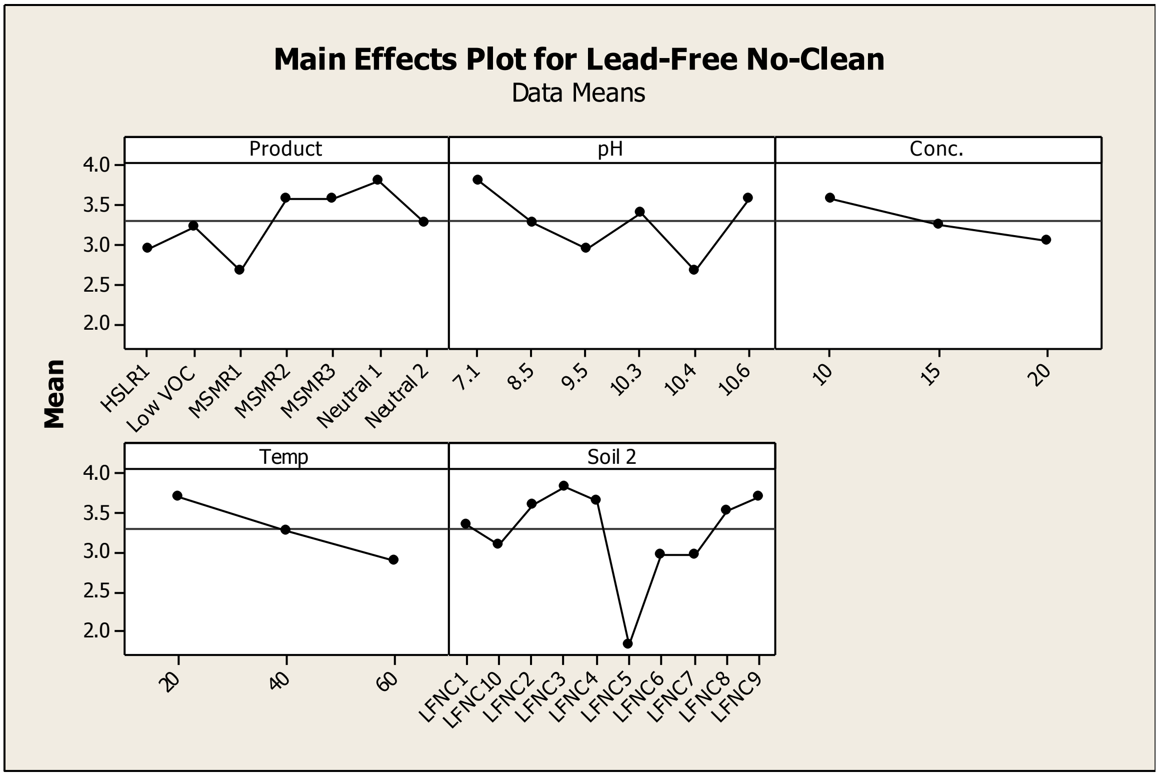

Figure 7: Main Effects Plot for Lead-Free No Clean Solder Paste Flux Residues

The main effect plot for the lead-free water soluble solder pastes finds that all of the seven aqueous cleaning agents will clean the post reflowed flux residues from each of the 10 solder pastes tested. The Neutral1 cleaning agent with a pH of 7.1 was slightly poorer than the other cleaning agents in the study. There was no improvement when increasing the wash concentration and wash temperature. The data findings indicates that the lead-free water soluble flux residues are much easier to clean than the no-clean flux residues.

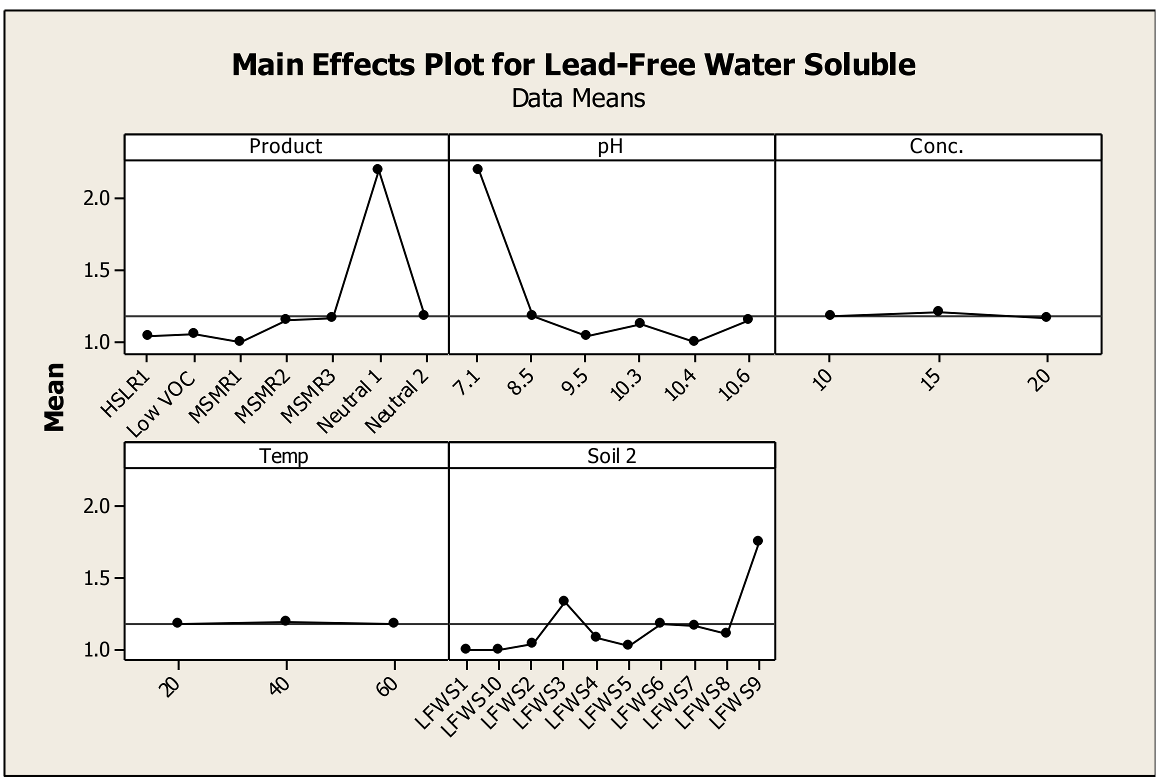

Figure 8: Main Effects Plot for Lead-Free No Clean Solder Paste Flux Residues

The interaction plot in Figure 9 illustrates how lead-free no-clean flux residues compositions have increased in cleaning difficulty. The static cleaning data indicates that the common cleaning agents designed to clean post soldering flux residues will clean lead-free no clean flux residues but longer wash time and mechanical designs will be important factors.

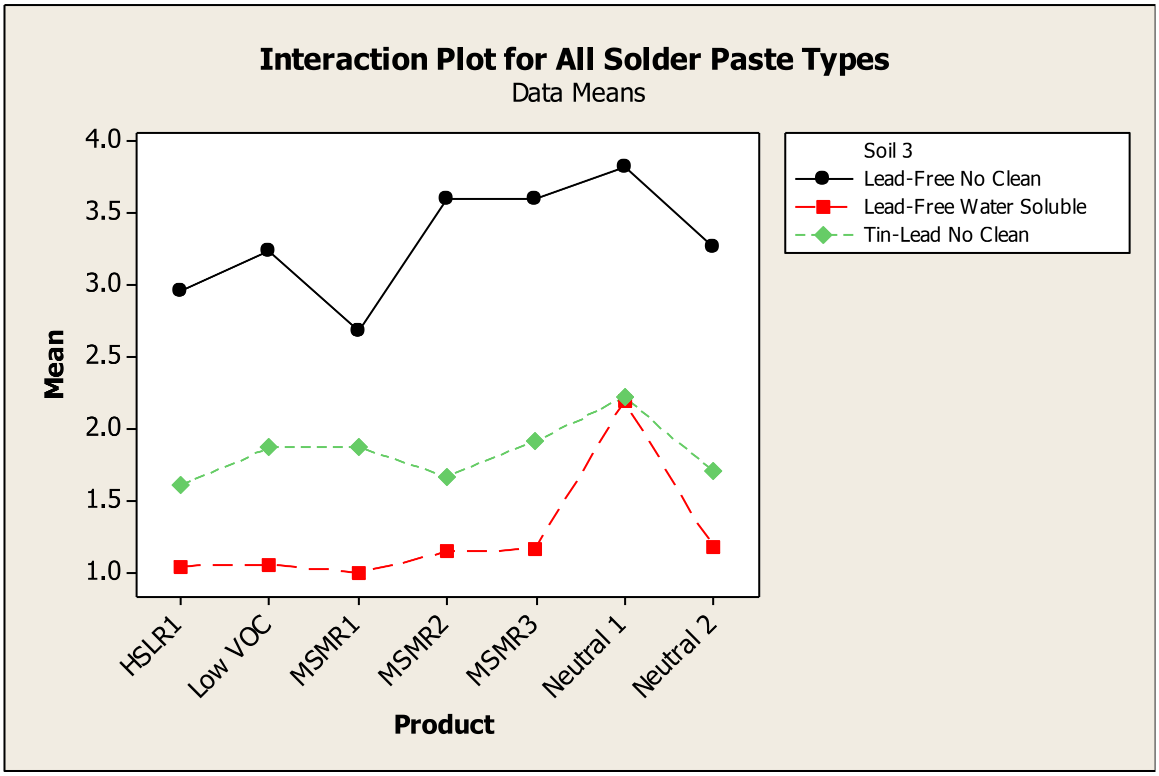

Figure 9: Interaction Plot for All Solder Paste Types

Inferences from the Static Cleaning Data Findings
The static cleaning rates indicated that the cleaning properties for lead-free no-clean flux residues are significantly harder to clean than tin-lead no-clean flux residues. To understand why this is the case, Lee (2009) reported that lead-free solder pastes required higher thermal stability to withstand elevated soldering temperatures. The flux composition required high molecular weight oxygen barriers (rosin/resin) structures. To dissolve these higher molecular weight resins, a high level of solvency, temperature and impingement energy will be needed. The data findings support this characteristic of lead-free no-clean flux residues.

The static cleaning rates for lead-free water soluble flux residues indicate that DI-water with an aqueous cleaning agent renders an easy to clean residue. In some cases, DI-water only will be effective cleaning lead-free water soluble flux residues. Due to the increased lead-free soldering temperatures and added functional additives needed to improve the thermal stability of water soluble solder paste, an aqueous cleaning added to DI water will most likely be needed.

Methodology 2
The static cleaning rate provides insight into the solubility properties of the soil and the driving forces needed to clean post soldering flux residues. Dynamic delivery systems convert energy into work. The gap height from the board laminate to the bottom of the component is consistently less than 2 mils. With shorter spacing between conductors, flux residue wets and fills the underside of the component during the soldering process. Flux residues that bridge the conductors block flow channels needed to wet and dissolve flux residues. Fluid dynamics are needed to deliver the cleaning agent to the under component gaps in an effort to dissolve the flux residue and create a flow channel under the component. Once a flow channel is established, the cleaning agent can wet and dissolve the residue.

Correlating the static rates developed in Methodology 1 with the dynamic rate provides insight into the process cleaning rate and how different aqueous cleaning agent designs perform on cleaning various flux residues from a number of different solder pastes sold by various suppliers. The test board used for this study is 3.0”x4.0”x.06” FR-4 board with LPI solder mask as illustrated in Figure 10. The board is populated with 1210 chip cap resistors with an average standoff height from 0.5-1.0 mil (Figure 10) and 1825 chip cap resistors with an average standoff height from 1.0 – 2.0 mils. The chip caps are sealed on two sides and arranged in the x & y directions. Thirty six component sites are populated and graded on each test card. After cleaning, all components are removed and graded for the percent flux residue under the component gap.

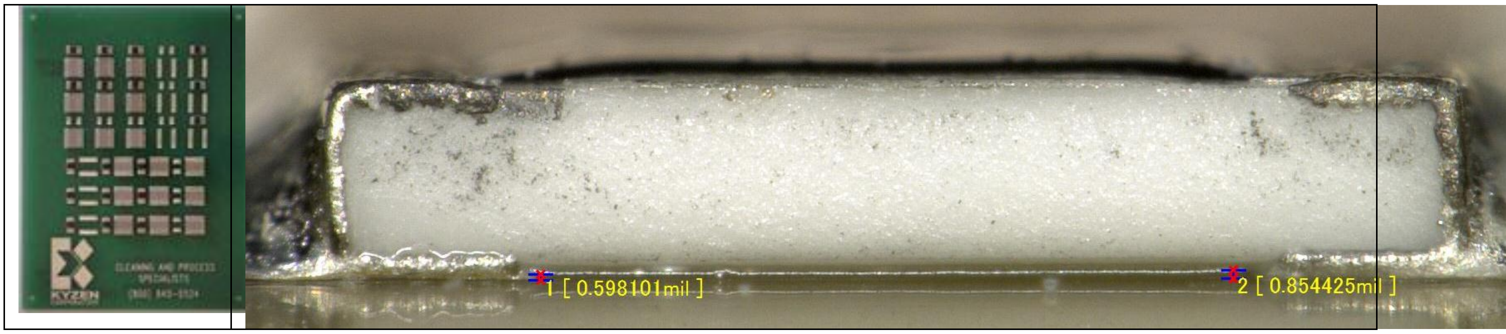

Figure 10: Test Vehicle and Low Gap Clearance Illustration

Data was extracted from four cleaning studies using the following aqueous cleaning agent product designs:

1. **HSLR1:** Aqueous cleaning agent formulated to clean with solvency combined with low reactivity and functional additives. The pH of this cleaning agent is 9.5.
2. **MSMR2:** Aqueous cleaning agent formulated to clean with solvency combined with reactivity and functional additives. The pH of this cleaning agent is 10.6.
3. **Neutral 1:** Aqueous cleaning agent formulated to clean with solvency and functional additives. The pH of this cleaning agent is 7.1.
4. **Neutral 2:** Aqueous cleaning agent formulated to clean with solvency combined with low reactivity and functional additives. The pH of this cleaning agent is 8.5.

Data Findings for Methodology 2

The data finds that the HSLR1 cleaning agent design performed well on three out of five lead-free no clean, one of one lead-free water soluble and four out of four tin-lead no clean solder paste flux residues under component gaps (Figure 11). Increased concentration was not significant. Longer time in the wash was significant.

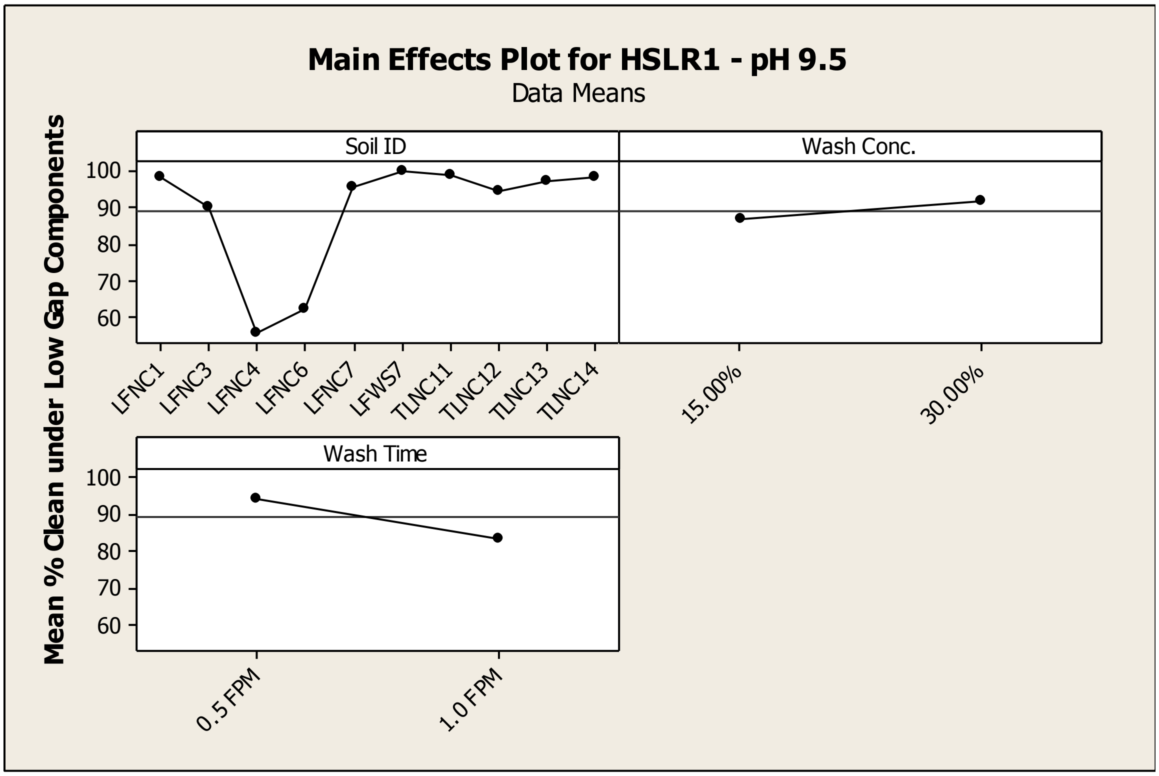

Figure 11: Static plus Dynamic cleaning using HSLR1 product design

The data finds that the MSMR2 cleaning agent design performed slightly poorer than the HSLR1 cleaning agent. The MSMR2 cleaning agent performed well on two out of four lead-free no clean and three out of three tin-lead no clean solder paste flux residues under component gaps (Figure 12). Longer time in the wash was significant.

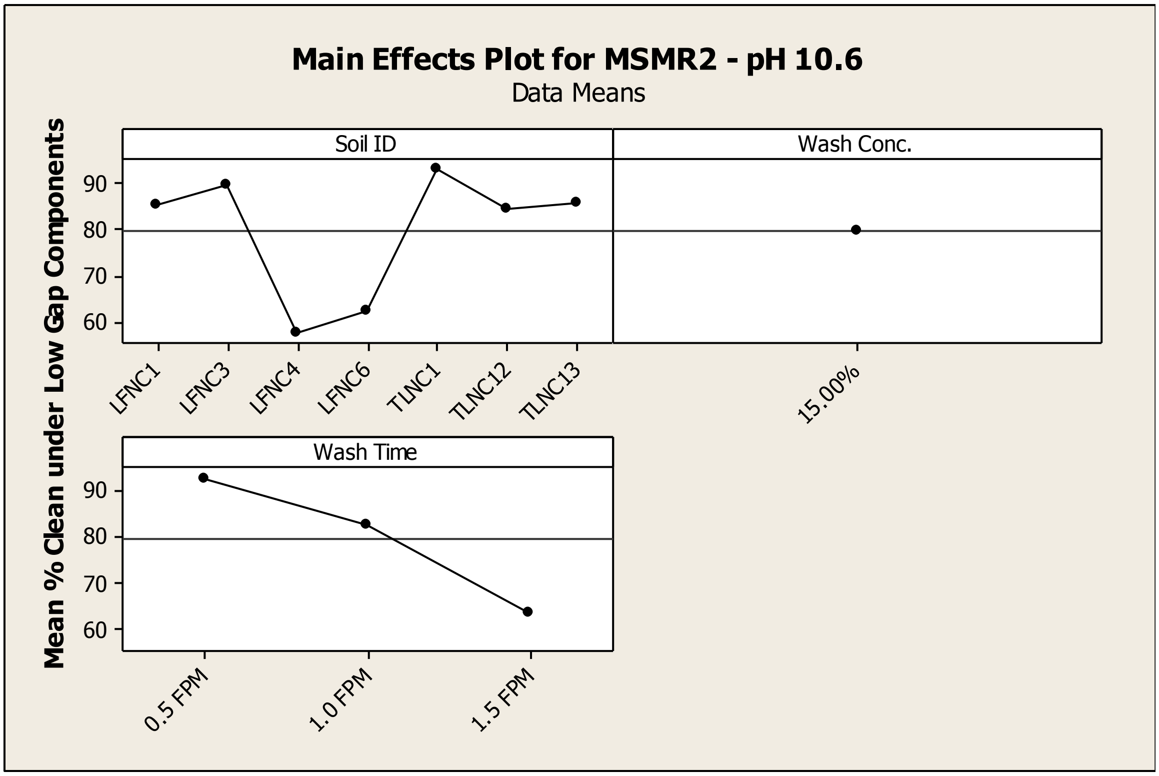

Figure 12: Static plus Dynamic cleaning using MSMR2 product design

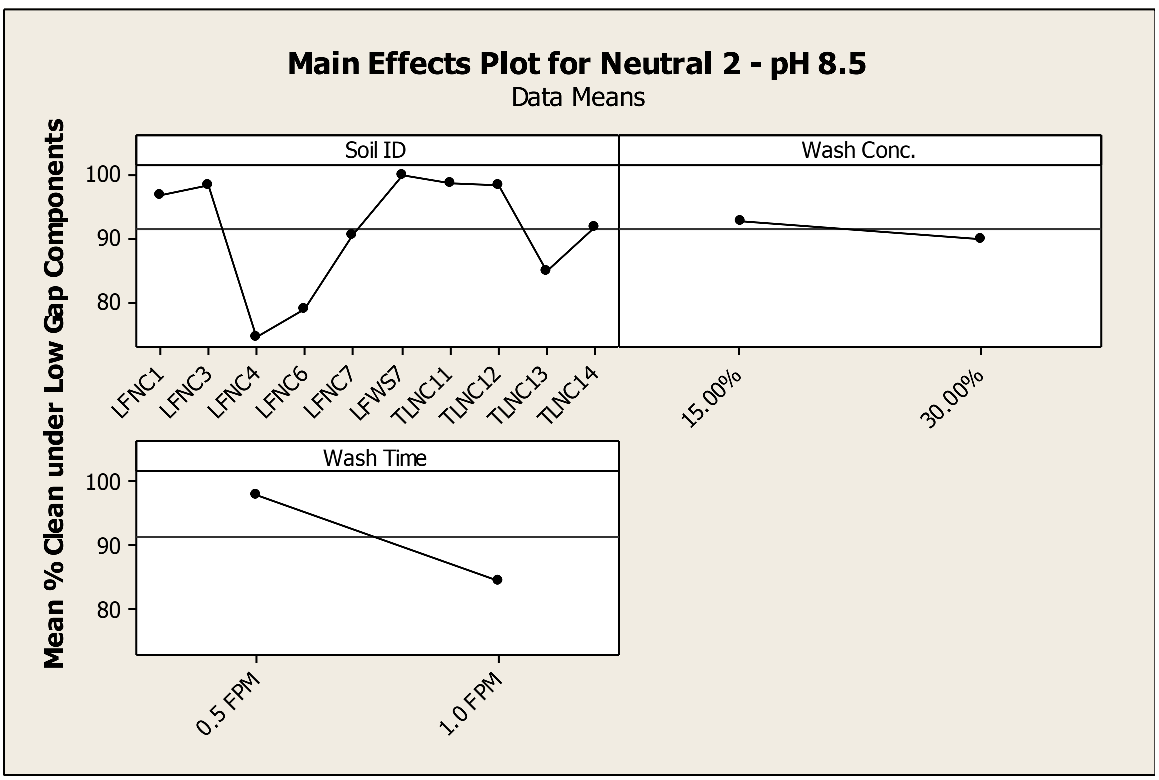

Figure 13: Static plus Dynamic cleaning using Neutral 2 product design

The data finds that the Neutral 2 cleaning agent design performed well on three out of five lead-free no clean, one of one lead-free water soluble and four out of four tin-lead no clean solder paste flux residues under component gaps (Figure 13). The Neutral 2 cleaning performance closely approximated the HSLR1 cleaning performance. Increased concentration was not significant. Longer time in the wash was significant.

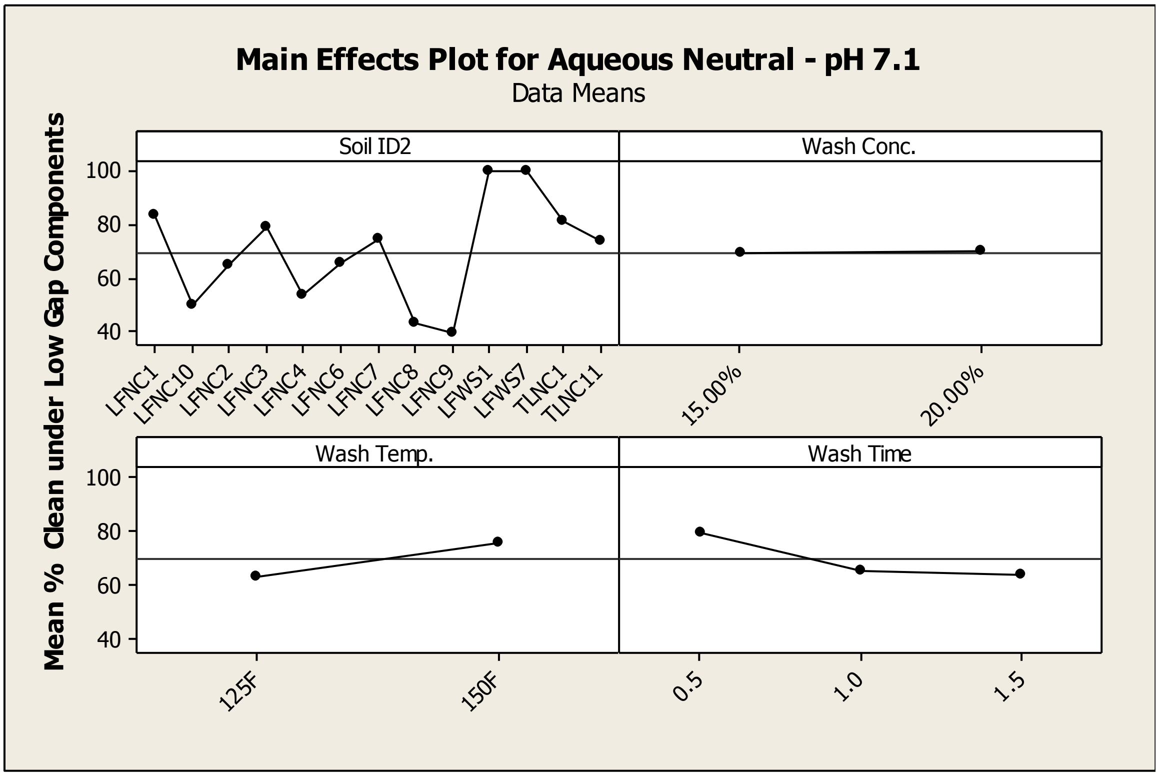

Figure 14: Static plus Dynamic cleaning using Neutral 2 product design

The data finds that the Neutral 1 cleaning agent design performed moderately on three out of nine lead-free no clean, well on two out of two lead-free water soluble and moderately on two of two tin-lead no clean solder paste flux residues under component gaps (Figure 14). Within aqueous cleaning agent designs, low levels of reactive agents have been shown to improve cleaning performance. Neutral 2 uses a low level of reactive materials with significantly improved cleaning properties. The data finds that the reduction of the reactivity component in aqueous cleaning agents did not work well on many of the lead-free no-clean solder paste flux residues. Higher wash temperatures and longer time in the wash were significant factors.

Inferences from the Dynamic Cleaning Data Findings

The cleaning properties of lead-free no-clean solder paste flux residues are more difficult. The data findings correlate with the Static cleaning data findings that illustrate the increased cleaning difficult of the lead-free no-clean solder paste flux residues. The data finds that high solvency with low reactivity provides the best cleaning agent performance for removing lead-free no clean flux residues. The data also illustrates that when a cleaning agent chemical properties do not match up well with the flux residue, mechanical energy is not sufficient in opening the process window for cleaning the residue.

Increased wash time is needed to remove lead-free flux residues under low clearance components. Flux residues that bridge the component gap between conductors must be penetrated to create a flow channel. For harder residues, breaking through the residue to create a flow channel requires increased time and impingement pressure in the wash.

Increased wash concentration provides marginal improvement. The design of many aqueous cleaning agents use oxygenated solvents that are partially soluble in water. Water is the carrying agent to deliver these solvent micelles to the flux residue. Higher cleaning agent concentration provides marginal benefit since the increased solvent micelles do not provide increased solvency.

Conclusion

The distances between conductors, and the under clearance gaps from the board to the bottom of the components on printed circuit boards, are smaller due to miniaturization. Smaller spacing increases the probability that flux residues or surface contamination will be sufficient to bridge all or most of the under clearance gap between conductors.

High tin solders used in many lead-free solders reflow at temperatures in excess of 230°C, which increased the need for thermal stability, oxidation resistance, and high oxygen barrier properties. The higher soldering temperatures may result in flux thermal decomposition, flux side reactions, and oxidized flux residue. These properties results in a greater cleaning difficulties. The flux residues from these higher molecular weight flux compositions have a greater degree of product to product variation, form hard resinous barriers, and increasingly difficult to clean.

Cleaning flux residues from under component gaps has become extremely challenging due to the nature of the flux residue, under component clearance from the board to the bottom of the component, time required for the cleaning agent to penetrate the gap, the cleaning agents ability to solvate and break the flux dam needed to create a flow channel, and the mechanical energy needed to deliver the cleaning agent to the flux residue. Flux residues that form a hard shell require longer wash times to dissolve in the cleaning agent, thus requiring increased time to clean these residues under the component gaps. The variability of flux residues from different solder paste manufacturer's places increased importance on the cleaning agent design.

Lead-free flux residues require cleaning agents with high dispersive forces. Aqueous engineered cleaning agents provide a viable approach toward meeting the requirements for cleaning lead-free flux residues. The data finds that high solvency with low reactivity provides the best cleaning agent performance for removing lead-free no clean flux residues. The data also illustrates that when a cleaning agent chemical properties do not match up well with the flux residue, mechanical energy is not sufficient in opening the process window for cleaning the residue.

Author

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5. Lee, N.C. (2009). Lead-Free Technology and Influence on Cleaning. SMTAI, San Diego, CA.

New Cleaning Agent Designs For Removing No-Clean Lead-Free Flux Residues

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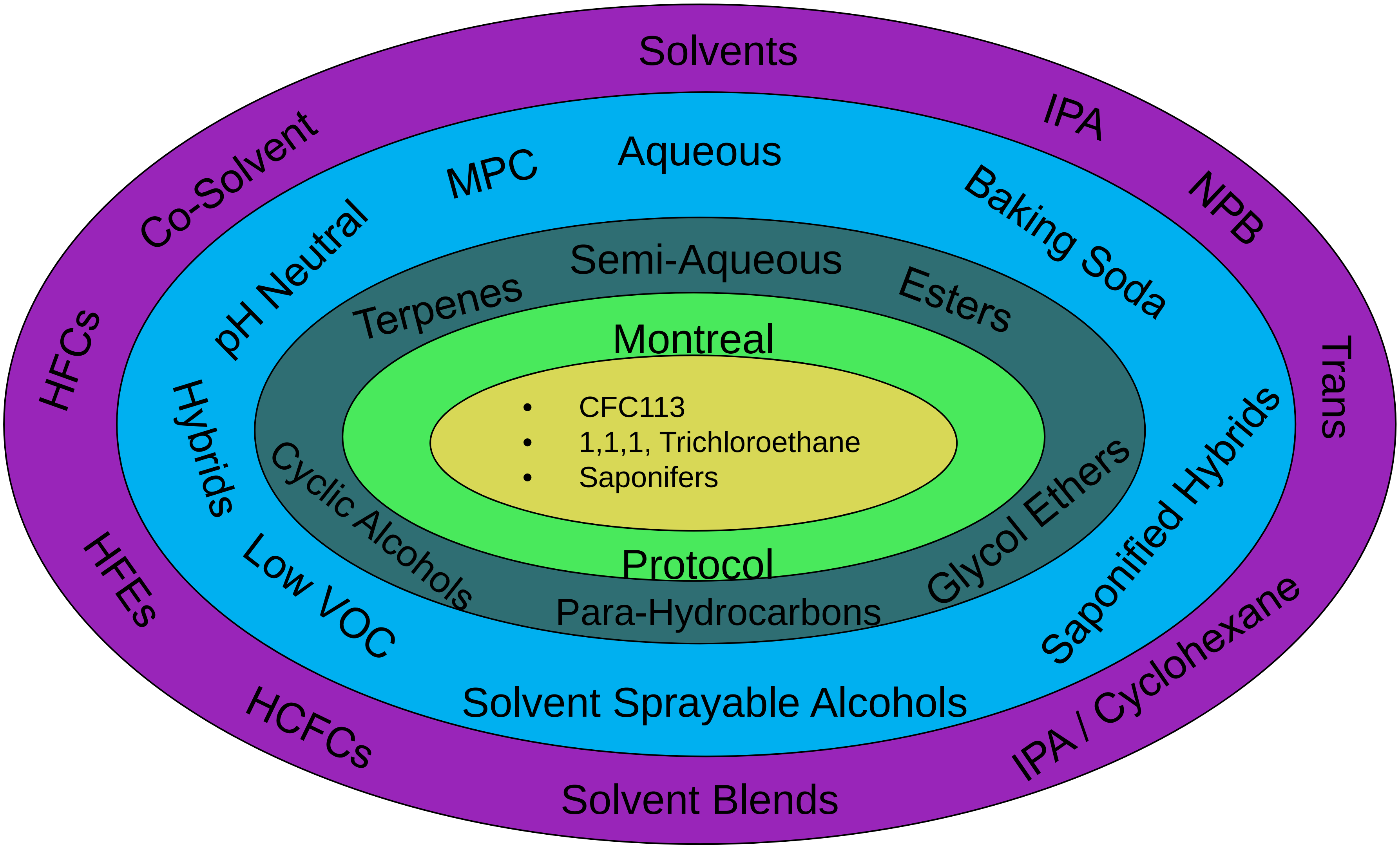
Agenda

- Is there one best cleaning agent design?
- Five Cleaning Forces
- DOE #1: Static Testing
- DOE #2: Dynamic Testing
- Inferences from Data Findings
- Conclusions

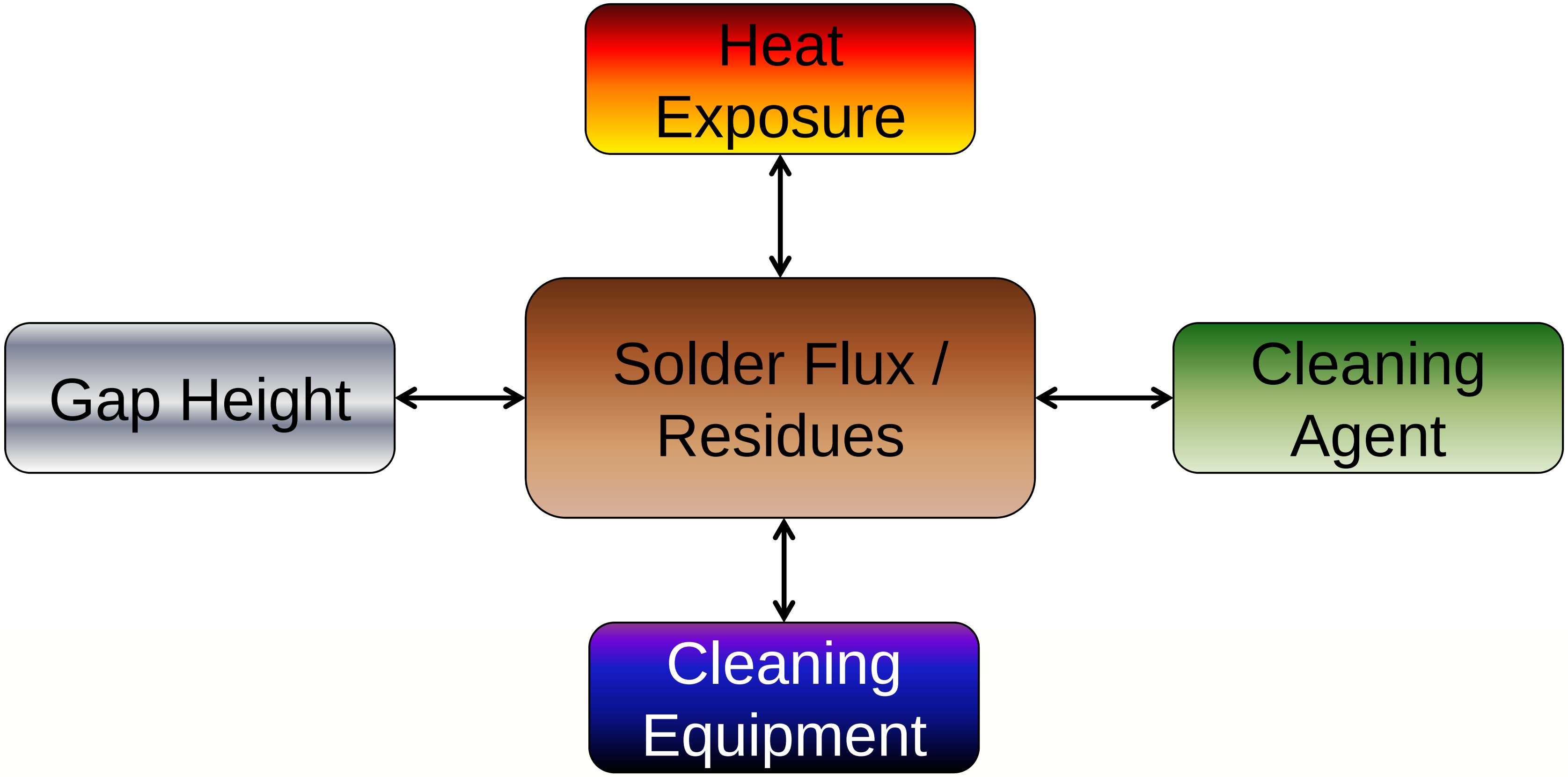
IS THERE ONE BEST CLEANING AGENT DESIGN?

Cleaning Agents Designs



FIVE CLEANING FORCES

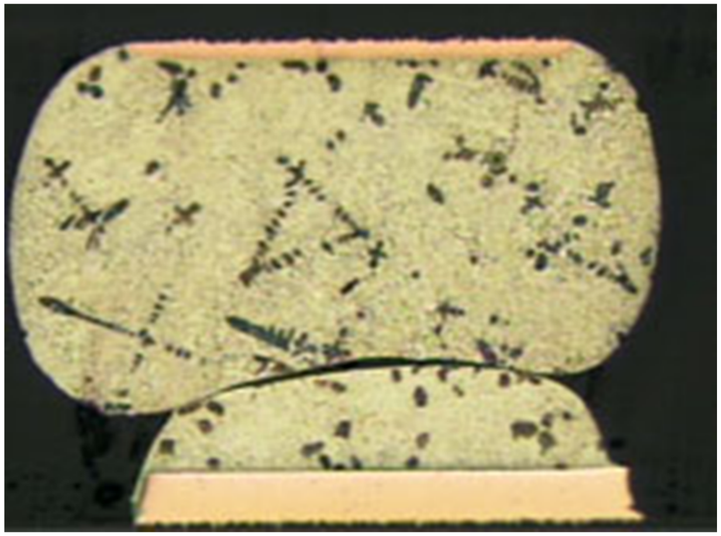
Factors Affecting Cleaning



FLUX RESIDUES

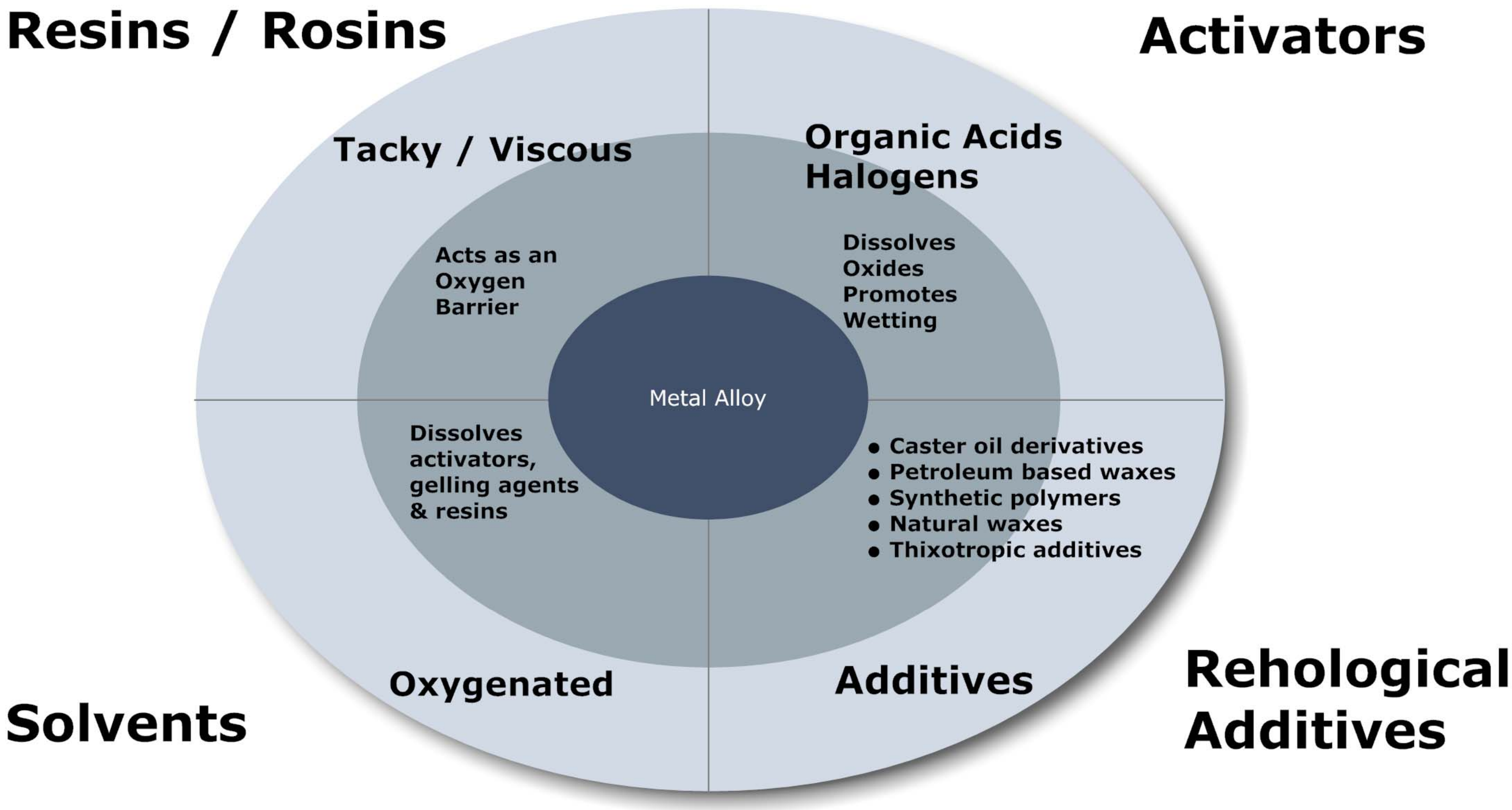
Miniaturization and Heat Drive Flux Designs

- Flux is a chemical cleaning that
  - Removes oxidation
  - Facilitates wetting
  - Oxygen barrier to prevent oxidation during the soldering process
  - Improves bonding



Courtesy of IPC

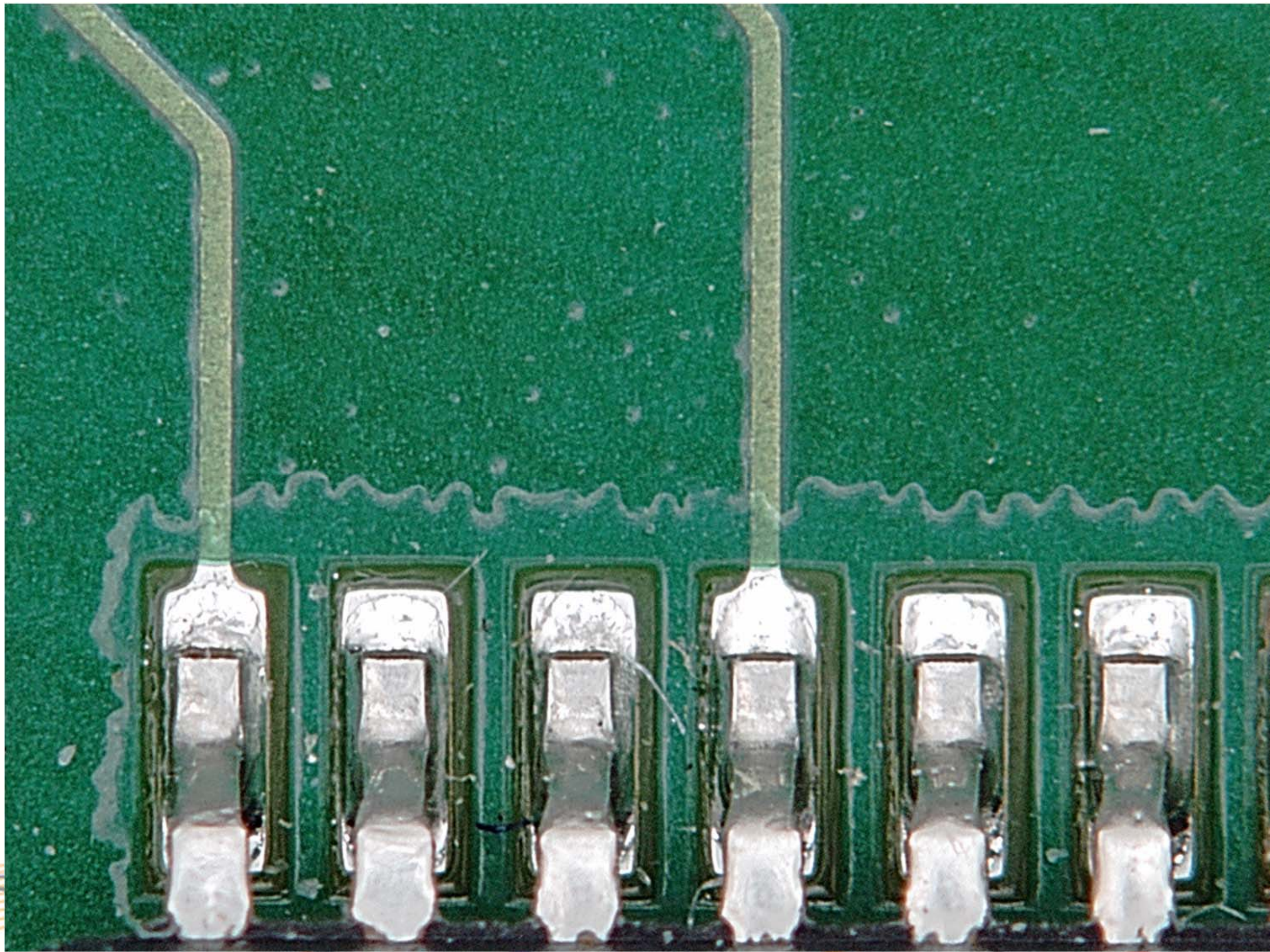
Flux Compositions



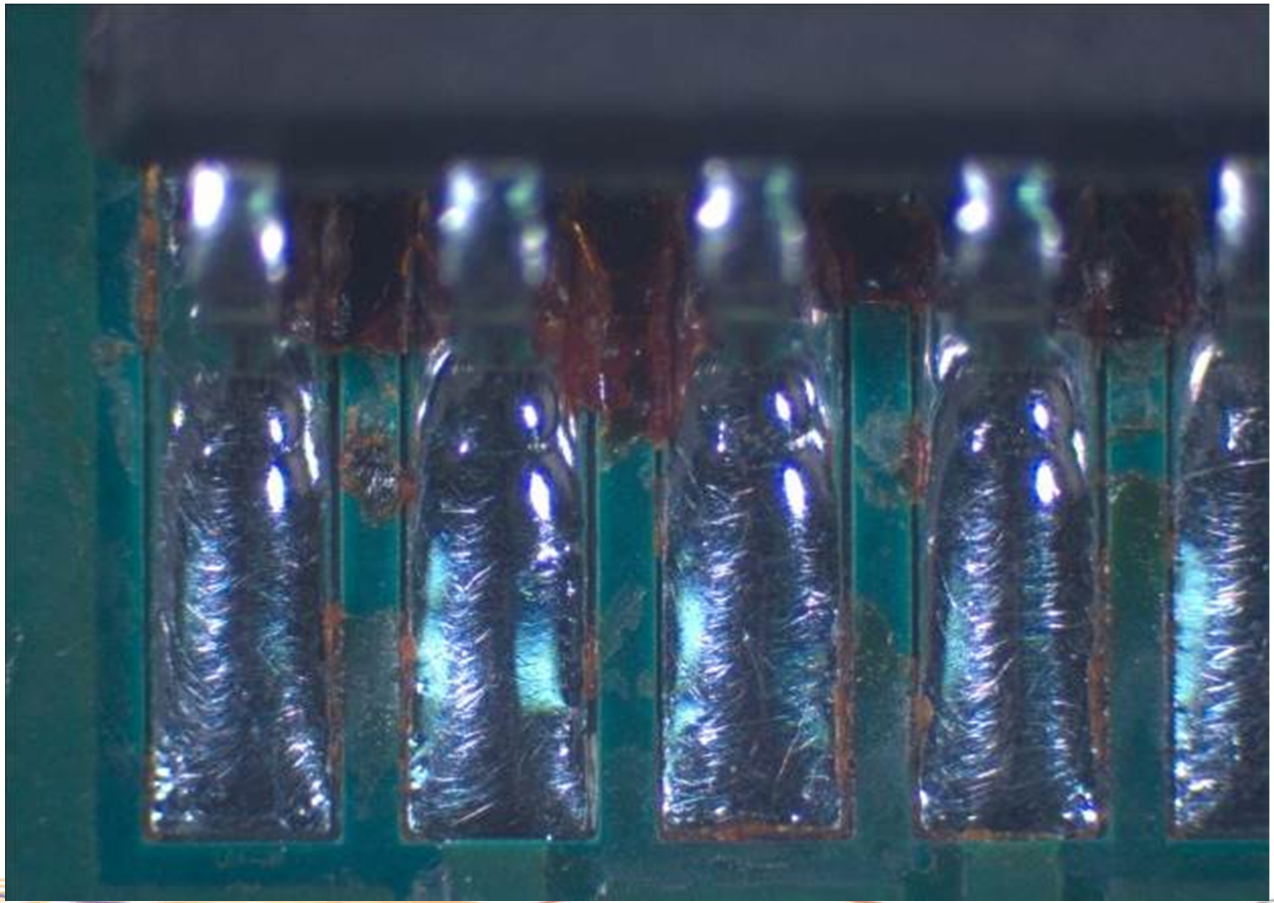
Lee, 2002

HEAT EXPOSURE

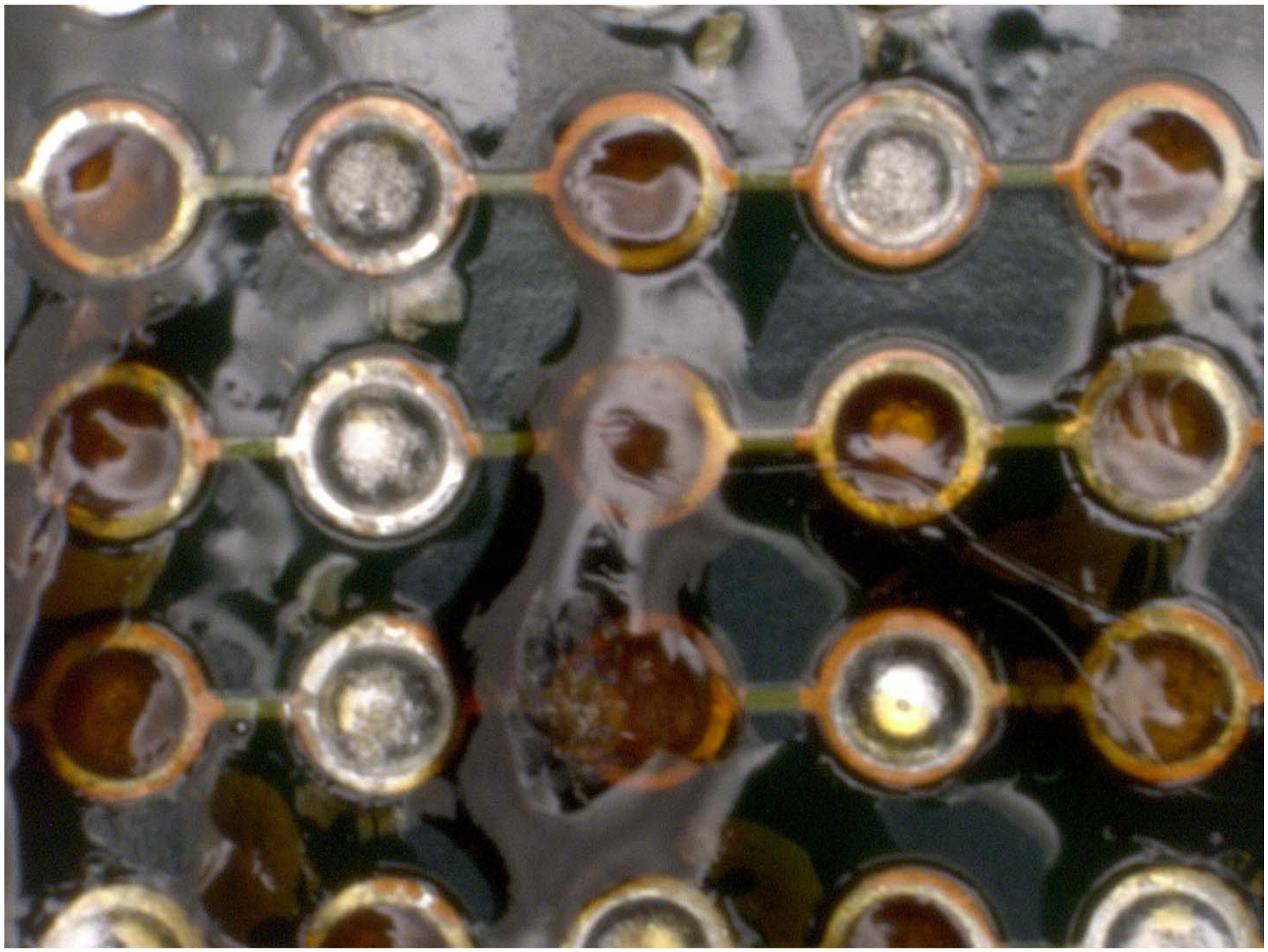
Excessive Heat can Initiate Polymerization



Char / Oxidize Residue

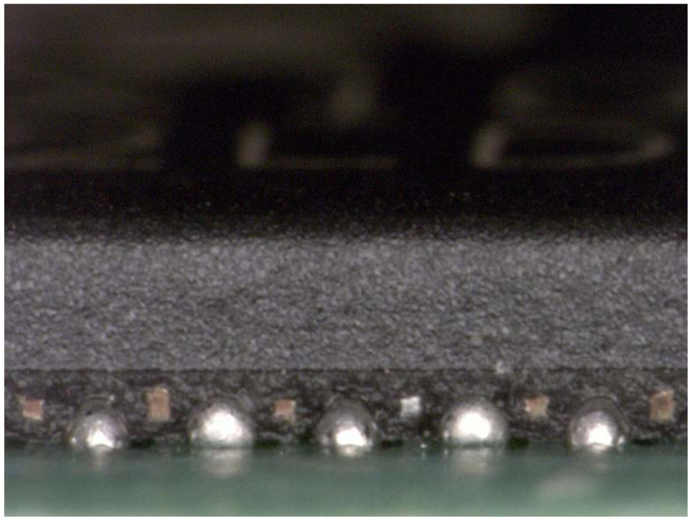


Render the Residue Uncleanable

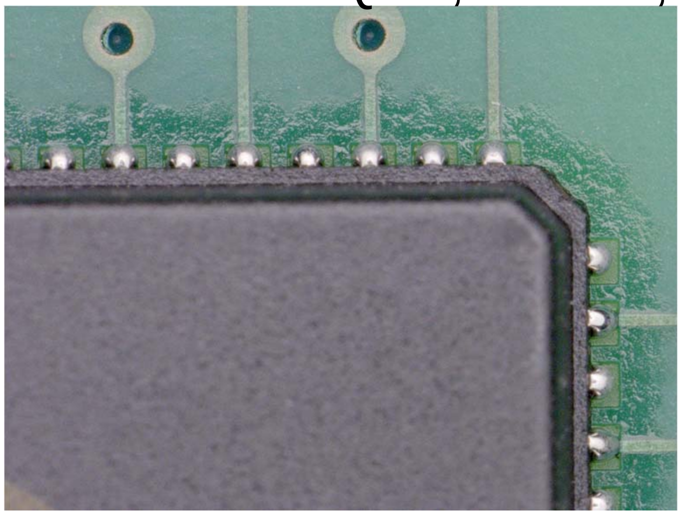


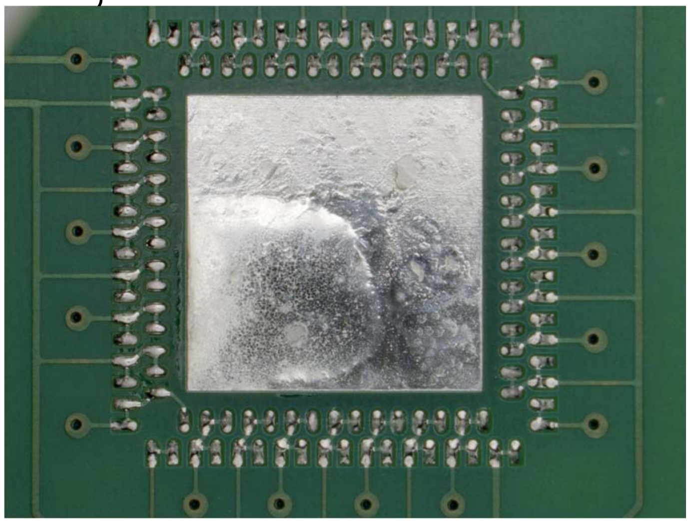
GAP HEIGHT

Leadless Components

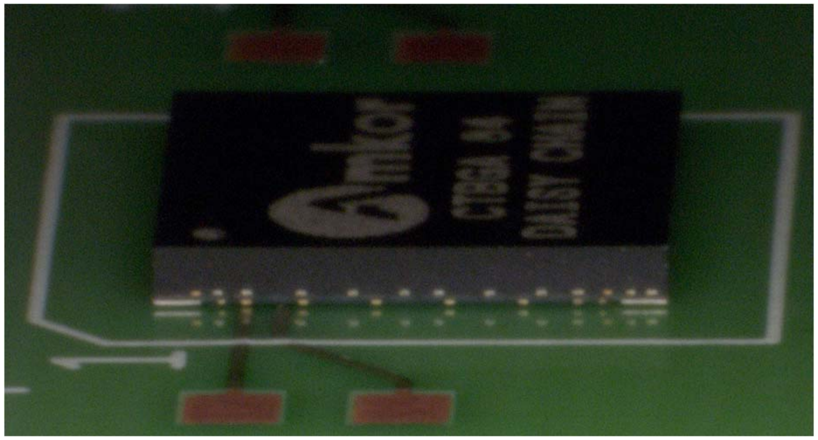


QFN, 160 I/O, 10x10 mm, 1.0 mm Pitch

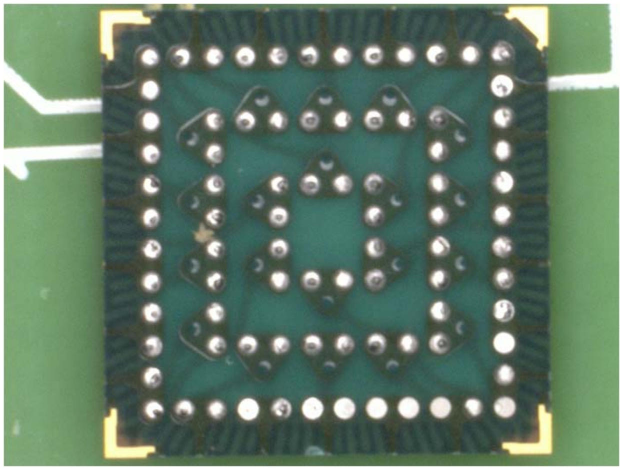


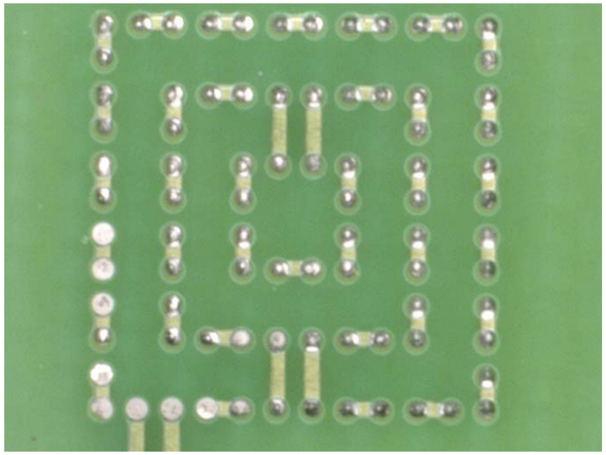


Leadless Components

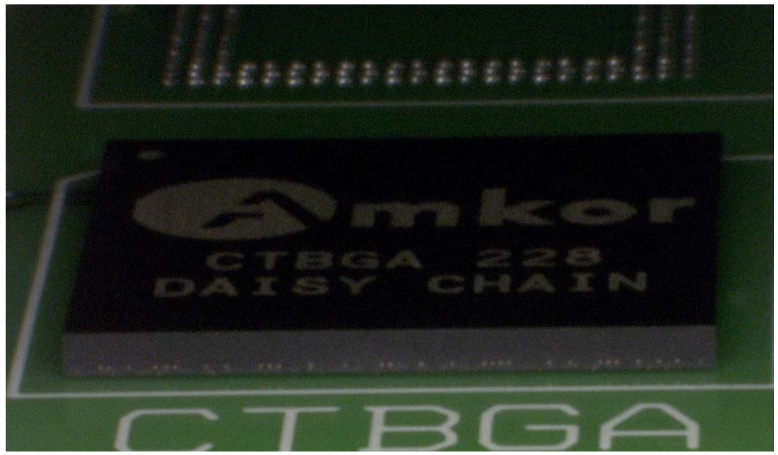


CTBGA – 84 IO, 7x7 mm, 0.5 mm Pitch

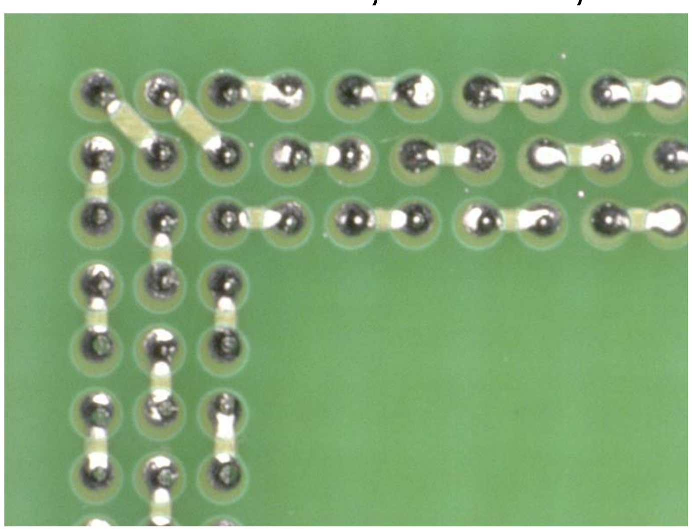


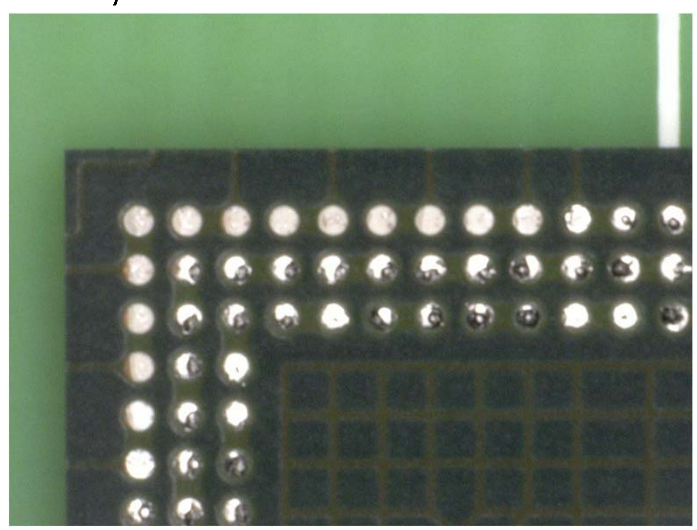


Leadless Components

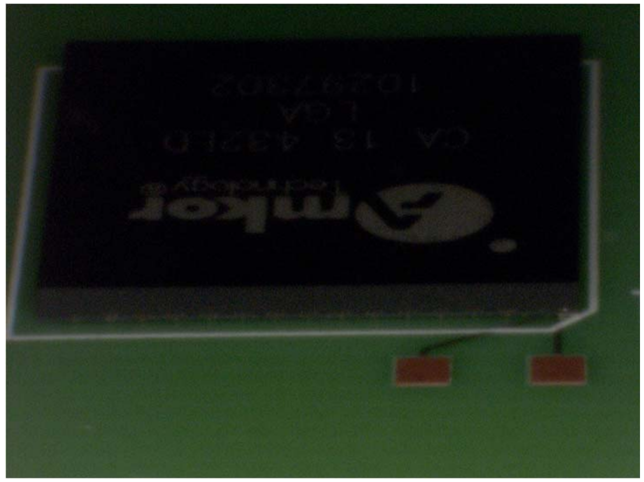


CTBGA, 228 I/O, 12x12 mm, 0.5 mm Pitch

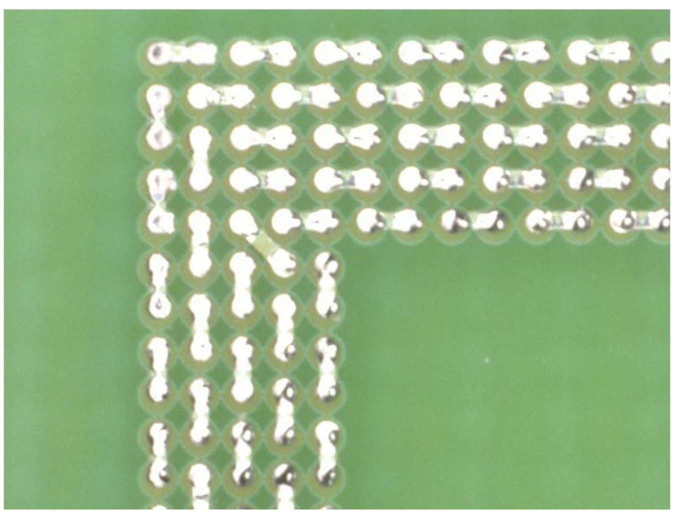


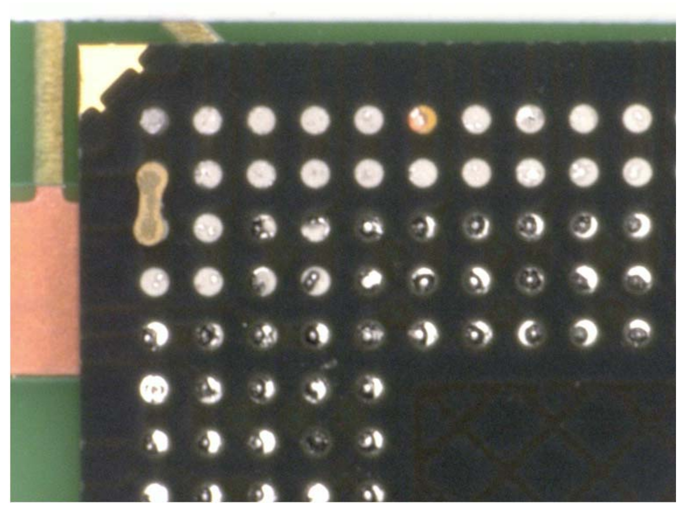


Leadless Components



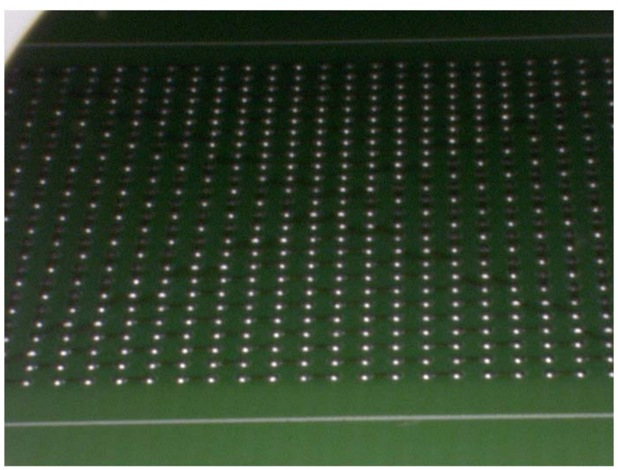
CTBGA, 360 I/O, 10x10 mm, 0.4 mm Pitch

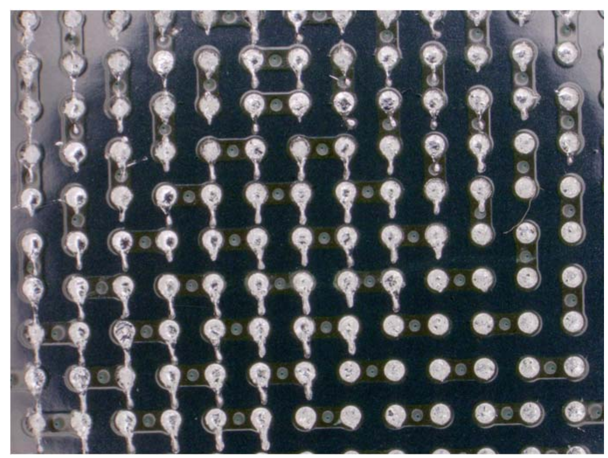




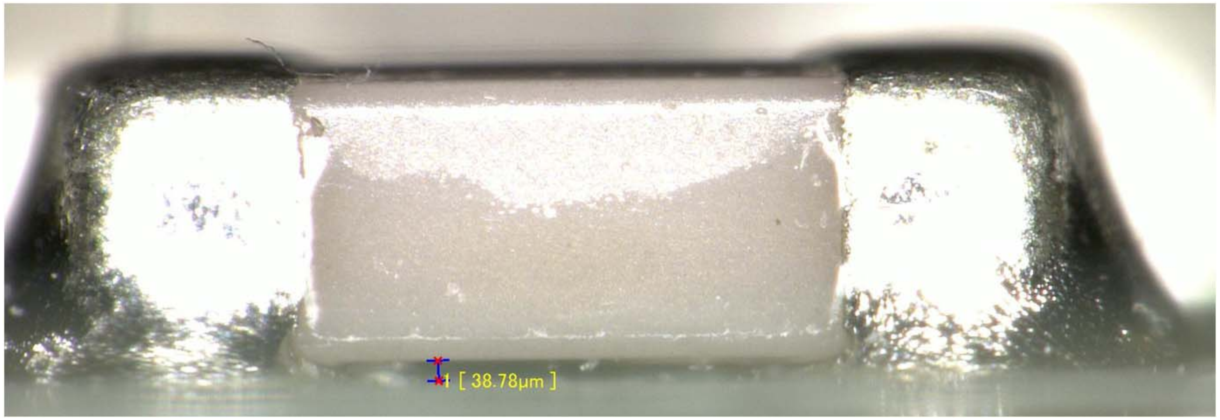
Leadless Components

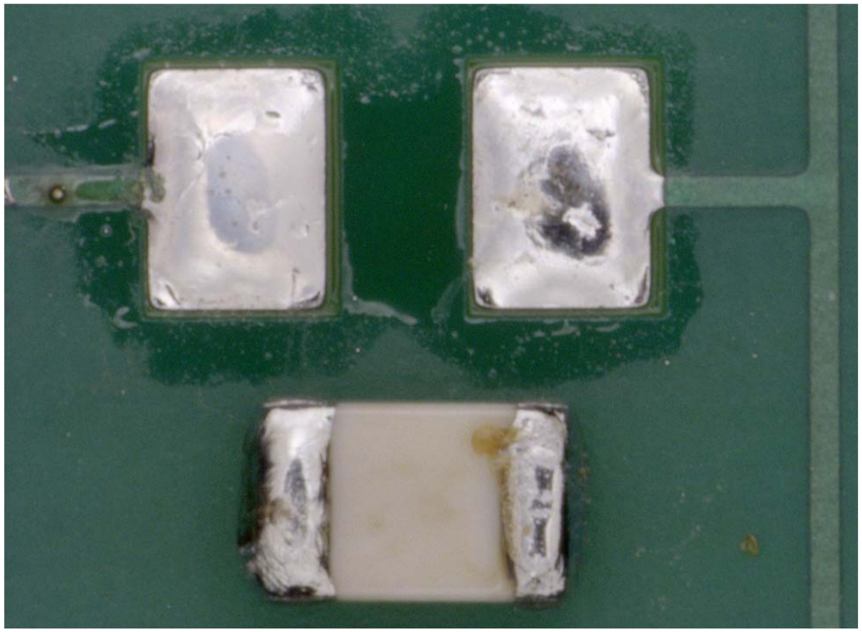
PBGA, 676 I/O, 27x27 mm, 1/0 mm Pitch





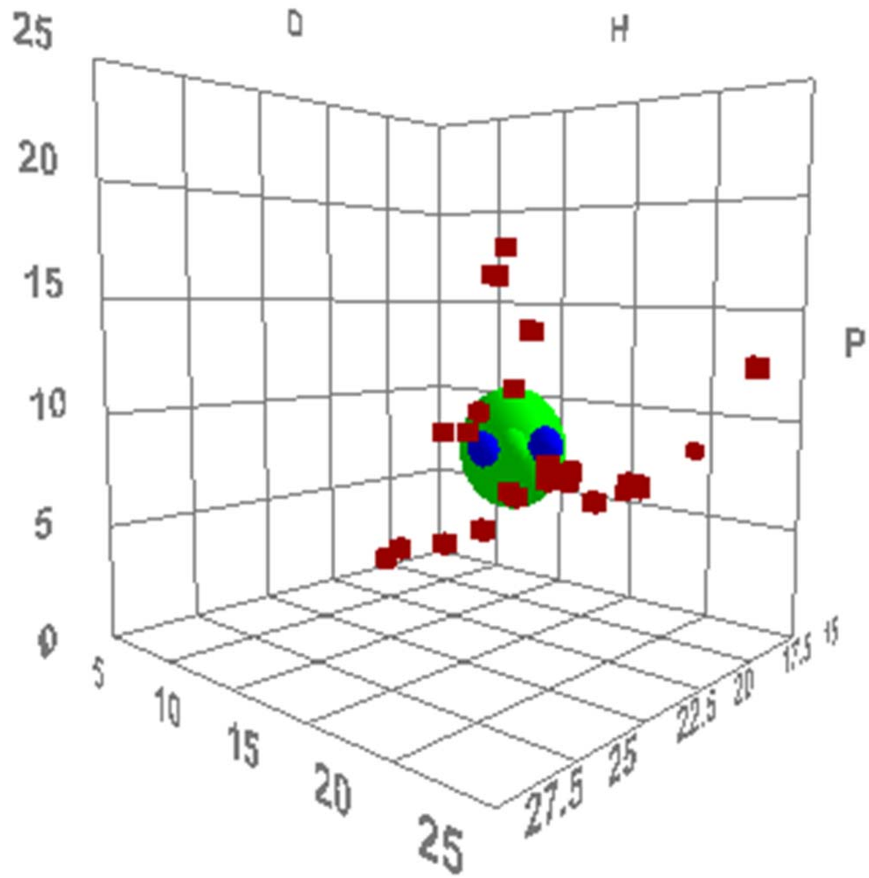
Leadless Components



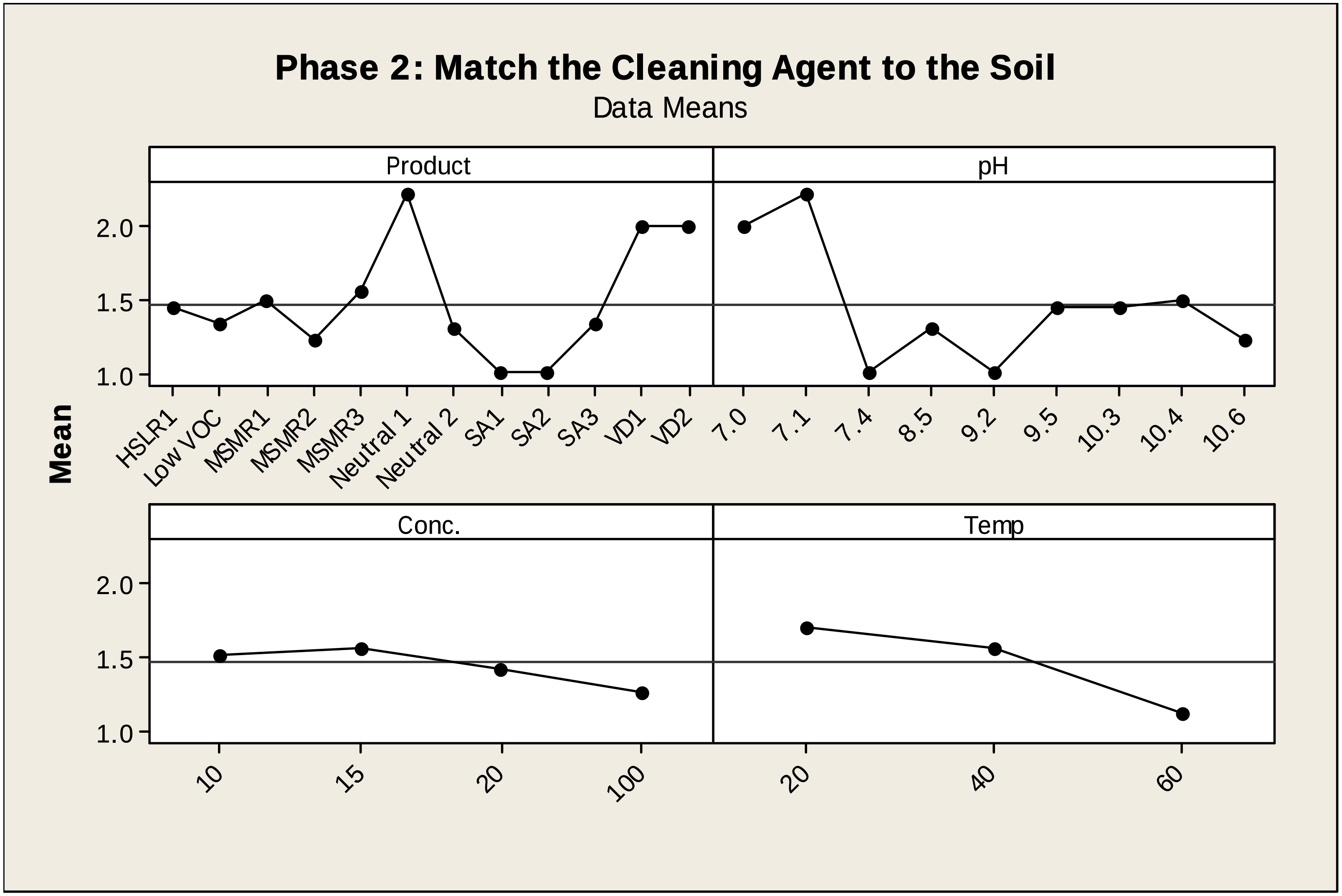


STATIC CLEANING RATES

Phase 1: Characterize the Soil

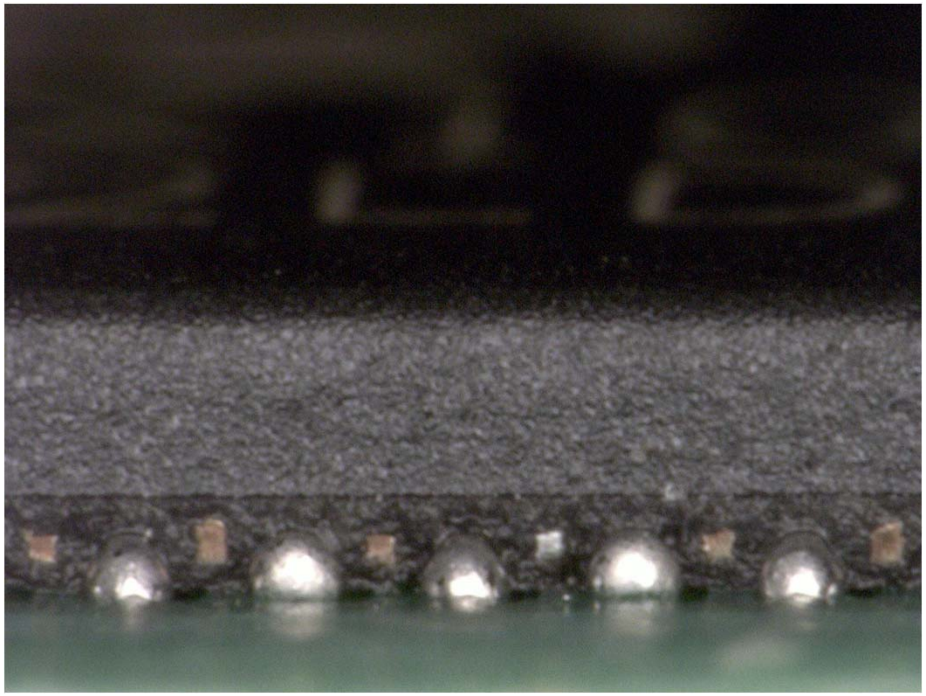


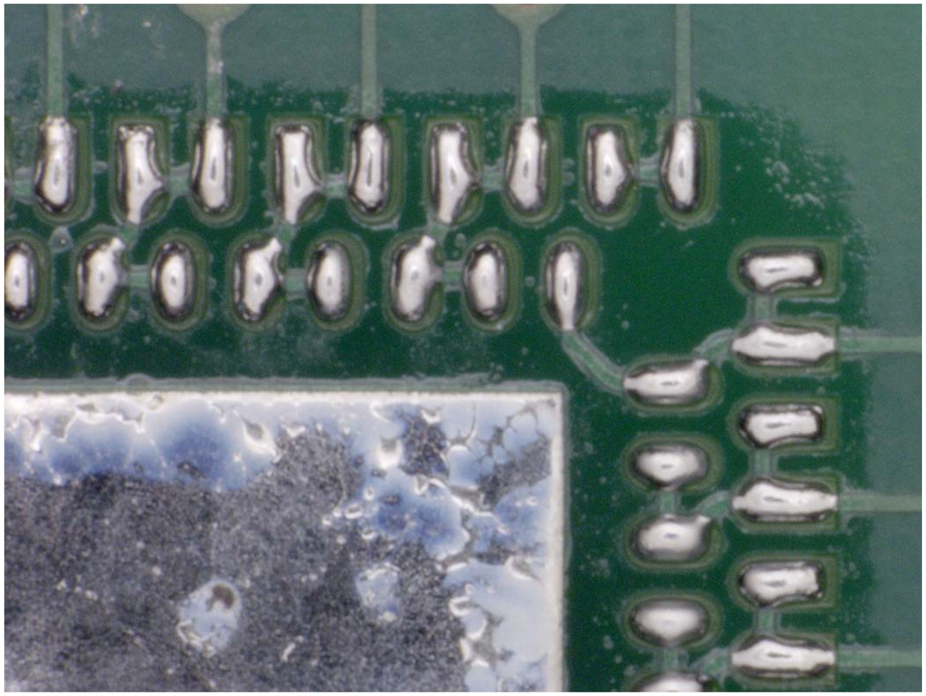
Phase 2: Match Cleaning Agent to Soil



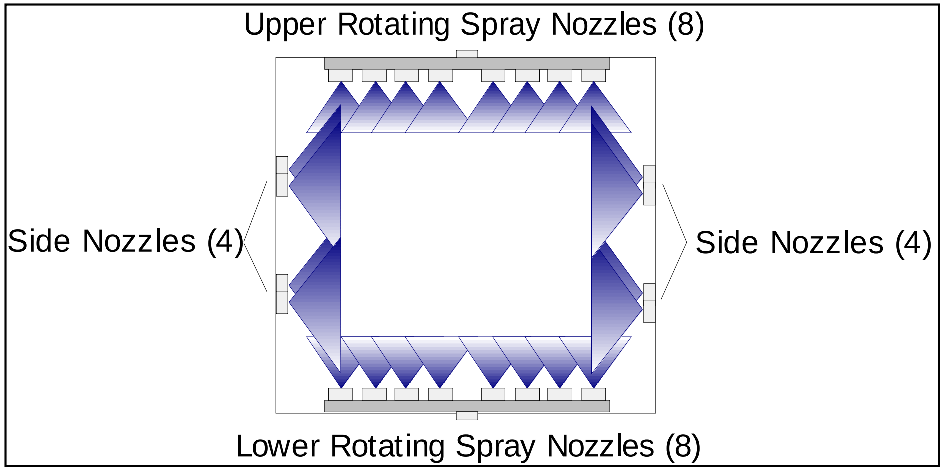
DYNAMIC CLEANING RATES

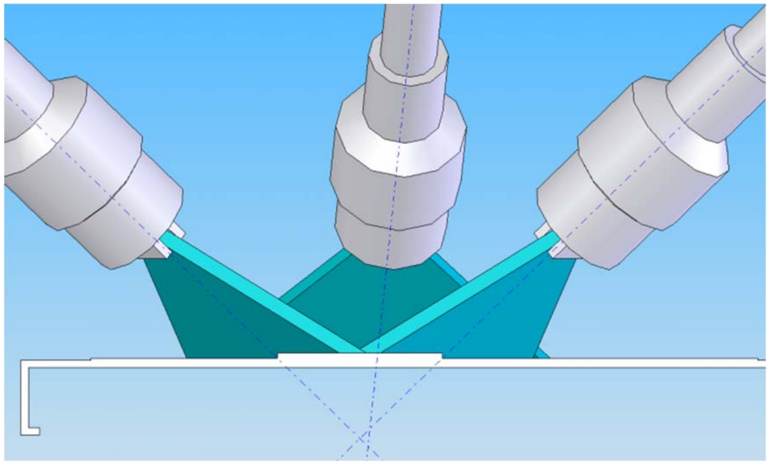
Energy to Penetrate and Clean

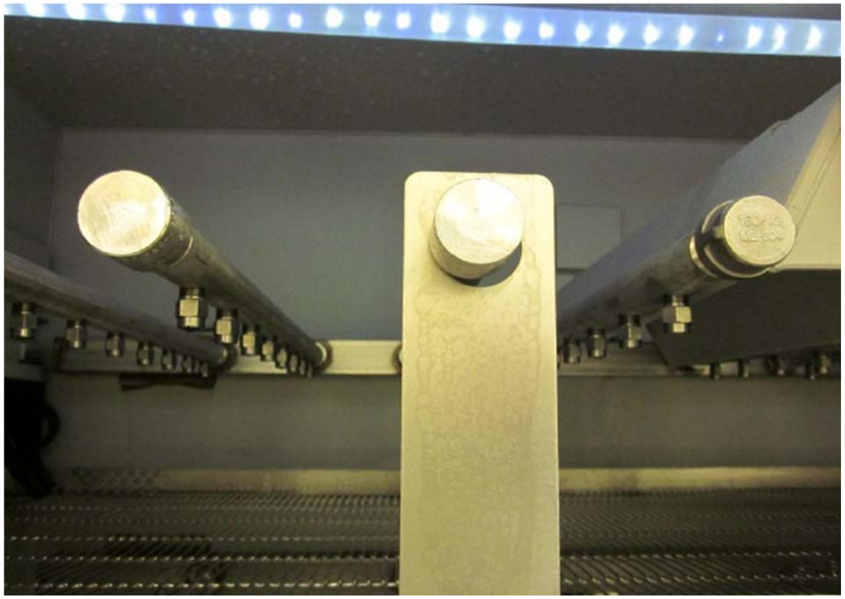




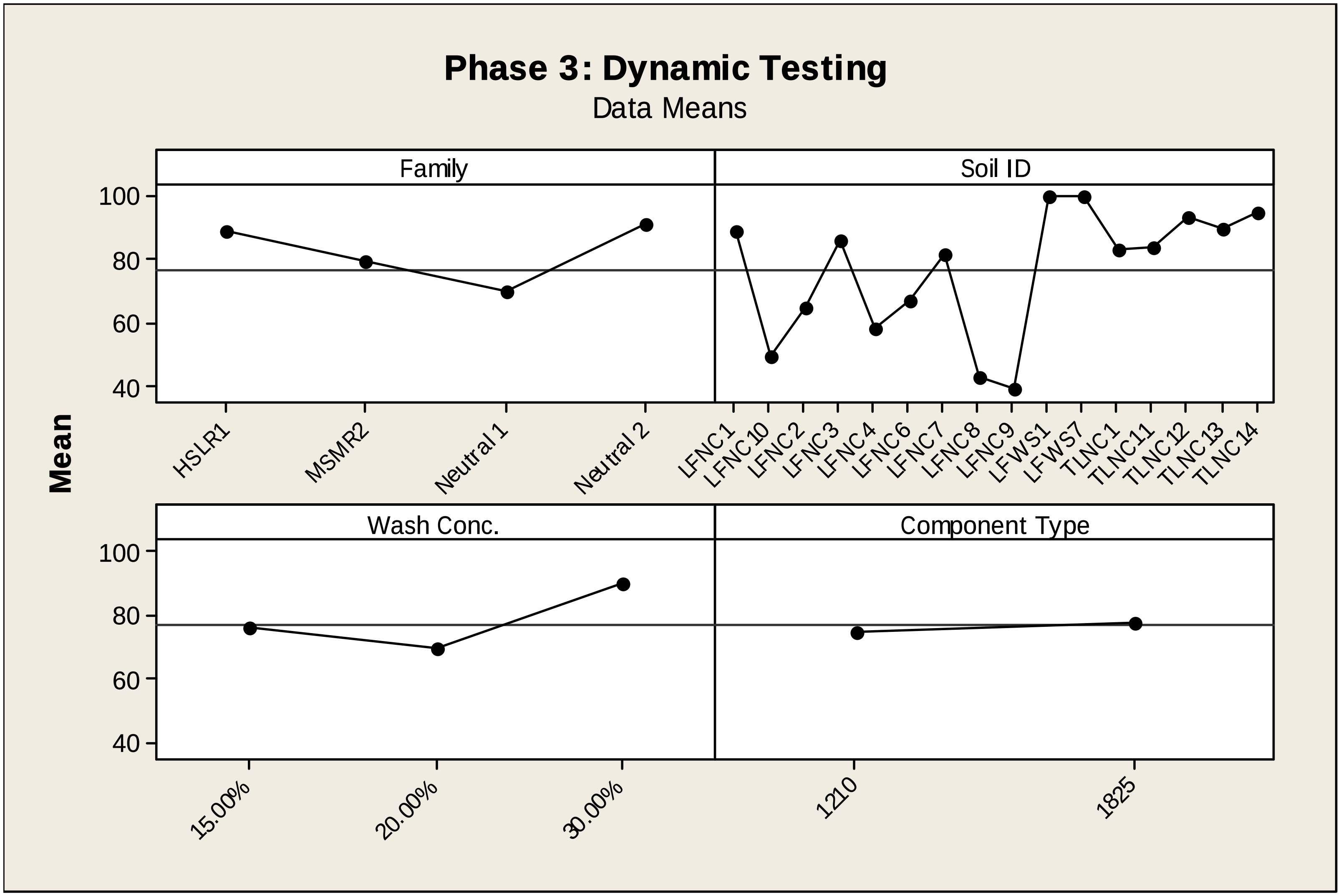
Energy Options







Phase 3: Dynamic Cleaning Rates



DOE # 1

Phase 2: Static Cleaning Rates

Factors / Levels

1. Cleaning Agents
   a) 7- Aqueous
2. Solder Pastes
   a) 10 – Sn/Pb No Clean
   b) 10 - SAC No Clean
   c) 10 – SAC OA
3. Wash Time
   a) 10 minutes
4. Wash Temperature
   a) 20° C
   b) 40° C
   c) 60° C

Cleaning Agent	pH	Engineered Design
HSLR1	9.5	1. High Solvency 2. Reactivity 3. Functional Additives
Low VOC	10.3	1. Low Solvency 2. Inorganic Builders 3. Functional Additives
MSMR1	10.4	1. Mid Solvency 2. Reactivity 3. Functional Additives
MSMR2	10.6	1. Mid Solvency 2. Reactivity 3. Functional Additives
MSMR3	10.3	1. Mid Solvency 2. Reactivity 3. Functional Additives
Neutral1	7.1	1. High Solvency 2. Acid/Base Reactivity to Neutral 3. Functional Additives
Neutral2	8.5	1. High Solvency 2. Reactivity 3. Functional Additives

Response Variable

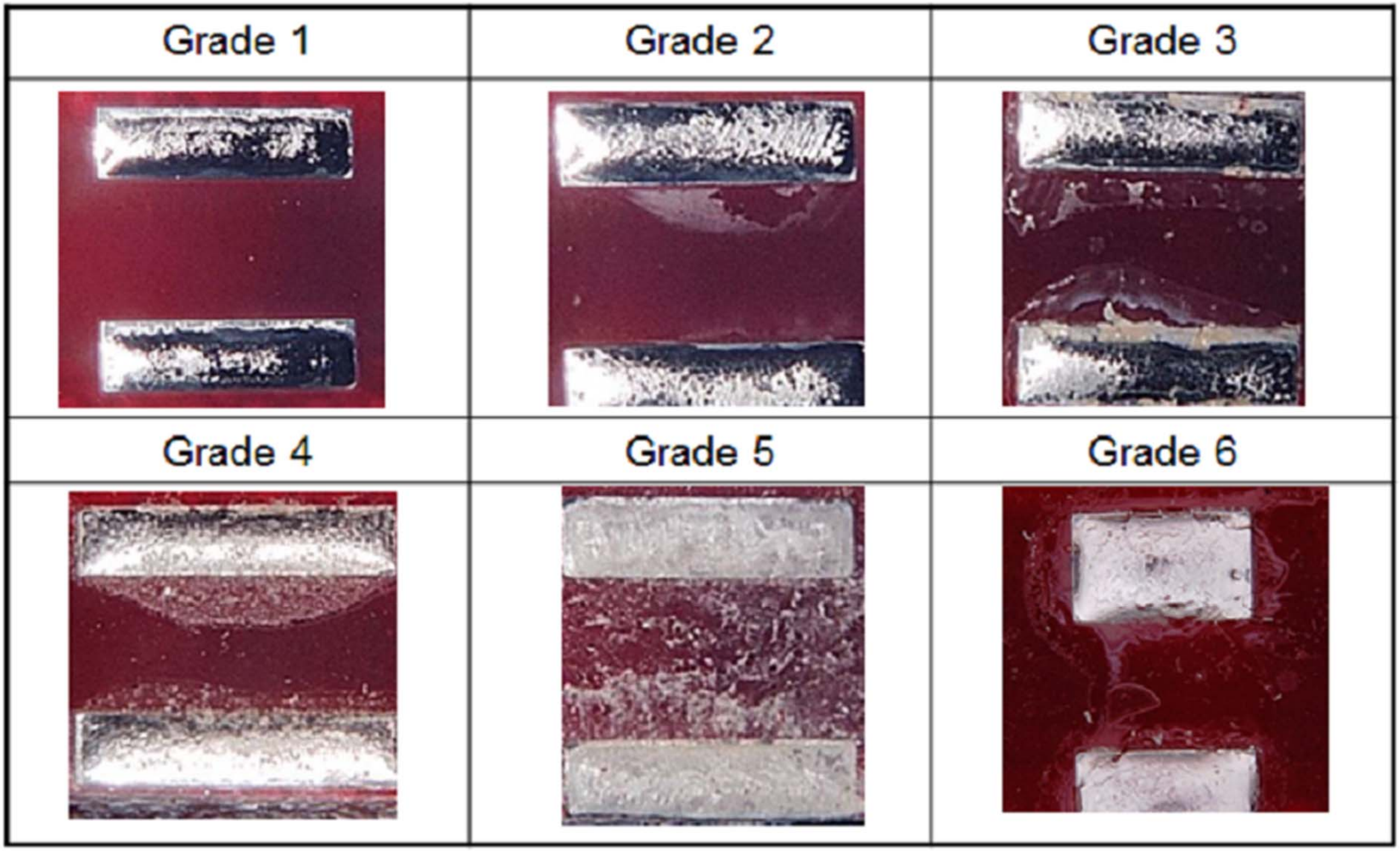


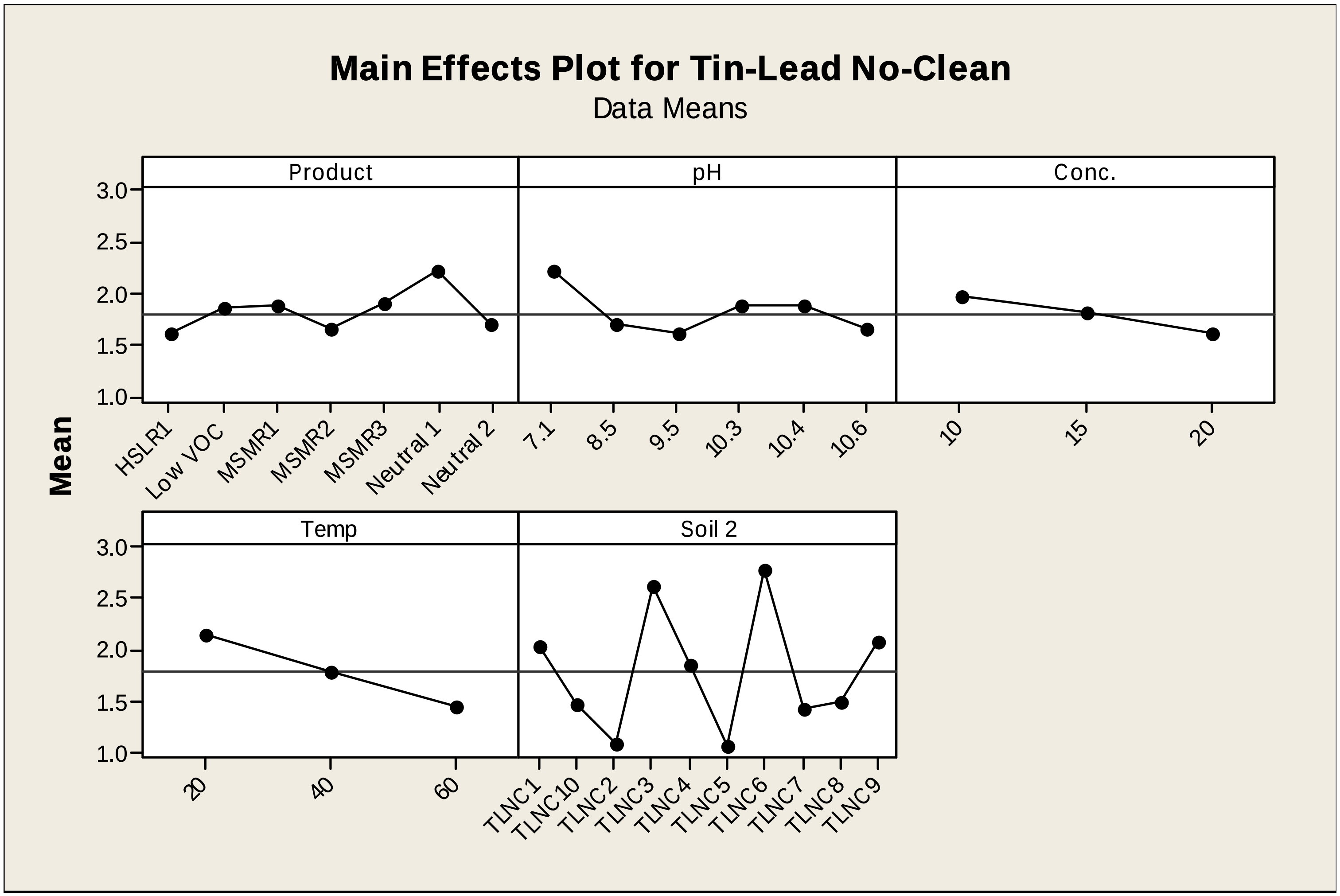
Figure 5: Grading Scale

Response Variable Description

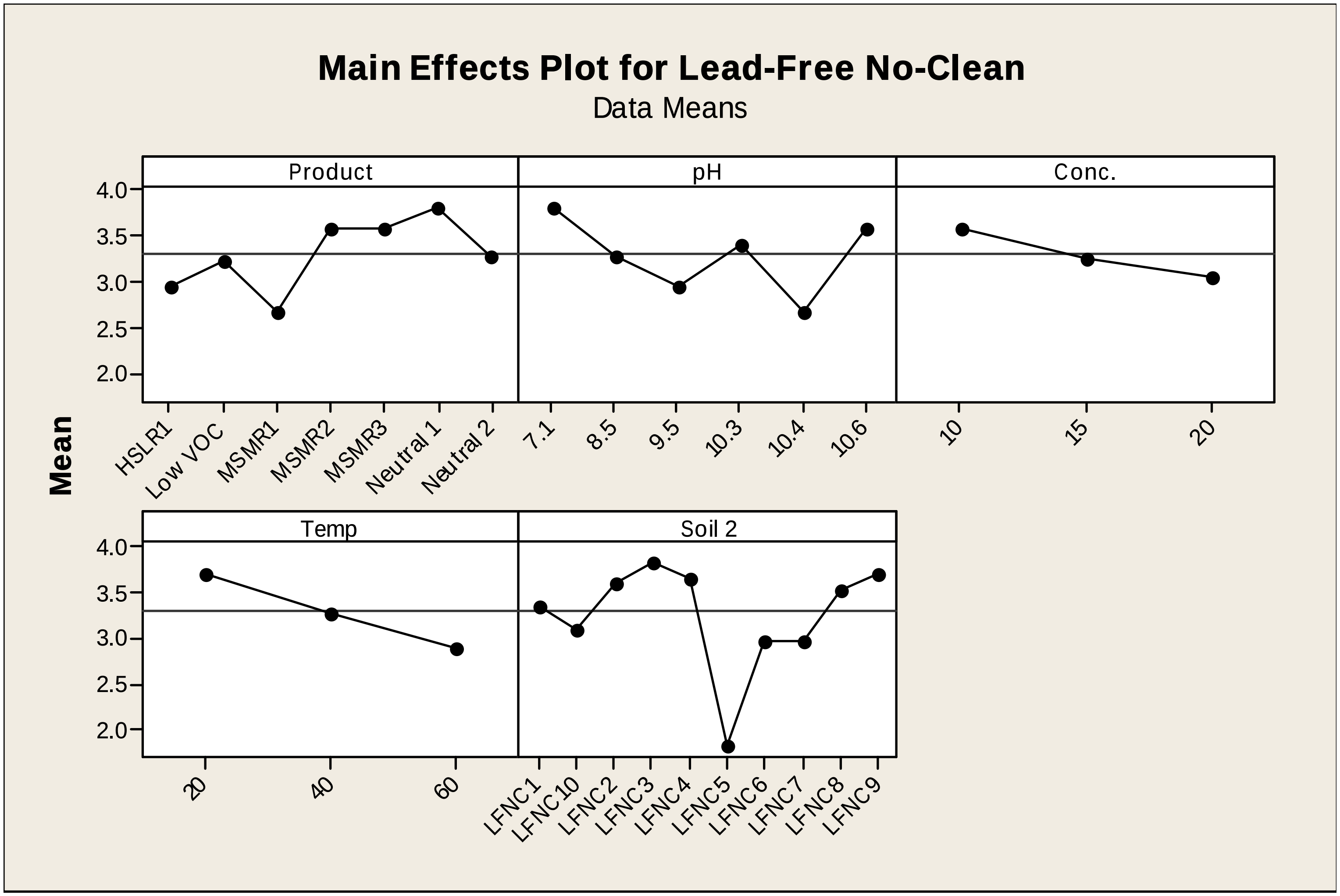
Score	Description
1	Clean, no visible residue
2	Small level of residue remaining
3	Cleaning interaction present, but impingement energy needed
4	Marginal cleaning agent, boundary cleaning agent
5	Very little cleaning of the soil
6	No interaction with the cleaning agent

Table 1: Grading Scale

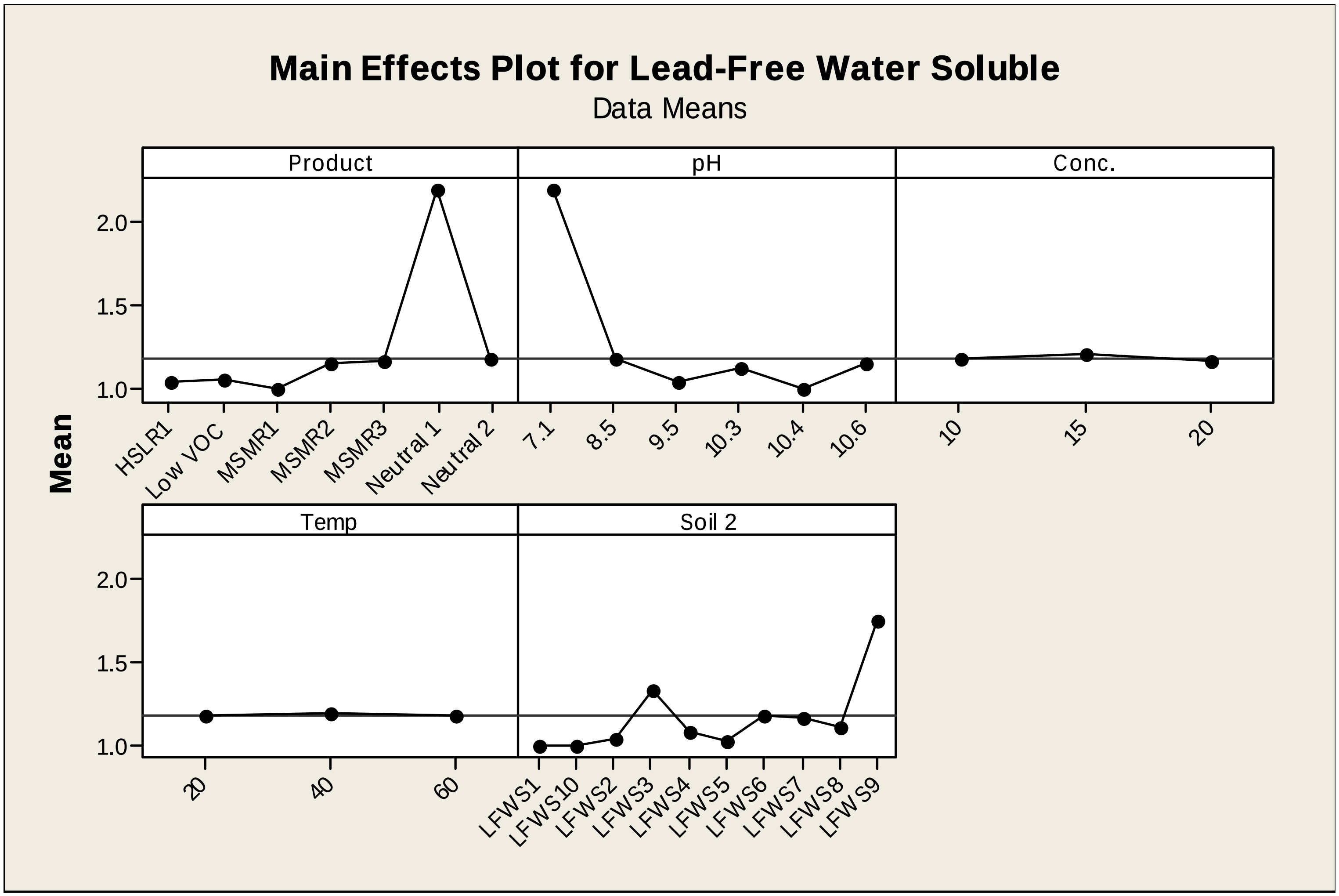
Tin-Lead Eutectic Static Rates



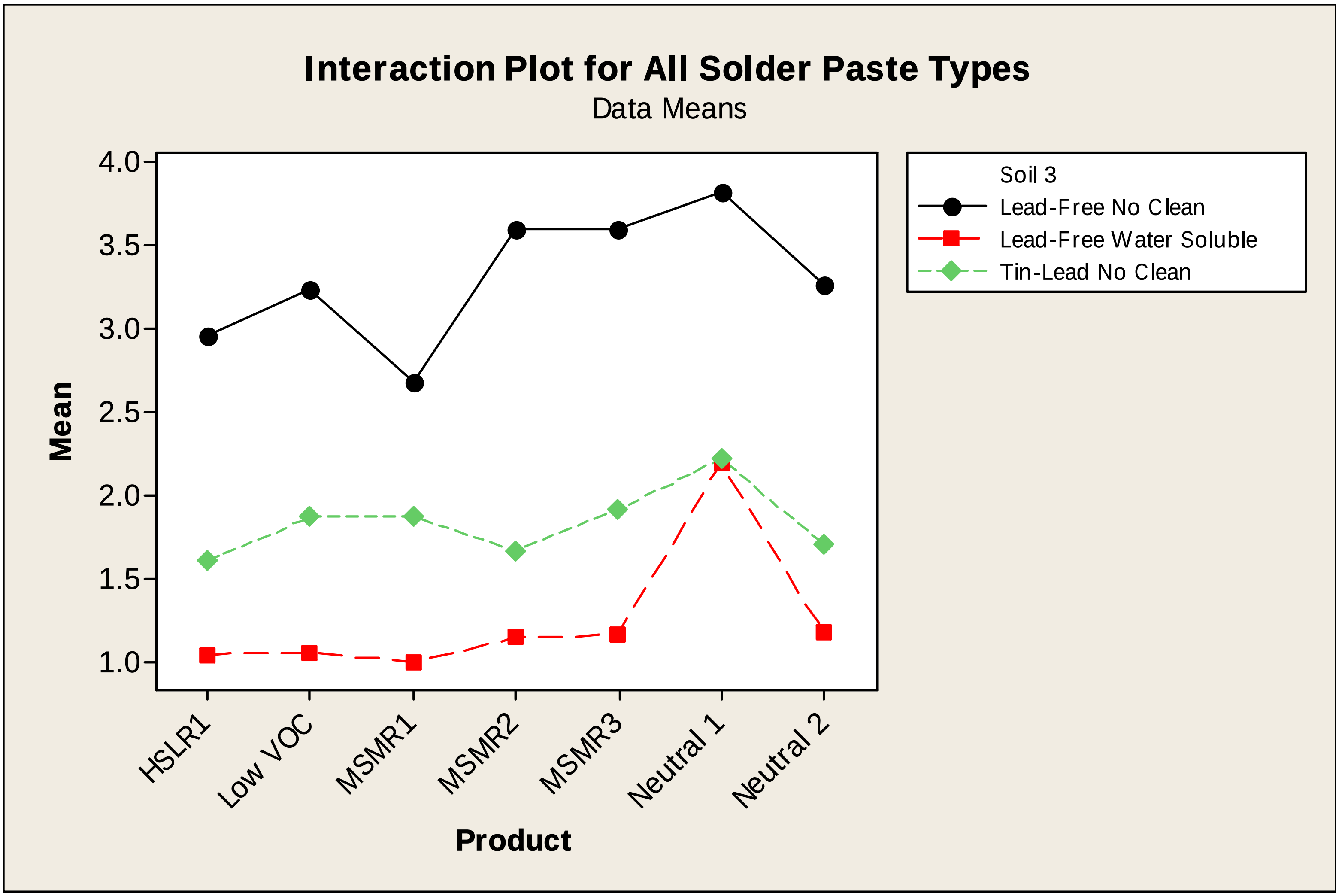
SAC LF – No Clean Static Rates



SAC LF Water Soluble Static Rates



Static Rate Comparisons



Inferences From Data Findings DOE#1

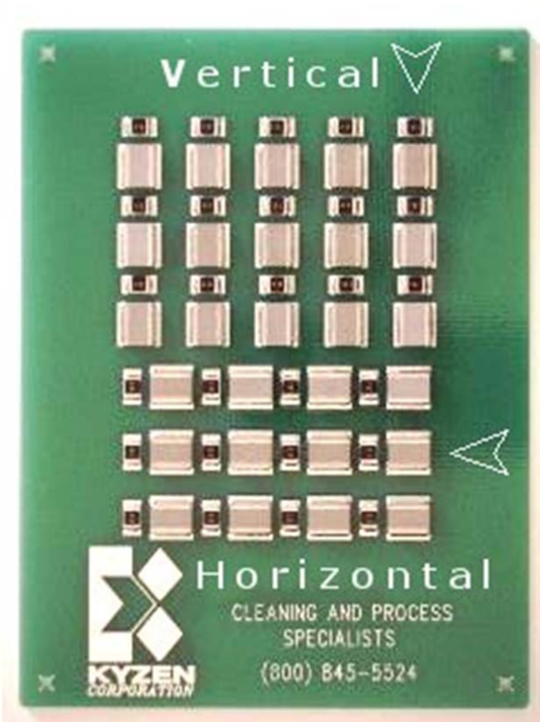
1. Lead-Free flux residues are significantly harder to clean
2. Soft residues clean well with all cleaning agent designs
3. Wash temperature improves cleaning
4. Good bit of variability among soils

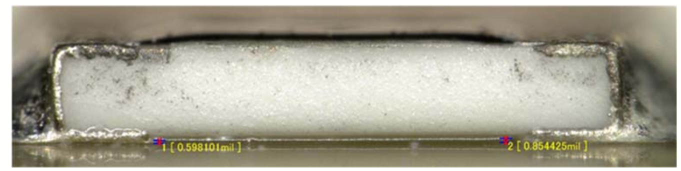
DOE #2

DOE#2 Objective

- Static testing provides insight into soil properties
- Without impingement energy
  - Is static testing relevant?
  - What are the benefits of static testing?
  - Is it possible to used static testing to model and predict performance characteristics?
- The objective of DOE #2 is to correlate dynamic with static testing data findings

DOE #2


Vertical
Horizontal
CLEANING AND PROCESS
SPECIALISTS
(800) 845-5524
KYZEN
CORPORATION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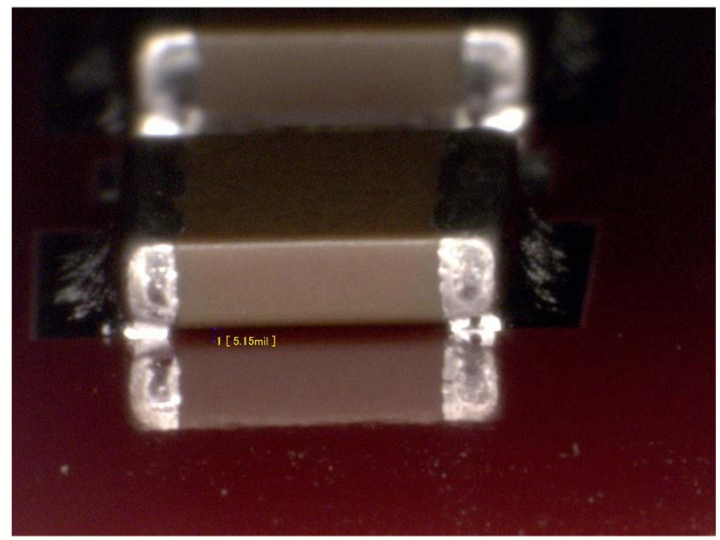
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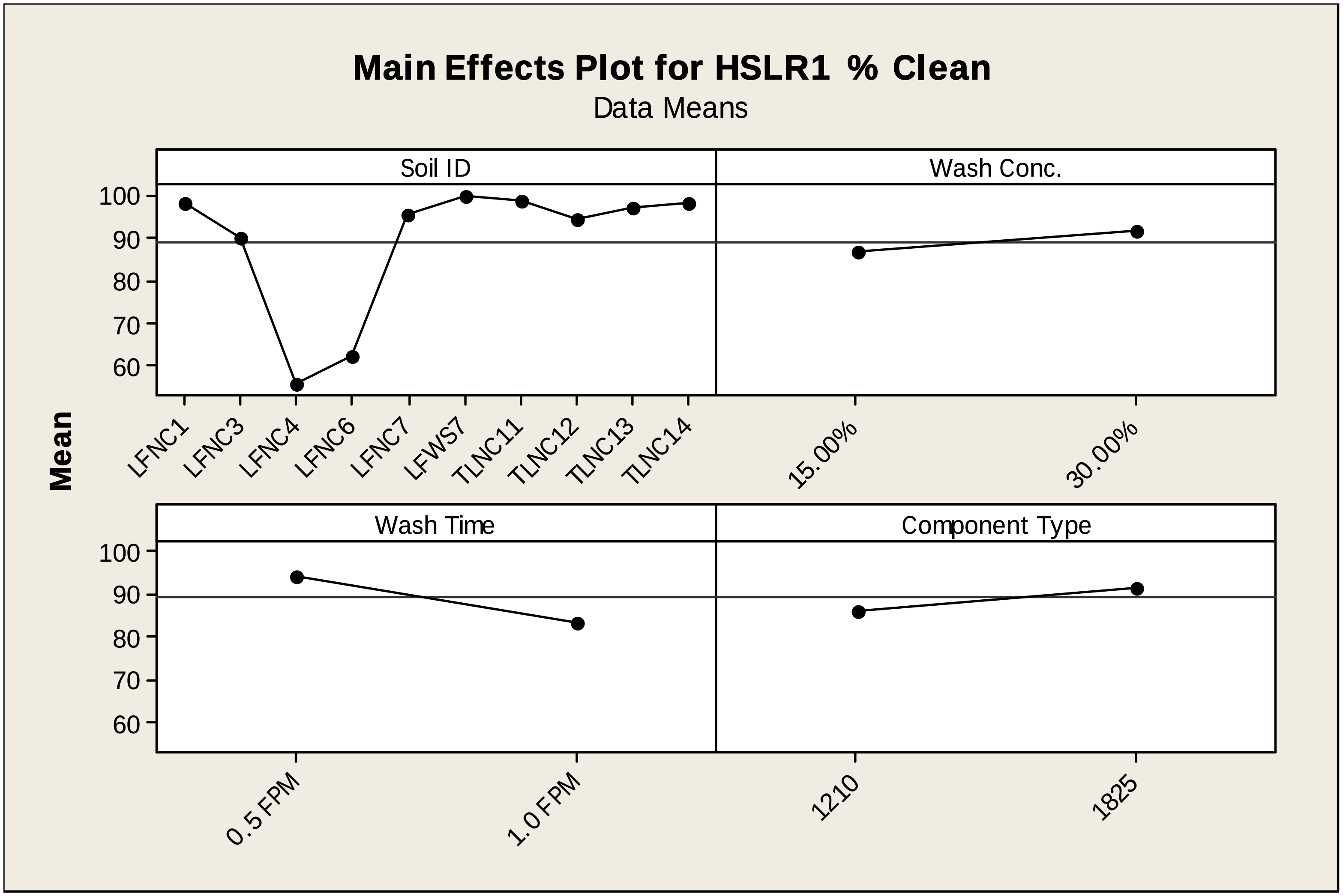
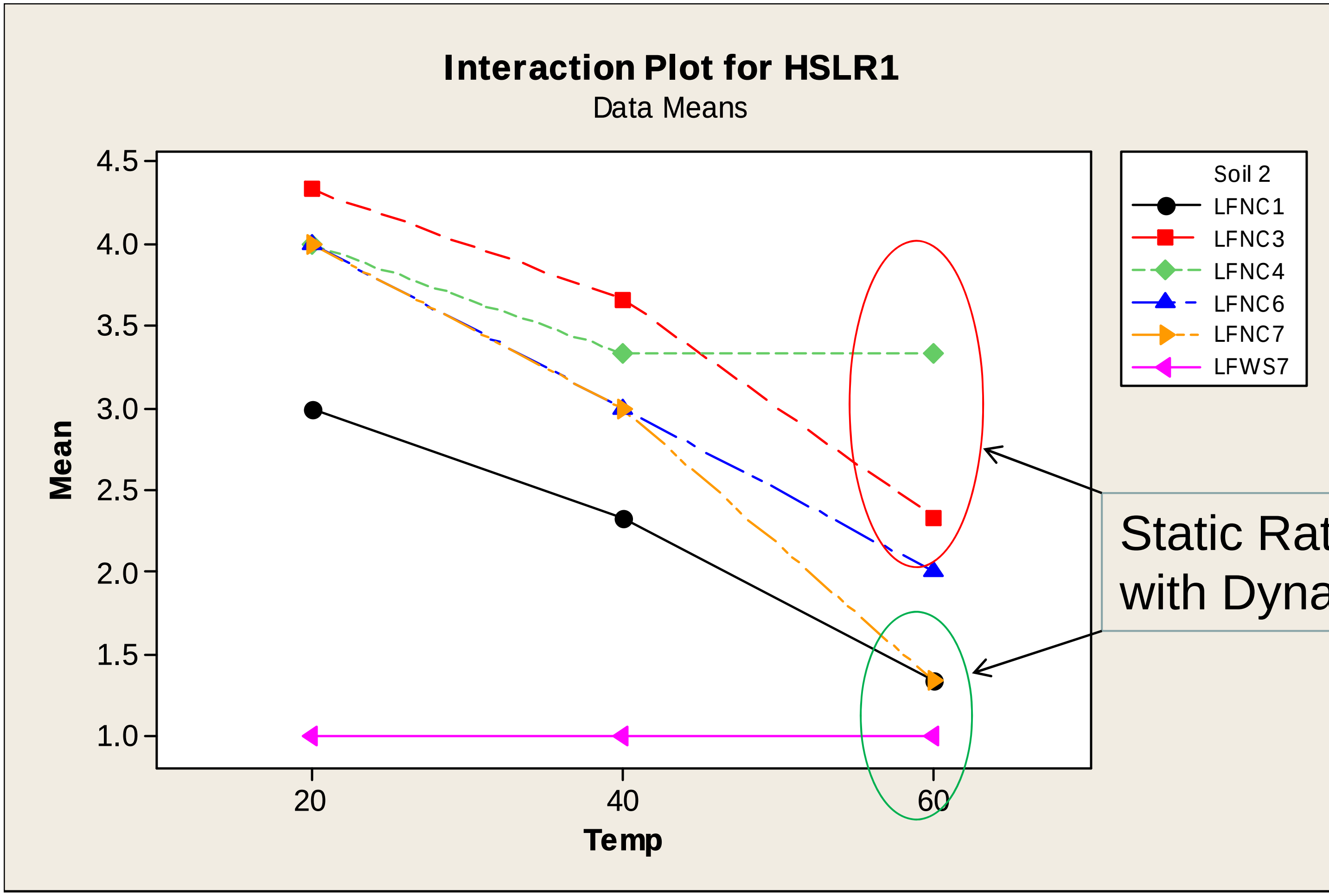
Factors / Levels

- Cleaning Agents
  - HSLR1 ~ 9.5
  - MSMR2 ~ 10.6
  - Neutral1 ~ 7.1
  - Neutral2 ~ 8.5
- Cleaning Equipment
  - Spray-in-Air
- Wash Temperature
  - 150° F
- Wash Time
  - 0.5 FPM
  - 1.0 FPM
  - 1.5 FPM
- Impingement
  - PEG
- Response
  - % Clean under Components

HSLR1 Dynamic Cleaning

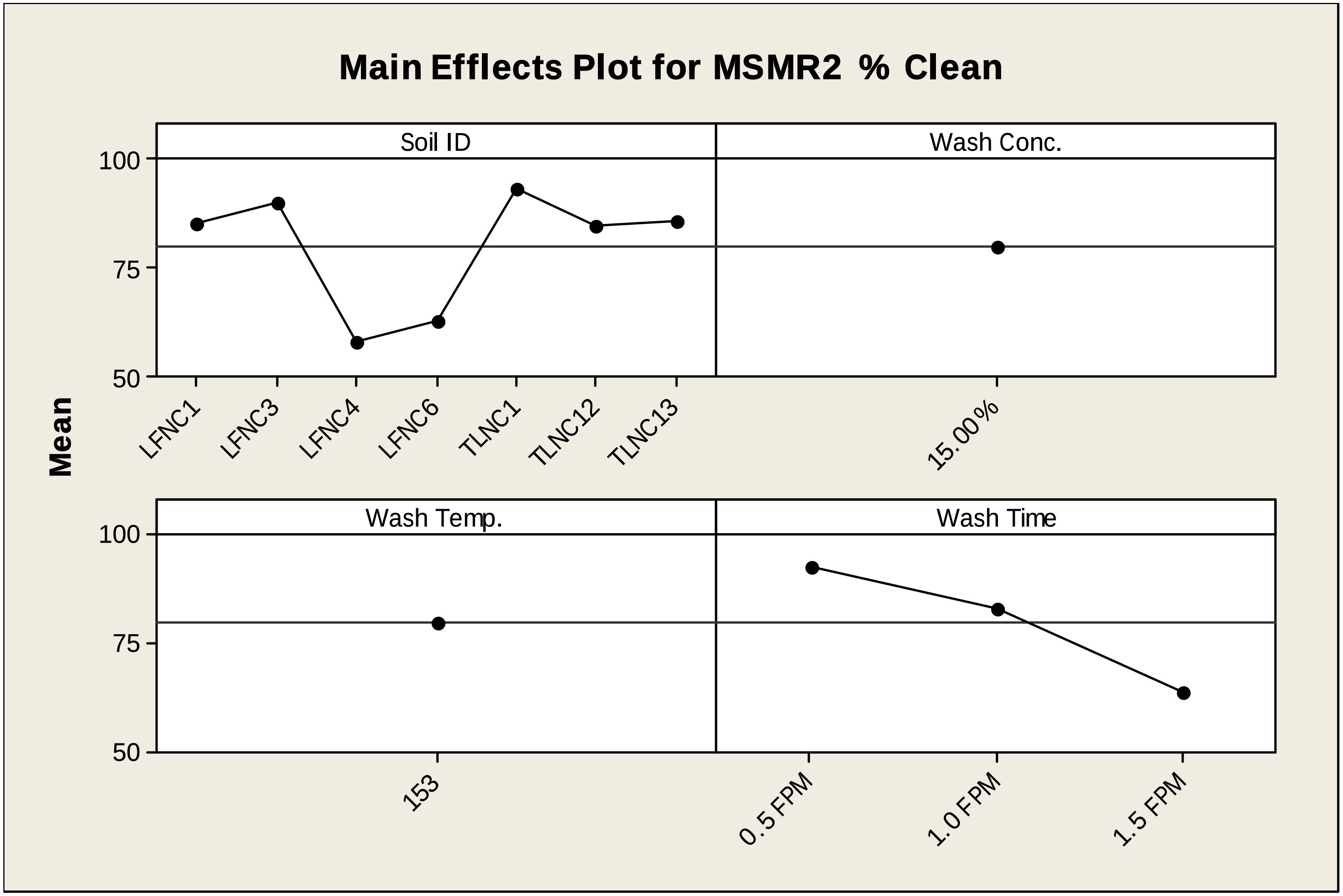


HSLR1 Static Cleaning Rates

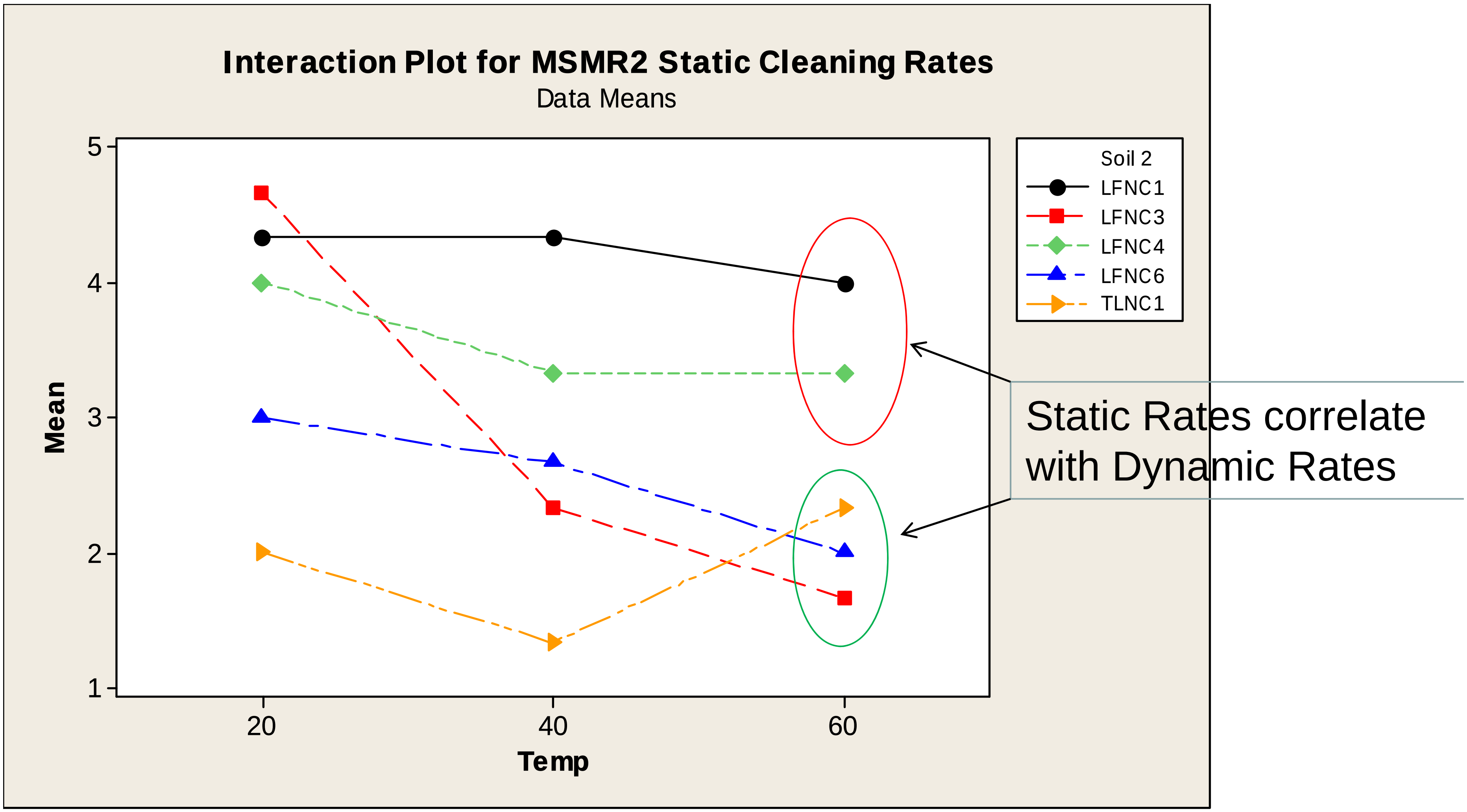


Static Rates correlate with Dynamic Rates

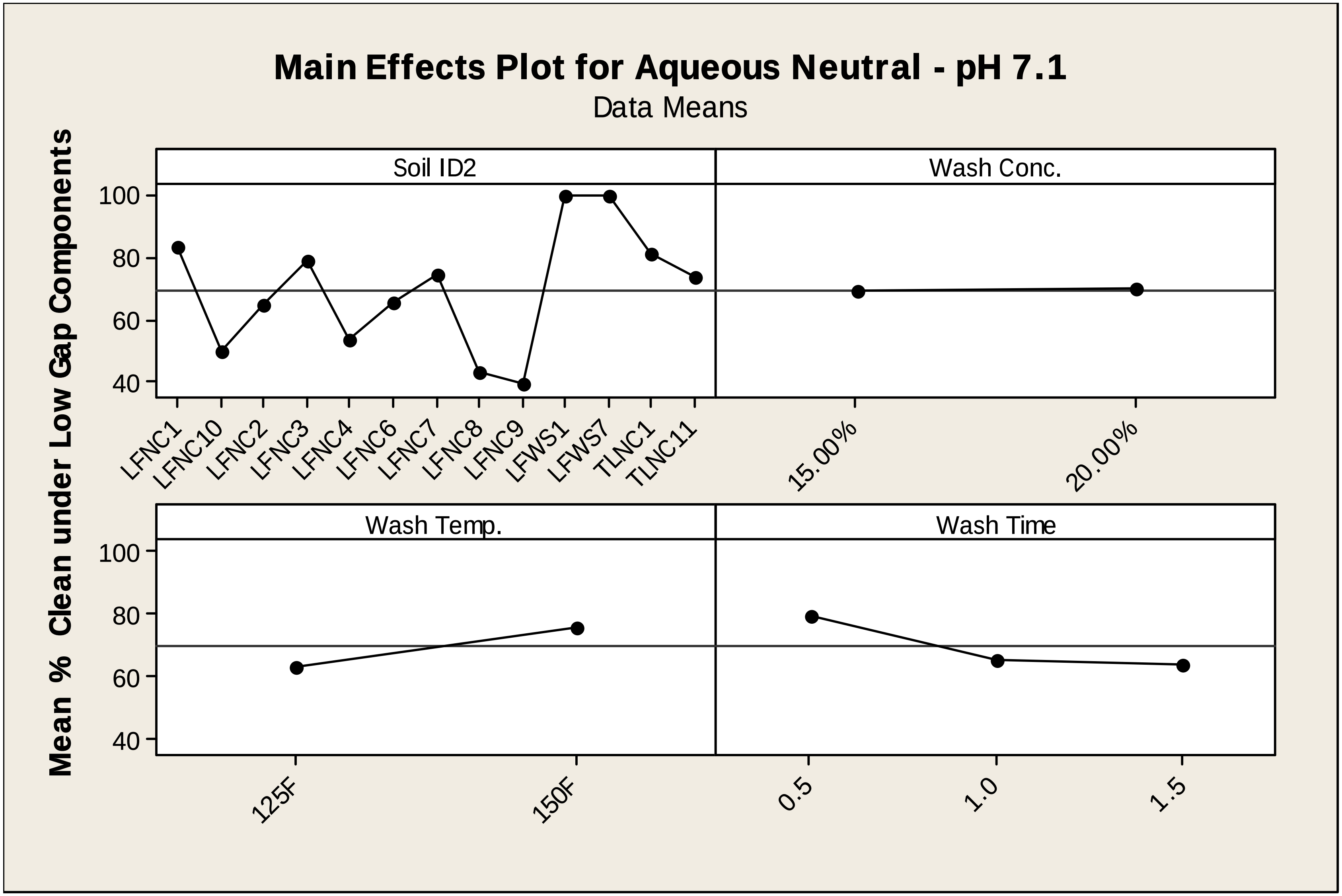
MSMR2 Dynamic Cleaning



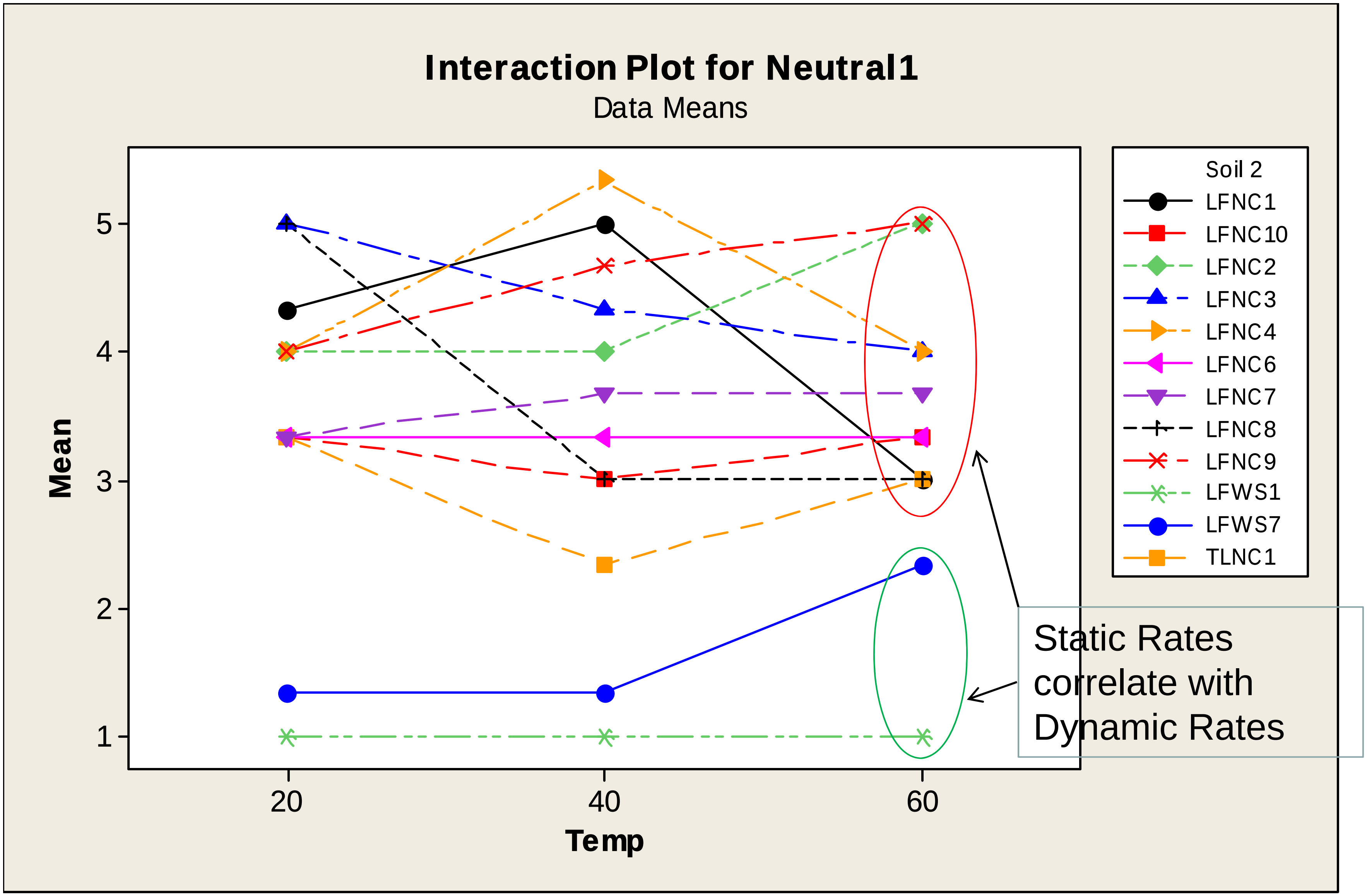
MSMR2 Static Cleaning Rates



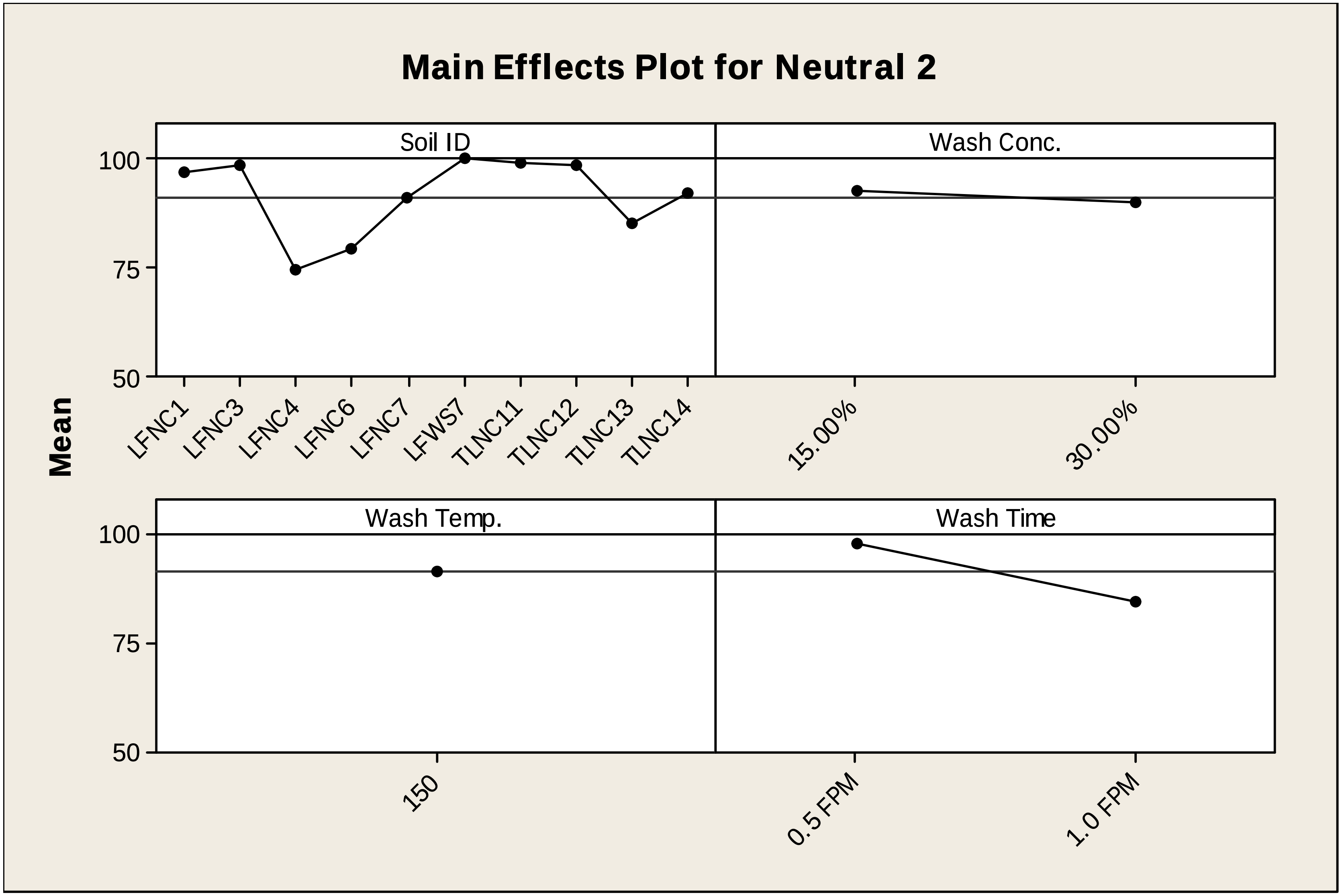
Neutral1 Dynamic Cleaning Rates



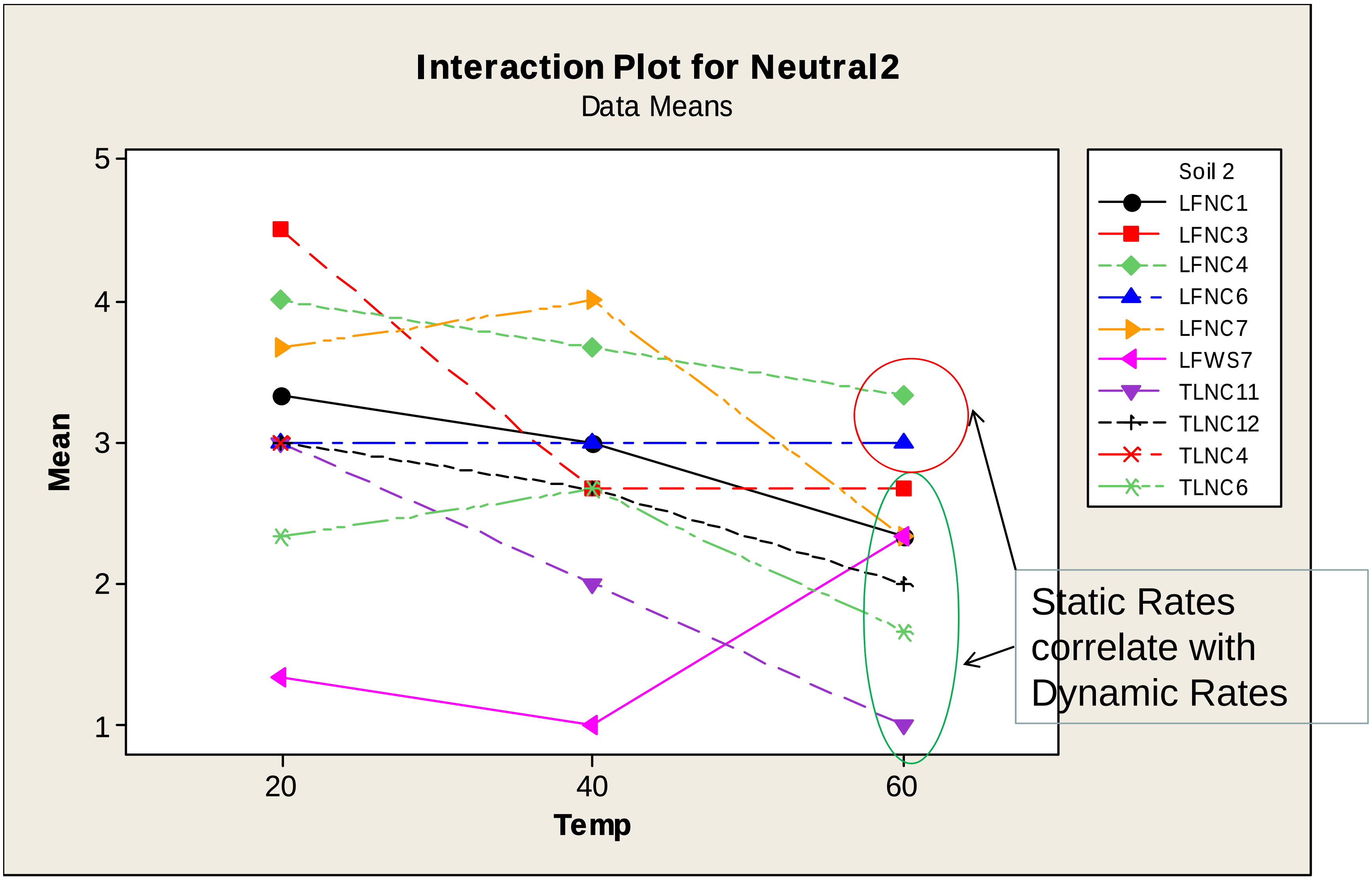
Neutral1 Static Cleaning Rates



Neutral 2 Dynamic Cleaning Rates



Neutral Static Cleaning Rates



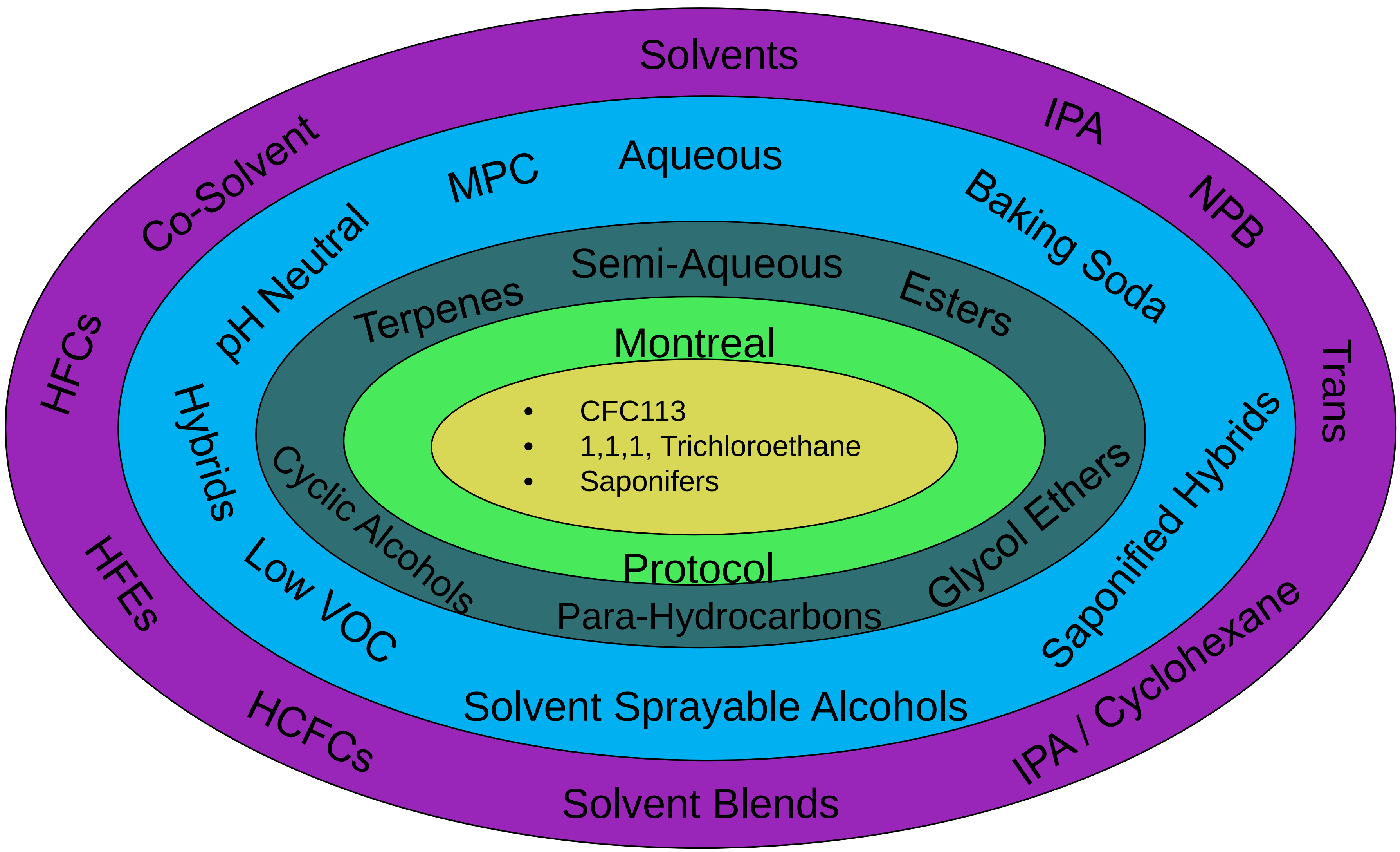
INFERENCES FROM DATA FINDINGS

Significant Findings

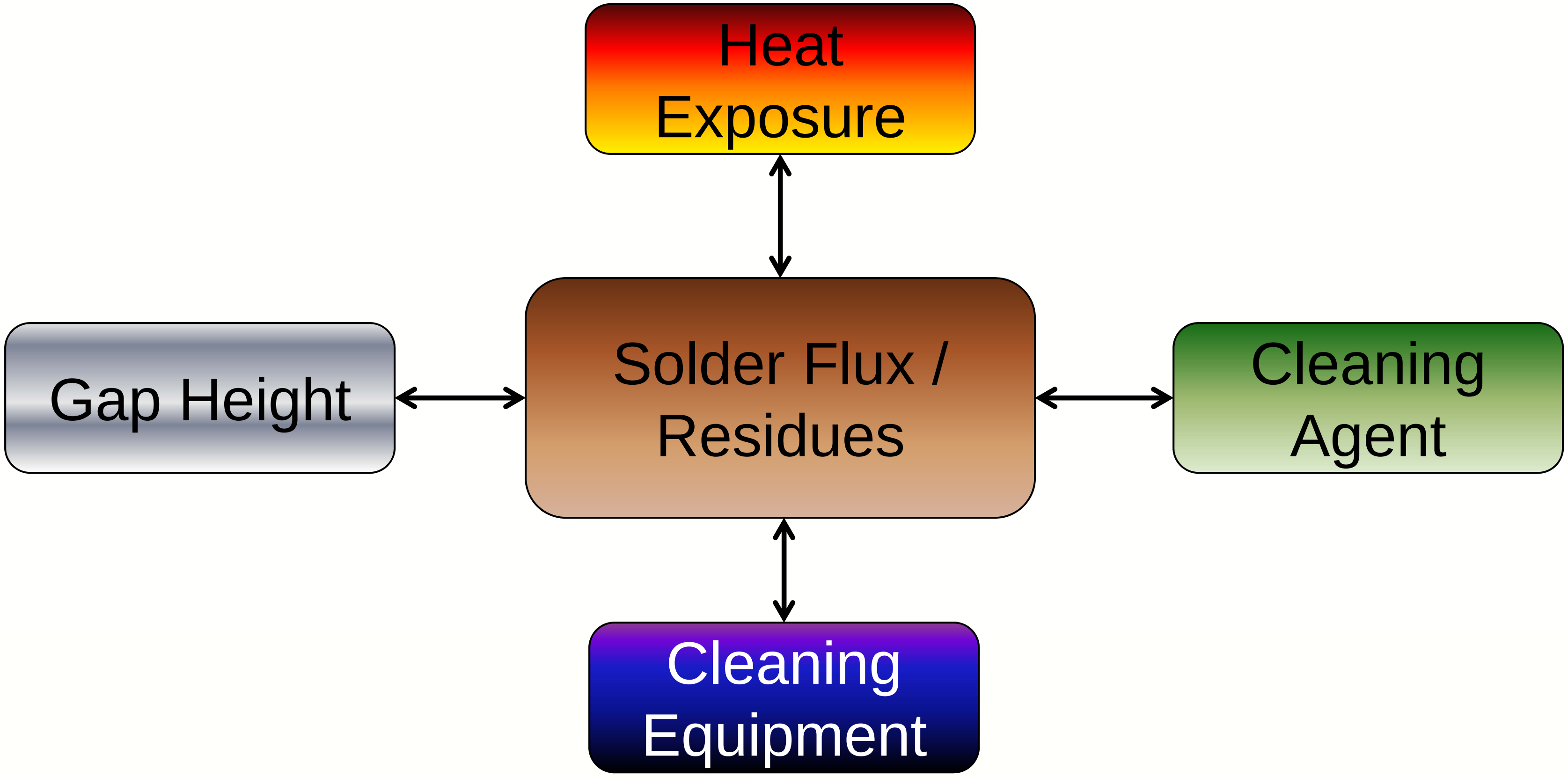
1. Static cleaning rates correlate with dynamic cleaning rates
   a) Model the cleaning process
   b) Identify significant factors
   c) Predict success/failure
2. Best cleaning agent matches with the
   a) Soil
   b) Part limitations
   c) Cleaning equipment

SUMMARY

Cleaning Agents Designs



Factors Affecting Cleaning



Questions