Cleaning Flux Residue under Leadless Components using Objective Evidence to Determine Cleaning Performance

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Abstract

Cleanliness is a product of design, including component density, standoff height and the cleaning equipment's ability to deliver the cleaning agent to the source of residue. The presence of manufacturing process soil, such as flux residue, incompletely activated flux, incompletely cured solder masks, debris from handling and processing fixtures, and incomplete removal of cleaning fluids can hinder the functional lifetime of the product. Contaminates trapped under a component are more problematic to failure. Advanced test methods are needed to obtain "objective evidence" for removing flux residues under leadless components.

Cleaning process performance is a function of cleaning capacity and defined cleanliness. Cleaning performance can be influenced by the PCB design, cleaning material, cleaning machine, reflow conditions and a wide range of process parameters. This research project is designed to study visual flux residues trapped under the bottom termination of leadless components. This paper will research a non-destructive visual method that can be used to study the cleanability of solder pastes, cleaning material effectiveness for the soil, cleaning machine effectiveness and process parameters needed to render a clean part.

The test vehicle for this research study will be an engineered glass ceramic test substrate. The test substrate is transparent, precise and can be used for repeated studies. The ceramic engineered components are mounted to the substrate in a series of columns and rows. The standoff gap is 60µm and gap between components is 300um. Flux vehicles from many industry specific no-clean solder pastes will be included in this study. The response variable of the percentage of flux cleaned under the ceramic dies will be collected using an AOI machine and from optical imaging. This study will report the potential for cleaning flux residues trapped under leadless components when processed in aqueous spray batch cleaning tools using a next generation cleaning agent.

Introduction

The cleanliness process of J-STD-001 Section 8 in all revisions up through Revision F, were based on ROSE (Resistivity of Solvent Extract) testing. ROSE Testing, developed in the 1970s, with the established 1.56 µg NaCl equivalence / cm^2 metric, should be considered obsolete [1]. A small working group of IPC members was tasked to come up with other methods that an assembler can use to obtain process acceptance. The objective of the working group is to address clean and no-clean processes, process validation, and process monitoring.

The team working on improved methods for obtaining product acceptance define a "Qualified Manufacturing Process (QMP)" as follows [1]:

- Unless otherwise specified by the User, the Manufacturer **shall** [N1D2D3] qualify soldering and / or cleaning processes that result in acceptable levels of flux and other residues. Objective evidence **shall** [N1D2D3] be available for review. See J-STD-001 Appendix C for examples of objective evidence.
- The use of the historical 1.56 µg/NaCl equivalence / cm^2 value for ROSE, <u>with no other supporting objective evidence</u>, is not considered an acceptable basis for qualifying a manufacturing process.

- Unless otherwise specified by design, or by the User, the acceptability of the residue condition **shall** [N1D2D3] be determined at the point of the manufacturing process just prior to the application of conformal coating, or on the final assembly if conformal coating is not applied. Rework processes **shall** [N1D2D3] be included in the process qualification.

Key Concepts

- ROSE testing for product acceptance (pass-fail) is an **obsolete** practice for determining **acceptably** clean
- ROSE testing for process control is perfectly acceptable, but the numbers have to MEAN something. And those values need to be scientifically / statistically determined.
- There is no ONE set **value** that defines the line between acceptably clean and unacceptably dirty
- There is no ONE **method** to determine acceptably clean and unacceptably dirty

Two testing levels are defined in the standard for requalification and for validating the current cleaning process.

Level 1 (Requalification Required)

- Flux or flux-bearing materials (e.g. flux, solder paste, paste flux, cored wire solder)
- Cleaning agents (e.g. solvents, aqueous detergents, topical cleaners)
- Changes in manufacturing suppliers
- Changes in solder mask type
- Changes in printed board fabrication processes or surface metallization
- Geographic change in manufacturing location

Level 2 (Objective Evidence)

- Changes in cleaning parameters (e.g. belt speed, pressures, temperatures) beyond the process windows established during process qualification.
- Changes in reflow profiles (wave solder, SMT reflow, selective solder) beyond the process windows established during process qualification
- Changes within a manufacturing location

Cleaning in Electronics

Removal of process residues is common practice to reduce the risk of dendrites and leakage currents from printed circuit boards. Visual inspection of flux residues is a common practice and considered the first step in obtaining objective evidence that the cleaning process is achieving the desired cleanliness levels. Today's high density circuit boards are increasing the use of leadless and bottom terminated components. As these leadless components reduce in size, the standoff gap and distance between conductors narrows. Another complexing factor is the higher thermal mass of solder placed under bottom terminated components. These conditions increase the potential for the flux residue to underfill the bottom termination. Additionally, the channels for flux activators to outgas can become blocked.

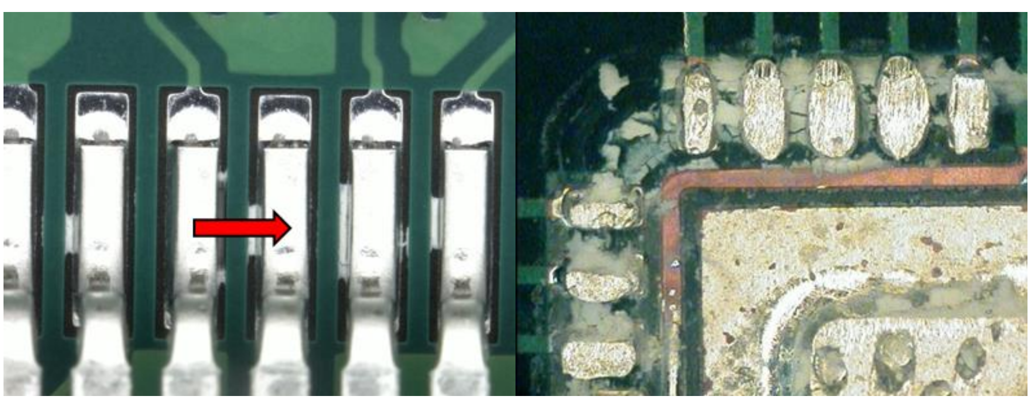

Figure 1: Visual Residues on Leaded Components compared to Residues under Leadless Components

From a reliability perspective, the flux residue trapped under the bottom termination may be problematic due to the residue being wet, pliable and active. For electronics exposed to humid environments, ionic contamination within the flux residue can become mobilized. The mobilized flux residue can dissolve metallic oxides present in the flux residue and at the pad area. When the part is biased, these metallic oxides can form leakage currents and dendritic growth. Flux residues under components are at the highest risk for electrochemical migration. As a result, cleaning is needed to improve reliability of the electronics, especially when the device is subjected to harsh environments.

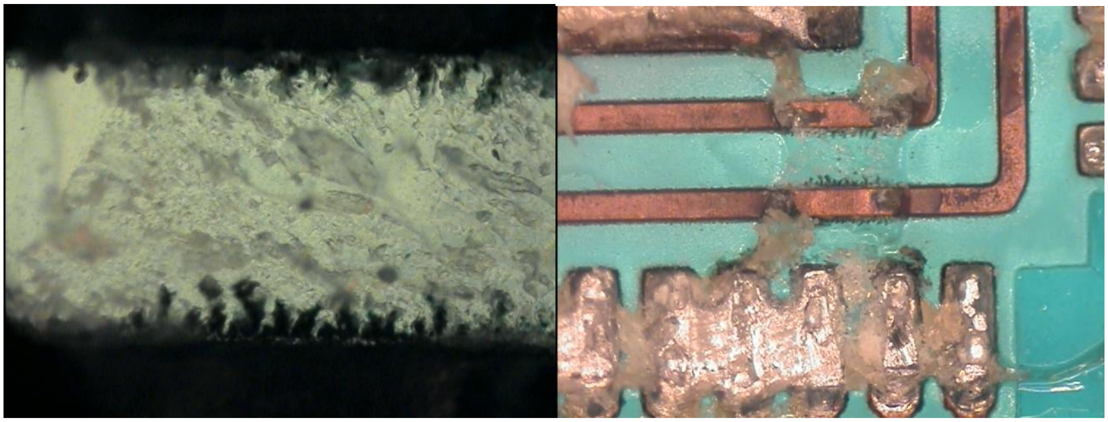

Figure 2: Residues trapped under leadless components forming leakage currents and dendritic growth

Most cleaning processes are very effective at removing flux residues on the surface of the circuit board and next to leaded devices. Visible residue is much easier to clean than residues under leadless components. One of the challenges that assemblers faced is the inspection process. Residues under leadless components are hard to visually see and inspect for. Desoldering components can distort the residues present under the bottom termination. The heat applied to remove the component can dissolve the flux residue and allow it to flow under the component.

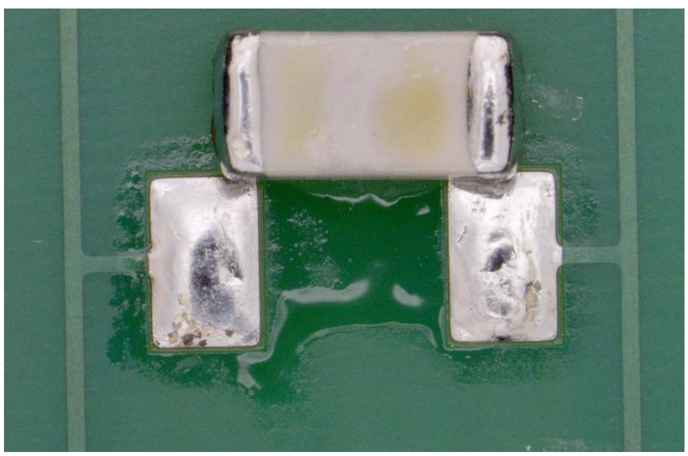

Figure 3: Desoldering Components can cause flux residue to flow under the component termination

Component Shearing is a technique that can be used to destructively remove the component without distorting the residue pattern. This technique is highly useful but requires a new a test board for each condition evaluated. As a result, this technique is done during process validation but used infrequently to monitor production processes.

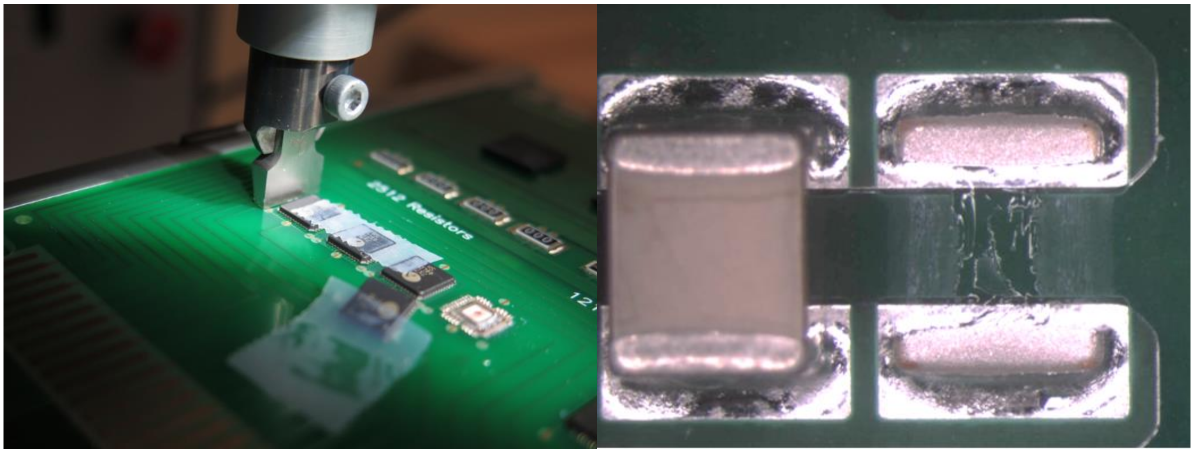

Figure 4: Shearing component to inspect for residues and electrochemical migration

Research Purpose

The purpose of this research study is to develop a method to inspect for visible flux residues under leadless components. The method is designed to address the requirement for visible residue as called out in Section 8 of J-STD-001. The standard states:

Assemblies subjected to cleaning processes shall [N1P2D3] be free of visible residues which violate minimum electrical clearance, unless the visible residues have been identified as benign through laboratory analysis or other means. All other visible residue requirements shall [N1P2D3] be AABUS [2].

- Residues which DON'T violate MEC are not a defect
- Residues which DO violate MEC are not a defect if you have objective evidence that the residue is not a reliability risk
- All of this can be over-ridden with AABUS

Test Vehicle

Ceramic test substrate is a precise model of a printed circuit board populated with leadless components. The test substrate is populated with 400 ceramic 0805 resistor chip caps. They are sealed to a glass substrate with a patent pending technology. The resistors have a standoff gap of 60um. The roads and streets within the component matrix are 300um.

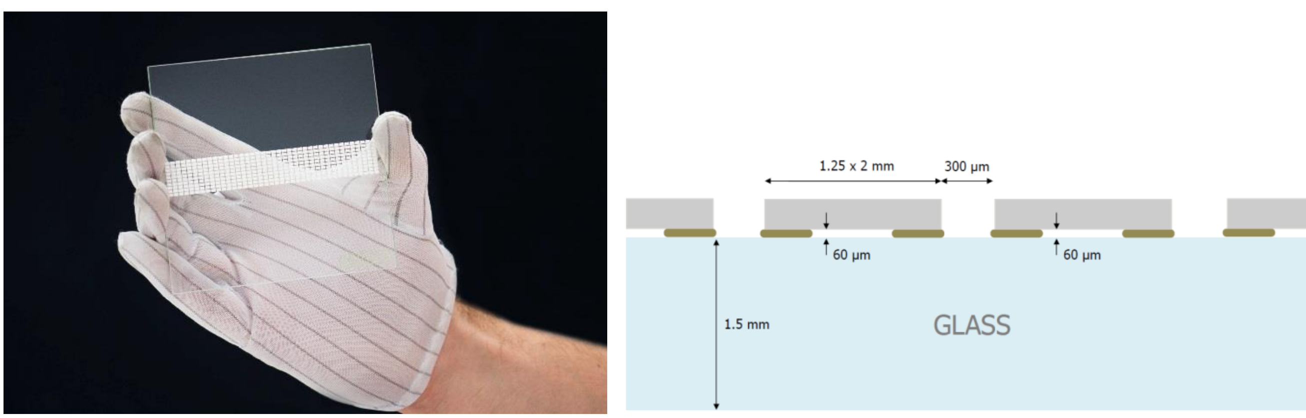

Figure 5: Ceramic Glass Test Vehicle

The test substrate is designed to be under filled with the flux component of the solder paste. The flux is heated on a hot plate to allow the flux to flow under the components. Following this process, the part is run through the reflow oven to correlate with the printed circuit assembly conditions. The residue patterns can be visibly or optically inspected after each cleaning cycle.

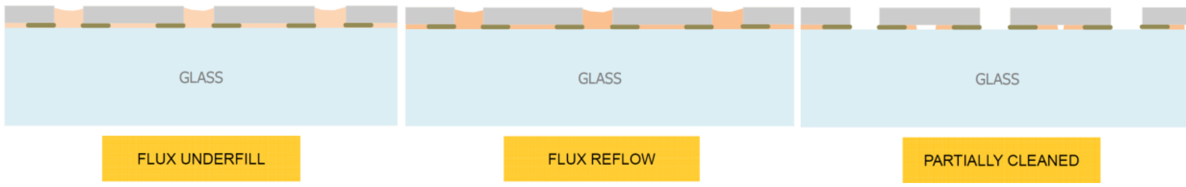

Figure 6: Preparing the Glass Slide for Cleaning Evaluation

Visual inspection can be done using automated optical inspection (AOI) or with the use of a standard microscope. The test vehicle is designed to allow for multiple cleaning cycles to determine the time required to remove all flux residues under components. This progression allows an assembler to dial in the process. Assemblers can compare cleaning agents, cleaning machines, reflow conditions, wash-temperatures, wash-times and other factors. Visual inspection can be accomplished without the need to remove the component. This method is non-destructive and provides insight into the cleaning process window.

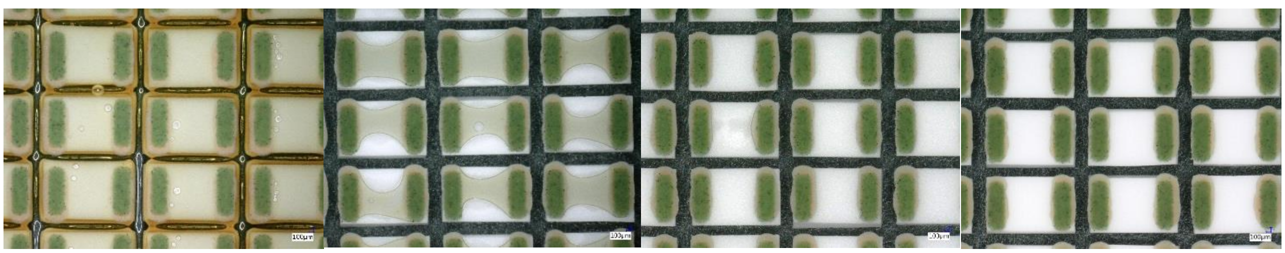

Figure 7: After Reflow with Three Cleaning Cycles to Total Clean

Design of Experiment

The factors and levels researched are as follows:

Solder Paste	Cleaning Machine	Nozzle span mm	Cleaning Agent	Wash Conc. %	Cycle	Wash Time min	Wash Temp. °C	Spray pressure Bar	DI Rinse I min	Rinse Temp °C	DI Rinse II min	Rinse Temp °C	Dry min	Dry temp °C	ID %	AOI	Total washing time

1. Solder Paste
    a. 5 – LF No-Clean
    b. 1 – LF Water soluble
2. Batch Cleaning Machine
    a. Spray-in-Air (Spray Against Surface using Linear Spray Arms)
    b. Dishwasher Style using Linear Nozzle Arms
3. Nozzle Span
    a. Spray-in-Air ~ 80 mm - 110mm (Distance Face- to Face of both nozzle orifices. Distance nozzle face to PCBA face is about 55mm)
    b. Dishwasher Style ~ Distance Face to Face of nozzles is 700mm - lower nozzle to substrate was 650mm - lower nozzle to substrate center 180mm - upper nozzle to substrate center 740mm
4. Cleaning Agent
    a. Engineered Aqueous
5. Wash Concentrate
    a. 20% Wash Chemistry / 80% DI Water
6. Wash Cycles to Total Cleaning
    a. 1 cycle
    b. 2 cycles

        c. 3 cycles
        d. 4 cycles
        e. 5 cycles
7. Wash Temperature °C
    a. 50°C
8. Spray Bar Pressure
    a. Spray-in-Air Linear ~ 2.9 Bar
    b. Dishwasher Style using Linear Nozzle Arms 2,1 Bar
9. DI Rinse Cycles
    a. Cycle #1 ~ 1.1 minutes
    b. Cycle #2 ~ 2.2 minutes
10. Rinse Temperature
    a. 40°C
11. Dry Time and Temperature
    a. 10 minutes @ 110°C

Data Findings

The first set of tests were performed in a batch cleaning machine designed with linear direct spray arms for equal washing across the cleaning area. The linear spray arms track forward across the surface to the end of the cleaning area and then reverse back across the cleaning area for a pre-set number of cycles. It takes roughly 30 seconds for the linear spray arm to make one cycle before reversing direction. There are two linear arms, one for cleaning the front side of the printed circuit board and one for cleaning the back side of the printed circuit board. The spray nozzles are placed sequentially within the linear spray arms and are roughly 2 inches from the surface of the board being cleaned. The spray patterns are uniform across the entire cleaning area, which prevents shadowing effects.

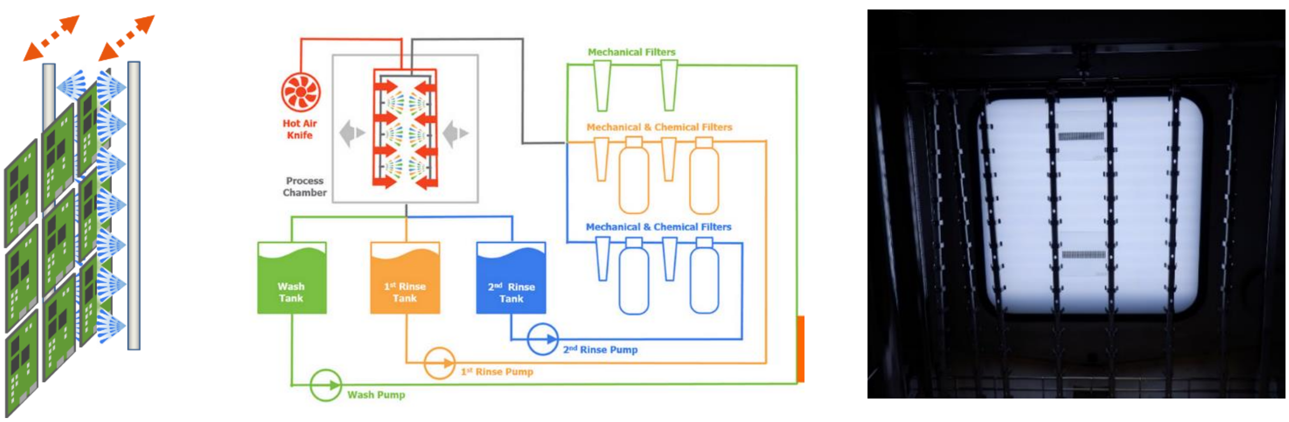

Figure 8: Spray-in-Air Cleaning Machine using Linear Spray Arms

For each solder paste within the cleaning study, the test board was cleaned and optically analyzed to determine the cleaning level under the 400 chip cap resistors. If residue remained, the board was placed back into the cleaning machine for consecutive cleaning cycles until the part was totally clean.

For the six solder pastes used for this research study, the data indicated that the solder pastes can be classified as follows:

- Highly Soluble Water Soluble Solder Paste
- Soluble No-Clean Solder Paste
- Marginally Soluble No-Clean Solder Paste

An automatic optical imaging machine (AOI) was used to analyze the level of flux left under the chip cap resistors. Figure 9 illustrates the scoring matrix. The flux level under the component is measured with specific ranges being shown with specific colors [3].

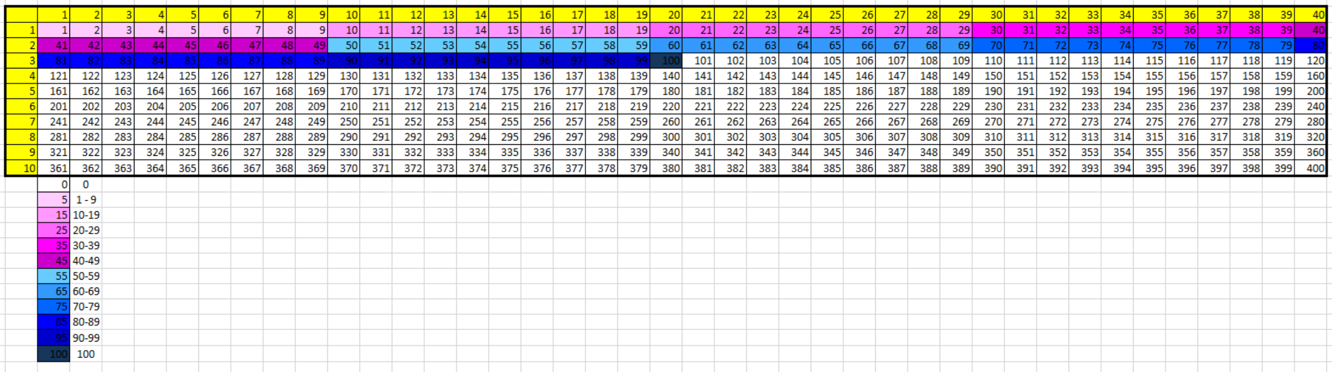

Figure 9: Scoring Matrix Based on Specific Colors for the Level of Flux Residue under Each Component

Figure 10 illustrates the AOI data for one of the soluble solder pastes.

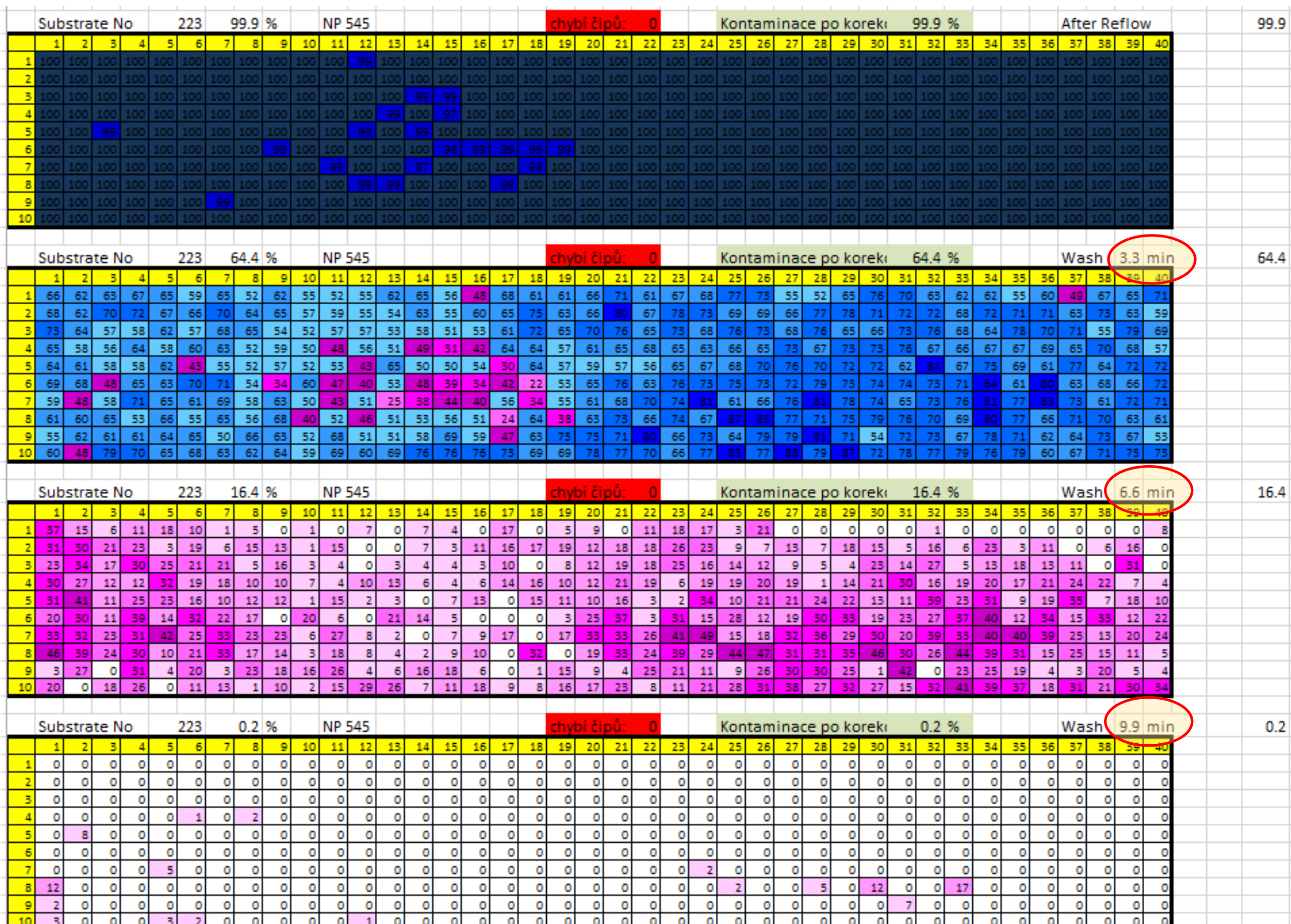

Figure 10: AOI scoring of one of the Soluble No-Clean Solder Pastes

The solubility of the solder paste in the cleaning agent dictated the number of cleaning cycles and the total amount of time required to totally clean all flux residues under the 0805 chip cap resistors. It took roughly 3 times longer to clean a soluble solder paste as compared to a highly soluble solder paste. When cleaning a marginally soluble solder paste, it took 10 times longer to clean over a highly soluble solder paste and 3 times longer to clean versus a soluble solder paste. Figure 11 summarizes the data findings for the six solder pastes run in the spray-in-air cleaning machine using the linear spray arms.

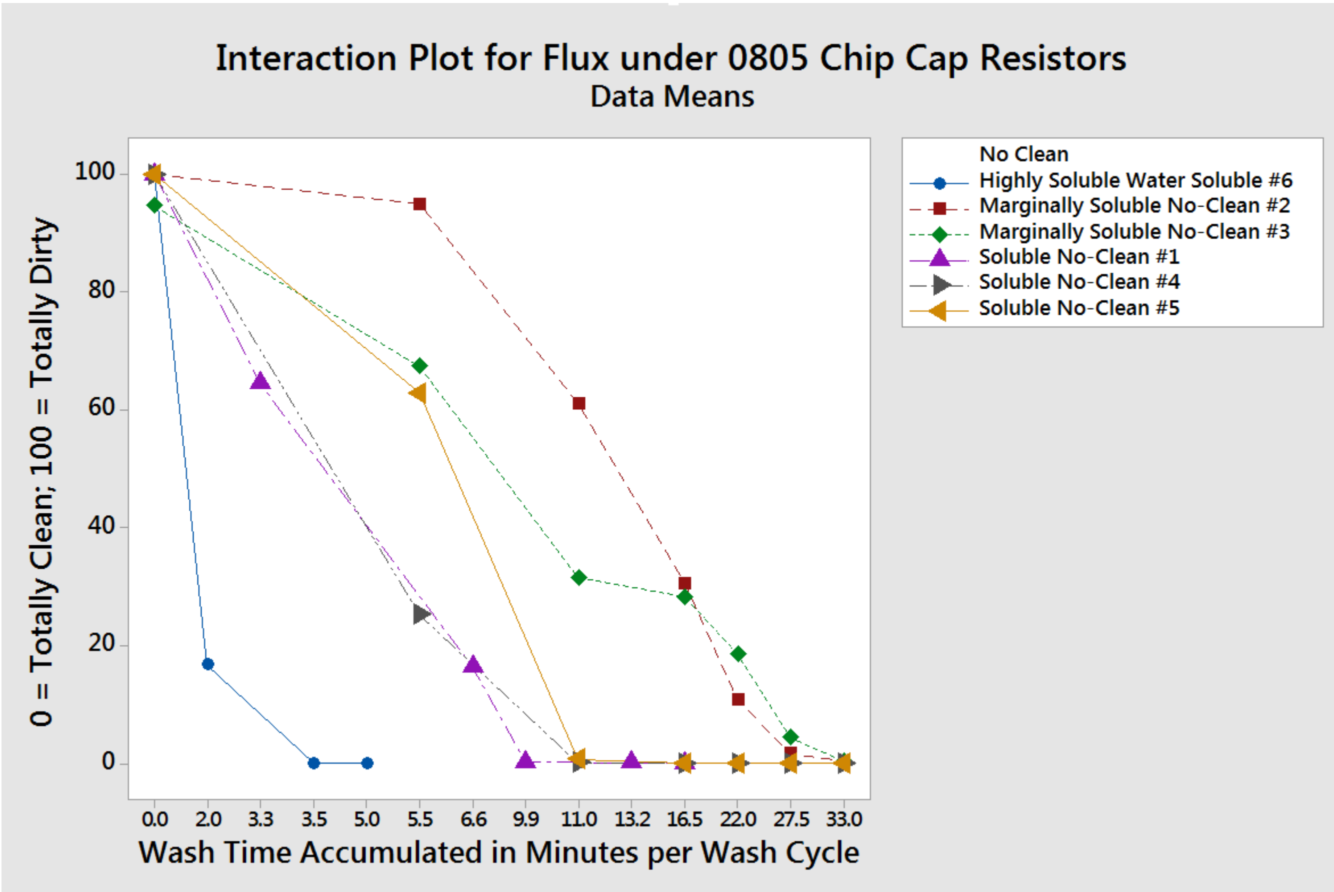

Figure 11: Wash Time required to Totally Clean Flux Residues under 400 Chip Cap Resistors

The second set of tests were performed in a dishwasher style batch cleaning machine designed with linear spray arms. The machine is designed with an oscillating rack to move the cleaning basket forward and backwards in an effort to reduce shadowing effects. The flow patterns in this dishwashing style machine create high flow to bombard the printed circuit board at all times with cleaning fluid during the cleaning cycle. The spray patterns are different than the linear spray-in-air manifolds, in that there is higher cleaning fluid flow across the assembly during the cleaning cycle but less direct impingement. Another difference is the linear spray-in-air impingement only bombards the assembly during the time the nozzles are in contact with the printed circuit board. The impact pressure is greater with the spray-in-air machine but the time of cleaning agent being delivered to the printed circuit assembly is far less.

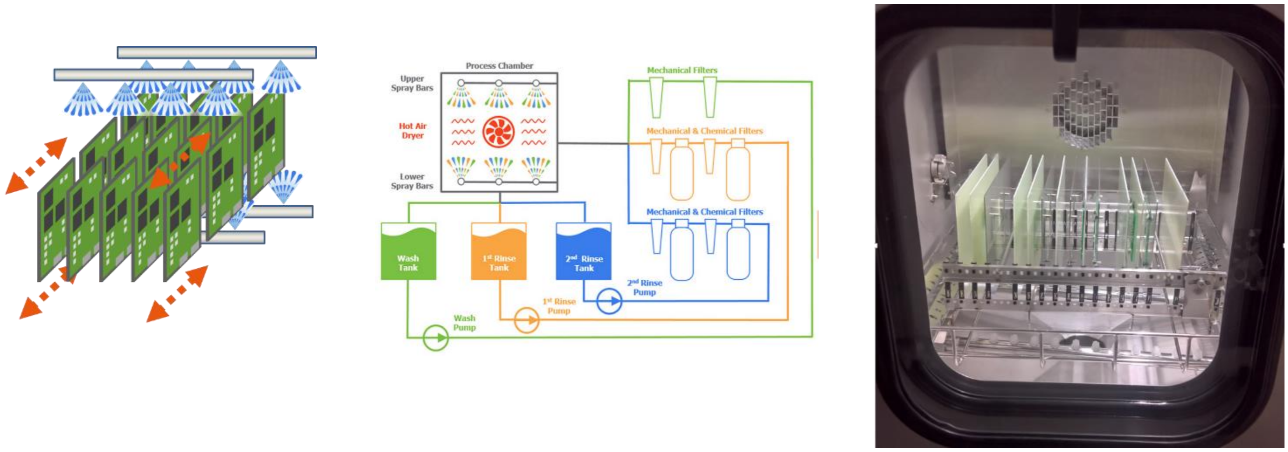

Figure 12: Batch Dishwasher Style Cleaning Machine using Linear Spray Manifolds

The AOI data for one of the soluble solder pastes using the dishwasher style cleaning machine designed with linear spray manifolds is illustrated in Figure 13.

Substrate No 223 99.7 % NP545 missing chips 0 Contamin after correction 99.7 % After Reflow

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	99	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
4	100	99	99	100	99	100	100	100	99	99	100	100	100	100	100	99	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100
5	100	100	100	100	100	100	100	100	99	99	100	100	100	100	99	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	99	97	98	100	99	100	100	100	100	96	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	100
7	100	100	100	100	99	100	100	99	98	96	99	99	98	96	100	99	100	100	100	100	100	100	100	100	99	99	100	100	100	99	100	100	100	100	100	100	100	100	100	100
8	100	100	99	100	100	100	100	99	98	97	99	91	96	96	99	100	99	100	99	100	100	100	100	100	99	100	99	99	100	99	100	100	100	100	100	100	100	100	100	100
9	100	100	100	100	100	100	97	96	99	96	100	97	98	100	100	98	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
10	100	100	100	99	100	99	100	100	100	99	99	99	100	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Substrate No 223 98.7 % NP545 missing chips 0 Contamin after correction 98.7 % Wash 10 min

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	99	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	100
3	100	99	100	100	99	100	100	100	98	100	99	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	100
4	100	98	98	99	95	100	99	98	98	97	98	99	99	100	99	98	99	100	98	98	99	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	100	96	99	100
5	99	98	98	95	100	100	100	100	96	99	97	96	98	96	97	99	99	100	99	99	99	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	97	89	100
6	100	94	100	100	98	100	99	97	99	87	92	96	99	98	92	99	98	90	100	99	99	100	99	100	100	100	99	100	99	100	100	99	99	100	100	100	97	96	97	100
7	100	99	99	100	97	99	99	93	96	96	94	95	88	90	79	98	99	94	100	99	100	100	99	98	95	97	100	100	100	97	99	100	100	100	100	99	97	97	100	100
8	100	100	100	99	98	100	99	98	91	98	94	76	88	87	93	98	93	100	88	99	99	97	100	100	100	99	99	94	100	99	100	100	98	99	100	100	100	100	99	100
9	100	99	100	100	100	99	96	89	98	90	95	96	92	99	98	89	99	98	100	100	99	99	100	99	99	100	100	100	100	100	100	100	100	99	100	99	100	100	100	100
10	99	98	100	98	99	98	100	98	98	99	96	96	99	97	100	99	99	99	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	97

Substrate No 223 65.8 % NP545 missing chips 0 Contamin after correction 65.8 % Wash 25 min

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	51	53	60	56	75	62	69	99	71	46	47	70	49	81	100	95	99	61	83	64	71	57	73	57	88	79	81	84	81	96	77	81	62	66	50	56	52	61	58	41
2	50	46	60	54	69	56	96	85	75	56	70	79	62	88	96	85	98	68	74	92	82	61	99	97	86	96	66	92	95	99	96	99	87	80	76	78	77	76	61	41
3	33	37	38	47	57	38	82	48	83	84	74	54	99	75	87	76	52	51	52	84	68	75	97	98	96	79	50	89	78	74	85	53	68	61	84	67	88	63	71	42
4	26	30	45	38	71	88	32	53	89	61	84	88	97	85	64	88	73	47	69	62	67	92	98	64	84	51	60	94	56	75	96	70	76	83	75	60	63	48	52	33
5	37	41	67	50	76	70	78	57	84	35	57	74	93	73	34	83	86	61	79	72	60	78	76	71	68	83	77	80	74	77	76	98	83	87	82	86	63	46	30	42
6	37	37	67	69	50	61	59	47	85	76	64	42	41	42	36	41	36	53	90	83	65	32	52	71	58	83	67	78	61	78	73	61	59	75	80	55	50	37	42	41
7	50	32	46	89	74	59	60	29	50	71	76	56	40	47	28	57	82	52	63	42	54	64	53	59	88	69	57	62	79	35	52	65	74	91	69	56	39	45	53	34
8	60	50	75	47	73	76	94	57	76	78	68	45	52	61	85	61	48	66	34	75	84	41	69	51	98	88	67	73	72	66	77	70	55	98	74	75	57	62	56	30
9	47	28	99	33	53	39	67	54	87	33	85	67	56	76	94	80	55	45	80	89	91	78	61	88	66	90	72	96	58	80	70	70	70	86	64	57	62	64	59	20
10	36	37	44	32	46	38	53	79	42	64	81	64	57	66	80	86	55	53	69	57	65	66	52	72	60	66	69	68	62	72	70	61	76	66	43	57	60	50	46	37

Figure 13: AOI data for a Soluble Solder Paste using the Dishwasher Style with Linear Spray Manifolds

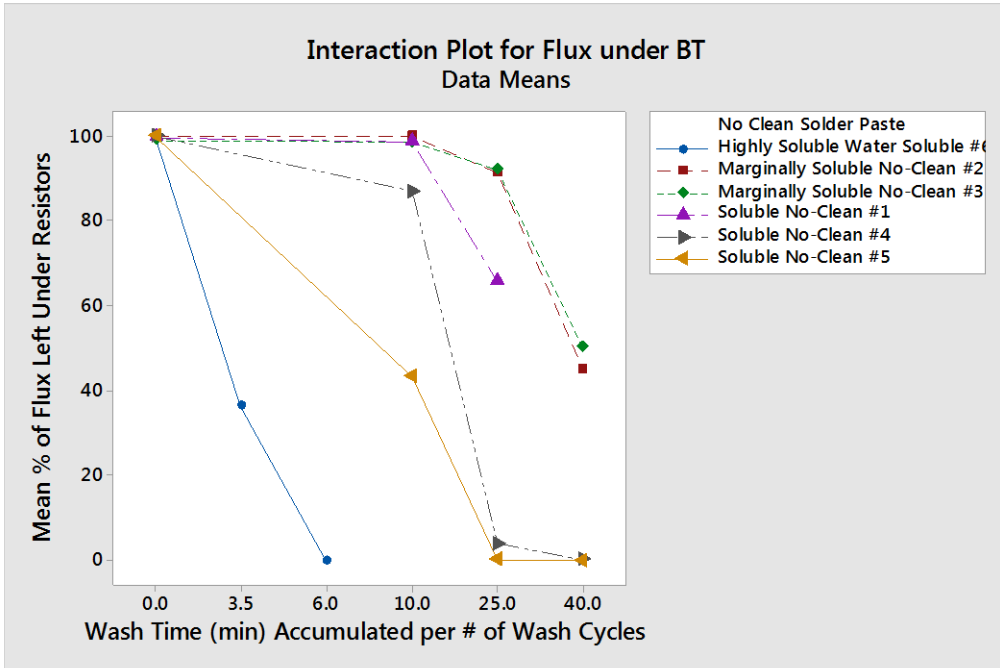

Figure 14: Batch Dishwasher using Linear Spray Manifolds Cleaning Data

The data finds that the dishwasher style machine left significantly more residues under the chip caps. At 25 minutes of wash time, 65.8% of the flux residue was left under chip cap resistors. Conversely, at 12 minutes of wash time using the spray-in-air batch machine with linear spray nozzles, the test board was totally clean. A Comparison of the both the rate function and cleaning performance are illustrated in Figure 15, 16 & 17.

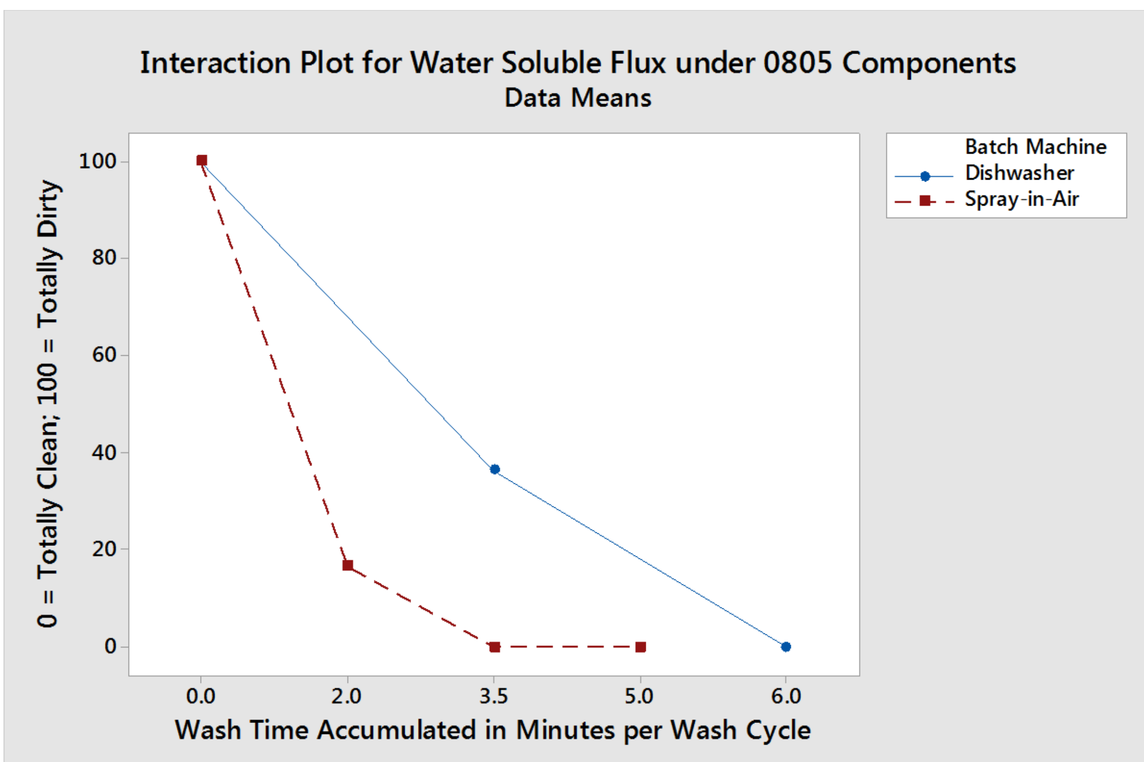

Figure 15: Water Soluble Flux Cleaning Comparison in Dishwasher versus Spray-in-Air

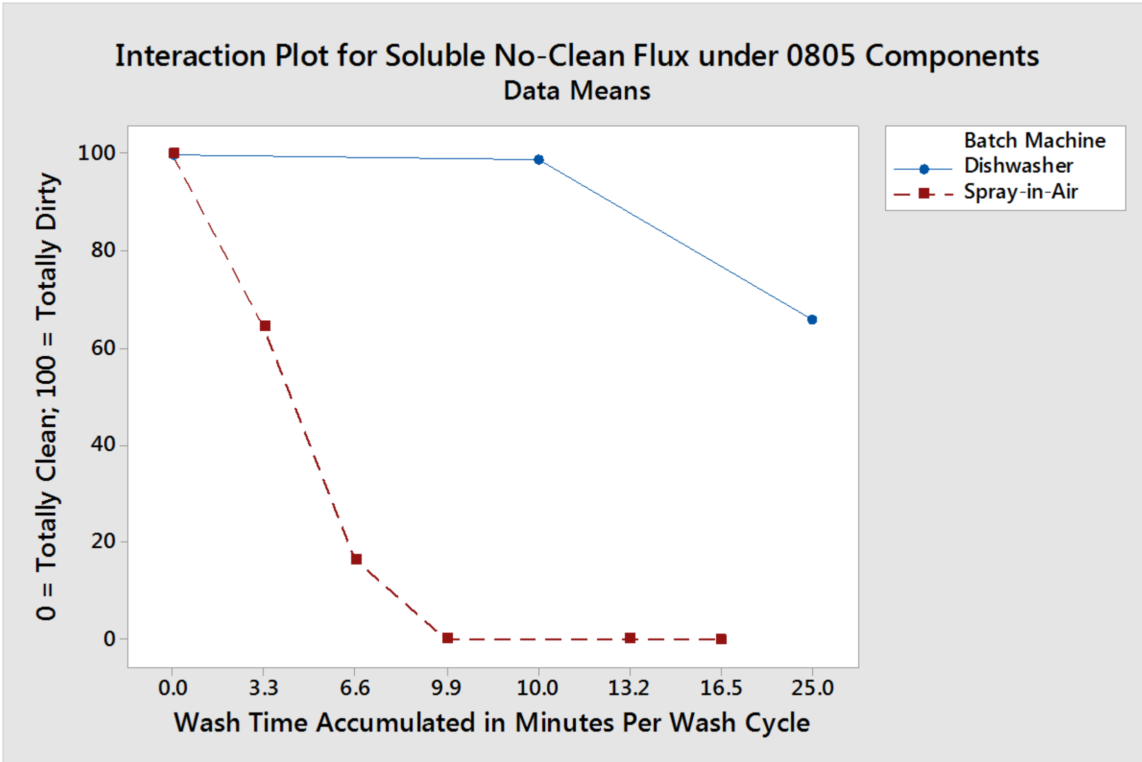

Figure 16: Soluble No-Clean Flux Cleaning Comparison in Dishwasher versus Spray-in-Air

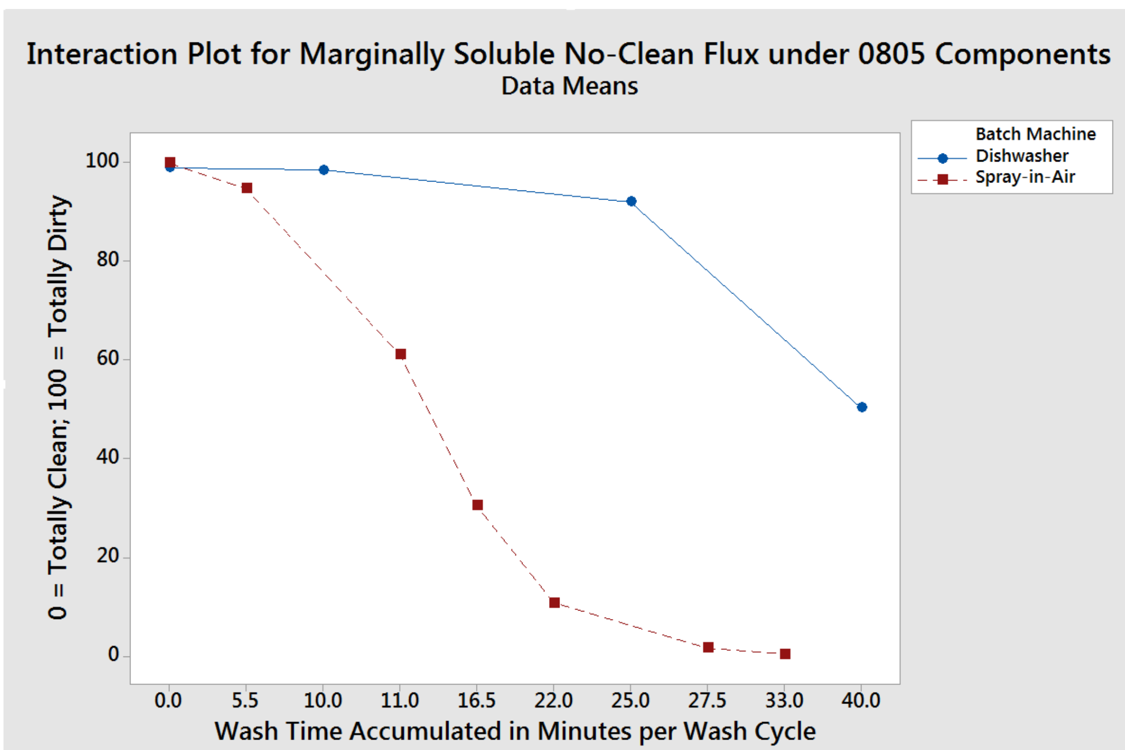

Figure 17: Marginally Soluble No-Clean Flux Cleaning Comparison in Dishwasher versus Spray-in-Air

Inferences from the Data Findings

To visibly clean all process residues, several factors must be dialed in to achieve desired cleanliness levels. The data findings provide insight into a number of these factors:

1. Solder Pastes
    a. The cleanability of the flux residue varies across different solder pastes.
    b. <u>**Water soluble**</u> solder pastes are hydrophobic and clean well with DI water. For the water soluble solder paste used in this study, the time required to clean this solder paste was **less than 5 minutes** of total wash time using the spray-in-air cleaning machine using linear spray arms. When cleaning the water soluble solder paste in the dishwasher style batch machine, the solder paste was completely removed at or about a **10 minute** wash cycle.
    c. When cleaning a <u>**soluble no-clean**</u> solder paste, the wash time ranges from **10-15 minutes** using the spray-in-air cleaning machine and **20-25 minutes** when using the dishwasher style batch machine.
    d. For the <u>**marginally soluble no-clean**</u> solder pastes, the wash time ranges from **25-35 minutes** using the spray-in-air cleaning machine and over **40 minutes** of wash time when using the dishwasher style batch machine.
    e. Other factors such as the reflow condition and the time following reflow can impact the cleaning time of the flux residue.
2. Cleaning Agent
    a. The cleaning agent static cleaning rate for dissolving the flux residue will impact the time to clean.
    b. For this study, a next generation aqueous cleaning agent was used. This cleaning agent is designed to remove all flux types. The cleaning agent has a wide compatibility profile for all metals, components, part markings and plastics. The cleaning agent has a clean safety data sheet and a safe product for the workplace.
    c. Wash temperature can improve the cleaning rate. For this experiment, the cleaning temperature was run at 50°C.
    d. Wash concentration can also improve the cleaning rate. For this experiment, the wash concentration was 20% cleaning agent / 80% DI water.
3. Cleaning Machine
    a. Leadless and Bottom Terminated Components trap flux residues under the body of the component.
    b. At standoff heights lower than 75µm, flux can accumulate and totally under fill the bottom termination of the component. To clean under these low standoff components, the cleaning machine must have sufficient deflection energy to wet, dissolve and create a flow channel under the body of the component in order to clean the part.
    c. Cleaning machines with higher deflection energy, reduce cleaning time.
4. Test Vehicle
    a. The ceramic – glass test vehicle populated with chip cap resistors can be used to dial in the cleaning process and create objective evidence for removing flux residues trapped under leadless components.
    b. The test vehicle can be processed over multiple cleaning cycles to determine the total time required to clean the flux residue.
    c. Automated Visual Inspection (AOI) instrumentation can be used to quantitatively score the level of flux residue left under the component following each cleaning cycle. This unbiased metric provides data than can be statistically analyzed to make accurate process decisions.
    d. The component does not need to be removed to determine the level of flux left under the component.

Conclusions

Cleaning is considered a "black art" by many. With residues trapped under leadless and bottom terminated components not being accessible for visual inspection, an assembler has to either desolder or shear the component to inspect for errant residue. Visible residue with minimal electrical clearance can cause reliability risks when the products are exposed to humid environments, high voltage and high temperatures. Problematic visible residue lead to a false / positive condition when dialing in the cleaning process. The selection of the cleaning agent or cleaning machine may not be the best choice for the board type and process residues.

A test vehicle that provides objective evidence for visible residue left under component terminations provides the assembler with an accurate metric for dialing in the visual cleaning of process residues. The test vehicle helps the process engineer test for changes in cleaning parameters, such as the cleaning machine, wash time, wash chemistry, wash concentration, wash pressures and wash temperatures. They have the ability to monitor the process window established during process qualification. The assembler can use this test vehicle to determine the solubility properties of the flux residue when changing reflow profiles beyond windows established during process qualification. The test vehicle can be used to determine the differences in cleaning machines and manufacturing location.

The methods reported in this research study provide valuable objective evidence required for building reliable electronics as defined in the IPC-J-STD-001G Requirements for Soldered Electrical and Electronic Assemblies [2].

References

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