Monitoring the Cleaning Process using Industry 4.0 Methodology

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Abstract

Assemblers of printed circuit boards seek to provide their customers with high-quality products at the lowest possible cost. The total cost of production must take into account the complete product lifecycle including warranty, recalls and repairs. Systems designed to achieve optimal use of materials and resources through the cleaning process can provide process engineers valuable information for reducing part to part variation and improved quality.

Industry 4.0 tracking, monitoring and data analytics systems applied to the cleaning process can give process engineers real-time process information and quality data. An external data acquisition system utilizing analog-to-digital, digital I/O, encoder interface and barcode reading capabilities gives process engineers data on each board processed through the cleaning system. Reflow conditions, wash chemistry control, temperature probes, pressure transducers, pressure switches, DI water resistivity and encoders can be integrated to monitor, track and accumulate data for real-time analytics.

Applying analytics to the cleaning process improve quality and consistency lot to lot. Analytics gives process engineers the ability to gain insight from process data monitored and tracked while cleaning production assemblies. They allow engineers to identify common threads and valuable intelligence about system operations. Traceability of cleaning process conditions is a sure proof of compliance. This designed experiment monitors reflow and cleaning process conditions over an extended period. Data analytics will be applied to data from production PCB cleaning operations. Process issues discovered and proactive actions to keep the system in control will be reported.

Contaminated Related Reliability Issues

Increased density and smaller form factor components are driving the industry toward a higher risk for electrochemical interactions from contamination present under component terminations.[1] Current leakage can lead to signal integrity loss due to a combination of board layout, assembly process, and sources of contamination. As component densities tighten, reduced spacing between conductors increases failure mode opportunities for signal integrity/signal loss. Increased component density also reduces standoff heights within the Z-axis of leadless and bottom terminated components. As standoff heights approach 30-50µms, there are smaller cubic areas for flux to outgas properly. Flux trapped under components can be active, even when using a no-clean solder paste.[2] Mobile ions within the flux residues form leakage currents and voltages, mainly when the device is operating within humid environments. Flux residue can contain ionic residues, which when trapped under a component can lead to shorts across adjacent pads, or voltage / current leakage pathways.

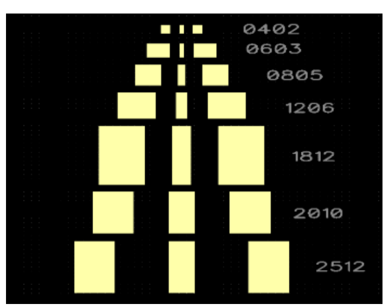


Figure 1: Example of Resistors with Reduced Spacing between Conductors

Companies who require devices to meet long-term reliability/warranty expectations need improved industry test specifications, monitoring, and tracking that allows for a stream of process knowledge that leads to improvement. Current measures of "clean" do not measure whether the product is clean enough across all components and process conditions.[3] The problem is that the risk assessment is a multi-variable issue influenced by flux type, flux make up (activators and inhibitors), activation temperature, component type, and placement. Cleaning circuit boards can also be misleading. Most cleaning processes remove all visible flux residues. Residues trapped under leadless and bottom terminated components are more laborious to both clean and inspect. Numerous research studies find that partially cleaned flux residues under these component types are problematic.

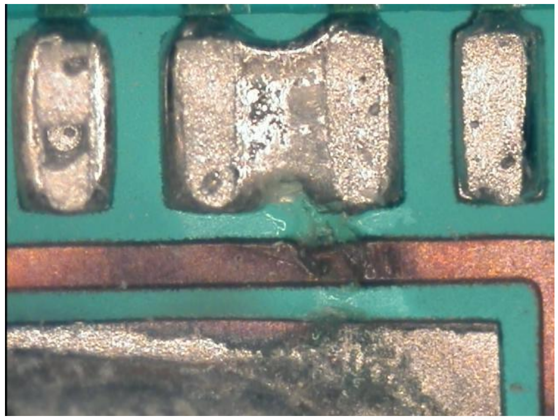


Figure 2: Residue remaining under the Bottom Termination can cause Leakage Currents and Dendritic Growth

Designing in reliability for cleanliness starts by defining the assembly process conditions, materials and their interaction. Characterizing risks due to material choices, and their interaction over the assembly process provides the OEM / design engineer with data for defining component types, solder material selection, processing/ building requirements, cleaning conditions and protective sealants. Designing the product layout is not trivial. Processing rules and requirements are needed to help accurately build a risk assessment. The process objective requires data that defines the optimal material choice and processing steps along with a cleaning specification that defines handling as well as cleaning and coating levels needed to meet long-term objectives. The highest risk for failure is residue trapped under leadless and bottom terminated components.[4] Industry 4.0 helps the process engineer understand the risks associated with cleanliness. Tightening process tolerances and maintaining parameters within this window is essential to meeting long-term reliability and warranty expectations. Any mistake in this realm could jeopardize the long-term reliability of the product and thus threaten human life as well as the OEM's financial viability.

The last part of the equation after the process specification is to minimize cleanliness risks by process monitoring and traceability. Monitoring and traceability enable the lot to lot repeatability. This allows the OEM to monitor and perform design verification and product reviews as well as periodic audits to ensure that everything is still in control and no variable has deviated from the norm or process control parameters. Monitoring ensures electronic designs meet reliability expectations by understanding quantitative failure rates, evidence of product and test capabilities, sound procedures for process control and a defined material control policy to ensure product and corrective action plans for identified weaknesses on a lot by lot basis. Taking this level of discipline enables sound procedures for building products that will meet and exceed expectations.

Industry 4.0 Improves Risk Mitigation

Industry 4.0 is the next level of digitization. Digital technologies enable the ability to capture data. Data collection combined with analytics provide real-time process outputs and speed up decision making. Generating useful insights from the data allow process operators to act on those ideas. This real-time information helps them to develop the process window, optimize process settings and reduce downtime. The intelligence helps the process operators to learn, reduce variability and to form a repeatable and reproducible product.

The first step is to automate manual process steps. Monitoring and tracking process data can be achieved by tracking the assembly using RFID tags or barcodes. Sensors strategically placed within the cleaning process capture the conditions that each assembly sees during the cleaning process. Analytics programmed within the system software provides process operators with real-time data outputs for monitoring the process. The inputs can be equated to knowledge. This knowledge sends corrective factors to clean production assemblies within the process window. The integrated system enables the process engineer with the capacity to learn and improve. Real-time diagnostics creates an intelligent system that works interactively.

Cleaning process test methods that quantitate the limits of ionic contamination and resistance values allow the process engineer to determine cleanliness levels for building reliable hardware. A record of the cleaning process conditions for each assembly cleaned provides for a better response to root cause analysis and warranty claims caused by contamination. The use of analytics to sift through warranty claims to identify common threads helps the engineer to have a deeper understanding of quality issues. The company gains valuable intelligence that can be fed back to failure analysis work. Developing insights on a real-time basis creates visibility onto quality issues. These issues can be quantified, focused on and fixed.

Cleaning Process Control

When cleaning is required, a three-phase approach is used to validate the cleaning process.[5]

- Phase 1: Screening experiments with inexpensive test vehicles
- Phase 2: Validation experiments with more representative test vehicles
- Phase 3: Verification runs on manufactured assemblies (e.g., first article inspection)

Once a manufacturing process is validated, process engineers set up process controls to create a tight process window. A process capability index (C_{pk}) is used to measure how close to the target as well as the consistency around the average target. A $C_{pk} > 1.33$ (4 sigma) is preferred.

Aqueous Spray-in-Air cleaning processes are commonly used to remove process residues, specifically flux residues, from printed circuit assemblies following the soldering process. Cleaning machine designs either come in a batch or inline format. The aqueous cleaning fluid comes in a concentrated form that goes into DI water at concentration ranges from 5-30%. The cleaning solution is typically heated to a range of 50-70°C. When spraying the cleaning fluid onto the PCB, losses occur from exhaust and drag-out.

Process control methods are needed to monitor and add both cleaning agent and DI water to the wash holding tank. The methods used within the industry are classified as follows:

- Manual Control: A sample of the wash tank is taken over the course of assembly operations. The timeline for sampling is typically dependent on the hours of machine operation over the course of a working day. Standard methods to measure concentration are refractive index for cleaning agents that are miscible in water. The accuracy of a refractive index reading is temperature dependent. Solvent splitting methods for cleaning agents that are partially miscible in water require the operator to wait for a specific amount of time for total phase separation. The accuracy of solvent splitting readings depends on consistent sampling, operator height (parallax) and waiting for a complete split.
- Semi-Automatic Control: Proportioning Systems are commonly used to add cleaning agent to the wash tank. A proportioning system adds a preset level of cleaning agent when the wash chemistry holding tank calls for water. One of the challenges of a proportioning method is that the cleaning agent and DI water losses are not uniform. Typically, higher levels of DI water will be lost. To address this challenge, process operators manually check the wash concentration and make adjustments over the course of operations. Figure 3 shows an example of data collected over a 6-week period. The C_{pk} was well below 1.33 (64 defects / million).

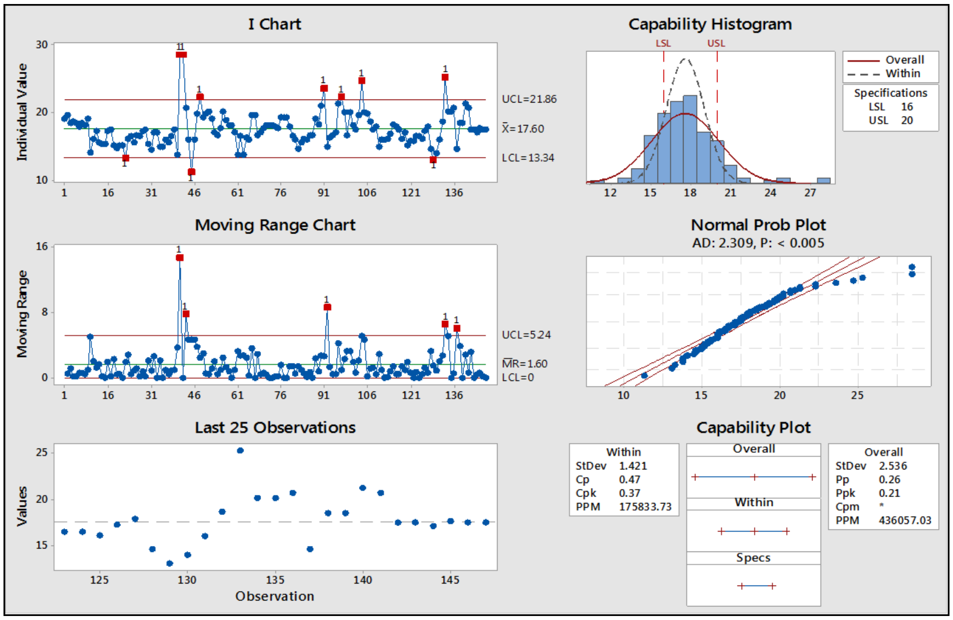


Figure 3: Wash Tank Control using Semi-Automated Methods

Automated Control: Automated process control systems continuously monitor the wash concentration and machine operation. The systems are designed to automatically add water and cleaning agent to maintain the targeted wash concentration. Systems log performance with alerts to system operations when support is needed. An automated system has far more significant precision as shown in Figure 4. Achieving the goal of a $C_{pk} > 1.33$ was accomplished.

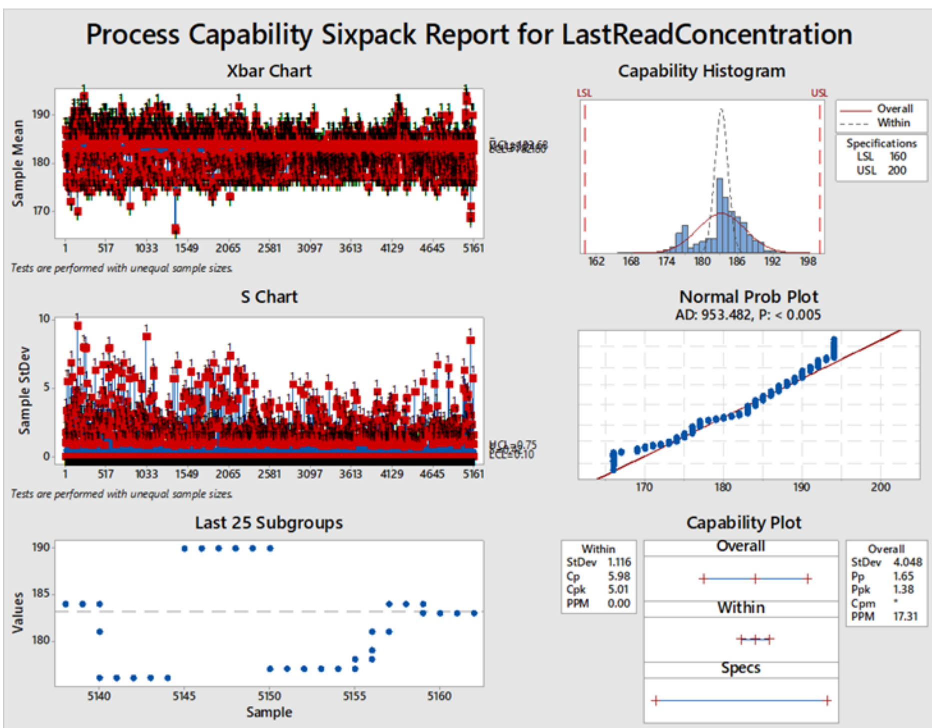


Figure 4: Wash Tank Control using Automated Methods

Automated Wash Chemistry control can improve board to board consistency by incorporating Industry 4.0 logic into the system design. This allows a process operator to monitor and analyze wash bath concentration in real-time. This data can be turned into knowledge through statistical analysis of the data feeds. The responsible engineer can securely access these analytical tools via any internet connected device. Additionally, users can set warning triggers so that if a parameter crosses a defined threshold, the system will immediately notify the responsible the person(s) via email or text message. This enables faster and better control of the wash process while the staff is focused on other duties. The automated process eliminates the need for manual wash bath sampling and logging. A process engineer can quickly and efficiently summarize data and analyze patterns.

The digital dashboard provides a view of the past 48 hours of operation.

Figure 5: Dashboard of the Past 48 Hours of Operation

The dashboard allows the process operator to dig into a specific time frame to diagnose a process change or condition. By selecting a particular time of interest, the panel will zero in on those process conditions during that period. Figure 6 provides an overview of the dashboard for a select period of interest from the timeline. During that time the wash pump operated continuously from 6:08:40 am to 1:50:36 pm. The operating temperature shows steady, and above the minimum value. There is a gradual decline of measured temperature after the wash pump is turned off. The concentration made a few step-changes throughout the day. After taking a closer look, the wash chemistry set point was changed from 16 to 17% at 1:27:41 pm. The automated control makes a chemistry addition to adjust concentration (Figure 7).

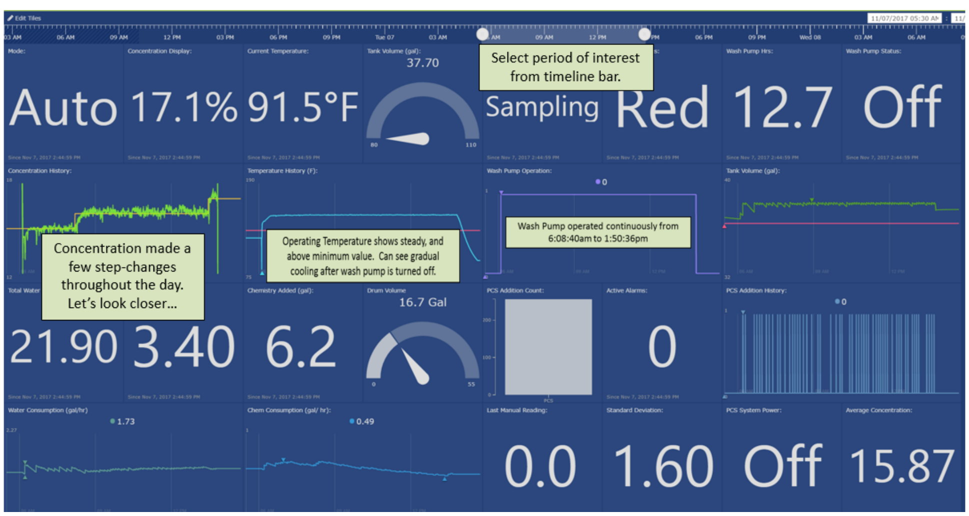


Figure 6: Past History across a Time Period is Easily Accessible

Figure 7: Adjustments to the Chemistry Concentration Set Point

Monitoring and Tracking

Wash chemistry is only one of the critical factors that take place during the cleaning process. To assure process traceability of all process conditions that an assembly sees during the cleaning process, a system that monitors and tracks all process conditions is beneficial. A system designed to monitor all process conditions can be achieved by scanning and sense each process parameter. Tracking each process condition that an assembly sees during the cleaning process provides traceability. Figure 8 provides an overview of the system design.

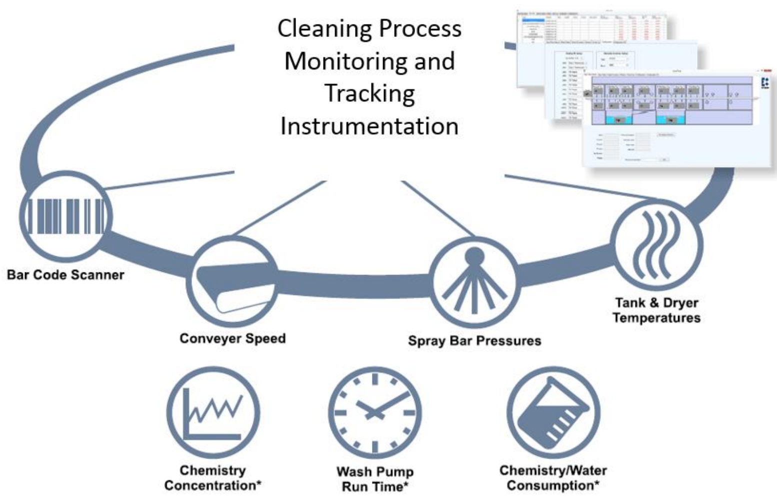
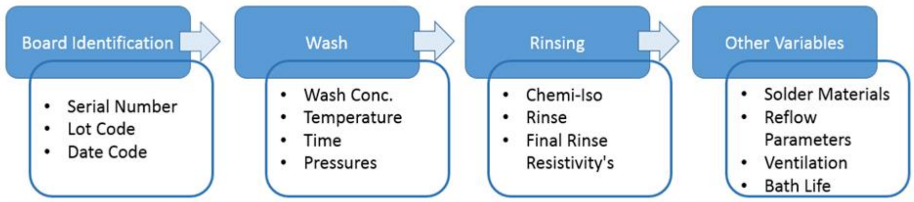


Figure 8: Cleaning Process Monitoring and Tracking Instrumentation

The external data acquisition systems utilize analog-to-digital, digital I/O, encoder interface and a barcode reader. Sensors are embedded into the cleaning machine and reflow oven to track all process conditions. Specific process conditions such as the reflow conditions, the time the assembly is in each of the process chambers, spray pressures, temperatures within each of the zones, DI water resistivity and dryer section are monitored. A bar code reader is used to scan and make a record of the process conditions that an assembly sees during the cleaning process. The date, time, serial number and other identifying information on the assembly can be tracked. If there is a quality issue, the record of all process conditions can be easily accessed.

Over time, patterns and detailed correlations emerge due to the fluid nature of a cleaning process. More than 20 machine parameters can be monitored and tracked. If any setting is out of spec., a process operator will be notified immediately of the data analyst features. A light tower with an alarm can also be used as a secondary warning to the process operator. The red/yellow/green light condition of the light tower provides a visual indicator on the cleaning machine. If any process parameter goes out of tolerance, alarm sounds and the light tower turns red. The event log page records the failed setting, and the audible alarm is acknowledged on this page. When the alarm occurs, any board in the machine is flagged in the database with a failure status. Once the process parameter is corrected, the light tower will turn green. The failed boards must be rescanned and run through the cleaner again.

The integrated systemprovides the process operator with the capacity to learn, improve and correct process issues.



Value Proposition	Board ID	Reflow	Wash	Rinse	Other Variables
Warranty	Tracking	Monitor	Control	Monitor	Monitor
Yield Improvement	Product-Process Client Data Mining, Proactive variable control limit alerts				
Reliability Improvement	Product-Process Client Data Mining, Proactive variable control limit alerts				
Diagnostics	Product-Process Client Data Mining, Proactive variable control limit alerts				

Figure 10: Learn, Improve and Control the Cleaning Process

- Residue remaining underspecific components
  - Reflow condition out of specification
  - Cleaning agent concentration too low
  - Low operating temperature
  - Nozzles clogged
  - Wash time and pressures are out of tolerance

- Foaming in the rinse section leading to an inadequate rinse
  - Ventilation not balanced
  - Steam bypassing condenser
  - Rinse temperature too low

- Low chemistry concentration in wash section
  - Ventilation not balanced
  - Condenser temperature too low
  - Measurement error

- Wash batch contamination
  - Process control issue
  - Need to control what goes into the cleaner

Process input mapping provides the engineer with critical, insights about the health of the process and where process improvements can be obtained.

- Cleaning Chemistry
  - % Concentration
- Soils
  - Estimated % soil load based on board count or pump run hours
  - Product type (i.e., bare boards, production boards, components, fixtures, etc.)
  - Kind of contaminate (i.e., flux, soldermask, silicone, acrylic, etc.)
  - Time since last bath changeover
  - Rinse tank loading

- DI Water
  - Resistivity and TOC
  - DI carbon and mixed resin status
- Tap Water
  - Measurement of quality
- Recirculation
  - Wash pressure
  - Rinse pressure
  - Final rinse pressure and flow rate
  - Chem-Iso pressure and flow rate
- Heat
  - Wash bath temperature
  - Chem-Iso temperature
  - Rinse temperature
  - Dryer temperature
- Process Time
  - Conveyor speed
- Exhaust
  - Stack pressure
- Wash baskets and fixtures
- Others

Data Capture and Analytics
The system is configured to upload the data feeds to a secure database. Only process data and other process information such as alarms and set points are being captured. The data is uploaded real time to a web-based server. For security, a 1-way communication to the cloud server is configured. The server will not respond to any attempts to communicate or query the uploaded data. Corporate firewalls can be configured to allow only outbound traffic and port limited for enhanced security.

The system software is set up to run diagnostics on the data. The data feeds back into a WiFi enabled the device that has log-in rights to the system information. The process owner can monitor and track cleaning process operations no matter where they are located in the world. By creating user-defined trigger parameters, the data service feature will continuously monitor the process and alert the designated people if a threshold is exceeded to control the operation and avoid costly mistakes.

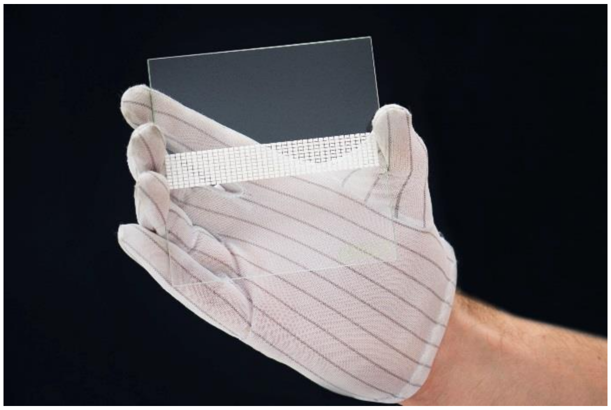
Real-time access, traceability, data analytics, customized dashboards, and alerts provide the process owner with a large stream of process information. Precise data resolution allows for instant analysis and response. Email or test notifications alert those responsible when there is a problem, or the process is trending out of spec. By uploading to the secure cloud service, process owners have a long-term historical record of the process. Tracking the data enables the ability to meet ISO standards and audit protection.

Figure 11: Real-Time Diagnostics

Experimental
A series of customized test boards were designed to evaluate the visual level of flux under QFN components and to test the activity of the flux residues trapped under the body of QFN components using IPC TM650 2.6.3.7 SIR test method. The

objective is to correlate reliability expectations with a range of design and process factors. The experimental test methods are designed to show the impact of reliability when running the cleaning process outside and within the validated process conditions. Systems designed to monitor, track and adjust process conditions within validation process conditions can reduce variability as well as improve reliability.

For visual inspection, the wash time to both partially clean and totally cleaned flux residues under the body of the QFN component was developed. A ceramic – glass 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. The test substrate is designed to be underfilled 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 using a ramp-to-spike profile with a peak temperature of 250°C, with a time over 217°C of 1:10 minutes. The residue patterns can be visibly or optically inspected after each cleaning cycle.



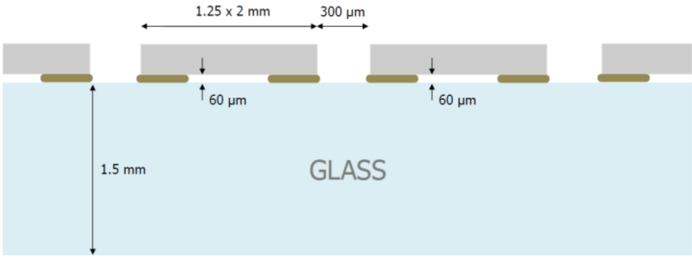


Figure 12: Ceramic Glass Test Vehicle

Visual inspection of the ceramic-glass test vehicle are shown in Figures 13, 15, and 17.

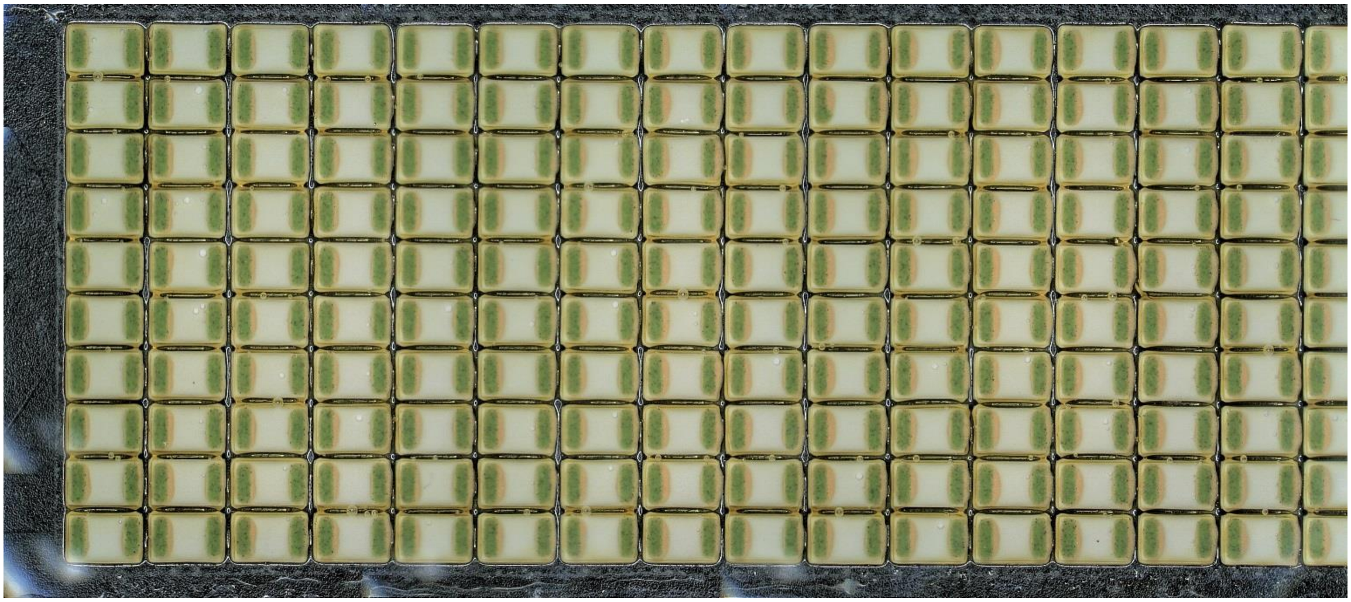


Figure 13: Ceramic – Glass Test Vehicle after Reflow and Before Cleaning

A dashboard of the process conditions for the partially cleaned boards is shown in Figure 14. The significant parameter change was belt speed, which represents the time the part is exposed to each of the process sections within the cleaning machine. At a belt speed of 1.5 feet per minute, the time within the wash section was 5 minutes. Visual test data finds that this residence time in the wash was not sufficient to remove all flux residues trapped under the component termination (Figure 15).

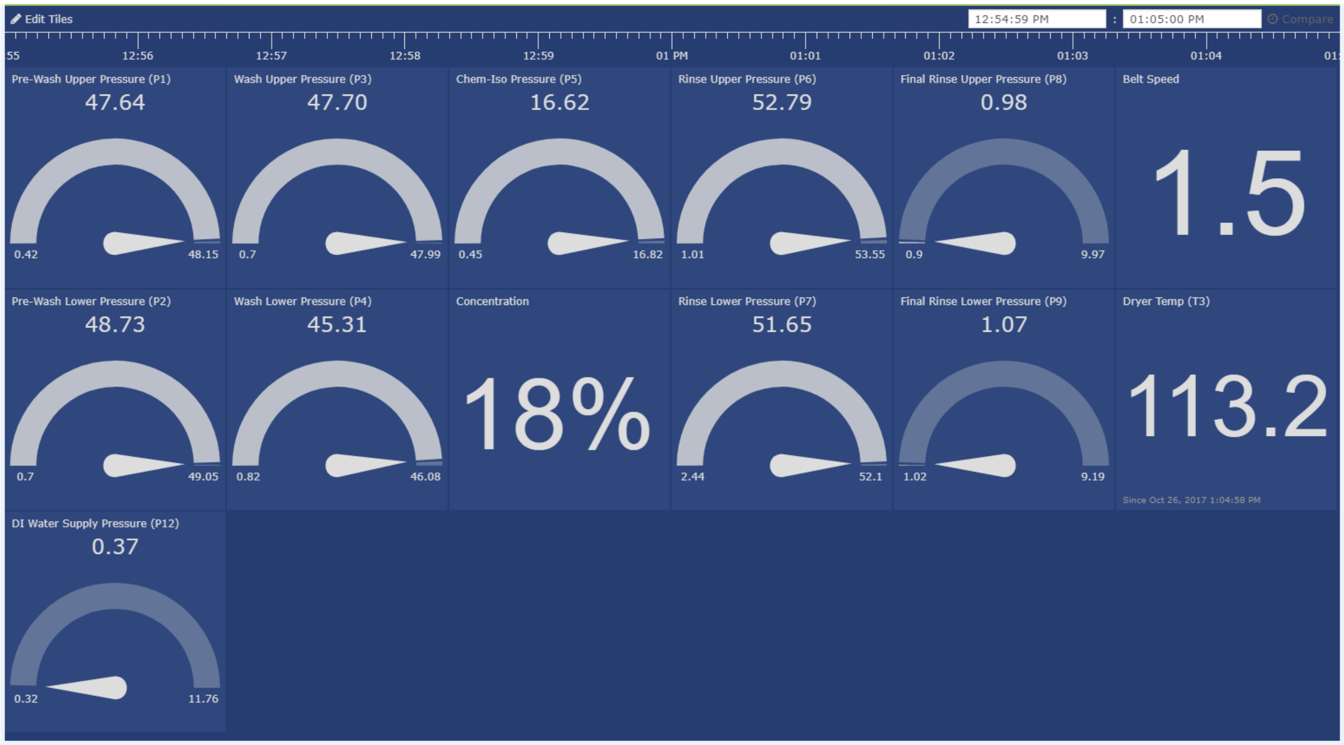


Figure 14: Process Conditions Monitored and Tracked on Boards Cleaned at 1.5 Feet per Minute

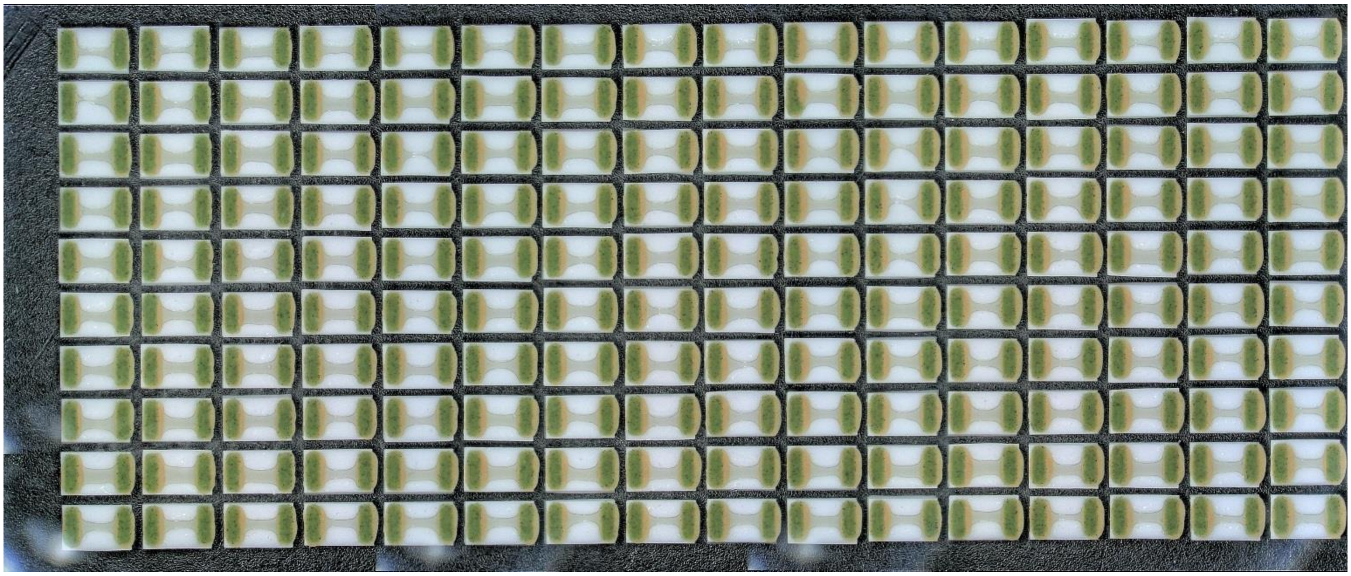


Figure 15: Ceramic – Glass Test Substrate Partially Clean based on Process Conditions

A dashboard of the process conditions for the entirely cleaned boards is shown in Figure 16. The belt speed was reduced to 0.5 feet per minute, which equates to 15 minutes of wash chemistry and pressure conditions onto the assembly. Visual test data finds that this residence time in the wash was sufficient to remove all flux residues trapped under the component termination (Figure 17).

Figure 16: Process Conditions Monitored and Tracked on Boards Cleaned at 0.5 Feet per Minute

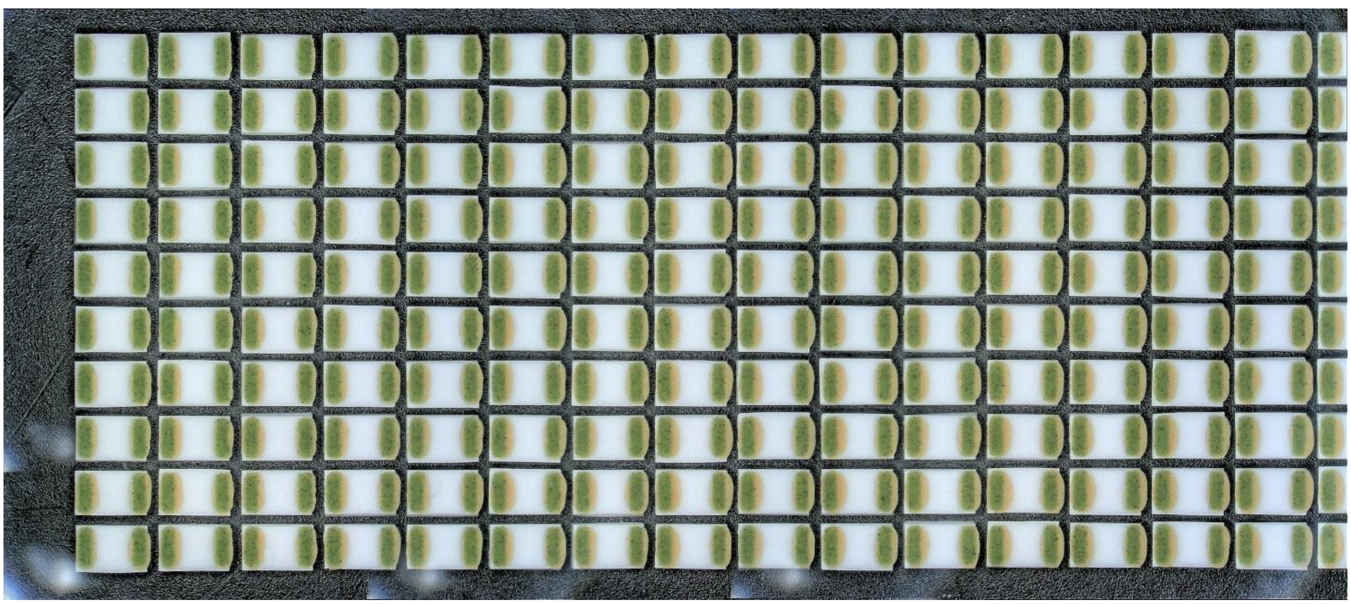


Figure 17: Ceramic – Glass Substrate Cleaned based on Process Conditions

Once cleaning parameters were defined, test boards not cleaned, partially cleaned and totally cleaned were tested for surface insulation resistance at the QFN component site using Surface Insulation Resistance (IPC TM650 2.6.3.7 SIR test method). The QFN test boards have sensors placed pin to pin and pin to ground lug (Figure 18). Two (2) test patterns at the component site were used: a “ring” pattern and a “comb” pattern. In the ring pattern, all lands are biased to either the measurement or bias voltage. The center thermal pad is grounded. In the comb pattern design, the center thermal pad is left floating and the lands are biased alternately. That is to say, for example, all even lands are bias/measurement voltage, and all odd lands are ground. The difference in the two patterns was used to investigate the effects of flux between lands and between the lands and thermal pad.

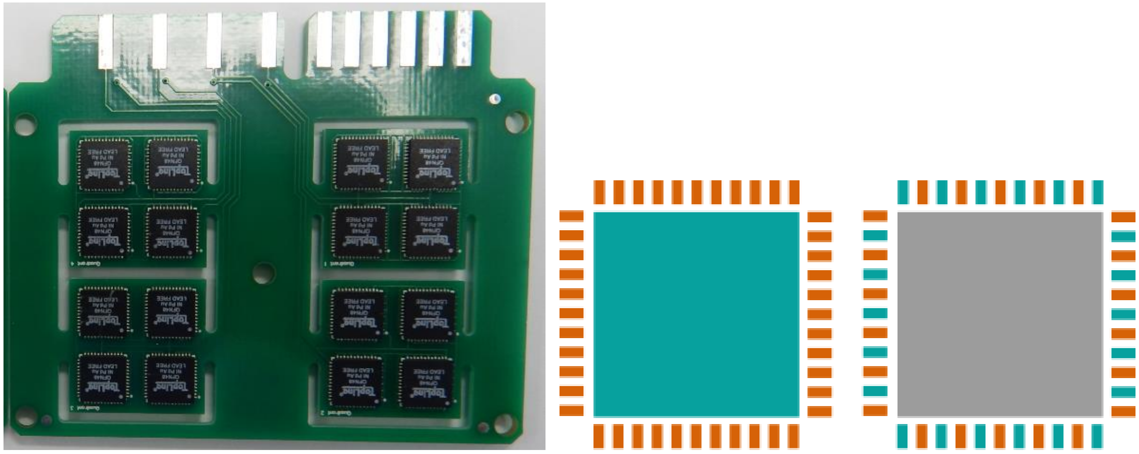


Figure 18: QFN Test Board using Ring (left) and Comb (right) Pattern. Colors Indicate Points at the Same Potential.

The SIR test parameters were as follows:

- Test Board: Component Specific QFN test board with sensors placed between the pin and ground lug
- Solder Paste: No-Clean ROL0
- Alloy: SAC 305
- Bias: 8 volts
- Test Voltage: 20 Volts
- Temperature: 30°C
- Humidity: 90% RH
- Measurement Interval: Every 20 minutes
- Test Duration: 168 hours

The cleaning process was equipped with Industry 4.0 tracking and monitoring instrumentation. One set of the boards was the "baseline" from which the boards were not cleaned post soldering. The second set of boards were processed through the cleaning tool with monitored conditions being outside the process window. This test point was used to illustrate a state where the cleaning process was outside the process window resulting in partially cleaned flux residue under the QFN component. The third set of boards were processed with all conditions within specification. This set of boards were clean to the validated process specifications.

Figure 19 is a summary of the SIR test data for the Not Cleaned, Partially Cleaned and Totally Cleaned test boards. The surface insulation resistance (LogR resistance) values are different for each condition tested. The surface insulation resistance values for the not cleaned flux residues between the ring and comb patterns exhibited roughly 4 decades lower resistance values under the QFN components. Test boards partially cleaned (residue still present under the QFN components) was approximately 2 decades lower resistance values under the QFN components. The Partially Clean boards were below a 95% confidence interval and considered a failure. When the cleaning process was in spec., SIR passed at values well above the failure range.

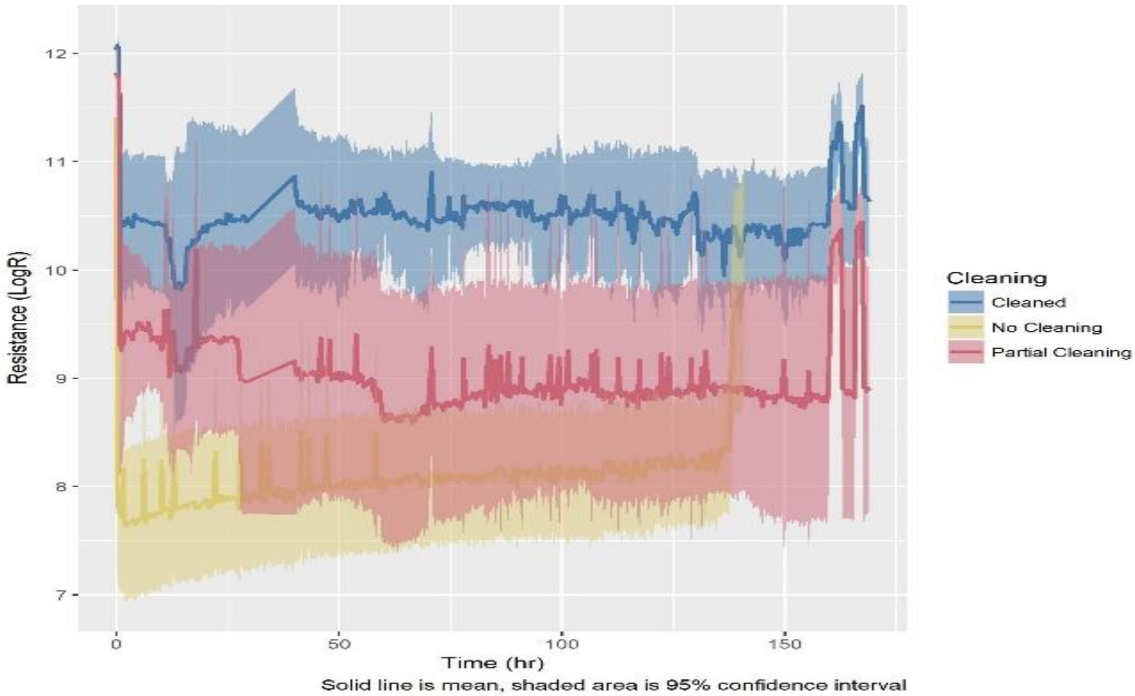


Figure 19: SIR values on QFN Components

Conclusions

Customers of electronic-based hardware expect highly reliable products. In many respects, they demand products that perform reliably over time. Highly reliable products save customers money by lowering down times, failure frequency and maintenance costs. Reliable products bring customers back. In a competitive environment, reliability is a differentiator.
Cleaning is not a simple process. Many process variables can impact cleanliness levels. Monitoring, tracking and controlling the process window is critical to meeting cleaning specifications for the device to function properly. With today's electronics becoming increasingly dense and populated with miniaturized, leadless and bottom terminated components, the need for cleaning has increased in importance. Problematic residues cannot be easily detected through visual inspection. Companies must first characterize the cleaning process using both chemical and electrical test methods to verify and validate the level of cleanliness needed to produce reliable assemblies. Once characterized, IPC J-STD-001 requires the assembler to provide objective evidence of adequate production and test facilities as well as sound procedures for process control. In some high-reliability industries, the assembler must maintain a failure recording and reporting system of the assembly process, test conditions, length of time the part has been operating in the field and for field failures a review and corrective action.

Industry 4.0 methodology applied to the cleaning process enables data-driven decisions. When OEMs experience a failure incident, they have a record of all cleaning process conditions that the hardware went through during product manufacture. Building in traceability into the model down to the component tier enables the failure analysis engineer to track by serial number, date codes and lots. This type of information could save a company millions of dollars in loss. There is information that can help them pinpoint root cause from incidents that occur during the useful life of its products. They have an information stream to assess the cleaning performance and where performance can be improved. Process improvement and value decisions can be made.

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Paper Outline

I. Building Reliable Electronics

II. Industry 4.0 Enables Risk Mitigation

III. Cleaning Process Monitoring and Tracking

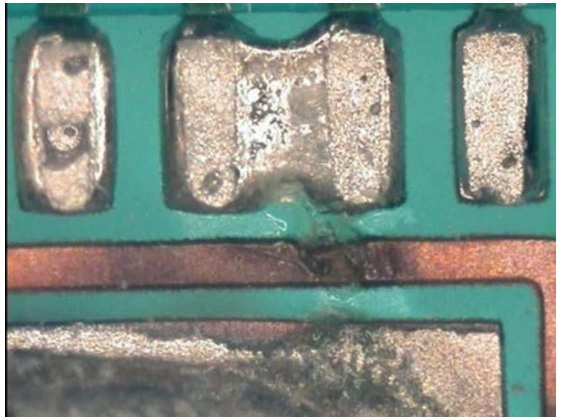
IV. Experimental

V. Monitoring / Tracking Conclusions

Building Reliable Electronics

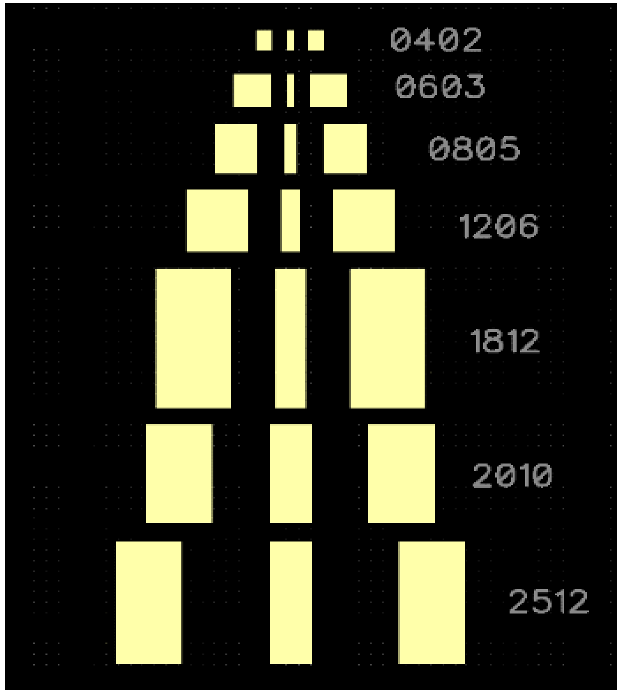
Process Monitoring / Tracking

- Current measures of cleanliness do not measure whether
  - *Product is clean enough across all components*
- Multi-Variable Challenge Influenced by
  - *Flux type, flux make-up, activation temperature, outgassing*
- Monitoring / Tracking
  - *Allows for a stream of process knowledge*
  - *Leads to improvements*

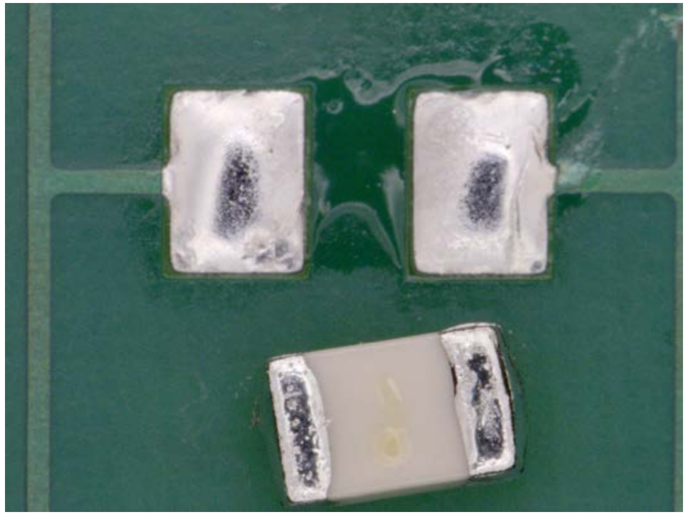


Smaller Form Factor Electronic Assemblies

- Miniaturization increases risk for electrochemical interactions
- Contamination under component terminations can cause
  - *Current leakage*
  - *Signal integrity losses*



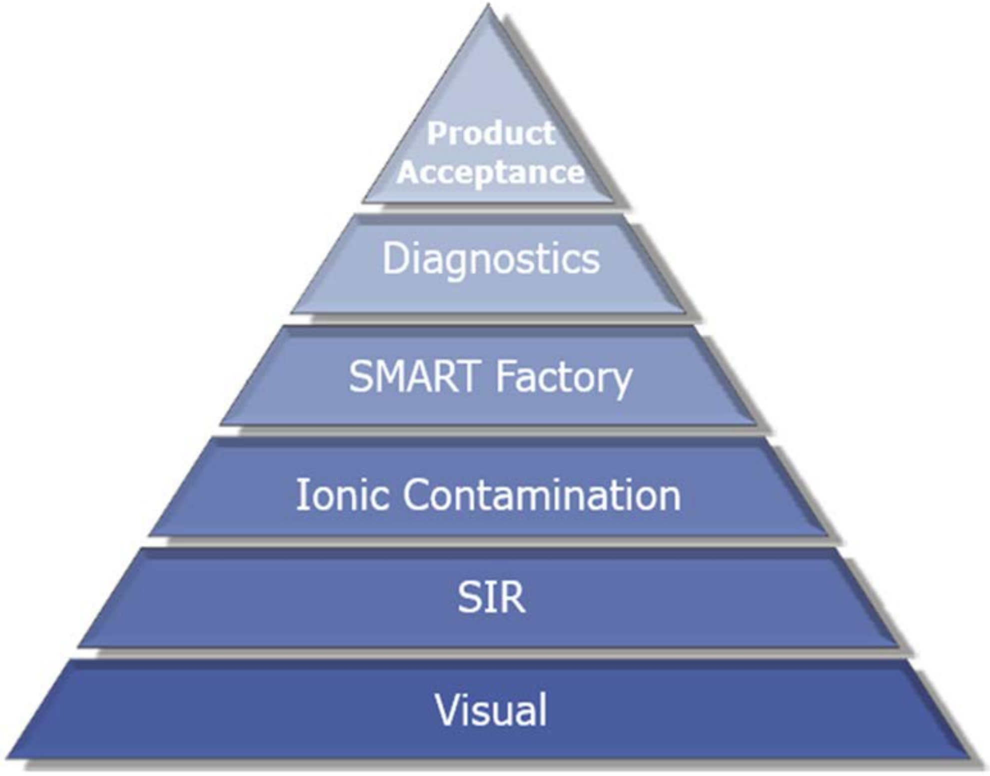
Z-Axis of Leadless Components



- Planar surfaces (OSP, ENIG, etc)
- Results in lower standoff heights
  - *Underfilling component with flux*
- Blocks fluid flow channel when cleaned
- Flux residue is active – Even when using a No-Clean Paste
- Increases electrochemical failures

Designing for Reliability

- Starts by defining
  - *Assembly process conditions*
  - *Materials and their interactions*
- Characterizing risks
  - *Data that defines optimal materials choices*
  - *Processing steps*
  - *Cleaning validation*
- Monitoring and Traceability
  - *Enables lot to lot repeatability*



Industry 4.0 Enables Risk Mitigation

Traditional data capture

- Manufacturing tools are capable of logging data
- Each device may store data differently / locally
- Periodically, the data feeds are manually retrieved and analyzed
- Engineers must calculate the data feeds to share the results

Industry 4.0 -- Smart Factory

- Multiple data streams combined with Analytics
- Real-time process outputs
- Speed up decision making
- Helps process owners to understand and reduce variability

Inputs equated to Knowledge

1. Automate manual processing steps
2. Track the assembly using barcodes
3. Sensors to monitor all conditions
4. Analyze data outputs real-time
5. Dashboard to report diagnostic information

Cleaning Process Monitoring and Tracking

Industry 4.0 Enables Chemical Reliability

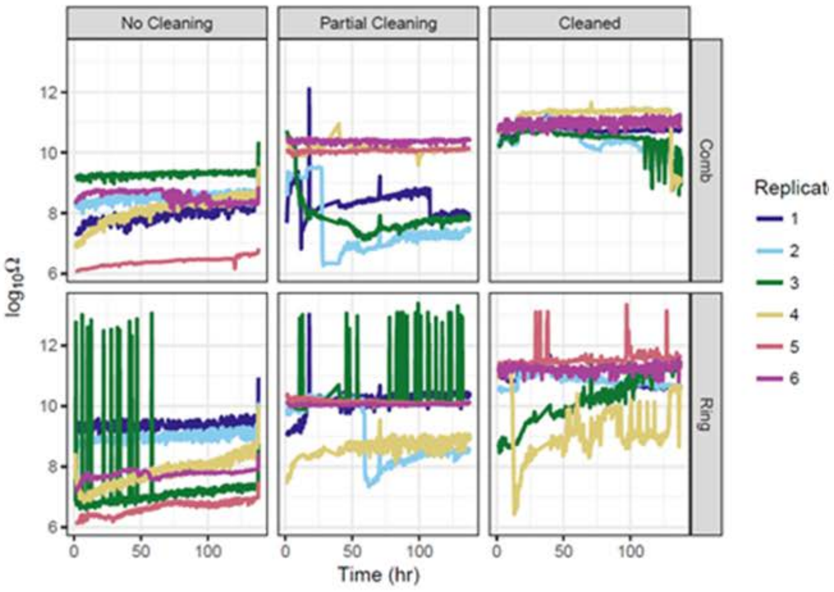
After validating production conditions that achieve required Cleanliness Levels:

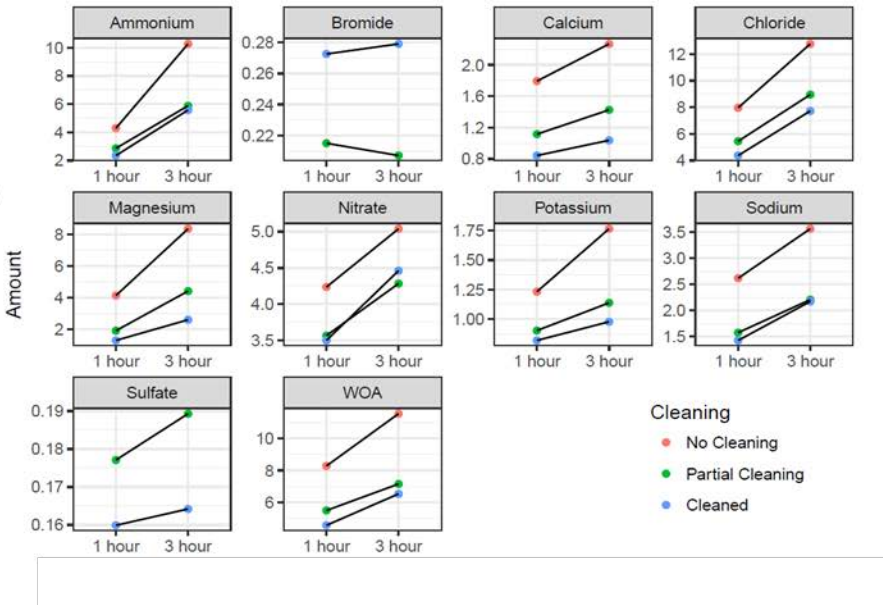
Monitoring and Tracking becomes critical to staying within the defined guidelines:

1. *Wash Chemistry*
2. *Bath Life*
3. *Cleaning Process Parameters*

Starts by Defining Cleanliness Levels

- How clean is clean enough can be determined by
  - *Surface Insulation Resistance*
  - *Ion Chromatography*
- The target defines the conditions that achieve desired cleanliness levels





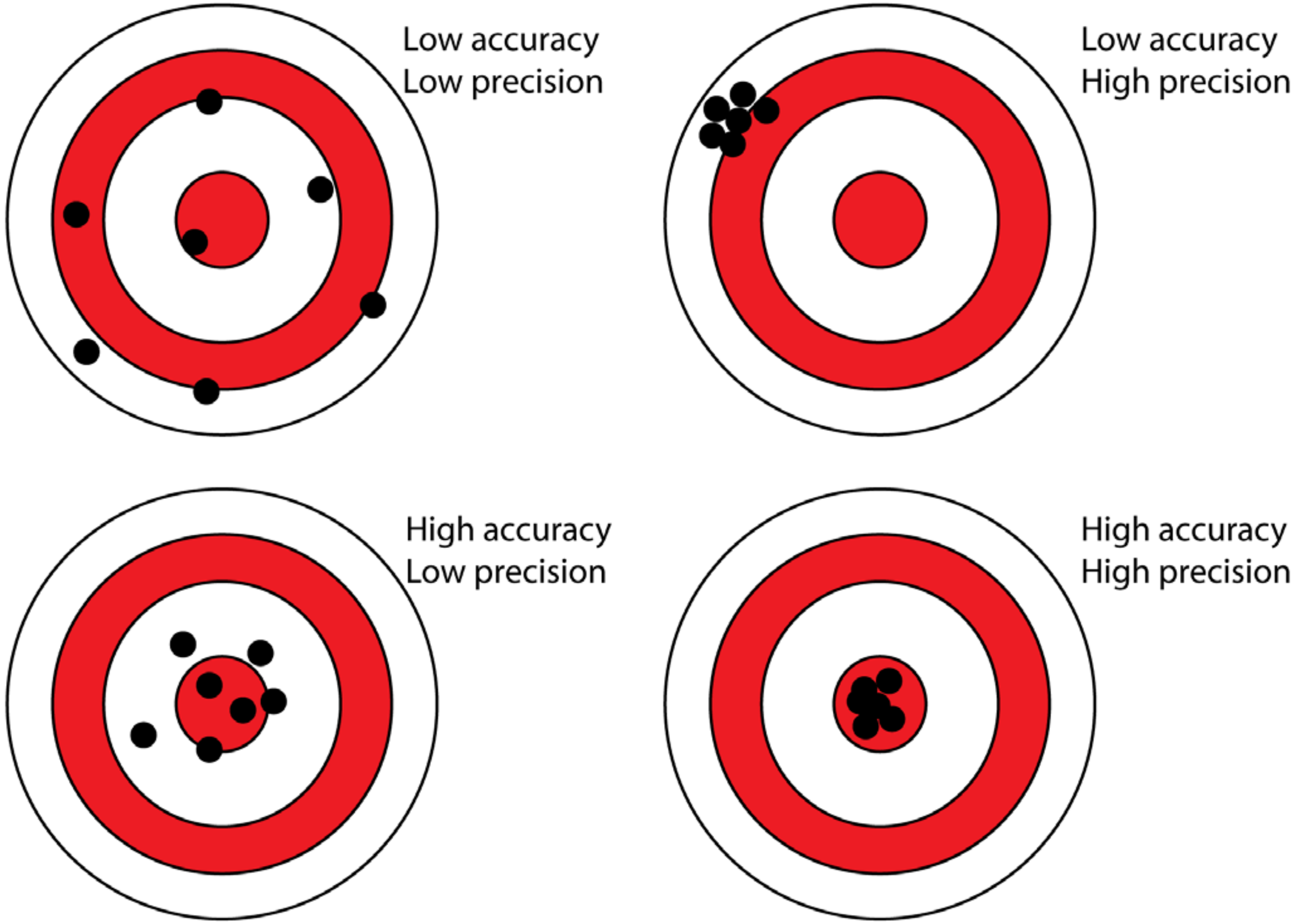
With Cleaning Defined

- $C_{p,}$ C_{pk} : **Process Capability Index**
  - *Measures how close you are to your target and how consistent you are around your average target*
  - *C_{pk} > 1.33 (4 sigma) is preferred = 64 defects / million*
- $P_{p,}$ P_{pk} : **Process Performance Index**
  - *Details how the process has performed in the past.*
  - *P_{pk} > 1.33 is also preferred*

Targeting: Accuracy & Precision

C_p = Low
C_{pk} = Low

C_p = High
C_{pk} = Low

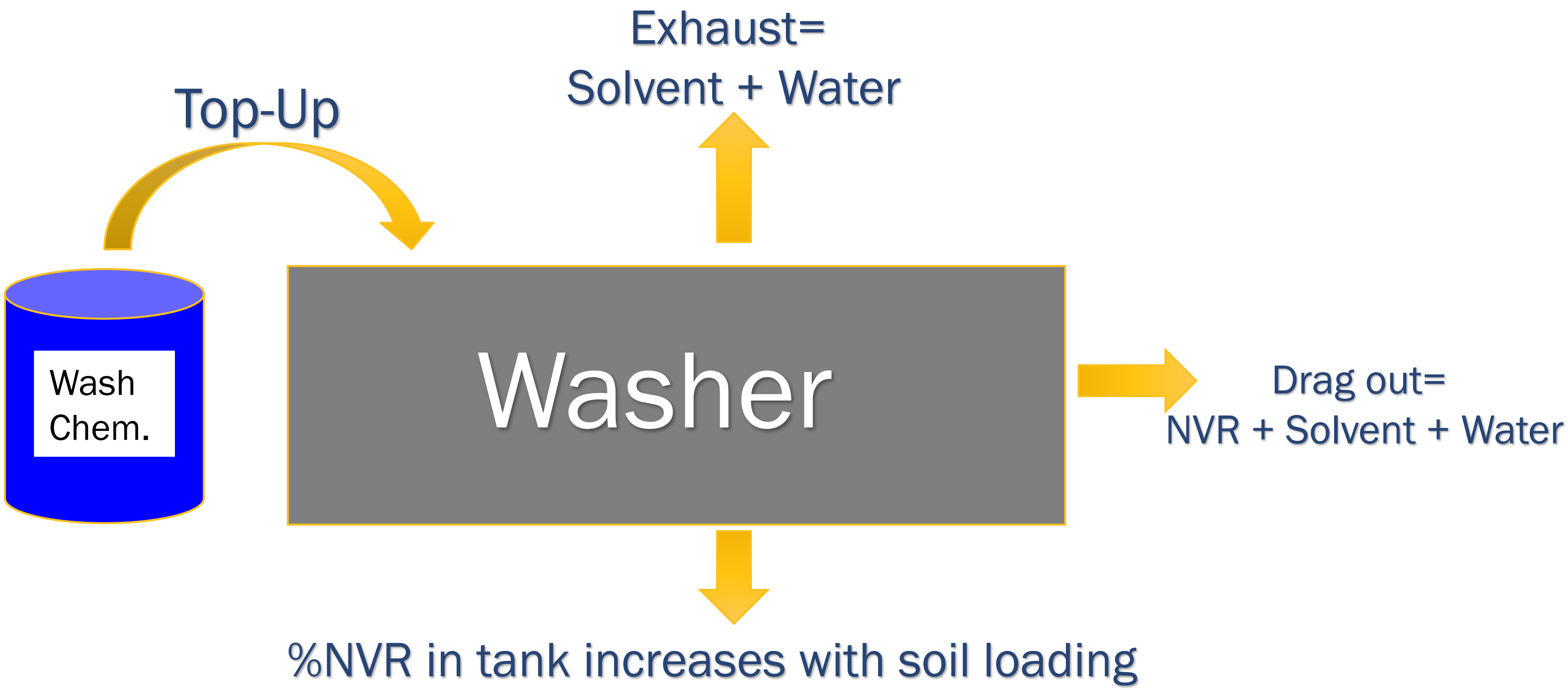


C_p = Low
C_{pk} = High

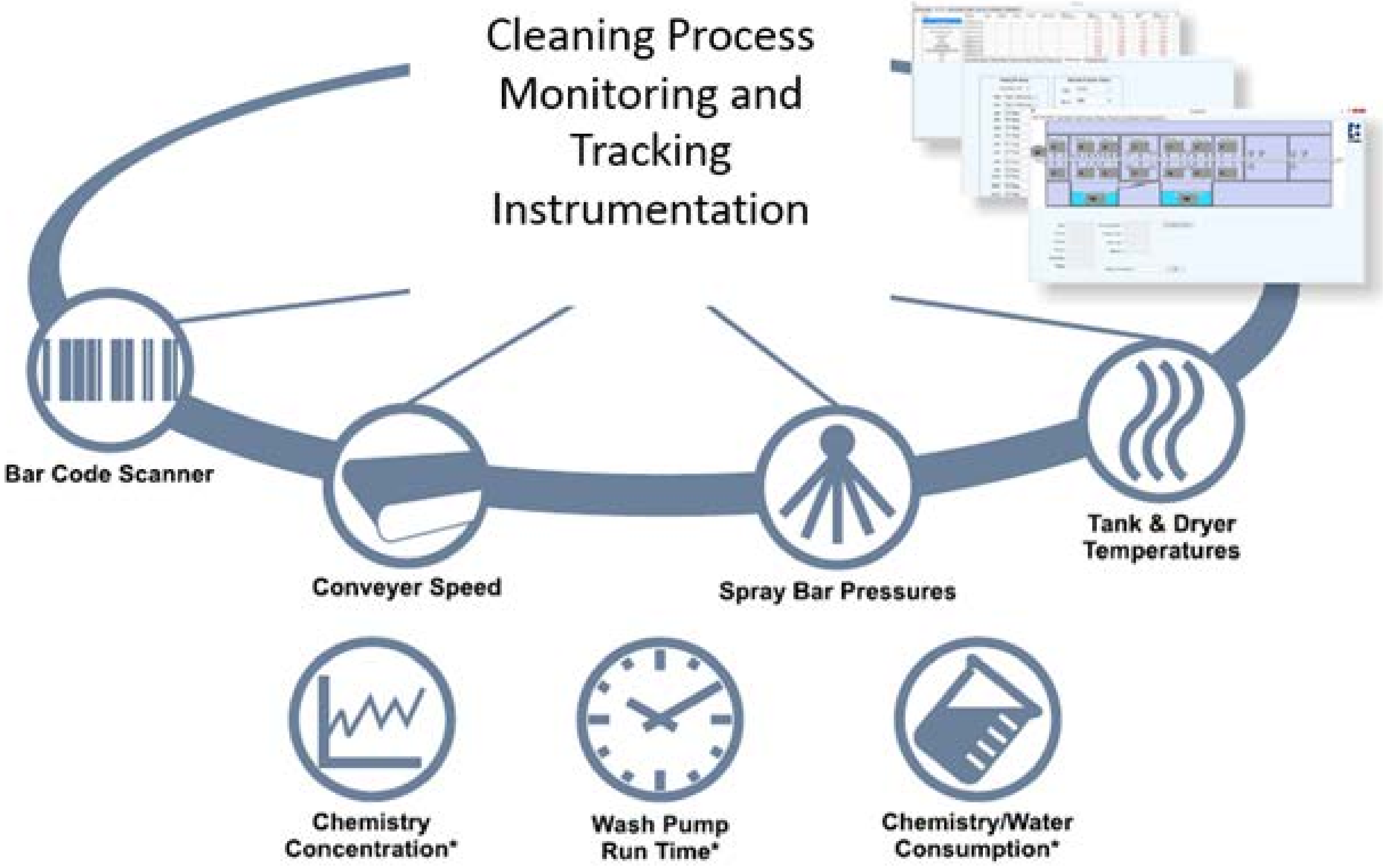
C_p = High
C_{pk} = High

Cleaning is a Dynamic Process

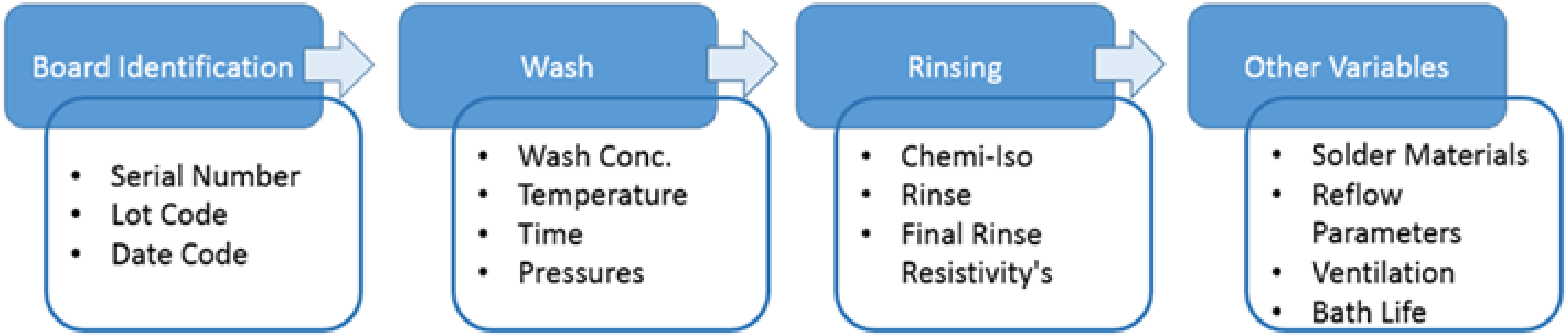
- Wash Chemistry Monitoring and Tracking



Monitoring / Tracking Process Parameters



Learn / Improve / Control



Value Proposition	Board ID	Reflow	Wash	Rinse	Other Variables
Warranty	Tracking	Monitor	Control	Monitor	Monitor
Yield Improvement	Product-Process Client Data Mining, Proactive variable control limit alerts				
Reliability Improvement	Product-Process Client Data Mining, Proactive variable control limit alerts				
Diagnostics	Product-Process Client Data Mining, Proactive variable control limit alerts				

Real Time Digital Dashboard

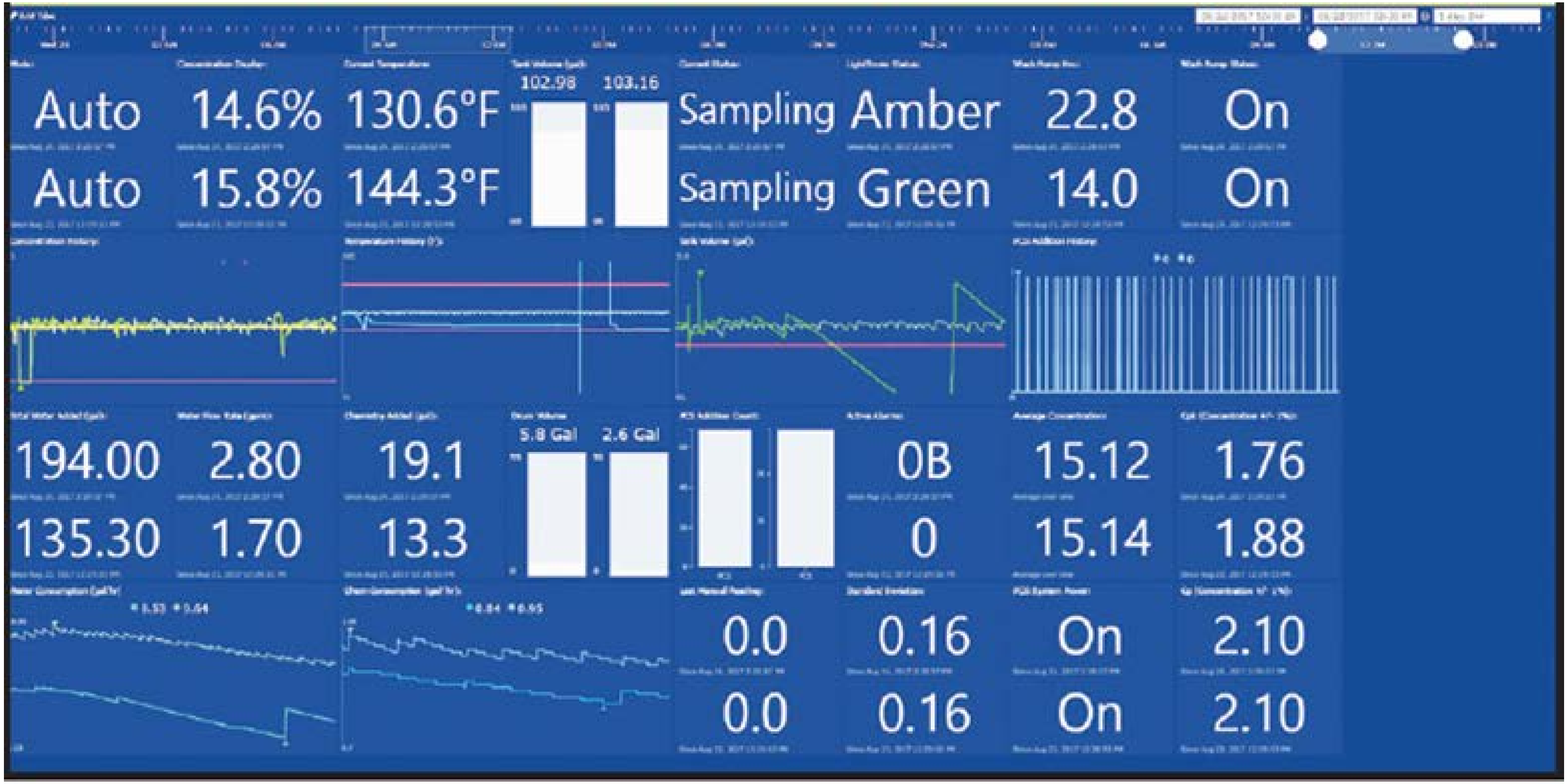
Monitored Information is Tracked for Diagnosis

Past History is Easily Accessible

Process Issues can be Tracked

- Reflow condition out of specification
- Cleaning agent concentration too low
- Low operating temperature
- Nozzles stopped up
- Wash time and pressures are out of tolerance
- Rinsing issues
- Wash bath loading
- Other ….

Data Capture and Analytics

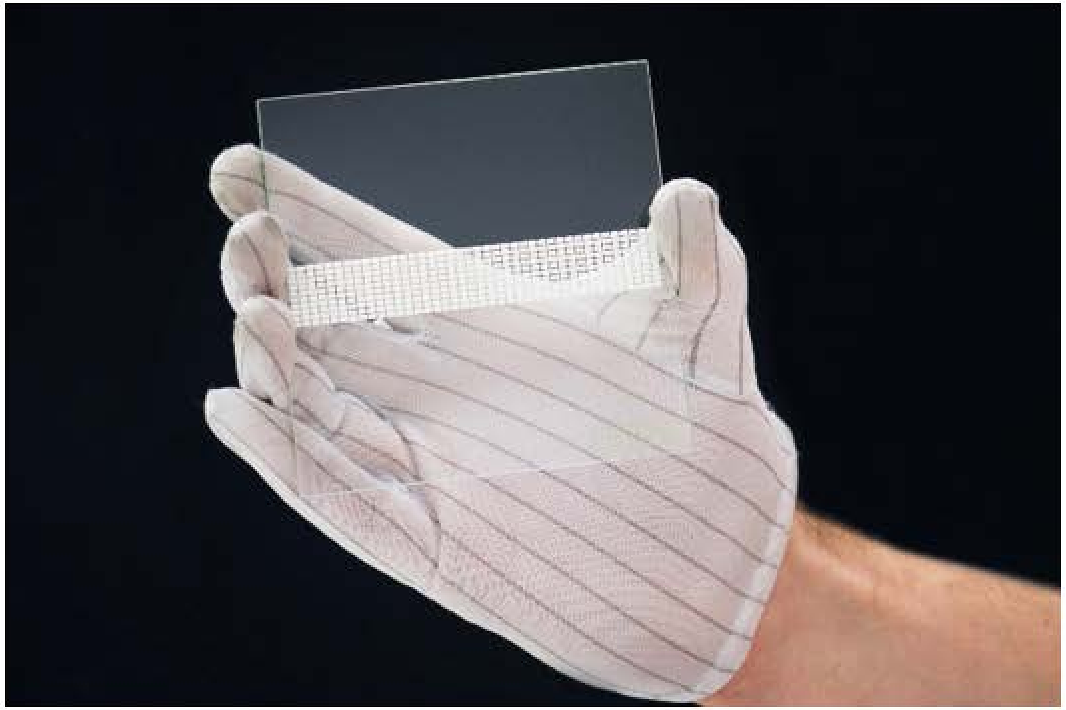


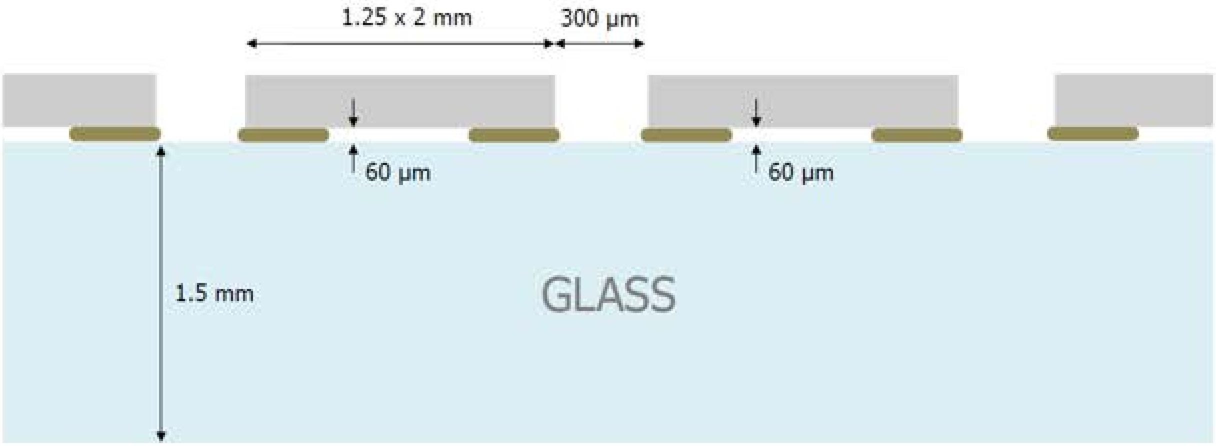
Experimental

Methodology

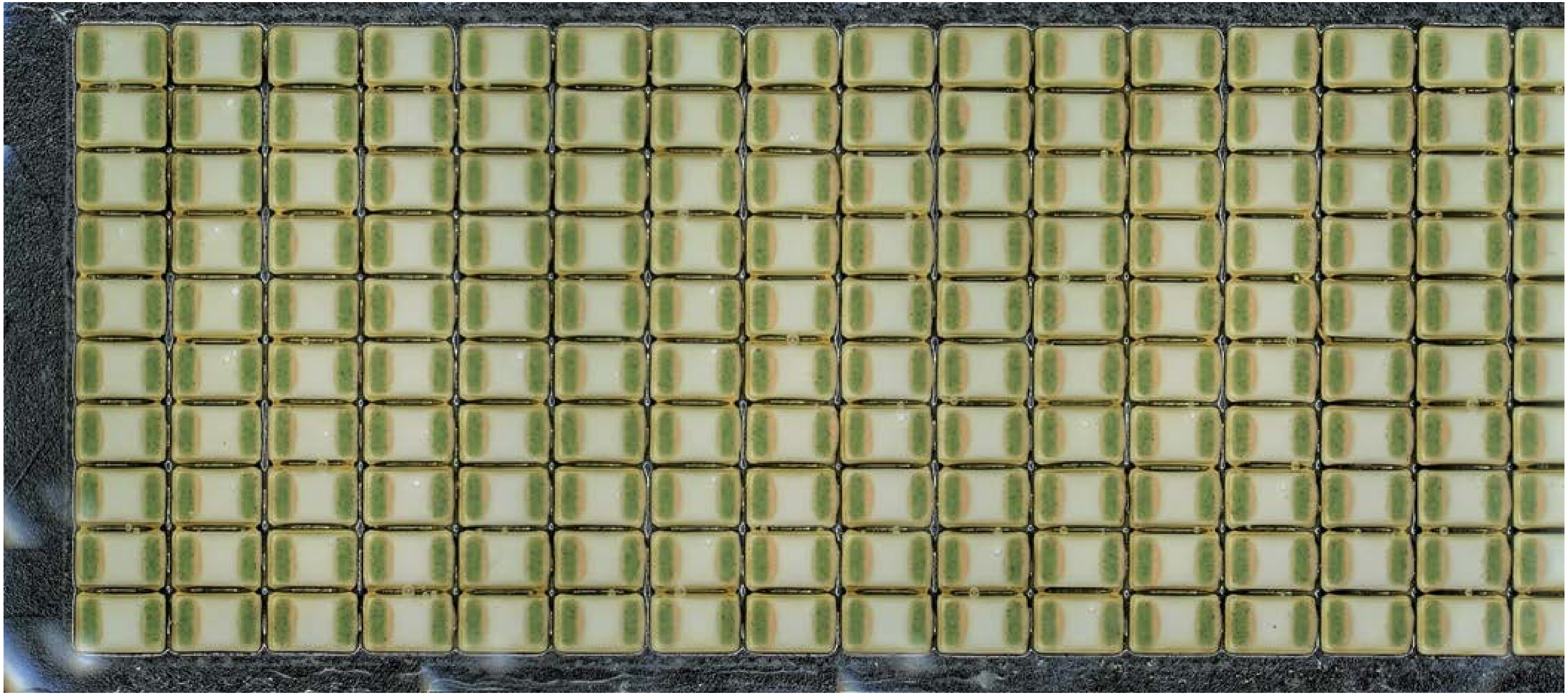
1. Process Conditions to Render Desired Cleanliness
2. Dial in Process Conditions
3. Validate the Process

Ceramic Glass Test Vehicle

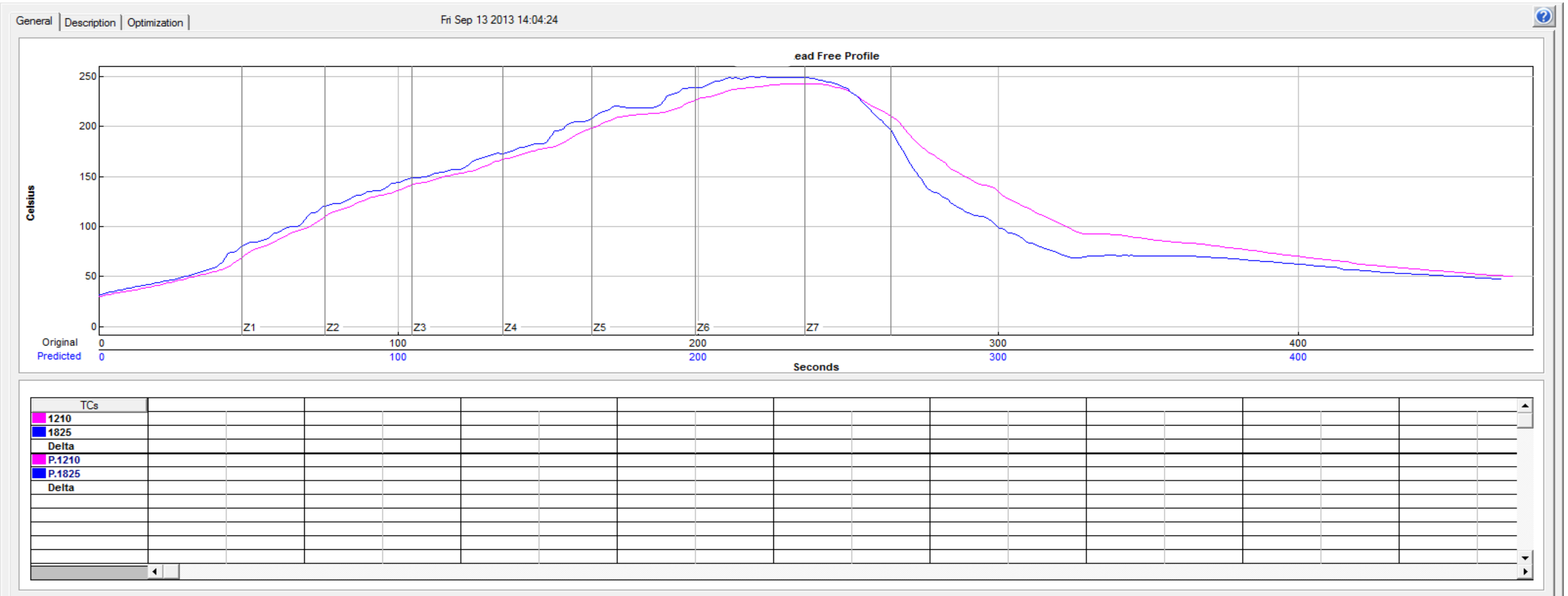




After Reflow / Before Cleaning Evaluations



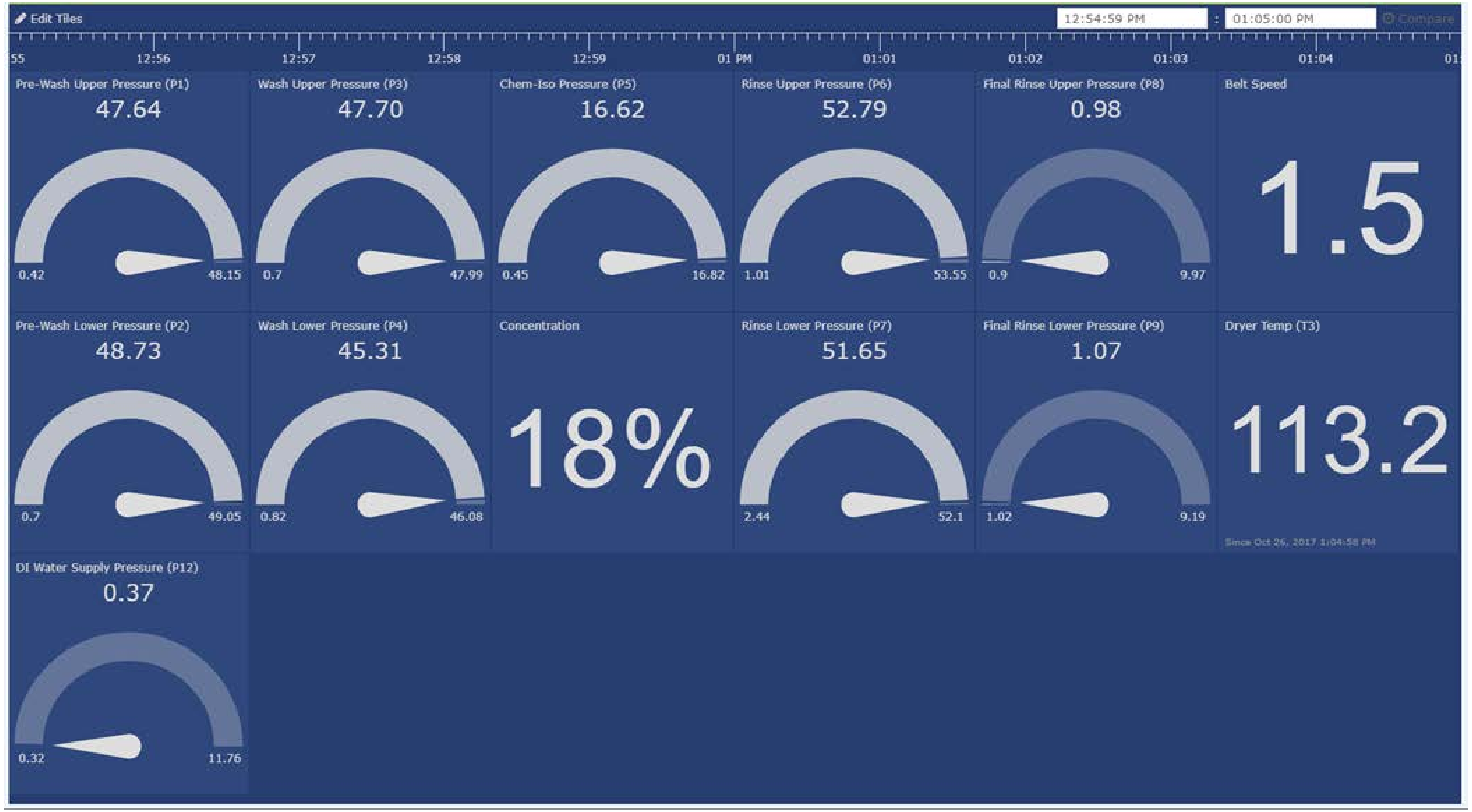
Reflow Profile



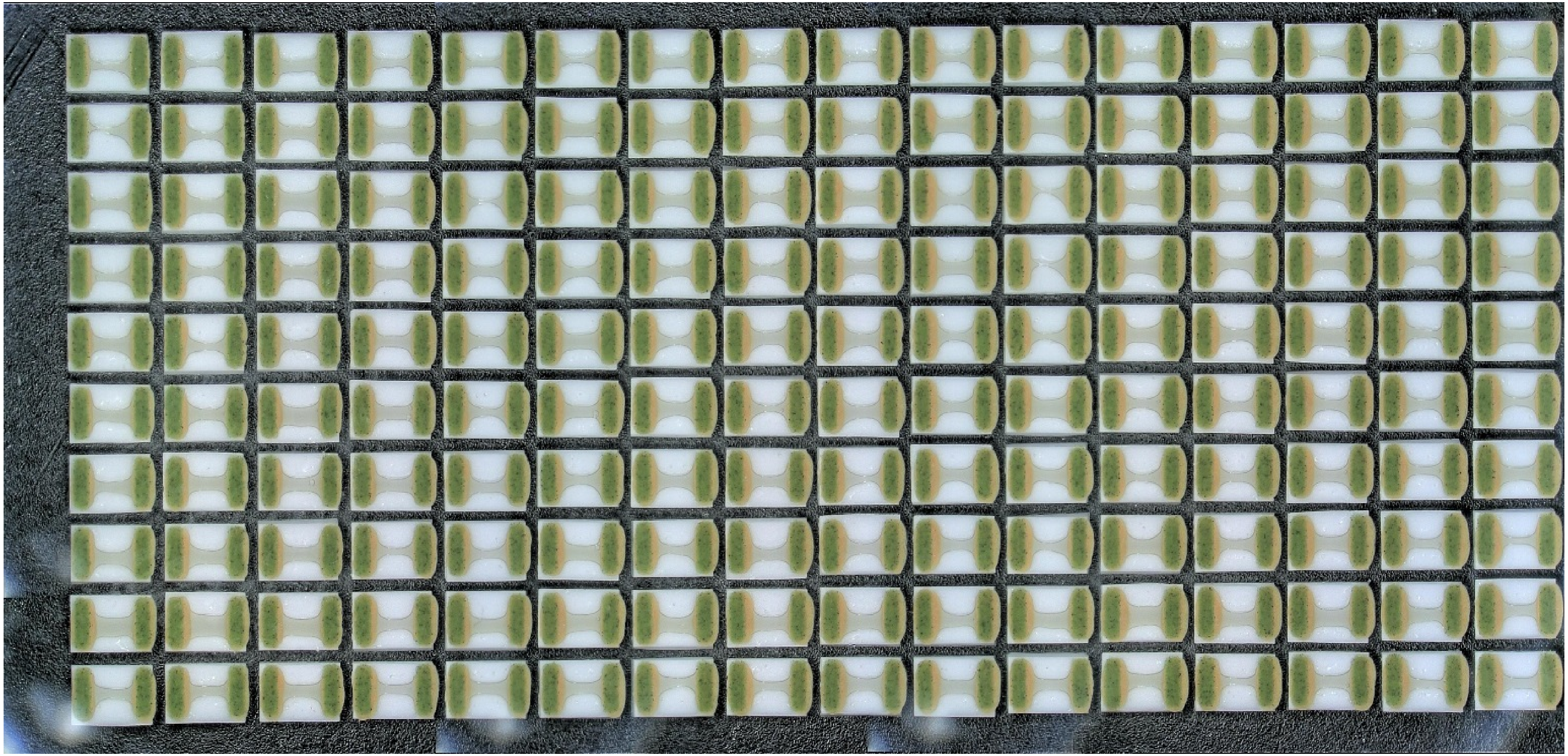
	inch/min	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Original Top	30.0	145	155	170	200	240	270	260
Original Bottom		145	155	170	200	240	270	260
Predicted Top	30.0	145	155	170	200	240	270	260
Predicted Bottom		145	155	170	200	240	270	260

☑ Top and Bottom are the same

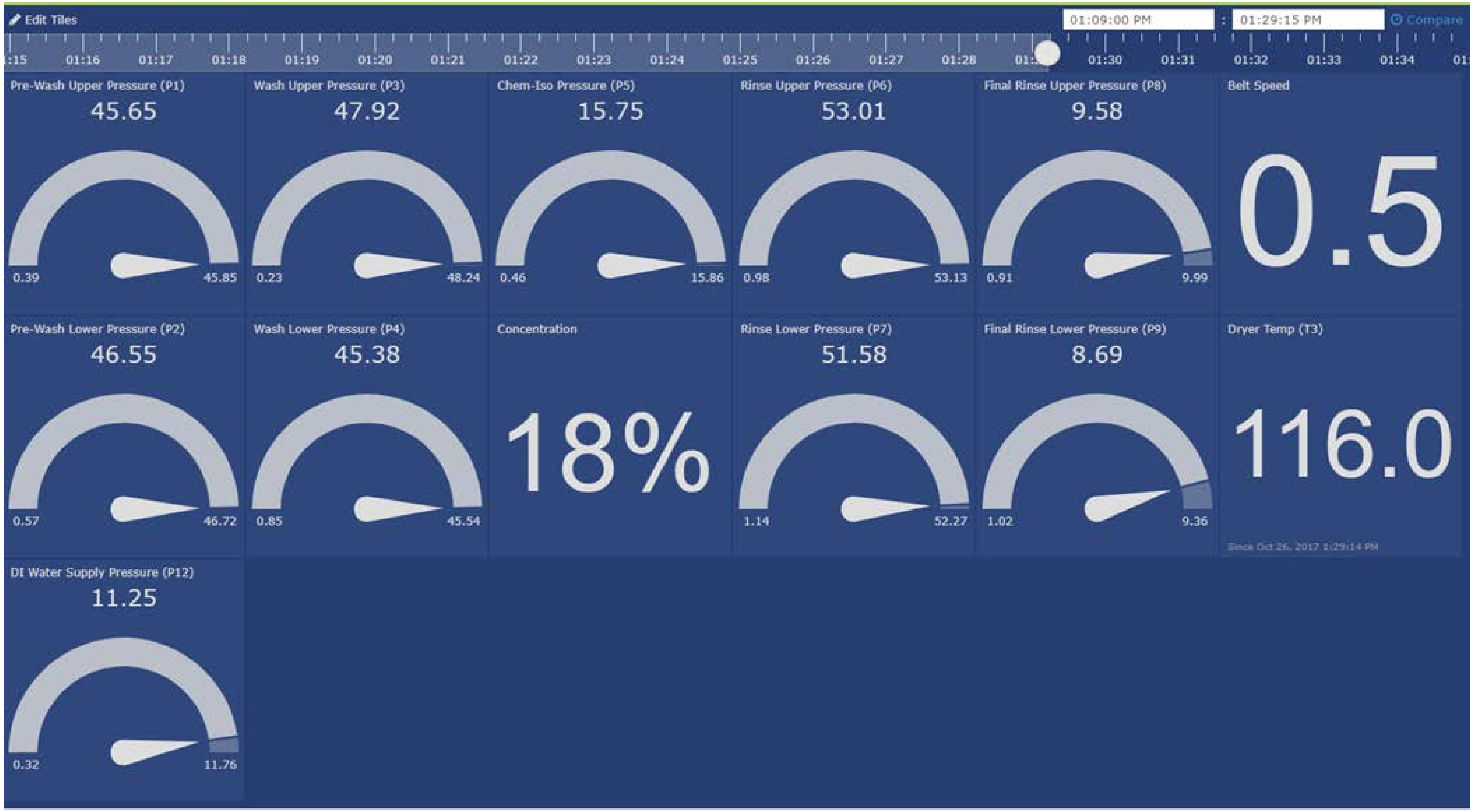
Process Conditions



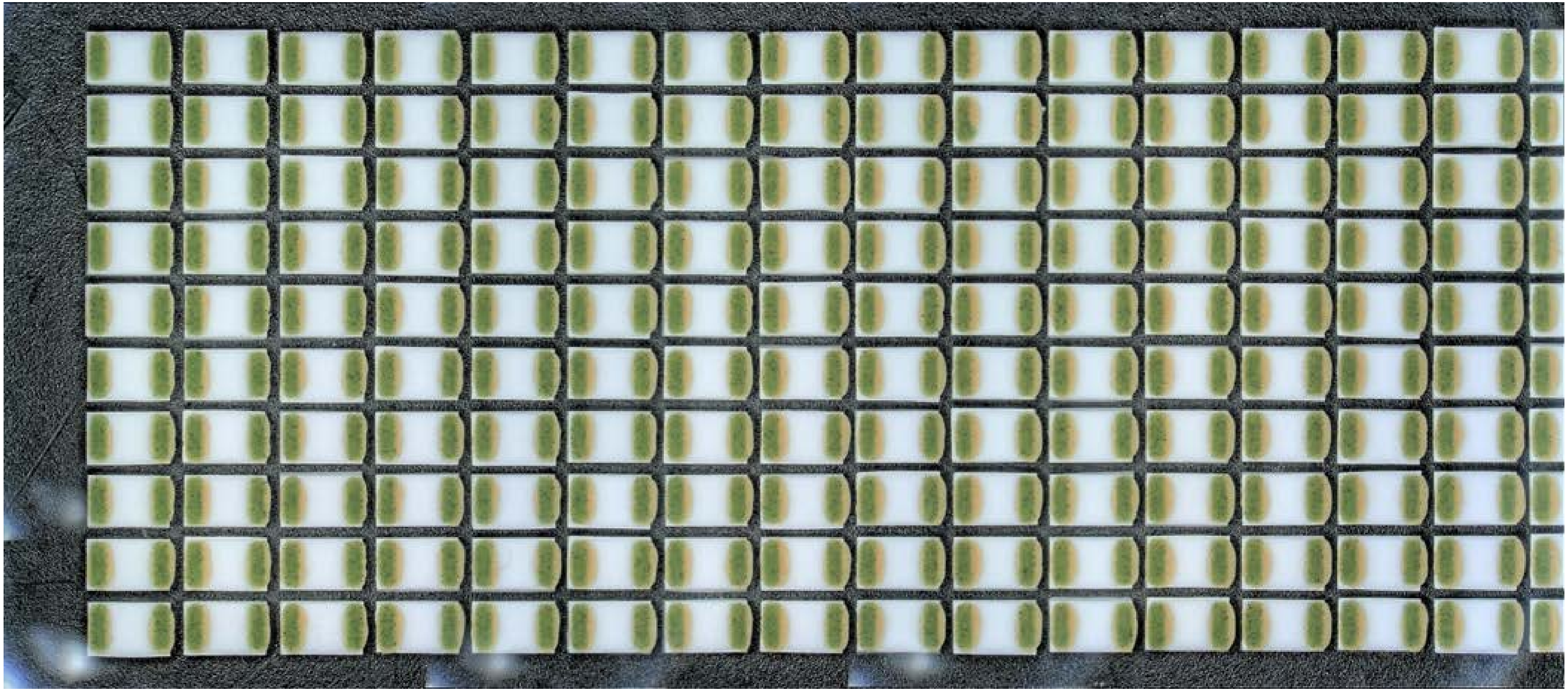
Cleaning Inspection



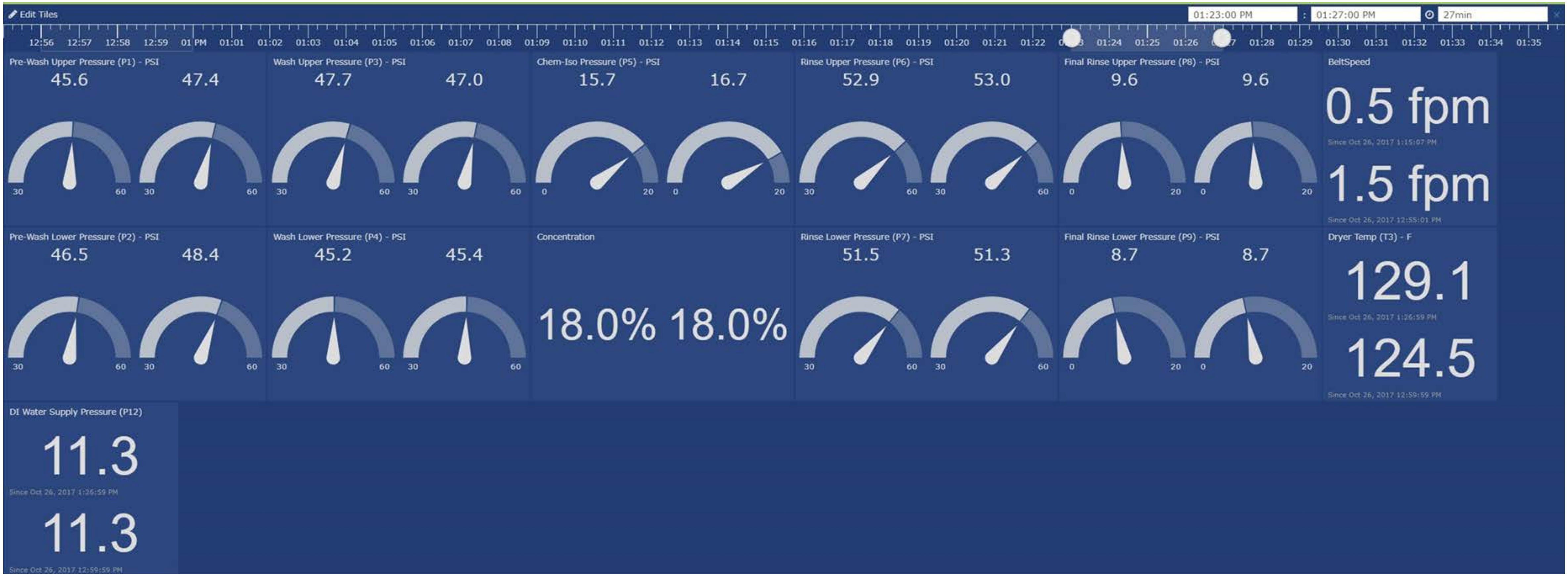
Increasing Time in the Wash Zone



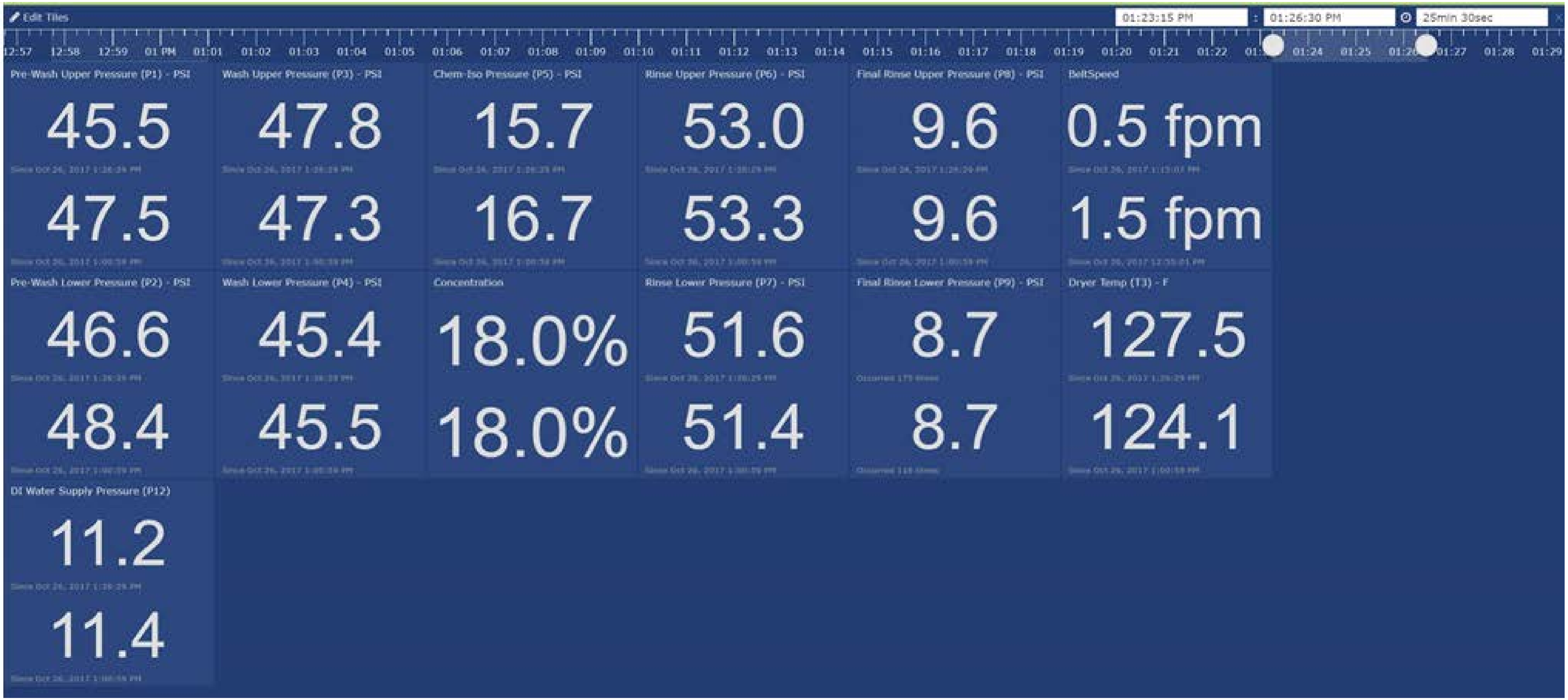
Cleaning Inspection



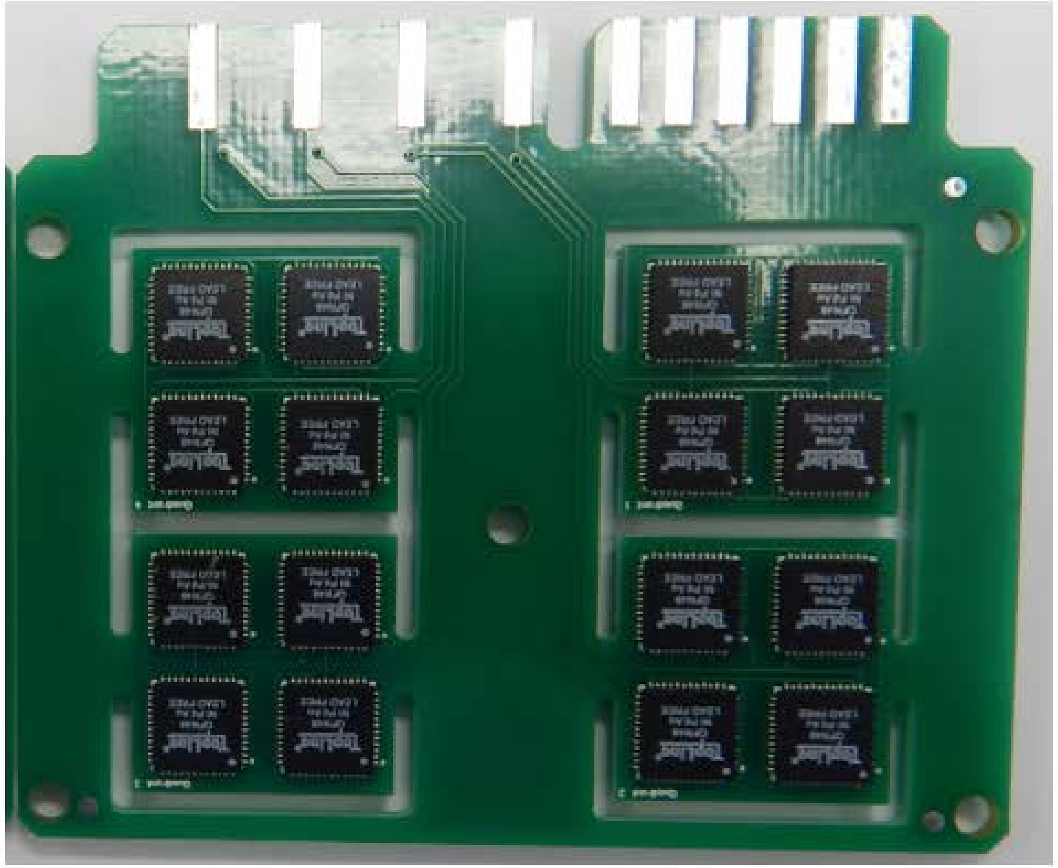
Summary of the Two Wash Conditions

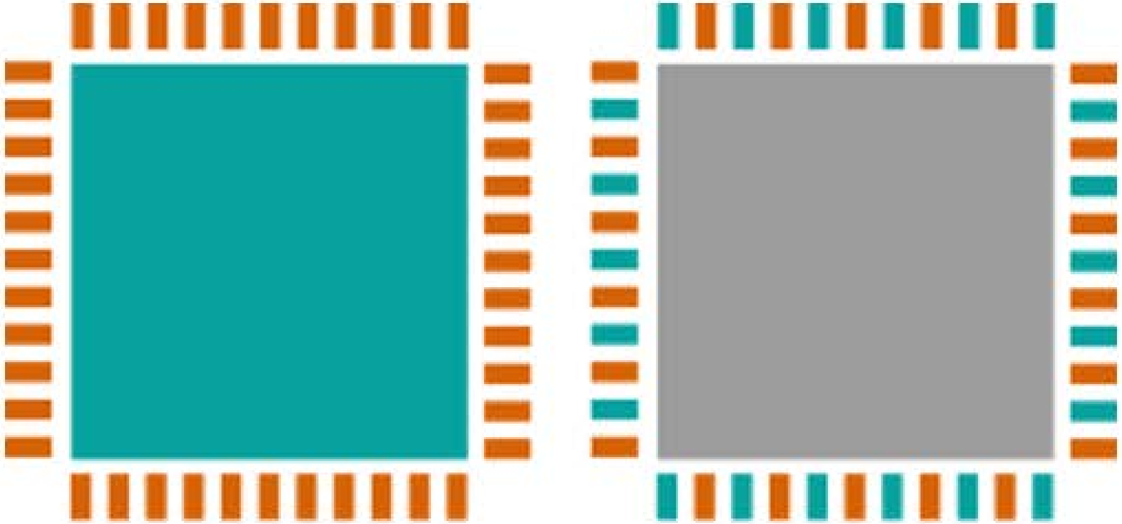


Summary of the Two Wash Conditions

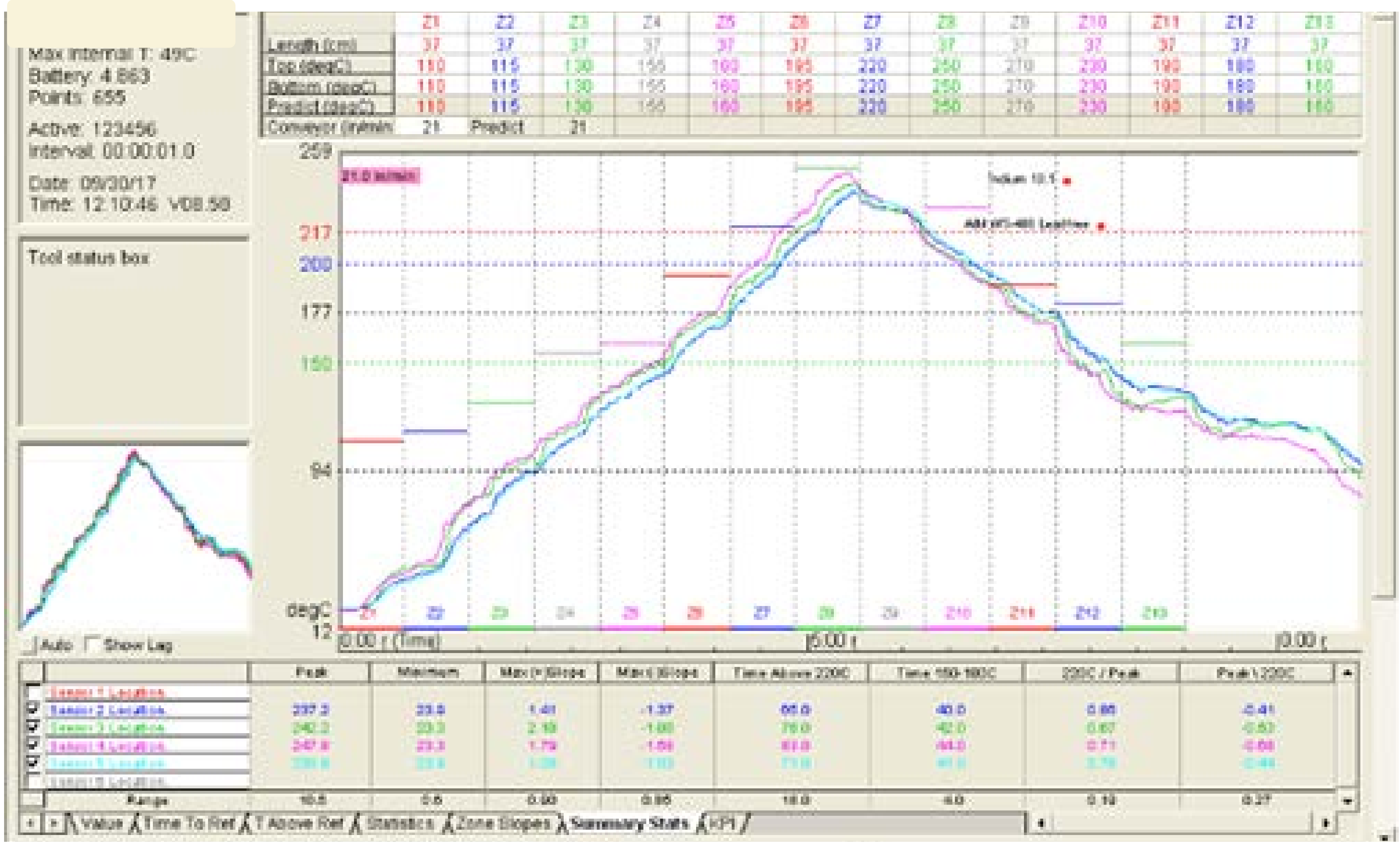


Validating the Process

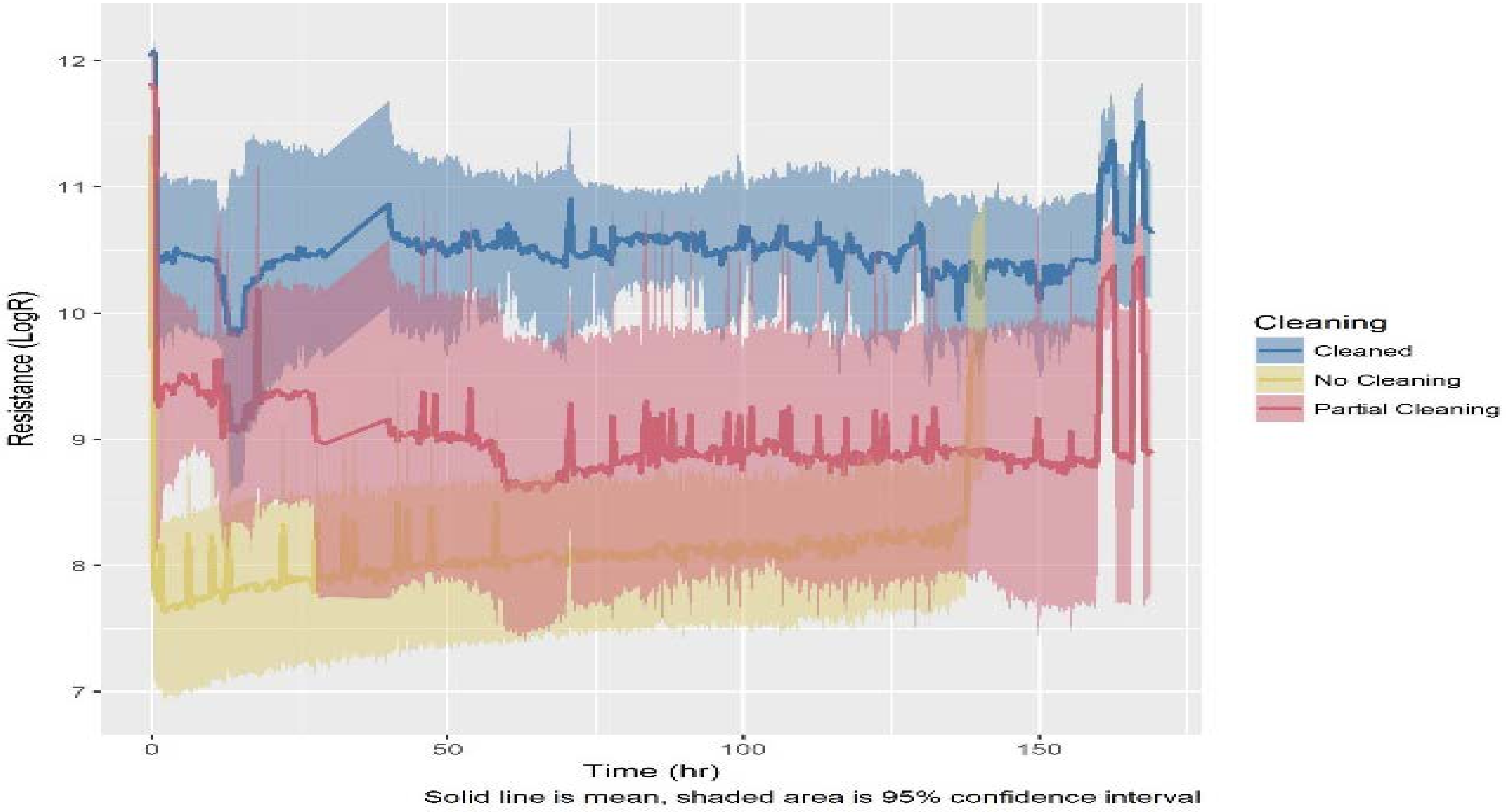




Reflow Profile



Cleanliness Reliability Defined



Monitoring / Tracking Conclusions

Electrochemical Reliability

- Cleaning is not a simple process
- Numerous factors can impact cleanliness levels
- Problematic residues are
  - *Trapped under leadless components*
  - *Residues cannot be detected visually*
- Validating cleanliness levels to achieve chemical reliability
- Monitoring and Tracking Process Conditions
- Process capability index maintained at desired levels

Industry 4.0 – Smart Factory

- Automates ingestion of data, which enables use of machine learning algorithms
- ML algorithms can study the data to identify correlations and make predictive inferences
- These can be applied to a single site or across a global infrastructure

Simplifying Science…

- Data collection and Analytics enable Learning
- Learning becomes Knowledge
- Applied Knowledge improves Quality and Reliability

- Manufacturing high quality and reliable devices is Wisdom!

Questions / Thank You!

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