Managing Wash Lines and Controlling White Residue by Statistical Process Control

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I. Abstract

A statistical-based method was developed for the management and control of conveyorized wash lines which employ aqueous cleaning chemistry for removing rosin fluxes. The method tracks reagent concentration, work load, and soils loading to determine replenishment rates, and when to dump process baths to minimize consumption of chemical reagents while maintaining effective cleaning.

While automatic process control systems monitor cleaning chemistry level in the bath and add concentrate as needed to maintain a set concentration and level, this equipment does not monitor soils loading. Wash solutions that contain the specified level of cleaning agents are rendered ineffective when saturated with flux residues and other soils. The testing procedure and statistical control methods developed here allow for forecasting the point of soils saturation. Bath dumps can be planned to avoid white residue defects while minimizing consumption of costly aqueous cleaning chemistry.

Case studies of equipment illustrate the differences in efficiancy and variability between two makes of wash line. The data also show why there is a difference, and what can be done about it.

FMEA disciplines are employed to develop troubleshooting guides and standard rework procedures which allows more rapid diagnoses and correction of wash problems. Some flux residues that have been left on assemblies for extended times and those residues formed by soldering/pre-heating at too high a temperature and/or for too long do not always wash off with the standard bath. Residues caused by operating the wash line off-spec (insufficient rinse, temperature wrong, concentration wrong, etc) do not always wash off in the line. The troubleshooting guide will help with determining what kind of residue is present, then lead line personnel to the appropriate rework method to remove it.

The data will show a before-and-after picture of chemical consumption for conveyorized wash lines and will quantify the cost savings.

Key words: Wash, SPC, White residue

II. Background

With the phasing out of freon, other chlorinated fluorocarbon (CFC) and similar organic solvents, Sypris Electronics opted for an aqueous cleaning chemistry to remove rosin flux residues. The cleaner concentrate is a high molecular weight alcohol with alkaline buffers. Its high wetting action lifts residues off of assemblies and the solvent action of the alcohol holds rosin in suspension. Concentration is measured by the refractive index. While this proved to be a very effective cleaner, it is also expensive, approximately $28 a gallon.

After transitioning from freon-based washing to aqueous methods, nearly all process control was manual. The wash line had thermostats to control temperature, and that was the limit of any automatic control. Operators took periodic samples and measured concentration. If the bath went outside of set limits, water or cleaner concentrate was added, then the bath measured again to verify the concentration, specified at 25% by volume. This method was less than precise, and often the bath concentration would see-saw up and down before settling into its 25% setpoint.

All adjustments were made to the wash bath on a reactive basis: If measurements showed the concentration off, then add or dilute. If boards came out dirty, yet the concentration was up to spec and the bath looks dark or dirty, then dump it. The bath was also routinely dumped when the machine was cleaned out for preventive maintenance.

Because the cost of cleaner concentrate began to mount higher than anticipated, it was decided to implement automated process control. The supplier of the cleaning chemistry sold automated Process Control Systems (PCS) for this purpose and units were installed on wash lines in the factory. This PCS is a fully automatic programmable system that continually samples the process bath. If concentration falls outside the setpoint, it adds water or cleaner concentrate as appropriate. If the overall level drops below the set point, it adds both cleaner and water at a 25% concentration to top off the bath. The PCS also monitors temperature and the availability of water and cleaner. If the temperature moves out of specification, the process water pressure drops, or the drum of cleaner runs empty, the unit sounds an alarm. Operators still take samples once a shift to verify that the PCS is in good working order, but otherwise, the machine takes care of bath maintenance. As expected, the PCS maintained concentration with far less variability, and the wash lines' consumption of cleaner concentrate went down with this increased efficiency.

Monthly maintenance still included dumping the wash bath, and the bath was often dumped any time boards were not coming out clean, e.g. white residues of any kind. The line was still managed in a reactive mode, although the automatic PCS reduced the overall consumption level of water and cleaner concentrate. In addition, the data display features of the apparatus allowed logging and tracking the following parameters:

- Hours running
- Chemical concentration
- Chemical usage
- Water usage
- Temperature.

These lend themselves readily to SPC and are useful measurements. The exact parameters and how to measure is addressed in Section III, Approach for Improvement.

Something that was never controlled or considered was the soils loading, the amount of flux residue and other contaminants in the wash bath. As the bath ages, it will continue to accumulate rosin flux residues and other soils from circuit boards. There is an upper limit to how much soils the solution will hold before becoming saturated and ineffective. Because the PCS does not measure or control soils loading, a saturated bath will read as acceptable on account of the cleaner concentration being up to spec.

Nonvolatile residue (NVR) testing was initiated to better understand how much soils the wash baths would hold before reaching saturation, and how fast they reached that point. The configuration of the wash lines was not set for deliberate overflow. The only way for anything to leave the wash bath was by drag-out, evaporation, and aerosols drawn out through the ventilation stack. This accumulative effect lead to unscheduled downtime to dump saturated wash baths.

III. Statistical Process Control Approach for Improvement

The first step was generating an Ideal Function Diagram of the wash process. This exercise identified the controls available to effect the process, the noise factors that must be overcome or accommodated, likely defects coming out of the process, and the desired output. By definition, controls are those factors than can be manipulated to effect the outcome of the process. Noise is any factor that effects the outcome, but is not or cannot be directly controlled. Working from the Ideal Function Diagram, the next step is determining cause-and-effect relationships: if the wash is not hot enough, some flux will remain on boards; if the soils level climbs too high, the boards come out dirty. Those cause-and-effect factors, both control and noise, are put under statistical process control (SPC).

SPC should be employed on those factors having the most significant effect on the process's output. Many things can be measured, but only measure the important ones. This is determined from careful study of the process, its controls, noise factors, and measurable cause-and-effect relationships. Typical controls to track include:

- Concentration
- Temperature
- Conveyor speed (dwell time)
- Spray pressure

Typical noise factors include

- Wash concentration variation
- Temperature variation
- Soils load of solution
- Rinse water cleanliness

By understanding the cause-and-effect relationship, it is possible to set process and action limits on these. Testing will be necessary to determine where the actual limits lie.

A new measurement of the wash process is the nonvolatile residue (NVR) test. This quantifies the amount of soils dissolved in the bath and can be used to determine the effective saturation point. A sample of the wash bath is weighed, then evaporated. The residue is weighed and a calculation of the weight percent solids is made. Because the virgin wash solution contains nonvolatiles, it is necessary to make a baseline measurement to note the NVR level of a pristine bath. NVR measurements below this level are either erroneous, or the bath concentration is low. The 25% solution used at Sypris was found to be 1.4% solids by weight.

Samples prepared for NVR testing

The apparatus for NVR testing is available to most facilities that solder circuit cards: convection oven, small disposable weighing pans, and scales accurate to 0.001 gram. The procedure is basic evaporation:

1) Samples of wash solution are taken from the spray manifold by running a tray into the wash line, then pulling it out. Samples taken from the tank may contain a floating film of contamination that the boards in process do not see.
2) After taking a tare weight of the pans, they are filled with roughly 10 to 15 mL of wash solution and weighed again.
3) These samples go into a convection oven. Industrial convection ovens used to bake circuit boards dry are ideal. Drying times will vary with the chemical composition of the wash. The high molecular weight alcohol cleaner in the recommended 25% by weight solution needed at least six hours at 220 F (104 C) to dry. It was found to be more convenient to let specimens bake overnight.
4) The dried specimens are weighed again, and the weight percent of residues is calculated.

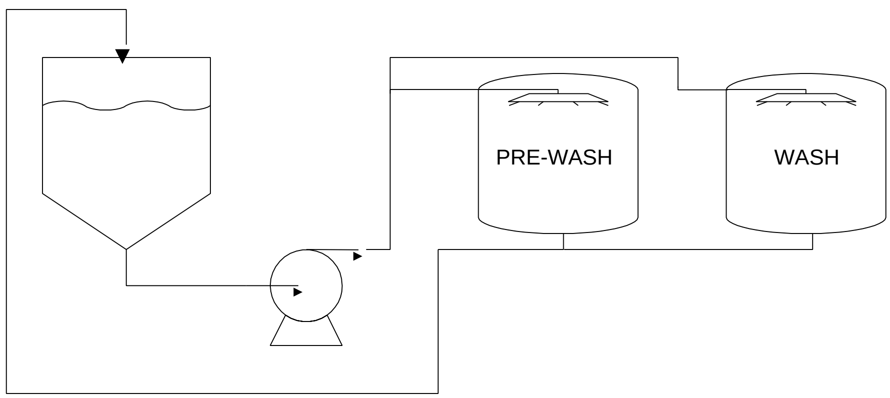
$W_{full} – W_{tare} = W_{content}$
$W_{dry} – W_{tare} = W_{residue}$
$(W_{residue}/W_{content}) * 100\%$ = Weight % nonvolatiles

Dried NVR test samples

The soils loading analysis is an important tool for understanding and controlling the wash process. In a closed-end process, where there is no draining or treatment of the wash solution to remove soils, the bath will accumulate soils until it is saturated. The wash chemistry may be at the specified concentration and temperature, but is ineffective because it cannot remove or hold any more soils. In some cases, a saturated bath will deposit soils. Many manufacturers may wait until this condition occurs and use it as a signal to dump the bath. This incurs unplanned downtime, and reworking poorly cleaned boards. The initial method to avoid that was dumping the bath at a regular interval as part of scheduled maintenance. This assures uptime, but incurs the cost of changing out wash baths when they may not need it. A soils loading analysis determines where that saturation point is and helps provide an indicator of how fast the bath will reach that level.

The method is rather simple. The wash line is run as usual, but not dumped. Instead, periodic NVR tests are run (daily or weekly) and tracked until the bath shows signs of saturation and boards no longer come out clean. NVR tests will show what level that is. The amount of time needed to reach saturation is also noted, and future NVR testing is used to monitor the process, now that the process limits are known. Appropriate action limits are set to ensure the bath is dumped before it reaches saturation. At Sypris, saturation was found to occur at 3% solids by weight by weekly measurements, and the action limit was set at 2.8% because wash baths were observed to increase at no more than 0.2% in a week. The specific saturation point will vary with wash chemistry, concentration, temperature, and type of wash equipment. It will be necessary to determine this individually for wash chemistries and apparatus.

amount of water or cleaner used could be an indication of an out-of-control condition or a maintenance problem. The cleaner-to-water ratio ideally would be steady as the PCS makes up for drag-out losses and evaporation. In the event this number swings to extremes, it is an indicator of an out of control system or a need for maintenance.



TYPE H ONE-TANK WASH

A revised control plan and SPC scheme was employed to make the most use of this new knowledge. SPC charts were employed to monitor:

- **Bath concentration.** This is automatically controlled by the PCS, and this chart tracked the system's effectiveness at holding the setpoint. Because two different wash lines were plumbed in two different ways to the process control system, the more effective way to use a PCS became evident.

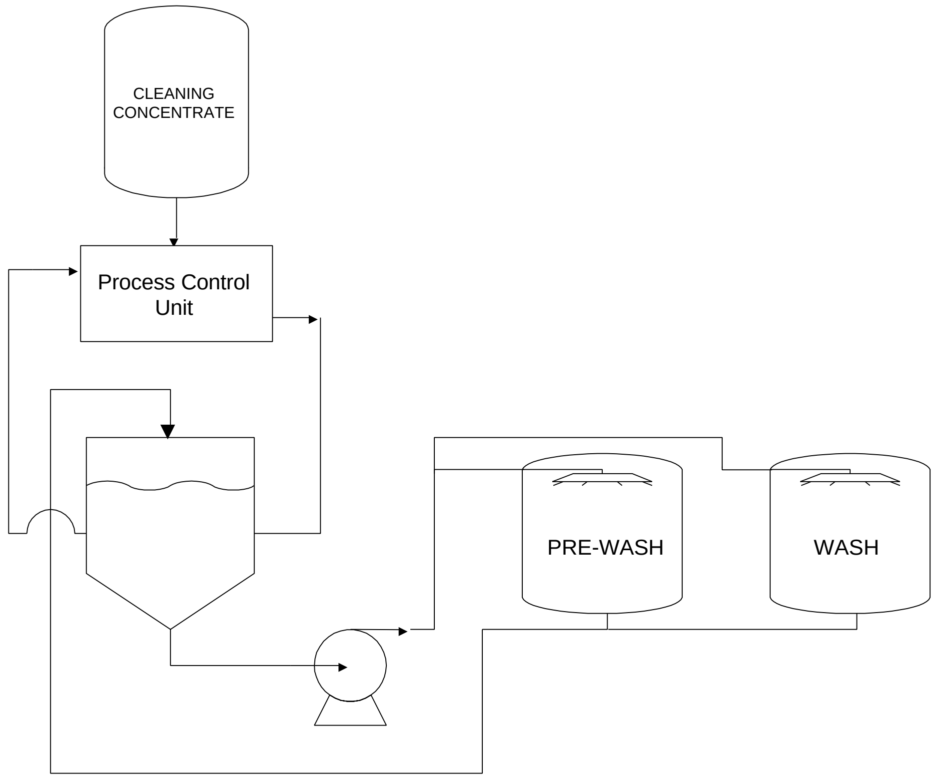
- **Nonvolatile residue.** By tracking soils load, it was possible to dump the bath only when needed, and before discrepant product came off the wash line.

- **Cleaner consumption**
- **Water consumption**
- **Cleaner-to-water ratio**

Cleaner and water consumption, and their ratio, while having no direct effect on clean boards, were charted be-cause they indicate efficiency and serve as vital signs of the system, like pulse, temp-erature, and blood pressure. Any significant changes in the

Two different makes of conveyorized wash are in use at Sypris, Type H and Type S. The Type H machine is an older design and has a single storage tank for the wash bath. This solution is pumped through two sets of spray manifolds: a pre-wash, the first set of spray heads, then the main wash in the next module in line. The end of the main wash includes a proprietary curtain spray. The Type S machine is a newer design and has two tanks for the wash bath. The pre-wash module and main wash module each has its own tank. The user can leave them isolated from each other, or open a valve on a connecting pipe to allow the contents of the two tanks to mix. After taking measurements for several months, numerous trends became visible.

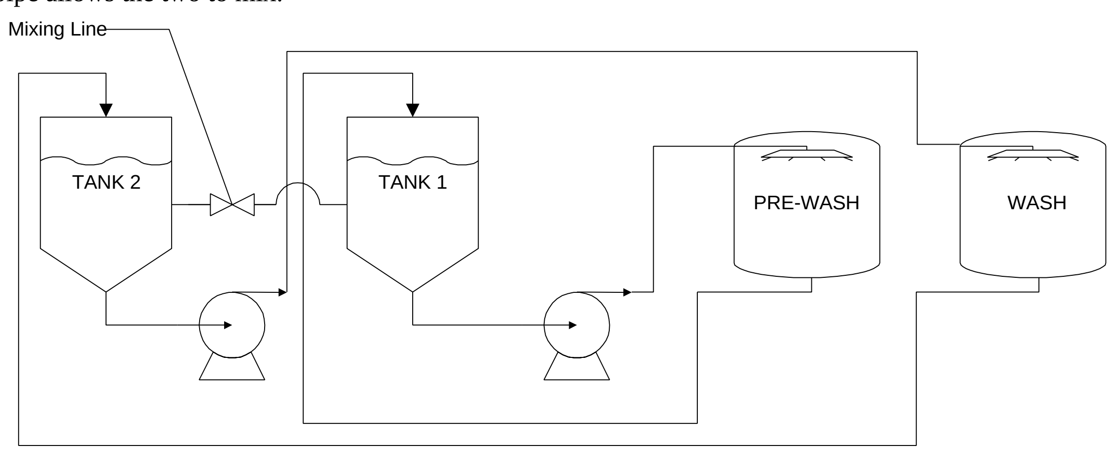
Implementing SPC not only allowed for keeping wash lines within specification to avoid defects, it also helped quantify process performance and efficiency. Statistical data showed which of the two different types was more efficient.



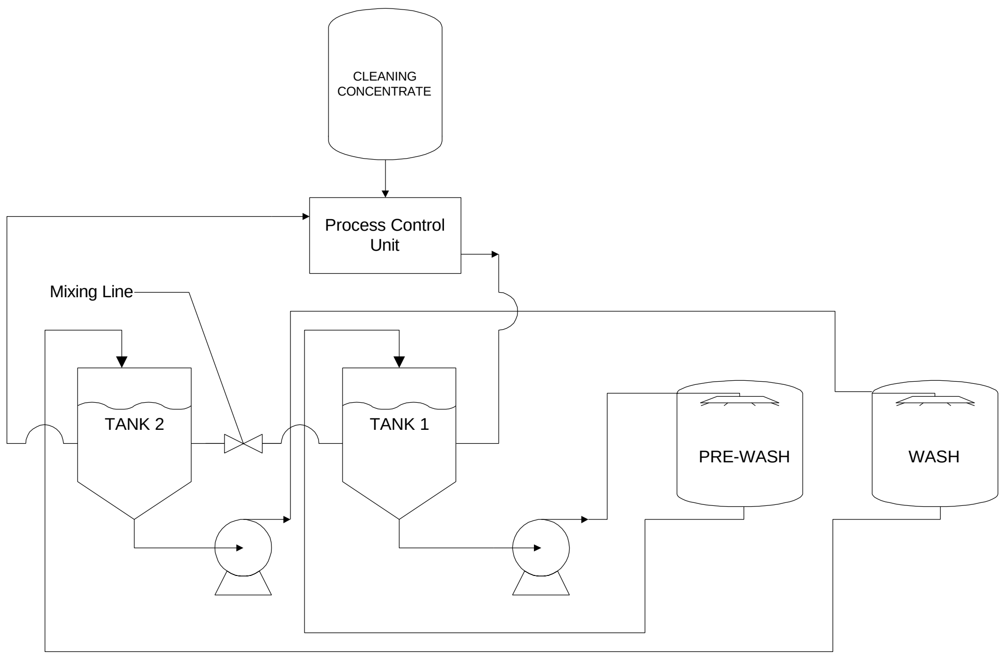
TYPE H ONE-TANK WASH WITH PCS

Outfitting Type H wash lines with a PCS is fairly straightforward. The intake and output from the PCS is plumbed to the single wash tank. Type S proved more challenging because it has two wash tanks, and is built from stainless steel. It was not an option to simply bore a hole in the side of a tank and screw in a fitting. Existing taps on the two tanks were used to connect the PCS. It draws from one wash tank and pumps into the second. The theory is that the system effectively acts like one big tank because the connecting pipe allows the two to mix.

All wash lines were tracked and charted for SPC, and several things soon became evident.

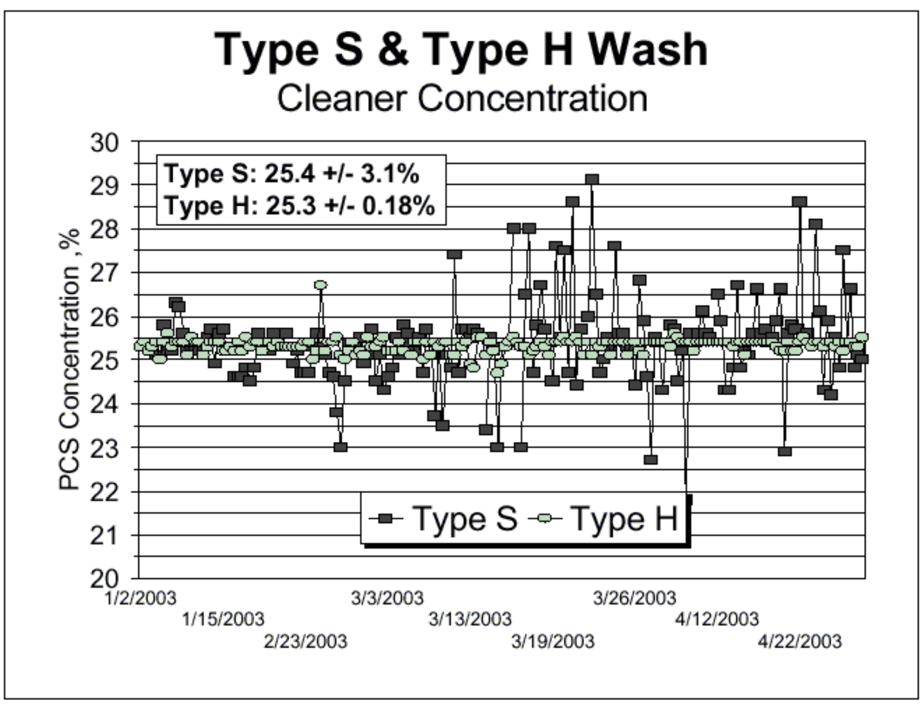


TYPE S TWO-TANK WASH

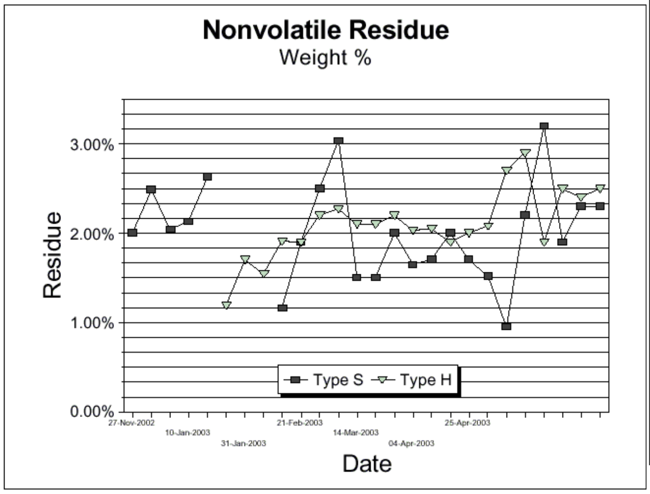


TYPE S TWO-TANK WASH WITH PCS

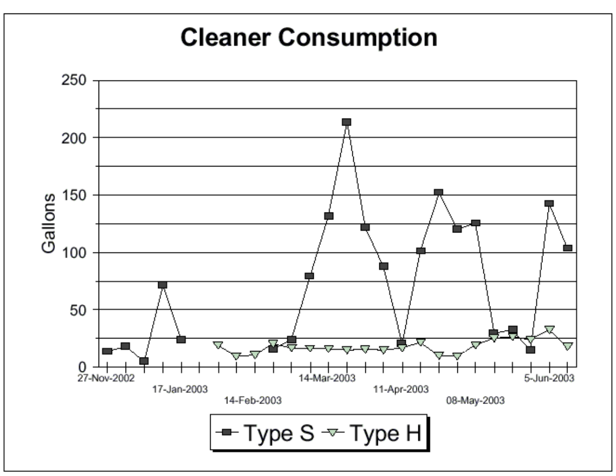
- **Concentration.** The type H wash lines exhibited more stability than Type S. Measured concentration was 25.3 ±0.18% compared to Type S at 25.4 ±3.1% (set point is 25 ±0.5%). This was attributed to Type S having two tanks. The mixing between the two is not sufficient to treat them as one large tank. The lag time between the PCS making an add to one tank, then reading it from the other is enough to cause the concentration to see-saw.



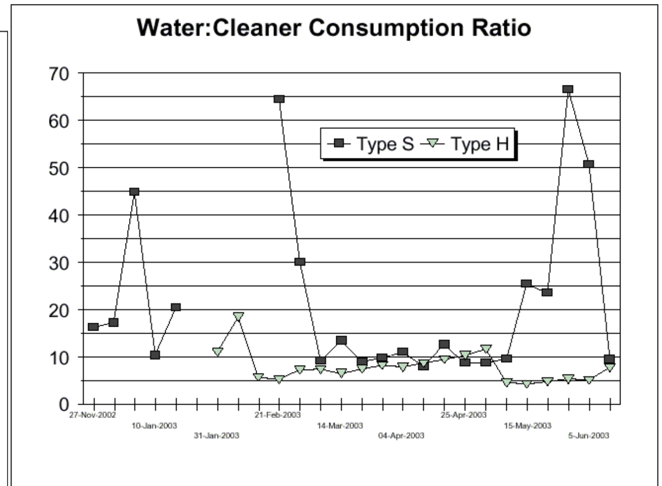
- **NVR.** Soils generally accumulated in a regular, predictable manner. Accumulation should be a function of the accumulated surface area cleaned (assuming all boards to be equally soiled). Working from NVR measurements, bath dumps were reduced to roughly one every five months. During scheduled maintenance and cleaning, the bath is drummed up and returned to the wash line.



- **Cleaner concentrate and water consumption.** The Type S wash uses more of each than Type H. Spikes indicate possible PCS problems, unscheduled dumps or significant loss of wash solution. The PCS maintains the overall fluid level in the wash line, and if a float valve sticks, it will continually add water and cleaner, the excess spilling through the overflow to the drain. This breakdown occurred on Type S, resulting in the spike in both water and cleaner consumption in the middle of the graphs.

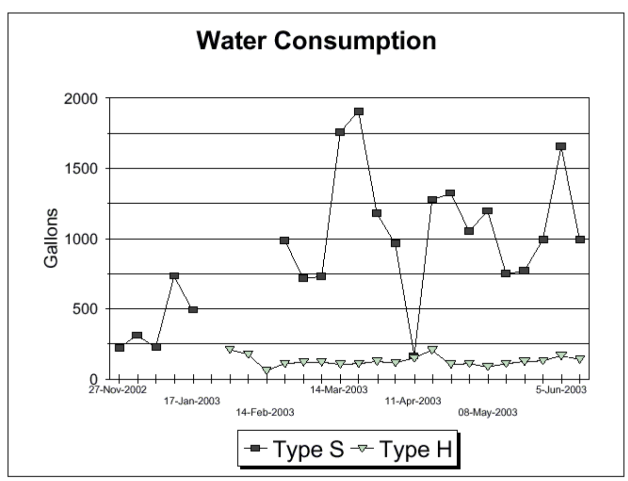


- **Water-to- Cleaner consumption ratio**. This should be a relatively constant value when the wash reaches steady state. The chart shows the variation in this. Again the Type S wash shows more variability than Type H. Variations in this ratio can be attributed to variations in concentration. If concentration see-saws, then this ratio will change as the PCS attempts to bring concentration to the setpoint.



SPC was the first step in taking a proactive approach to managing wash lines. Future steps include developing means to project soils loading and bath dumps. Analysis will show a trend for bath life by either hours of operation or square footage processed. This can be used to project and schedule bath dumps and maintenance as part of the production schedule. Downtime can be planned in advance as a function of workload rather than suddenly happening as a result of NVR testing.

The cause-and-effect relationships used for implementing SPC led directly to developing a troubleshooting guide for manufacturing to use



on the floor. The effort began with the Ideal Function diagram. The number one problem that occurs with wash lines is white residue. While at least six different causes can produce white residues, the old fix was to dump the bath and mix up a fresh wash solution. This method did not address the real root of the white residue problem.

Failure Modes Effects Analysis (FMEA) methods were used on the white residue problem and for developing means to prevent and correct it. Prevention included identifying those factors that are, or need to be under SPC. The primary causes for white residues were identified in approximate order of frequency as:

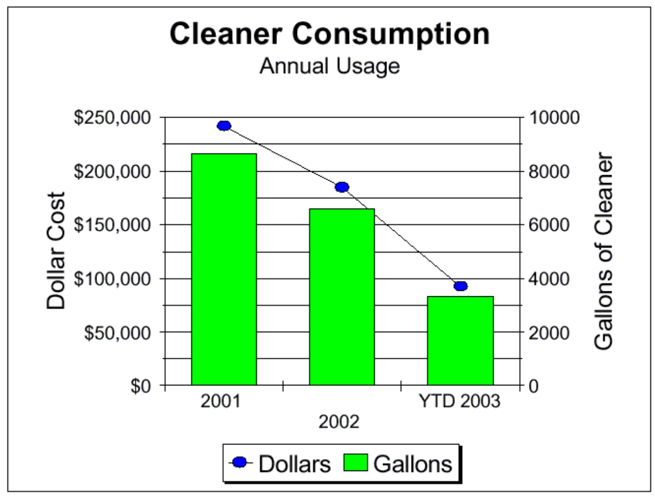
- Dried-on or cooked-on flux
- Rinse temperature too low
- Wash temperature too low.
- Not enough rinse
- Wash saturated with soils
- Wash concentration too low
- Mixed water-washable and rosin fluxes
- No-clean flux

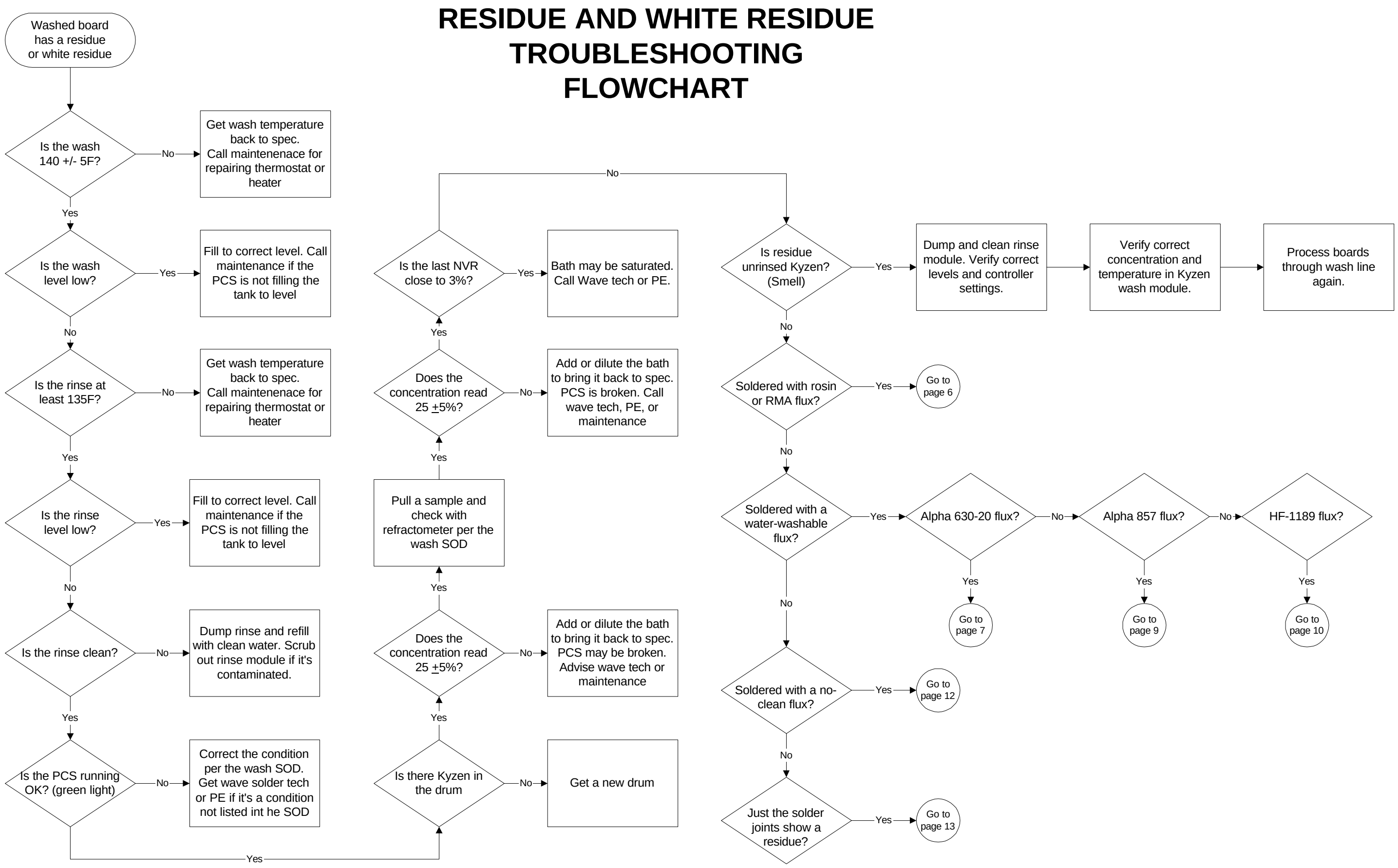
All of these causes are either under SPC control, or addressed in written process instructions. Temperatures are already under thermostatic control and found to be very stable. Operating instructions are being revised to include scheduled temperature checks to ensure thermostats are working. The wash line already has low level alarms and the process calls for shutting down in the event the alarm trips. Soils loading is now monitored via NVR and is under SPC. Wash concentration is automatically controlled by the PCS, which sounds an alarm if it cannot bring concentration back into range.

The remaining causes: mixed flux chemistry, dried-on and cooked-on flux, and no clean, are process instruction issues. Manufacturing instructions call for washing or pre-cleaning boards within 30 minutes of soldering. The troubleshooting guide mentions all of these causes and will guide the user to determine which was/were the likely reason(s) for the defect, then onward to standard corrective action and rework instructions. Part of the diagnostic process is reviewing SPC charts and checking charted controls.

IV. Improvements

Implementing SPC methods and controls on the wash process dramatically reduced cleaner concentrate consumption by 24%, saving some $57K in chemical costs in the first year, 2002. Year-to-date figures for 2003 indicate similar to reduced chemical consumption with the addition of new controls. NVR testing has reduced bath dumps from monthly to approximately once every four months. For Type S washers this is a minimum additional annual savings of 320 gallons ($8960) each, and for Type H washers the yearly savings is 240 gallons ($6720) each.





V. Conclusion

SPC is a powerful and effective tool for increasing the efficiency of the wash process. Successful SPC requires identifying and measuring the most significant factors that effect results. An understanding of cause-and-effect relationships between factors and the process' output is essential for any successful use of statistical methods. By understanding and charting the most relevant factors, it was possible to make substantial improvements in efficiency, quality, and prevent unplanned downtime.