# NO CLEAN(LINESS)- NO(T) ACCEPTABLE!

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## ABSTRACT

No-clean pastes have specific physical properties, which directly impact industry standard electronic assembly cleaning processes. This paper sets out to establish new benchmarks for cleaning no clean surface mount solder paste residues (including the most challenging latest lead free product formulations) by incorporating leading cleaning technologies, the actual impact of different spraying technologies, temperature air vs. nitrogen atmosphere, as major variables. The cleaning evaluations were conducted in a controlled application technology center while using thermally profiled reflow conditions and cleaning equipment. The response variables used were qualitative visual inspection of cleaned surfaces (i.e. white residues) as well as the solder joint appearance. This innovative approach has now provided for new solutions and will help future users to minimize their cleaning challenges.

Key Words: Cleaning, No Clean, Lead Free, Spraying Technology, Ambient Temperature.

**Experiment:**

- Determine the impact of spraying technology and cleaning technology on eutectic and lead-free no-clean formulations.
- Establish that „Temperature“ can potentially be a disposable cleaning process variable!

**Process Parameters Used:**

- 7 no-clean formulations were tested, eutectic and lead-free based formulations
- Electrovert OmniExcel 7 reflow oven was used.
- Standard reflow profile for eutectic and adjusted profile for lead-free.
- Commercially available Aquastorm AS 200 Inline cleaning machine
- Cleaning Chemistries: Aqueous MPC® based VIGON® A 300.
- Temperatures: unheated and 122°F
- Spraying Technology: Hurricane™/V shaped Jet and Delta Jet/JIC
- Belt speed: 1, 2 and 3 feet/min
- Test boards were unpopulated

**Summary of Findings:**

- All eutectic and lead free no cleans tested were fully cleanable without additional heating, while soldered under regular atmospheric conditions.
- The spraying technology was found to be an important process optimization tool.
- Lead-free under nitrogen atmosphere was very easily cleanable under standard process conditions.
- Recommendation to future users of no-cleans: Find partners that support and overall process optimization and can integrate mechanical, thermal, and chemical interactions.

## IS NO-CLEAN A REAL CLEANING CHALLENGE?

Successful spray in air inline cleaning involves three different energies, thermal, chemical and mechanical. Mechanical energy for example is represented in the form of translational kinetic energy where $1/2mv^2$ is the governing equation. The mass in this equation is directly related to droplet size and velocity is created by the spraying pressure. Further derivation of this equation translates into the impact force = 0.0527 (gpm) pressure $^{0.5}$. For any set pressure and flow rate if the flow rated is doubled the impact force increases 100% and if pressure is doubled the impact force is increased 40%. Three factors having the most effect on both droplet size and velocity are spray pressures, fluid viscosity and temperature. Of these three only increases in pressure and temperature yield increase on impact energy. These energies are typically delivered by nozzles that are placed about 4 to 5 inches away from the PCB.

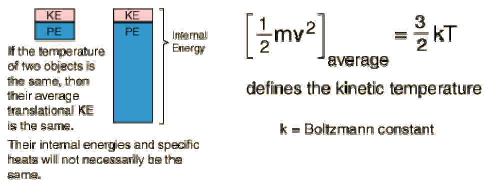


Figure 1. Definition of Kinetic Energy

How much impact force is needed to clean no clean residues? Some residues may require little impact force and rely on the chemical action, water temperature and rinse down provided by the nozzle. Other residues may require high levels of mechanical force including high pressure solid stream nozzles working in concert with chemical and thermal energies for aggressive cleaning.[i]

Throughout the past 20 years many different nozzle designs have been utilized for spray in air aqueous cleaning. One of the most common is the flat spray (Hurricane/V shaped Jet). (Figure 2b) These nozzles provide a V shaped spray pattern through the air that is specified by the spray angle and flow rate. When assembled in a line on a manifold their Vs meet each other at the process level or slightly overlap in a long flat spray. These nozzles are then staggered on altering manifolds providing complete coverage across the process width. Flat spray nozzles excel in the two of the three energy areas. By applying a flooding action to the PCB it allows residues to soften both chemically and thermally. But when compared to other nozzle designs, these nozzles offer the least amount of delivered mechanically energy to the PCB. As the distance from the nozzle to the PCB increases, the droplet size decreases, decreasing the kinetic energy.

The solid stream spray (Delta Jet/JIC) is another common nozzle. (Figure 2a) These nozzles are probably the most simplest in design. They can apply the maximum amount of mechanical energy of any nozzle independent of the pressure. This is achieved by keeping the spray in a solid stream of fluid and retaining all of the droplets mass and therefore all the kinetic energy. This solid stream may take on a couple of shapes either in a pin point or sheet. As a pin point the nozzles are typically spaced at equal increments on the manifold and then alternated on each subsequent manifold. Due to the small size of the pin point spray, approximately 1/8” diameter, it is a bit more difficult to cover the entire process width. However, the round nature of the pattern gives good dispersion in all directions on impact with the PCB.

Figure 2a. Examples of solid stream nozzle

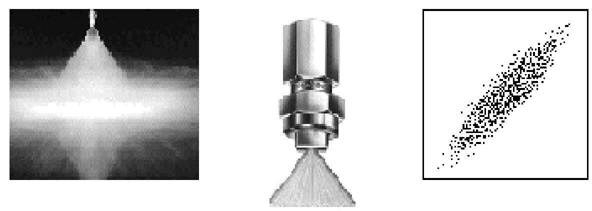

Figure 2b. Examples of flat spray nozzle

Figure 2c. Example of solid sheet nozzle

If in a sheet pattern (Figure 2c), this will traverse the process width with no breaks applying complete absolute 100% coverage. This design ensures that all components on the PCB will be sheeted. The dispersion of this sheet pattern is parallel to the PCB surface allowing great penetration under all components. Cleaning can be achieved under standoffs as low as 1 mil.

And for as many nozzle designs there are that many pressure and flow philosophies. Generally the four primaries have been high pressure-high flow, low pressure-high flow, low pressure-low flow and high pressure-low flow. This paper focuses on what the authors consider as the extreme of these combinations, *high pressure-high flow*.

The necessity of thermal energy on the other hand (i.e. temperature) has played a pivotal role in the past in order to allow the solvation process of residues left on assemblies. It was not until recently that the industry had blindly assumed that temperature could not be reduced further to more acceptable values. That was partially the case due to the widespread use of surfactant based products and their need (140-160°F) for activation.[ii]
This study was therefore initiated to evaluate the most recent surge in cleaning process related problems with current solutions („surfactants trying to clean no-clean“) used in the market. In particular, this evaluation was tasked to develop cleaning process protocols that particularly took lead-based and eutectic no-clean paste/flux formulation (most challenging) into account and at the same time evaluate that cleaning at lower temperature would be feasible! When a high temperature object is placed in contact with a low temperature object, then energy will flow from the high temperature object to the lower temperature object, and they will approach an equilibrium temperature.

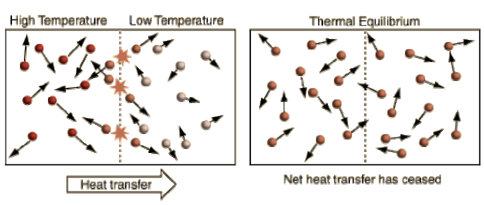


Figure 3. Thermal Energy and its interactions

Over the years the assumption of energy in and output has been largely ignored in the electronics cleaning industry. It has not been until recently, and due to cost saving initiatives by companies and employees that this viewpoint has been challenged. A general estimation of energy consumption per hour and equipment was found to be at least as high as $100. A fraction of that cost is related to the heating modules of the cleaning agent holding tank. It was therefore imperative to evaluate and benchmark the product technology that were designed and proven to effectively remove all types of flux based residues even <u>at ambient temperatures</u>. This was of particular interest, since it had been assumed that temperature was not a variable that could be amendable to change. With these new cleaning technologies (i.e. cleaning agents) this antiquated viewpoint is NOW subject to change.

Surfactant based product technologies are known to require sufficient heating in order to effectively work during the cleaning process. This is the explanation for example why all currently available batch and inline cleaning equipment are only sold with heating units. At the time alternative cleaning products were simply not available. It is foreseeable, that such product innovations will lead the way to even more cost effective process solutions, if only one can effectively establish that thermal energy can be neglected to a large extend.
It is estimated that most current users of surfactant based formulations loose up to 60% of their cleaning agent through continuous evaporation. In addition the evaporation rate doubles with every 10°C (18°F) difference of temperature. For example, a reduction from 160°F to 140°F, minimizes the evaporative losses by 50%. A product used at ambient temperature, will provide even more significant process savings (Figure 4)!

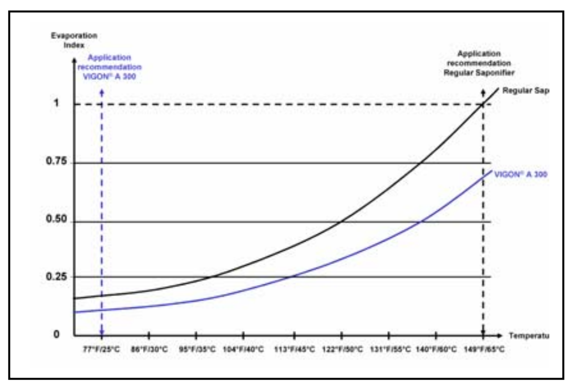


Figure 4. Reducing evaporation losses by 80%!

Besides the savings on cleaning agent, it is furthermore established that operating at the current temperature limit of Polypropylene cleaners (160°F), harshly impacts the life time of the actual equipment. Reducing such drastic wear and tear does not only mean less equipment cost, but at the same time a significant change in process maintenance. In summary the following process related advantages are realized with cleaning at lower temperature:

- Minimizing the evaporative losses
- Lowers the risk of corrosion and oxidation.
- Minimize any wear and tear on the cleaning equipment (body, pump, etc)
- Minimizes any component related MOC issues (coatings, masks, heat sensitive components, etc.)
- Brighter solder joints.
- Wider process window (always the option to increase temp.)
- Less fluctuations in cleaning agent concentration » more cleaning stability.

Apart from mechanical and thermal energy the basic chemical interaction between cleaning agent and particle completes the most important variables. Chemical reactions typically involve breaking and making some (or even all) of the bonds that hold together the atoms of reactant and product molecules. Energy is required to break bonds, and since the strengths of different kinds of bonds differ, there is often a significant overall energy change in the course of a reaction. With the latest cleaning technologies, bonds are not being broken or formed, and chemical interactions are solely based on aspects such as solubility, physical and electrostatic properties. In contrary to older, surfactant based product technologies where dissolution was based on acid base reactions and unfortunately this meant that active ingredients (surfactant molecules) were depleted during the cleaning process.
As indicated above, one very important aspect toward achieving cleanliness is the fact that the cleaning agent (chemical energy) being used, has to be fully "compatible" with the residues that are being removed. In other words, equipment related efforts to remove residues from PCBs are most easily avoided by conducting cleanability evaluations. These are aimed at the general removability of contamination with an appropriate cleaning agent. Depending on the respective cleaning technology they can either lift, dissolve, or temporarily suspended various particles and contamination.

**CLEANING OF EUTECTIC-NO CLEAN**

Based on previous tests conducted with MPC® based cleaning technologies, the initial experiments were started at 122°F with assemblies soldered under regular atmosphere (Figure 5a). Any variation in belt speed did not have any significant impact on the cleaning results. Also a variation in spraying technology proved no different. The authors believe that a further increase in the belt speed at 122°F would have been even possible while maintaining the excellent cleaning outcome. With all cleaning results being very satisfactory (visually clean, bright solder joints), the authors furthermore argue that such "process reserve" might be helpful for the removal of more challenging flux residues, i.e. lead-free no-clean formulations (figure X1).

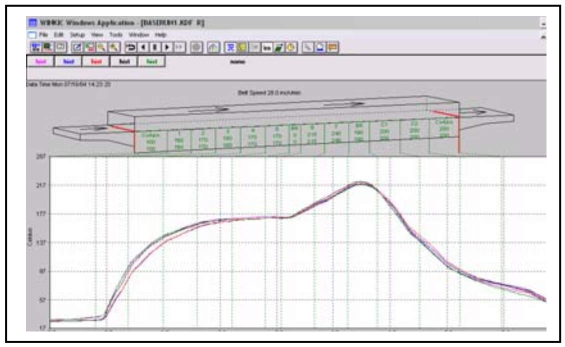

Figure X1: Eutectic Reflow Profile

Based on the encouraging results obtained at elevated cleaning agent temperature, the soldered boards (regular atmosphere) were subjected to the standardized cleaning process, with the cleaning agent being in an unheated state. Initially, the belt speed was set to 1 feet/minute to ensure sufficient soaking and cleaning intervals. Here the flat spray nozzles were used and upon achieving positive results the nozzles were substituted for solid stream to measure any perceived difference. It was concluded that for all pastes tested the results were very satisfactory and no visible difference between the different spray technologies was seen.
Subsequently, the same parameters were used to evaluate whether higher belt speeds (shorter soaking/spraying) might have a greater influence on the cleanability of these eutectic pastes and fluxes with different nozzles.
The belt speed was therefore increased to 2 ft/min. and the tests were repeated. Still no change in the cleaning behavior was noticed, and both spraying technologies afforded again excellent cleaning

results. The very bright and clean solder joints were particularly noteworthy. The cleaning agent at this point was still in an unheated state. Increasing the belt speed to 3ft/min. did not show any further limitation and it was therefore concluded that for the products evaluated the difference in spraying technology had no effect on the effectiveness of ambient defluxing of eutectic no-clean formulations (Figure 5b).

| Nozzle Type | Flat Spray | | | | | |
|---|---|---|---|---|---|---|
| Cleaning temp. | Unheated | | | 122°F | | |
| Belt Speed in ft/min. | **1** | **2** | **3** | **1** | **2** | **3** |
| Solder paste A Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste B Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste C Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste D Sn63 Pb37 | + | + | + | + | + | + |

Legend: + = 100% cleaned, 0= optimization, - = not cleaned

Figure 5a. Results Eutectic no-clean reflow in air – cleaning with flat spray nozzles

| Nozzle Type | Solid Stream | | | | | |
|---|---|---|---|---|---|---|
| Cleaning temp. | Unheated | | | 122°F | | |
| Belt Speed in ft/min. | **1** | **2** | **3** | **1** | **2** | **3** |
| Solder paste A Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste B Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste C Sn63 Pb37 | + | + | + | + | + | + |
| Solder paste D Sn63 Pb37 | + | + | + | + | + | + |

Legend: + = 100% cleaned, 0= optimization, - = not cleaned

Figure 5b. Cleaning Results Eutectic no-clean reflow in air – cleaning with solid stream nozzles

For eutectic no-clean formulations the use of an inert atmosphere (nitrogen) for the soldering was deemed unnecessary since further cleaning improvements were not required. This also widened the process window, added process flexibility, and exemplified an unprecedented ease of removability.

Most importantly, these results illustrated for the first time ever, that the process variable *"temperature"* could be considered as a variable soon to be eliminated from the cleaning processes in the electronics. This of course requires that the appropriate cleaning technology (i.e. cleaning agent) is combined with the most suitable process parameters (i.e. equipment, nozzles, pressure, etc.).[iii]

## CLEANING OF LEAD FREE-NO CLEAN

The electronics industry, along with different associations and committees, is intensively looking into the development of solder paste systems that serve as an alternative to the traditional tin/lead solder pastes previously used. Currently, a number of alternative solder pastes have been developed, among tin/silver/copper (Sn,Ag,Cu) based systems for example, that seem to be best suited for standard use. One of the currently experienced problems is that in order to guarantee reliable soldering at higher temperatures, the addition of new flux formulas are necessary. That includes for example solvents with higher boiling points, increased rosin content (solid content), and in particular more aggressive activators to inhibit the oxidation of the solder at higher temperatures and to provide for adequate wetting characteristics.[iv] These factors are all expected to cause an increase in the amount of remaining flux residues, and at the same time the demands on the cleaning process. The high affinity of silver to form hydroxides and sulphides is the major reason for the observed electrochemical behavior. The larger the quantity of activators that is required by the higher reflow temperatures, the higher the amount of moisture that is adsorbed by these hygroscopic residues. Coinciding with the increased amount of fluxes used, is the question of fully reliable encapsulation.[v] Various companies have already acknowledged the limited reliability of lead free soldered components. Especially due to the previously mentioned higher reflow temperatures required for most lead-free solder pastes (up to 40°C or 104°F), additional oxidation and polymerization reactions of the fluxes in use will occur. These reactions cause these flux residues to be firmly "baked on" during the soldering process, thus making them significantly more difficult to remove with chemically based cleaning agents.
Such behavior can certainly be depressed through the use of Nitrogen that provides for a generally inert atmosphere during the soldering. Thus, various oxidation induced or based reactions are therefore prohibited. The immediate result is that flux residues are simply not baked on as much as with an oxygen containing environment.

| Nozzle Type | Flat Spray | | | | | |
|---|---|---|---|---|---|---|
| Cleaning temp. | Unheated | | | 122°F | | |
| Belt Speed in ft/min. | **1** | **2** | **3** | **1** | **2** | **3** |
| Solder paste E<br>Sn 95.5 Ag4.0 Cu0.5 | **0** | - | - | + | **0** | - |
| Solder paste F<br>95.5Sn 3.8AG 0.7Cu | **0** | - | - | + | **0** | - |
| Solder paste H<br>Sn95.5 Ag4.0 Cu0.5 | + | - | - | + | + | **0** |

Legend: + = 100% cleaned, 0= optimization, - = not cleaned

Figure 6a: Lead free reflowed in air - cleaning with flat spray nozzles

| Nozzle Type | Solid Stream | | | | | |
|---|---|---|---|---|---|---|
| Cleaning temp. | Unheated | | | 122°F | | |
| Belt Speed in ft/min. | **1** | **2** | **3** | **1** | **2** | **3** |
| Solder Paste E<br>Sn 95.5 Ag4.0 Cu0.5 | **0** | - | - | + | **0** | - |
| Solder Paste F<br>95.5Sn 3.8AG 0.7Cu | + | - | - | + | **0** | - |
| Solder paste H<br>Sn95.5 Ag4.0 Cu0.5 | + | - | - | + | + | **0** |

Legend: + = 100% cleaned, 0= optimization, - = not cleaned

Figure 6b. Lead free reflowed in air - cleaning with solid stream nozzles

Regular atmosphere was initially used with all lead-free formulations. Also the cleaning agent was used at 122°F for the first set of experiments. Here it was observed that the belt speed could be increased to 2 ft/min. in some cases and at 1 ft/min. all lead-free no-clean formulations provided very satisfactory cleaning results. Interestingly, the change from flat spray to solid stream nozzles did not change any of the results obtained at all. Hence, it was concluded that for the standard process parameters used, the difference in cleaning results was mainly attributable to the thermal and chemical energies.

As with the eutectic products the cleaning agent was subsequently cooled down (only pump agitation) to further establish the limits of this process. With unheated medium under standard process parameters (1ft/min.), it was noticed that only 30% of the results were satisfactory. Nevertheless the amount and nature of the remaining residues were such miniscule, that the authors argued their full removability upon further process optimization (Judged as “0”). Simply changing to solid stream nozzles provided for the second successful cleaning result. Here the amount of cleaning agent required played an important role, all other process parameters remaining unchanged (Figure X2). Further alteration of belt speed and/or spraying technology did not provide any additional positive test results. In total only one (“0”) result remained for the removal of lead free no-clean formulations at ambient temperature.

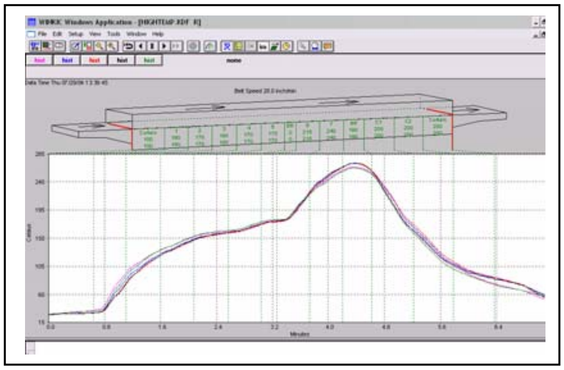

Figure X2: Lead-free reflow profile

For each product tested favorable process parameters were achieved, to fulfill the set forth goals of this study. The authors concluded at this point, that for the no clean–lead free products the required chemical compatibility between contamination and cleaning agent is of utmost importance. Given an adequate compatibility process parameters can be easily optimized to provide for an overall more cost effective cleaning process.

Subjecting the soldering of all test vehicles to a fully inert atmosphere did provide for a very different outcome however. In all cases, the unheated cleaning agent was able to remove the contamination very effectively. Changing the belt speed proved of no significance. Here the authors argued that an increase in belt speed beyond 3 ft./minute would have been even feasible.

| Nozzle Type | Solid Stream | | | | | |
|---|---|---|---|---|---|---|
| Cleaning temp. | Unheated | | | 122°F | | |
| Belt Speed in ft/min. | 1 | 2 | 3 | 1 | 2 | 3 |
| Solder Paste E<br>Sn 95.5 Ag4.0 Cu0.5 | + | + | + | + | + | + |
| Solder Paste H<br>95.5Sn 3.8AG 0.7Cu | + | + | + | + | + | + |
| Solder Paste H<br>Sn95.5 Ag4.0 Cu0.5 | + | + | + | + | + | + |

Legend: + = 100% cleaned, 0= Optimization, - = not cleaned

Figure 8. Lead-free reflowed in $N_2$ with solid stream nozzles.

With the higher soldering temperature of lead-free, the “baked on” flux residues did indeed polymerize to a higher extend still, allowing for full removal under standard process conditions. From a users perspective this study provides valuable tools to *effectively* remove even the most difficult contamination know at present, so called **"lead-free-no clean formulation"**. These findings stand in strict contrast to previously published findings on cleaning lead-free formulations.[i]

## CONCLUSIONS

In concluding, these results do raise valuable aspects of general cleanability versus overall economics of conveyorized inline processes. Using inert atmospheres in some cases might prove advantageous to meet certain throughput objectives, while adversely impacting the overall economics. Most cost effective processes are generally achieved with optimized process conditions such as spraying technologies, belt speeds and/or unheated cleaning technologies.

From the results presented in this study the extent of strain exerted on flux has become noticeable. As mentioned previously, additional oxidation, polymerization as well as more aggressive flux residues are more thoroughly baked on and therefore harder to remove. Modern Cleaning Technologies have therefore been designed to cope with 95% of no clean formulations and with adequate equipment optimization this goal remains realistic.

Authors:

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**Dirk Ellis** is an Application Engineer for Speedline Technologies, Inc. Camdenton, MO. Speedline Technology is a market leader for electronic assembly and advanced packaging engineered cleaning equipment. He has served in multiple support roles in wave soldering, reflow and cleaning since 1992. He has published articles in SMT magazine and co-published papers for the IPC, SMTA and IMAPS. Dirk Ellis is a 1985 graduate from the University of Missouri-Rolla with a BS. in Mechanical Engineering.

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[i] Bixenman, M. (March 2004). "Lead free Soldering: DOE Study to understand its affect on Electronic Assembly Defluxing", IPC Printed Circuits Expo, SMEMA Council APEX Designers Summit 04.

[ii] B. N. Ellis (Feb 1997) "Cleaning and contamination of electronics components and assemblies". *ISBN 0 901150 20 7* and Dr. C. Lea (1990) "After CFCS?: Options for electronics Cleaning Assemblies". *ISBN 0901150 258*

[iii] Thus, various oxidation induced reactions can therefore be circumvented by an inert atmosphere. The immediate result is that flux residues are simply not baked on as much as with an oxygen containing environment.

[iv] For a excellent review on current lead-free trends & materials see: J. Lau, (2003) "Electronics Manufacturing: with Lead-Free, Halogen-Free, and Conductive-Adhesive Materials" *ISBN 0-07-138624-6*

[v] Schweigart H. (Oct.2002, p.46) „Lead-free and no-clean: A contradiction in terms?" SMT Magazine.