As originally published in the IPC APEX EXPO Conference Proceedings.

The Effects of Human-Induced Contamination on PCB Assembly Electrical Reliability

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With the ever-present pressure toward miniaturization in electronic devices, smaller distances between traces and component terminations are likely to increase the devices' sensitivity to contamination scenarios that may cause current leakage. Traditionally, with "no-clean" processes, the focus has been on the conductivity of flux residues, which can be measured with industry accepted techniques such as IPC J-STD-004B SIR (Surface Insulation Resistance) testing (IPC-TM-650 2.6.3.7). However, the manufacturing environment, especially in low-cost labor markets, and even on otherwise well-controlled shop floors, may be far from representative of the "perfect world." Other materials may find their way on to the surface of the PCB, often introduced through negligent human activity and handling that may or may not have a negative impact on the electrical reliability of the device. This paper will discuss an experiment that was performed to investigate the effects of "contaminants" that could be measured with SIR testing. The contaminants were tested by themselves as well as in conjunction with a halogen-free, Pb-free, no-clean solder paste. The materials investigated as contaminants were: human skin oil/perspiration, high temperature reflow oven chain oil, pepperoni pizza grease, hand cream/lotion, and tap water.

The contaminants and solder paste were derived from sources readily available to the author.

1) Human Skin Oil/Perspiration – taken from the author's forehead (Figure1).

Figure 1 – Human Skin Oil/Perspiration

2) Reflow Oven Chain Oil – courtesy of Seho North America, Inc. (Figure 2).

Figure 2 – High Temperature Reflow Oven Chain Oil

3) Pizza Grease – pepperoni and cheese pizza (Figure 3).

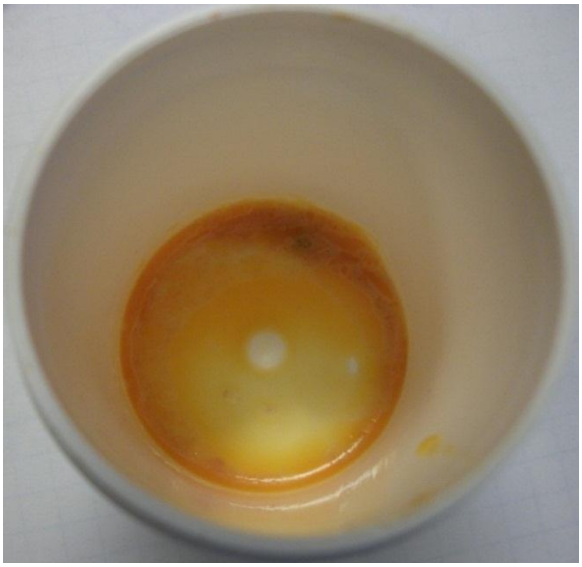

Figure 3 – Pepperoni and Cheese Pizza Grease

4) Hand Cream – (Figures 4 and 5).

Figure 4 – Hand Cream

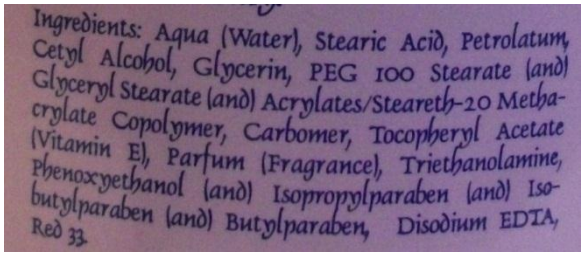
Ingredients: Aqua (Water), Stearic Acid, Petrolatum, Cetyl Alcohol, Glycerin, PEG 100 Stearate (and) Glyceryl Stearate (and) Acrylates/Steareth-20 Methacrylate Copolymer, Carbomer, Tocopheryl Acetate (Vitamin E), Parfum (Fragrance), Triethanolamine, Phenoxyethanol (and) Isopropylparaben (and) Isobutylparaben (and) Butylparaben, Disodium EDTA, Red 33.

Figure 5 – Hand Cream Ingredients

5) Tap Water – taken from the author's municipal water supply, which is sourced from an underground lake. The water is chlorinated by the municipality as a means of making it sanitary for human consumption.

6) Solder Paste – A halogen-free, Pb-free (SAC305), no-clean solder paste.

For this experiment, the standard IPC-B-24 SIR test coupon was used. The SIR test coupons were first cleaned per IPC recommendations. Two SIR test coupons were prepared for each scenario (Table 1). (Because the total quantity of SIR test coupons prepared exceeded the capacity of the test chamber, the SIR test coupons were broken into 2 groups for testing: Run 1 and Run 2.)

Table 1 – Test Matrix

No Reflow Cycle		
Material	Board Count	Run
Human Oil/Perspiration	2	1
Reflow Chain Oil	2	1
Pizza Grease	2	1
Hand Cream	2	2
Tap Water	2	2

One Reflow Cycle		
Material	Board Count	Run
Human Oil/Perspiration	2	1
Reflow Chain Oil	2	1
Pizza Grease	2	1
Hand Cream	2	2
Tap Water	2	2
Human Oil/Perspiration and Solder Paste	2	1
Reflow Chain Oil and Solder Paste	2*	1
Pizza Grease and Solder Paste	2	1
Hand Cream and Solder Paste	2	2
Tap Water and Solder Paste	2	2
Solder Paste	2	2

Controls		Run
Controls	2	1
Controls	2	2

*Note: Only one coupon was successfully prepared and tested. The oil provided too much adhesion to the underside of the stencil during the solder paste printing process. It was very difficult to get the coupon to properly separate from the stencil.

Preparation of the SIR coupons consisted of applying the contaminant to each of the test coupons, then smearing them with a gloved hand to ensure that the contaminant covered each SIR comb pattern entirely. Each contaminant was tested "as is"; with no exposure to a reflow cycle; with exposure to a reflow cycle; and in combination with a solder paste (and a subsequent reflow cycle). The intent was to see the effect of the contaminants by themselves; when introduced after reflow (not exposed to the reflow cycle); before reflow (exposed to a reflow cycle); and also in conjunction (co-mingled) with a solder paste (exposed to a reflow cycle). For those samples prepared with a contaminant and solder paste, the contaminant was first

applied to the SIR coupon, then paste was printed over the contaminant (followed by a reflow cycle). The coupons prepared with tap water or hand cream were allowed to air dry before any further processing. A couple coupons were prepared and tested with only reflowed solder paste, establishing a baseline for the paste. This allowed the level of the effect that a contaminant had on the SIR performance of the solder paste to be detected more readily.

Figures 6 through 20 show the SIR test coupons for the various materials at different stages of preparation. It is interesting to note that only the pizza grease and tap water provided any significant interference with the solder paste's ability to wet to the copper comb pattern. (If a photograph for a particular material and/or scenario is not shown, it is because nothing notable was observed or worthy of mention.)

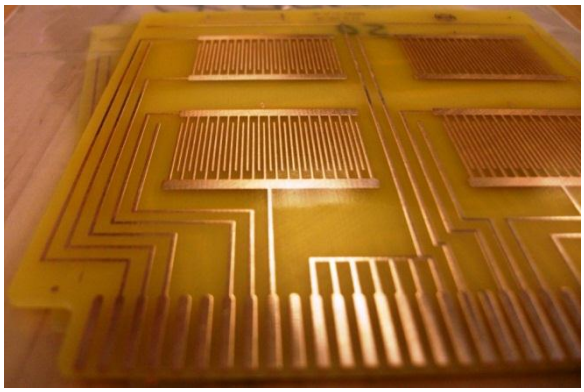

Figure 6 – Skin Oil/Perspiration on SIR comb pattern (visible sheen on the surface) as it appeared before or without a reflow cycle

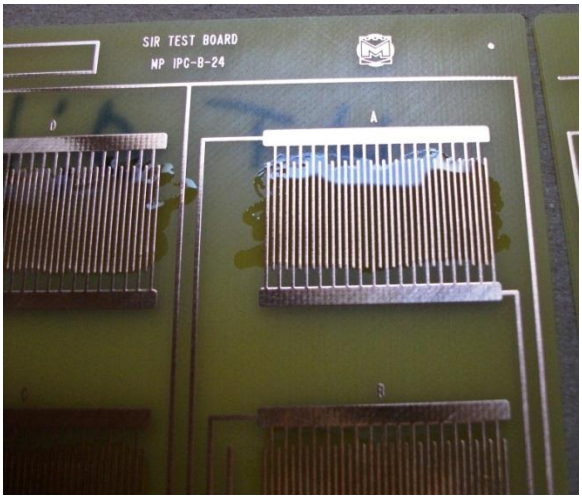

Figure 7 – High Temperature Reflow Chain Oil on SIR comb pattern as it appeared before or without a reflow cycle

Figure 8 – Pizza Grease on SIR comb pattern as it appeared before or without a reflow cycle

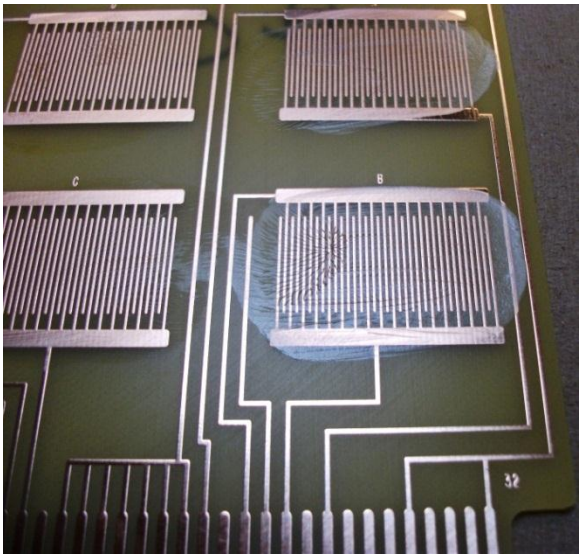

Figure 9 – Hand Cream on SIR comb pattern as it appeared before or without a reflow cycle

Figure 10 – Dried Tap Water on SIR comb pattern as it appeared before or without a reflow cycle (visible light staining)

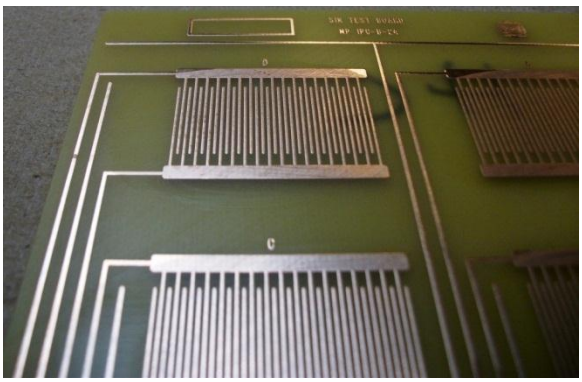

Figure 11 – Dried Hand Cream on SIR comb pattern as it appeared before or without a reflow cycle

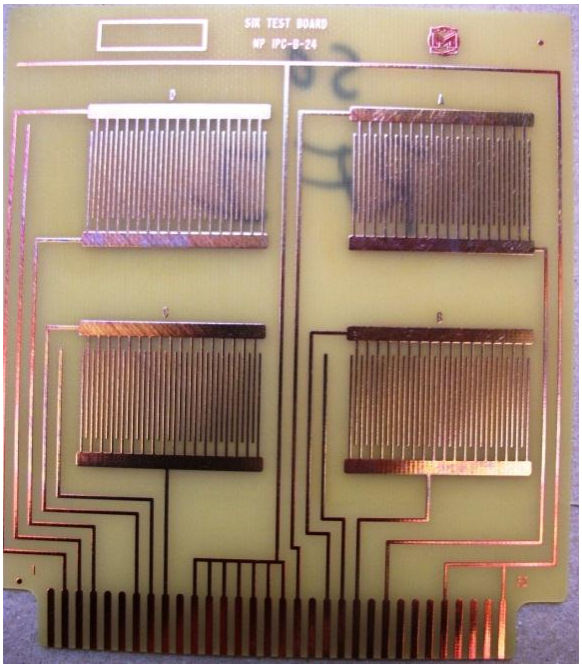

Figure 12 – Human Skin Oil/Perspiration on SIR comb pattern as it appeared after exposure to one reflow cycle (visible discoloration – most likely oxidation of the copper)

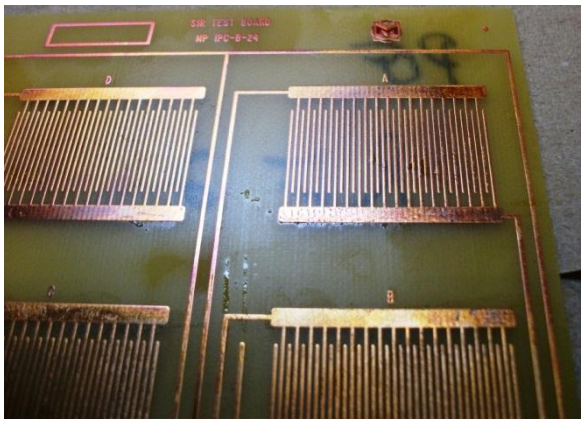

Figure 13 – Pizza Grease on SIR comb pattern as it appeared after exposure to one reflow cycle

Figure 14 – Hand Cream on SIR comb pattern as it appeared after exposure to one reflow cycle (visible discoloration)

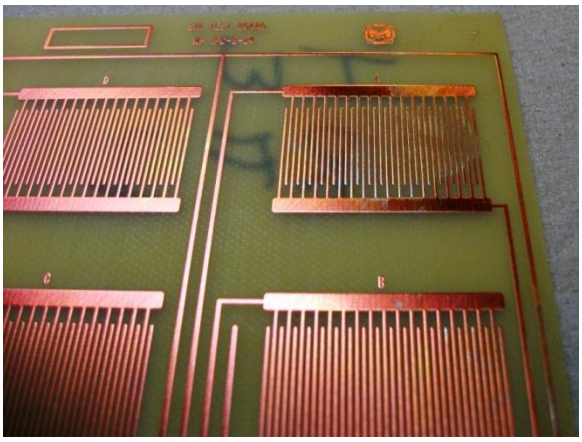

Figure 15 – Tap Water on SIR comb pattern as it appeared after exposure to one reflow cycle

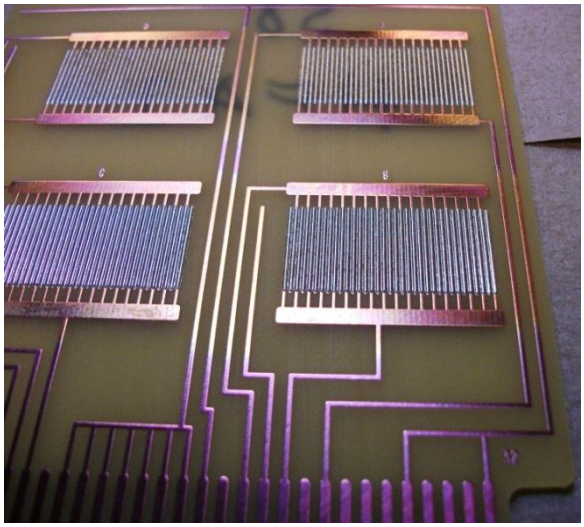

Figure 16 – Skin Oil and Reflowed Solder Paste

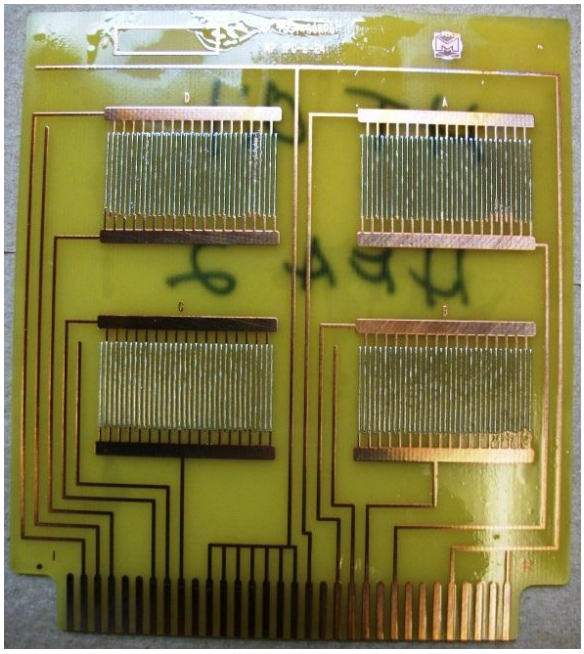

Figure 17 – High Temperature Reflow Oven Chain Oil and Reflowed Solder Paste

Figure 18 – Pizza Grease with Reflowed Solder Paste

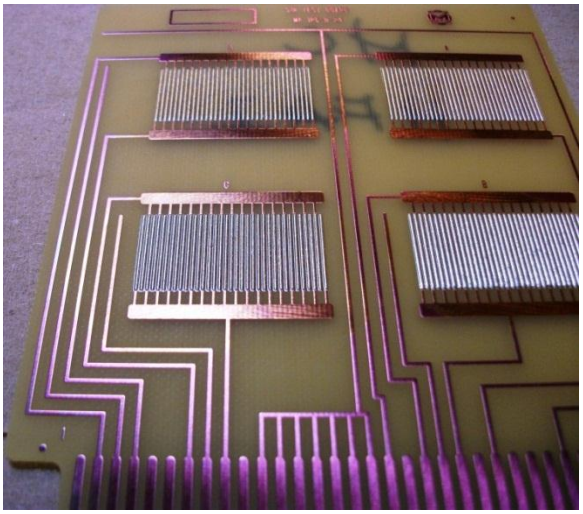

Figure 19 – Hand Cream and Reflowed Solder Paste

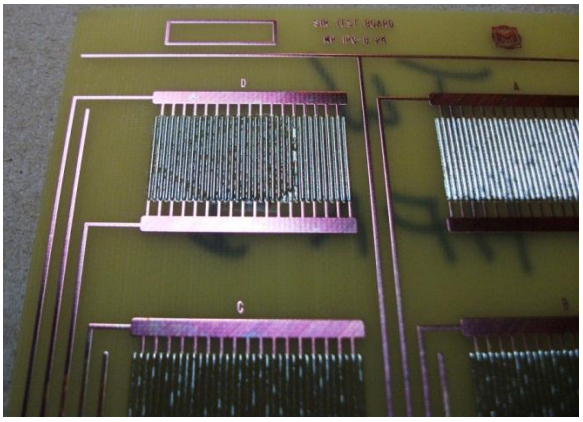

Figure 20 – Tap Water and Paste

The reflow cycle (profile) used is shown in Figure 21.

Figure 21 – Reflow Cycle (Profile)

The following graphs (Figures 22 through 39) show the SIR results. As mentioned earlier, due to test chamber capacity limitations, the SIR test coupons were tested in two separate groups: Run 1 and Run 2. Each group is shown separately. The average SIR value of all four comb patterns on each test coupon was plotted. Some find the practice of averaging SIR readings to be rather improper and odious. However, this work is intended to show the *general* effect of the contaminants and not an infinitesimal, reading-by-reading, scrutiny of each material. Therefore, the author believes that averaging the SIR readings for each board is acceptable. There are a few instances, especially in the second run, where one or more of the SIR patterns do not agree with the general trend, or a general trend could not be recognized among all the SIR patterns for a given scenario. In these cases, the "aberrant" SIR patterns are not averaged with the trend-supporting SIR patterns. However, they are plotted separately on the SIR graphs for the sake of full disclosure. A lighter-weight line is used to show the non-conforming SIR patterns in the graphs. In the cases of the tap water (1 reflow) and the tap water with solder paste, no trend could be identified, so all SIR patterns are plotted independently.

Run 1 SIR Results

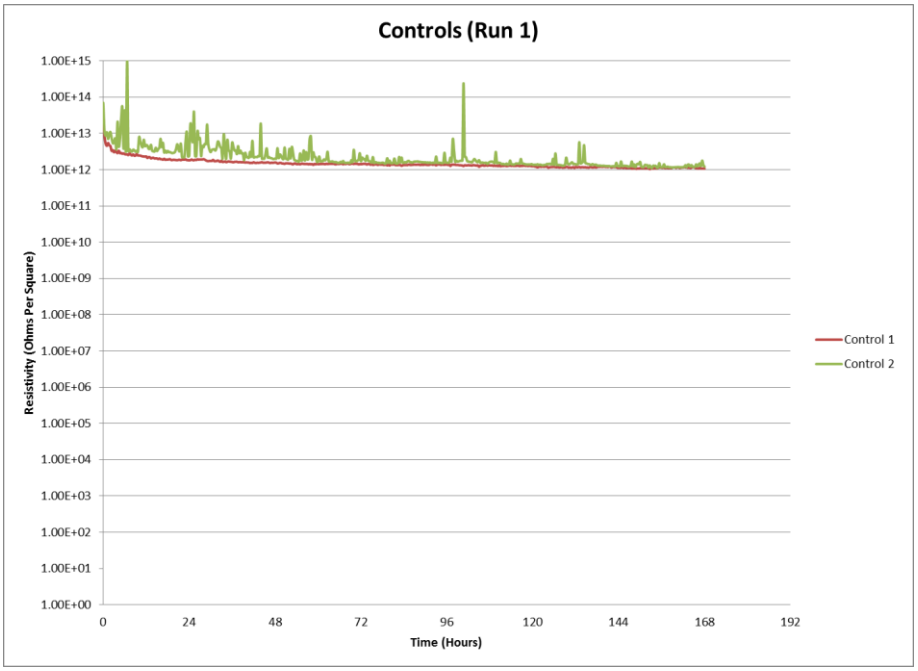

Figure 22 – SIR results of the Controls

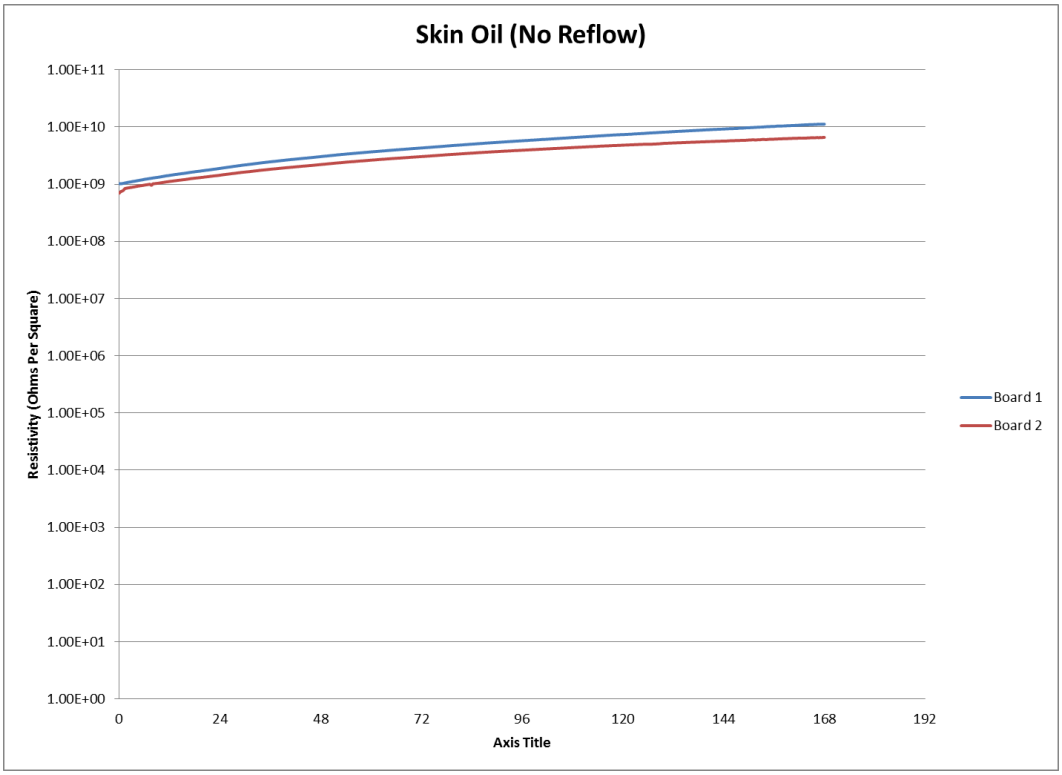

Figure 23 – SIR results of the Human Oil/Perspiration (No Reflow Cycle)

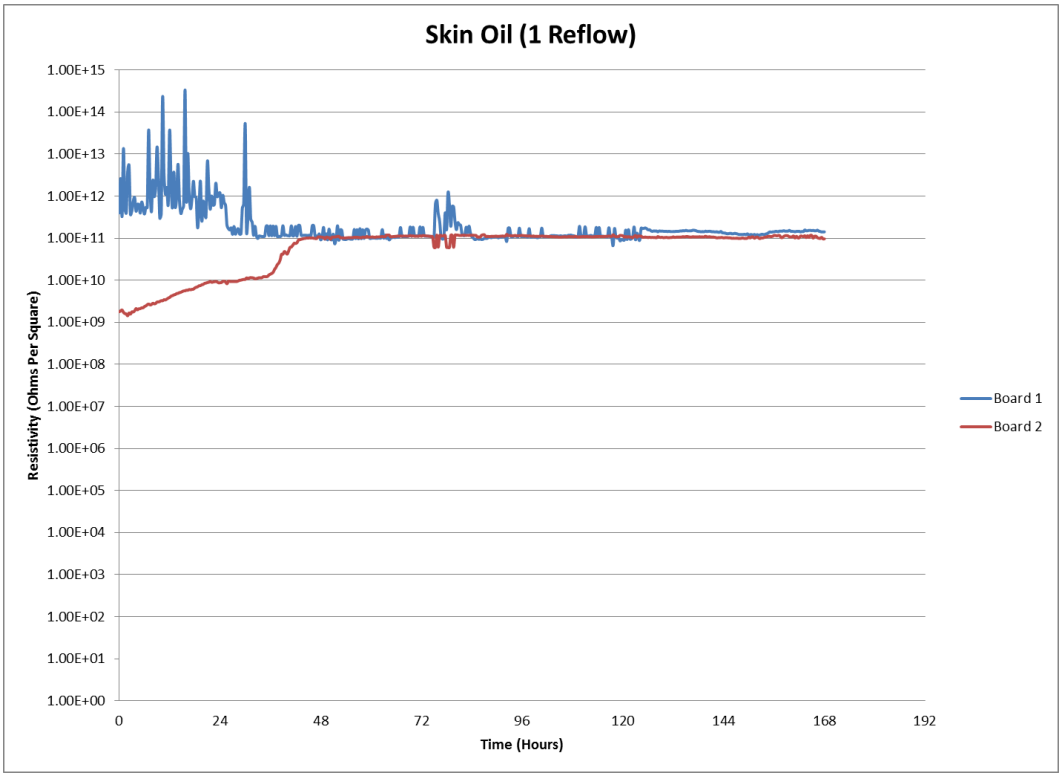

Figure 24 – SIR results of the Human Oil/Perspiration (One Reflow Cycle)

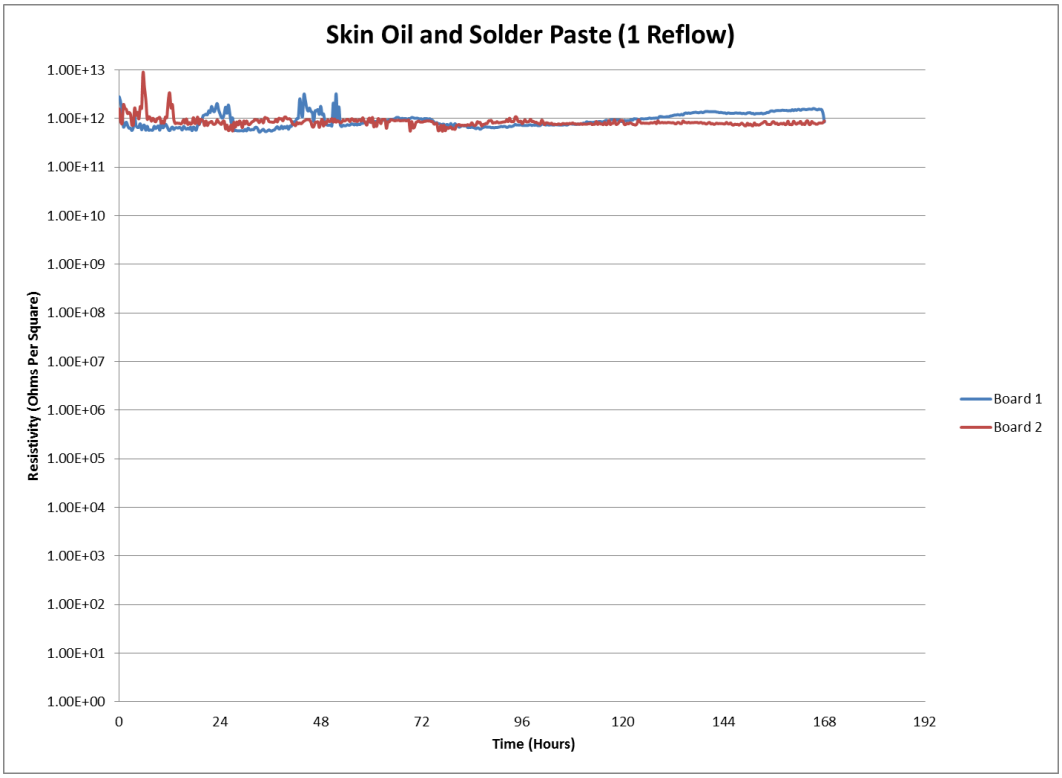

Figure 25 – SIR results of the Human Oil/Perspiration and Solder Paste (One Reflow Cycle)

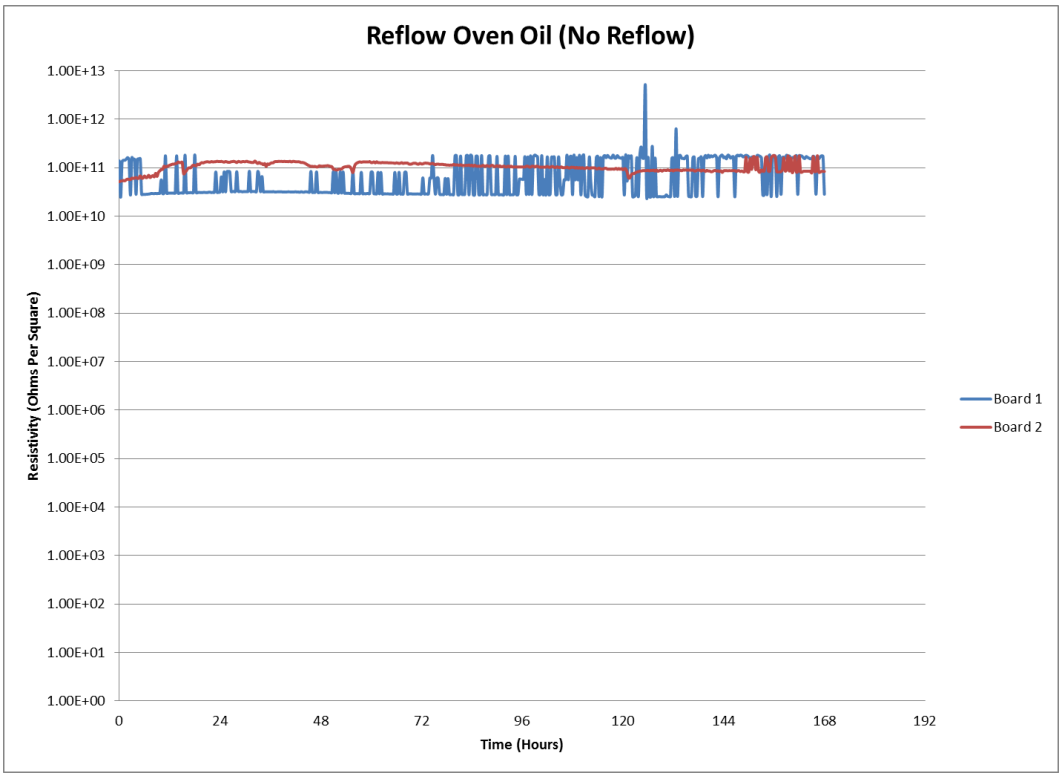

Figure 26 – SIR results of the High Temperature Reflow Oven Chain Oil (No Reflow Cycle)

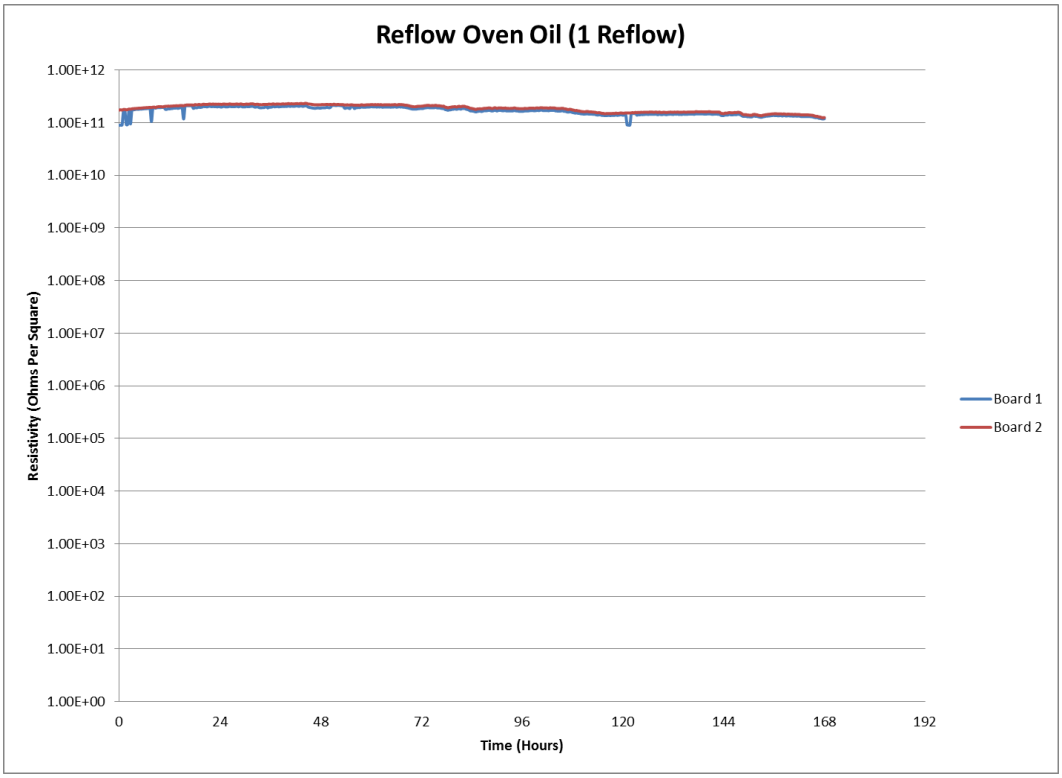

Figure 27 – SIR results of the High Temperature Reflow Oven Chain Oil (One Reflow Cycle)

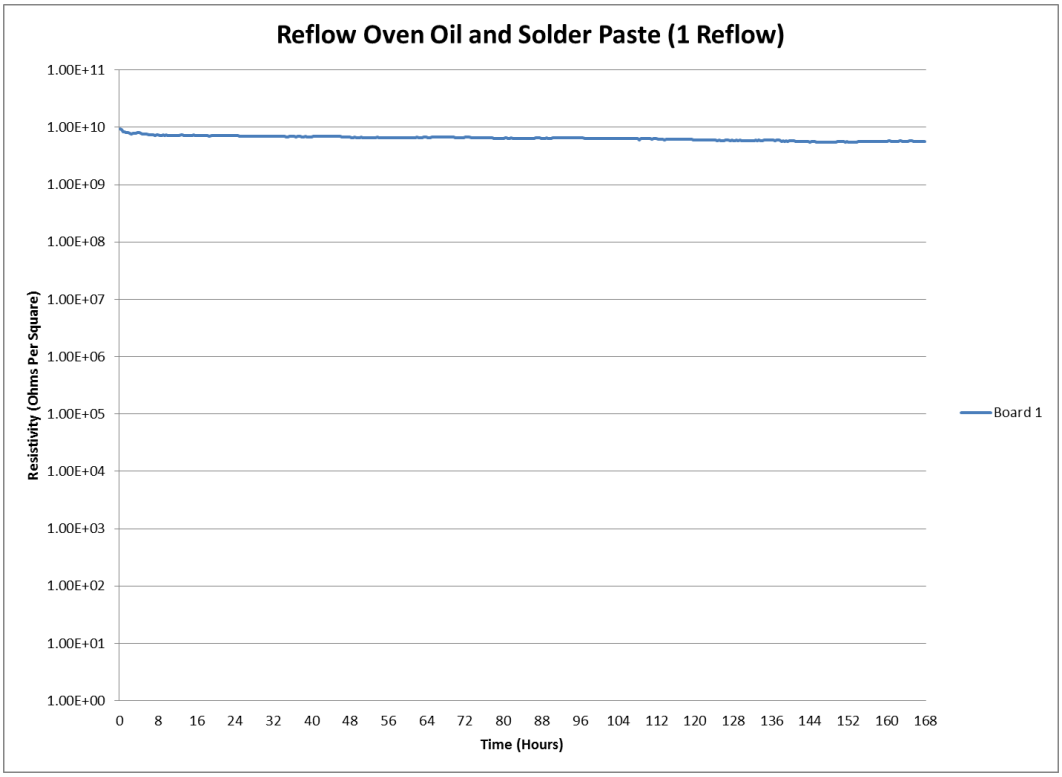

Figure 28 – SIR results of the High Temperature Reflow Oven Chain Oil and Solder Paste (One Reflow Cycle)

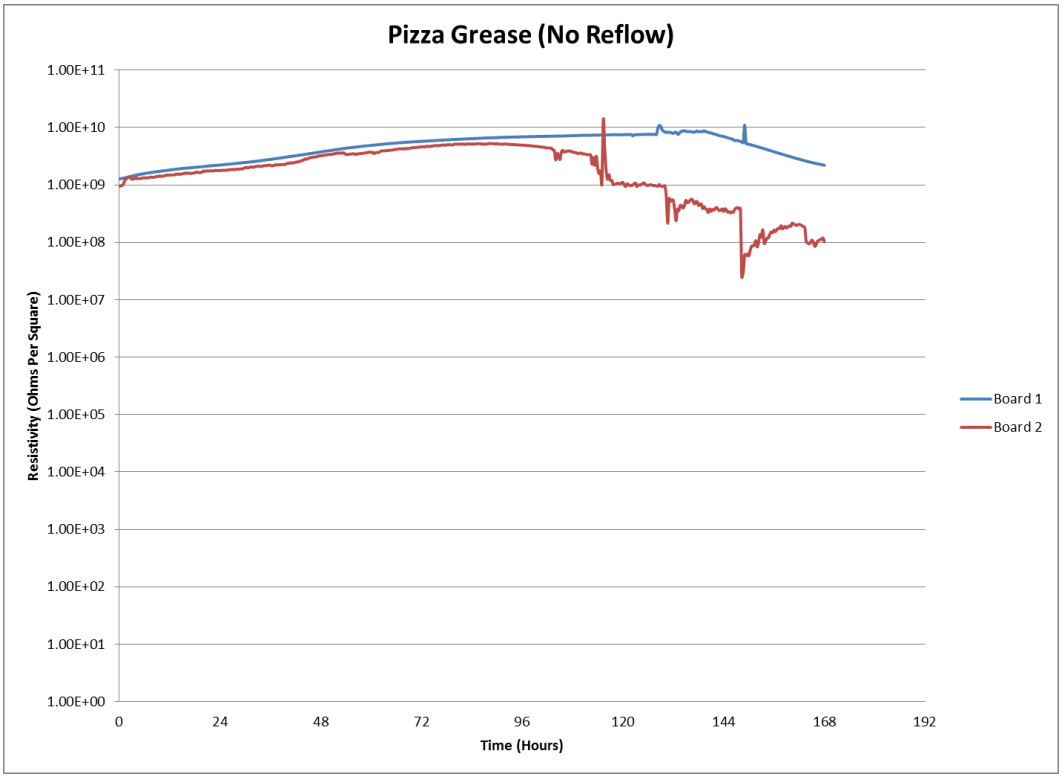

Figure 29 – SIR results of the Pizza Grease (No Reflow Cycle)

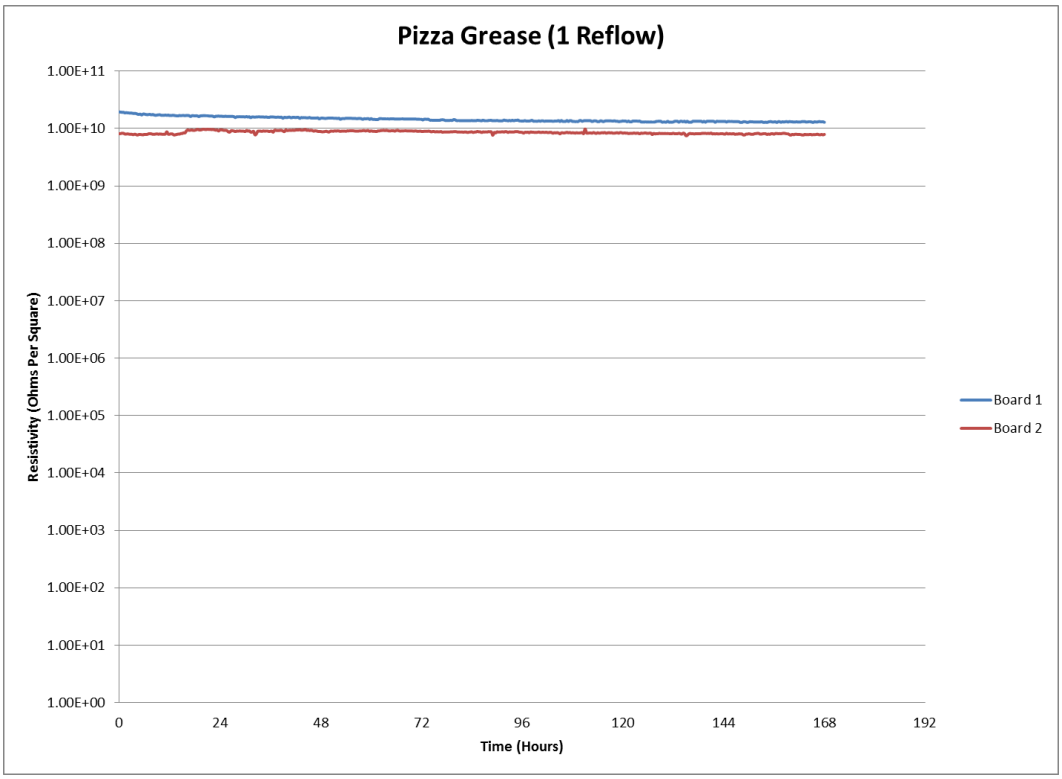

Figure 30 – SIR results of the Pizza Grease (One Reflow Cycle)

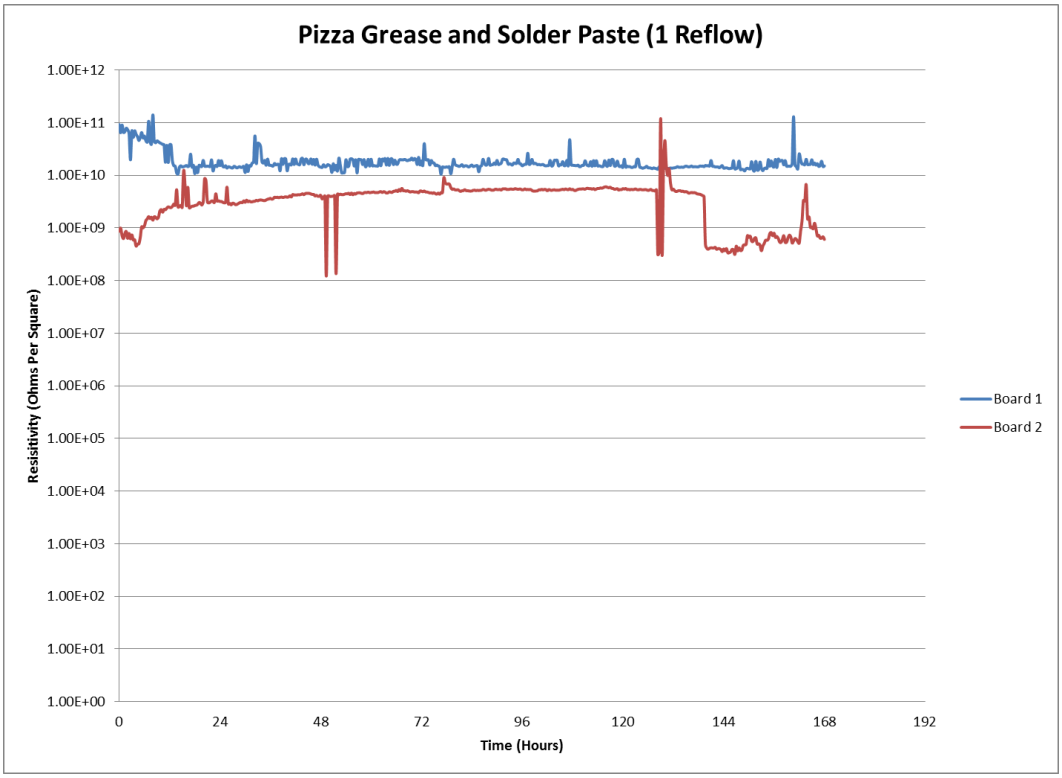

Figure 31 – SIR results of the Pizza Grease and Solder Paste (One Reflow Cycle)

Run 2 SIR Results

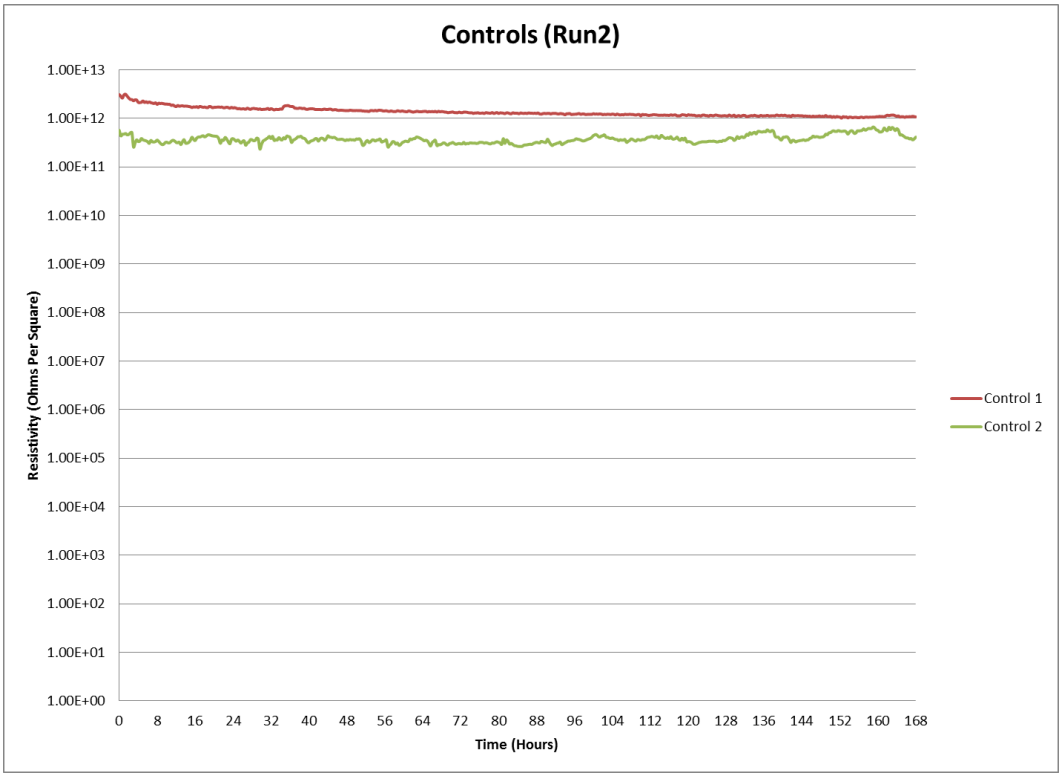

Figure 32 – SIR results of the Controls

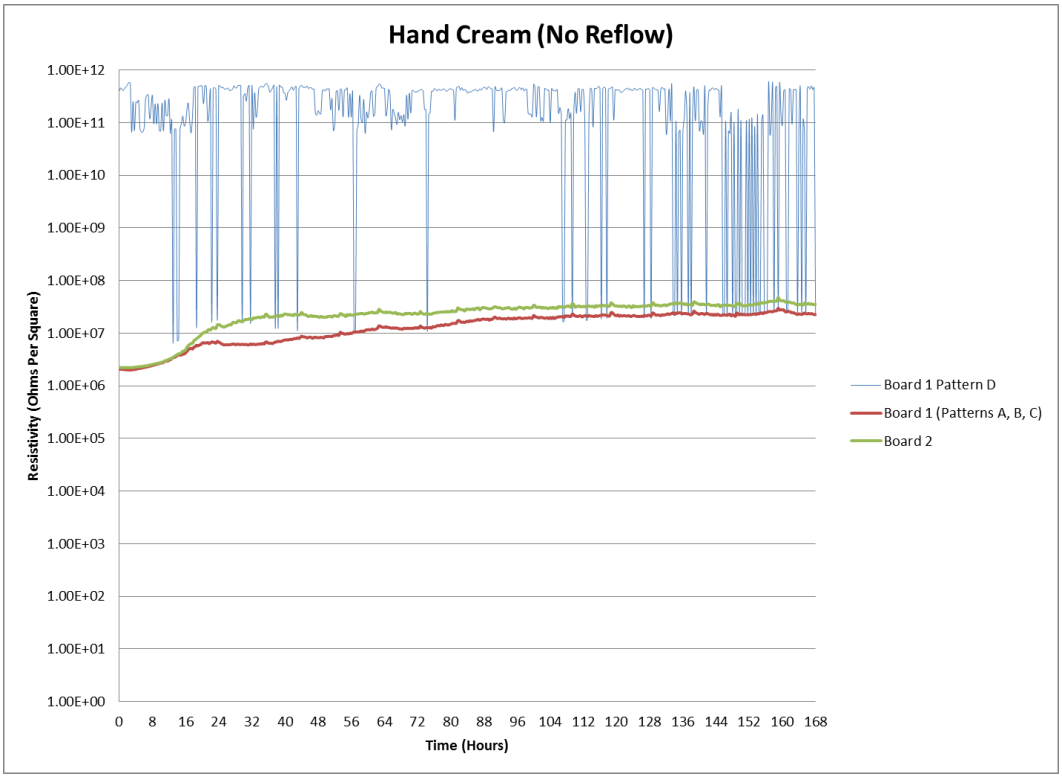

Figure 33 – SIR results of the Hand Cream (No Reflow Cycle)

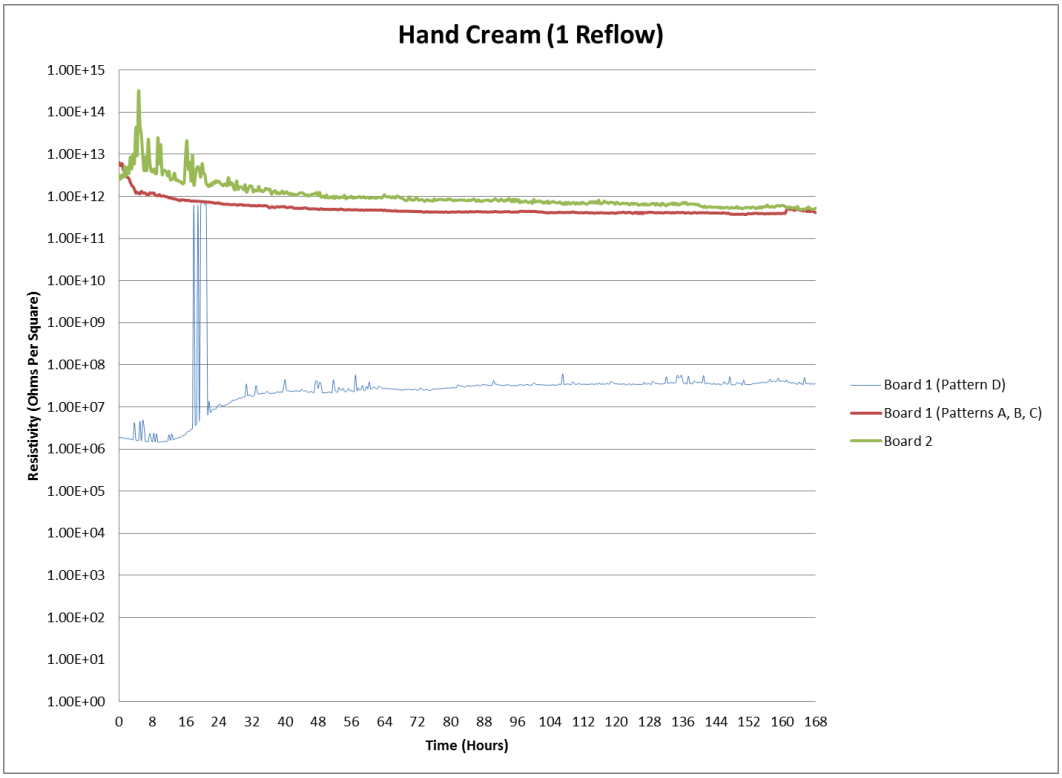

Figure 34 – SIR results of the Hand Cream (One Reflow Cycle)

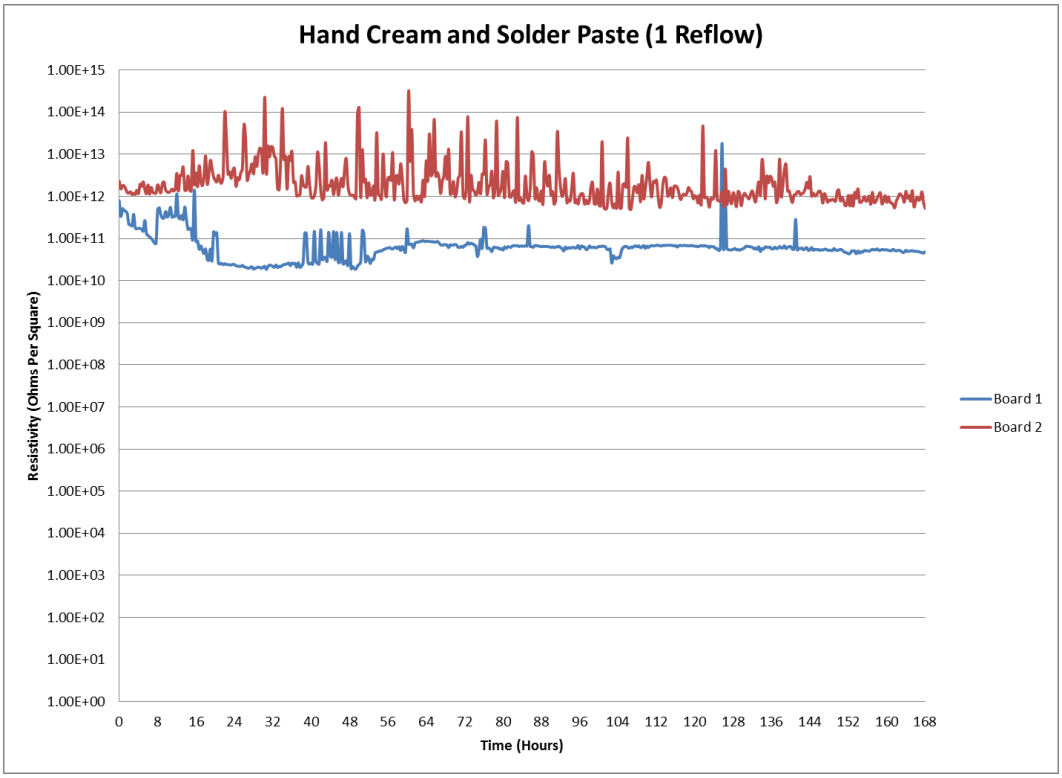

Figure 35 – SIR results of the Hand Cream and Solder Paste (One Reflow Cycle)

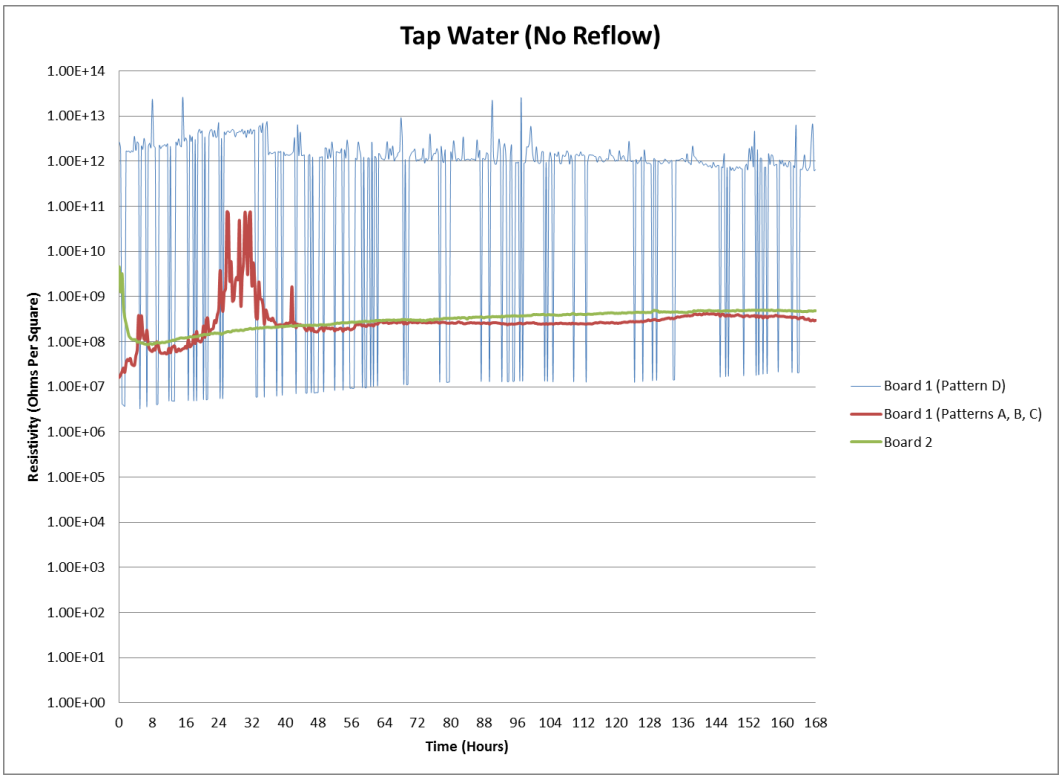

Figure 36 – SIR results of the Tap Water (No Reflow Cycle)

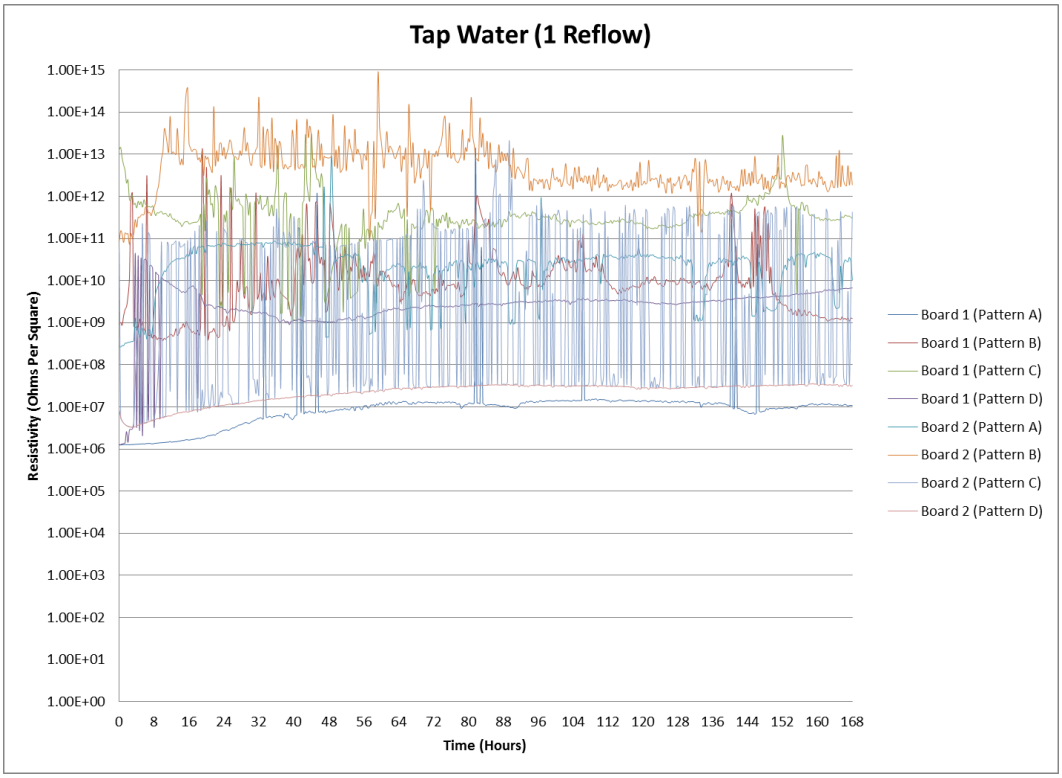

Figure 37 – SIR results of the Tap Water (One Reflow Cycle)

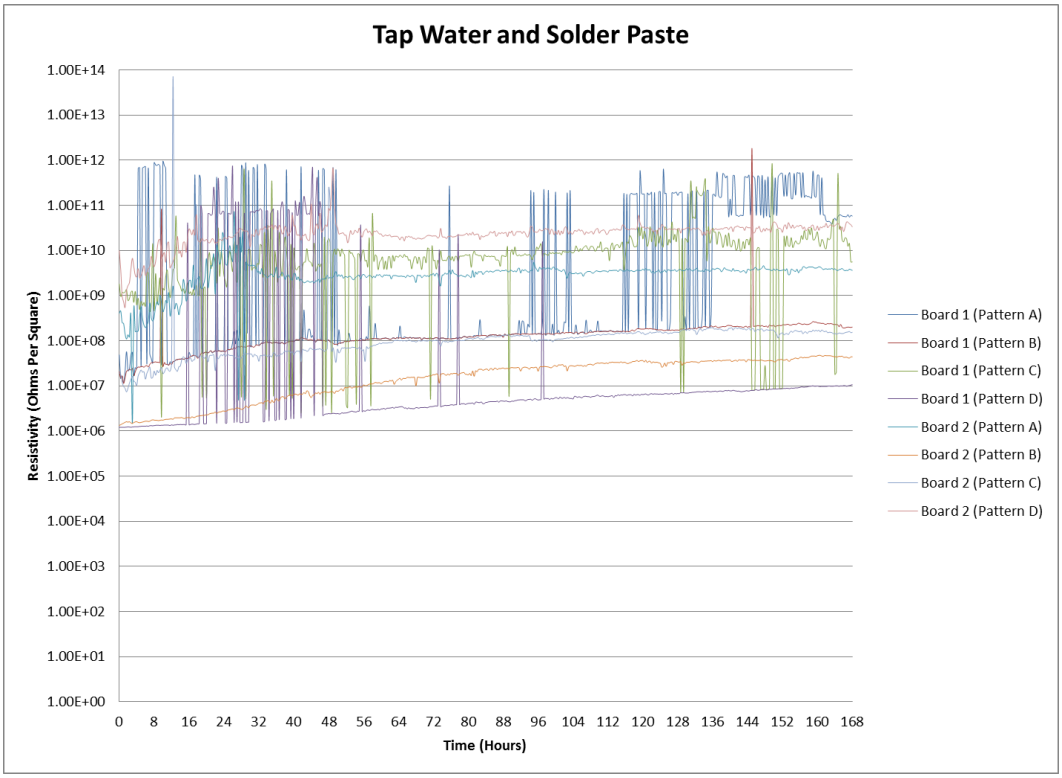

Figure 38 – SIR results of the Tap Water and Solder Paste (One Reflow Cycle)

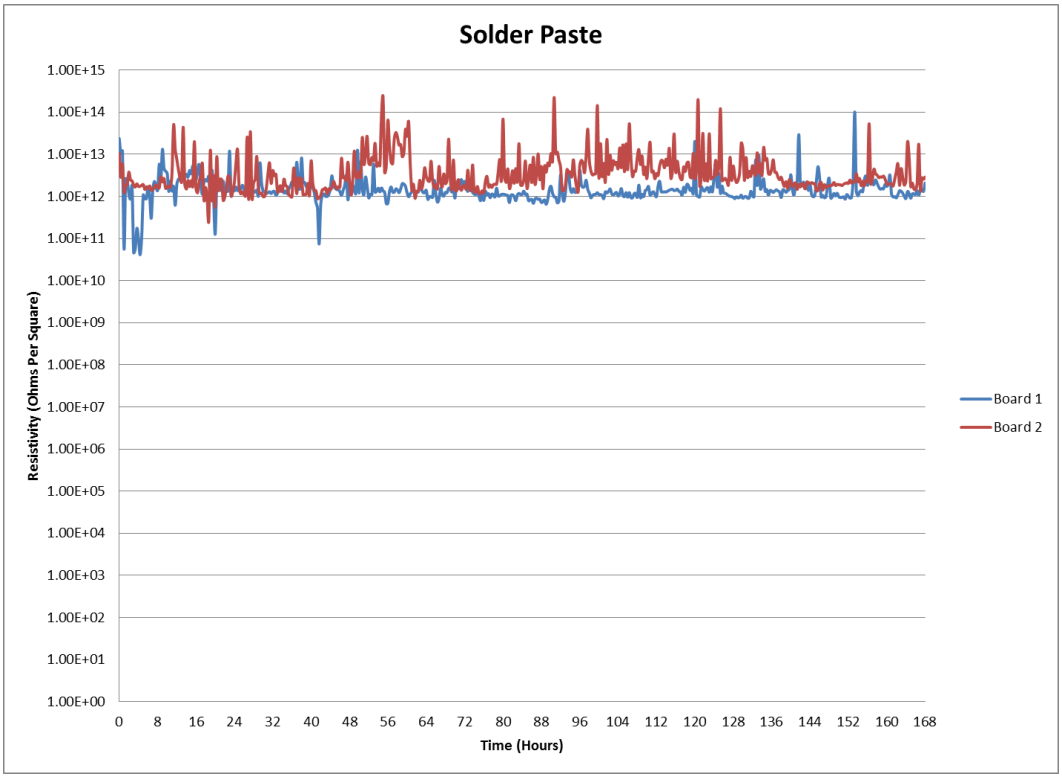

Figure 39 – SIR results of the Solder Paste (One Reflow Cycle)

To accurately assess the impact of the contaminants, it is logical to compare the SIR results of each contaminant when tested without the solder paste to the bare control boards, and compare the SIR results of each contaminant/solder paste combination to the solder paste. The following discussion of the results is based on this premise.

Human Skin Oil/Perspiration:
This contaminant produces SIR values that are 2 to 3 orders of magnitude lower than the controls with no reflow cycle, 1 order of magnitude lower with one reflow cycle, and does not have any noticeable impact when reflowed in combination with a solder paste. The greatest impact of skin oil/perspiration contamination would be experienced when applied to the board surface after solder assembly was completed (not exposed to any reflow cycles). Exposure to heat (a reflow cycle) improves the SIR performance, and, when reflowed with a solder paste, the effect is negligible.

High Temperature Reflow Chain Oil:
The typical performance of this contaminant, with and without a reflow cycle, appears to be about 1 x 10^11 ohms per square, approximately 1 order of magnitude lower than the controls. When combined with a solder paste, the oil drops the performance 2 orders of magnitude (based only on 1 SIR test coupon). In all scenarios, the oil caused a noticeable reduction in SIR performance; the worst was when it was combined with a solder paste. The oil caused only very minor interference with the solder paste's ability to wet to the copper patterns.

Pizza Grease:
The unreflowed pizza grease provided SIR values 2 to 3 orders of magnitude lower than the controls. Significant degradation took place on one of the coupons about 100 hours into the test. The SIR values of the reflowed coupons were very stable at about 1 x 10^10 ohms per square, about 2 orders of magnitude lower than the controls. The pizza grease with solder paste coupons had similar performance, with values in the 1 x 10^10 ohms per square, approximately 2 orders of magnitude lower than the paste by itself. In all instances, this sort of contamination causes a significant reduction in SIR performance. (The author is surprised that the SIR values were not worse given the likely high salt (halide) content derived from the cheese. Perhaps, the fat content of the grease acts as an encapsulant that immobilizes and entraps the halides, mitigating their typical negative impact.)

Hand Cream:
The unreflowed hand cream showed very poor performance, 4 to 5 orders of magnitude lower than the controls. However, when exposed to a reflow profile, the performance is very similar to the controls. The combination of the solder paste and hand cream also provides results similar to the paste by itself. Therefore, hand cream applied to the assembly at a point when

the PCB would not see any further heat cycles could be a reliability threat. Otherwise, a reflow cycle is sufficient to "neutralize" the negative effects of the contaminant.

Tap Water:
The SIR performance of the tap water was erratic. Almost all patterns on all coupons gave results lower than the controls or solder paste (only) coupons. These readings prompted the author to have an IC analysis performed on the water. The IC results are shown in table 2. (The author assumes that calcium content would also be significant.)

Table 2 – IC analysis of the Tap Water

Name of sample	Ionic F content	Ionic CL content	Ionic Br content
Tap water from Eric	0.02 PPM	41 PPM	0.2 PPM

The coupons prepared with the tap water also showed noticeable stain outlines on the SIR patterns after being removed from the SIR chamber (see Figure 40). These stains likely represent areas of high concentration of water-borne contaminants that accumulated in specific areas due to how the water pooled and dried on the surface of the coupon. These areas also likely correspond to areas where the solder paste had difficulty wetting to the copper traces when solder paste was applied and reflowed on top of the dried water as seen in Figure 20. In all scenarios, tap water contamination of a PCB can have a noticeable detrimental impact on reliability.

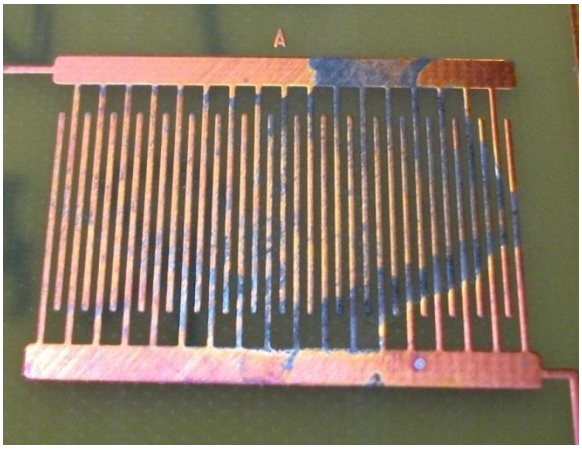

Figure 40 – SIR pattern showing Tap Water staining as observed after the SIR test

A casual inspection of all the SIR coupons for dendrites was made upon completion of the SIR test. However, given the high amount of other materials (contaminants) on the surface of the patterns, positive identification of any dendrites was not possible. With the cursory inspection, no obvious dendrites were noted.

In conclusion, the message that these experiments provide is that contamination has the potential to reduce the surface insulation resistance (SIR) of an assembly. The level of reduction may or may not create a reliability issue. However, it is important to note that the test vehicle has 0.4 mm lines and 0.5 mm spaces and tested at 5 VDC. One has to ask the question, if contamination produces a measurable reduction in SIR performance in these test conditions, what is the impact if the spacing is smaller and/or the voltage is higher? In such cases, the level of tolerance toward contamination could be, and should be, much less.