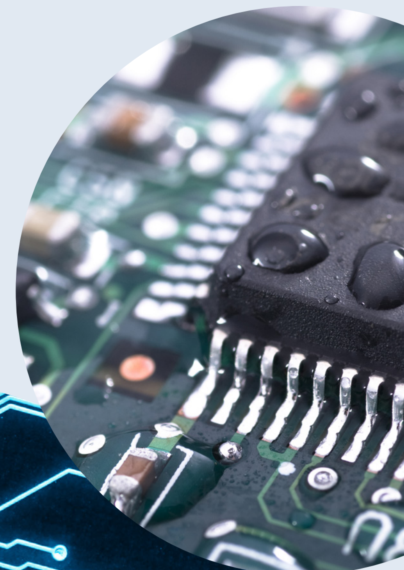
PROPERTY



COMMENTARY PAPER

Addressing water contamination: What happens after equipment is exposed

efi global

caring counts | efiglobal.com

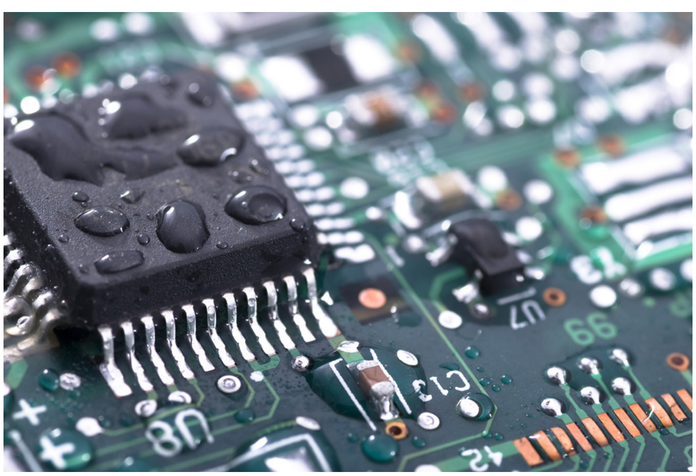
COMMENTARY PAPER

Addressing water contamination: What happens after equipment is exposed

Terminology matters

When considering a disaster event, there is a tendency to group the aftermath into one category: damage – whether it be from fire, physical impact, hurricane or water. A great deal could be at stake depending on the choice of words used to describe a loss. During a fire suppression sprinkler release for instance, outer covers of equipment are exposed to water. Rain also causes water exposure as does a ruptured water line.

The Oxford dictionary defines damage as, “Physical harm caused to something that makes it less attractive, useful, or valuable”. Water settling on a surface does not automatically constitute “damage” unless it alters its appearance, such as formation of corrosion. There’s the possibility that it will alter its functional state or cause it to lose value, which could happen if corrosion forms and/or the equipment’s functional state is not restored to a pre-loss condition. Water accumulation may lead some equipment to be submerged, which is an additional type of exposure to consider.

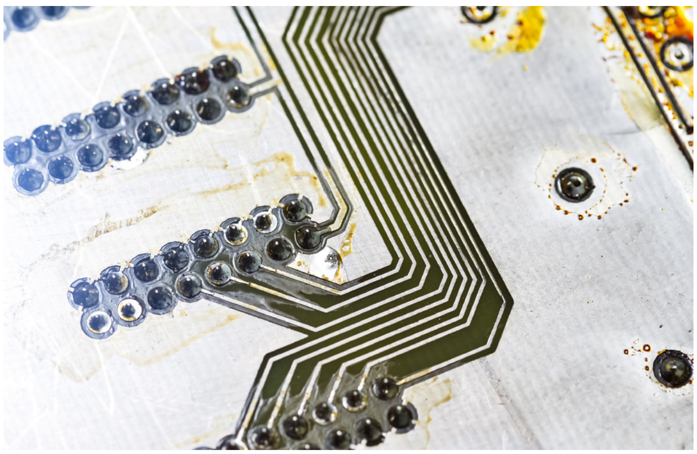


History of circuit board cleaning

In order to appreciate the history of printed circuit board (PCB) cleaning, let’s take a look first at the evolution of PCB’s. In 1925, the concept of PCBs came about when a method of printing electrical paths directly onto nonconductive surfaces – by using electrically conductive inks – was patented by American inventor Charles Ducas. The name “printed circuit” originated as a result of this method. In 1947, Bell Labs – today part of the Finish telecommunication company Nokia – completed work on the transistor, a component that revolutionized the field of electronics. Transistors are used as amplifiers and switching devices.

In 1956, the United States Army waived their right to a patent for the “Process of assembling electrical circuits”. The private sector had a method now of holding electronic components (via a board) and establishing connectivity between components with copper traces. The 1960s usher in the era of through-hole technology – components that are mounted on the top side of the board and soldered on the bottom – and surface mount technology (developed by IBM) that enabled component leads to be soldered on the same side. In the 70s, Texas Instruments introduced the microprocessor in the form of an integrated circuit (IC), or what many refer to as a “chip”. The 1980s, 90s and 2000s were all about switching from hand drawn circuits to computer aided design, minimizing the size of components and boards, and introducing multiple layers within PCBs. The densest chips in 1970s incorporated about 1,000 transistors. Chips of the mid-1980s contained as many as several hundred thousand. By the mid-1990s, some chips the size of an infant’s nail incorporated 20 million transistors.

Now that we have a clear picture of the race to miniaturize PCB boards and increase the density of components as a result, we can start to appreciate the need for cleaning. PCB cleaning dates back five decades. The reason cleaning became an obvious part of manufacturing a PCB is because of the soldering process. In order to ensure a true metallurgic bond between the component and the PCB board, manufacturers utilized solder flux. Flux is a chemical used in both automated PCB assembly and hand soldering. Flux removes oxide films which form on the surface of metals being soldered. Thereafter, flux acts as an oxygen barrier by coating the hot surface, hence preventing oxidation. However, solder flux residue is acidic. The residue can corrode electronic components and damage the PCB board over time.



Mike Konrad, founder of Aqueous Technologies, notes in a paper titled "Cleaning and contamination equipment & environment guide" that, *"In an automated soldering environment, flux was often applied using a foam fluxing system where the entire bottom-side of the printed circuit board (and frequently part of the upper portions) was exposed to flux. Frequently, so much flux was applied to the board that flux would drip onto the pre-heat section of a soldering machine and, in extreme cases, would catch fire. Cleaning was deemed necessary to remove the thick and sticky flux residues present on assemblies after soldering".*

Mr. Konrad goes on to say that *"Even in the exclusively through-hole days, excessive flux residues could lead to unintentional electrical conductivity and electro-chemical migration. Additionally, the sticky flux residue would attract dirt and dust particles and removal was required".*

In 1987, the "Montreal Protocol on Substances that deplete the Ozone Layer" banned production of chlorofluorocarbons (CFC)-based chemicals including some utilized to clean electronic assemblies. CFCs are chemicals that contained atoms of carbon, chlorine and fluorine. They were used in aerosol sprays, packing materials and refrigerants. In 1995, production of CFCs ceased in the US. While aerosol spray cans produced in other countries might still contain CFCs, they cannot be sold legally in the US.

Companies that sold flux and solder scrambled to develop a solution that would comply with the Montreal protocol and ensure a quality metallurgic bond between the surface and the electronic component. No-clean flux and solders were introduced and what used to be an obvious part of the manufacturing process (cleaning the boards) ended – excluding companies that had to keep cleaning because the end user required it. Cleaning did not stop for PCBs utilized in high-reliability assemblies, such as medical products and military applications.

No-clean flux and solder became problematic as PCB manufactures continued the race to miniaturize circuit assemblies and increase the density of components. No-clean fluxes and solder pastes were employed based on the theory that little to no residue would be left behind. While the theory was correct for the most part, when PCBs were originally cleaned (besides the flux residue) contaminants from board and component fabrication, the assembly process and environmental debris were removed as well. When the industry stopped removing flux, it stopped removing all the other contaminants, some of which were electrically conductive.

The increased density of components on modern boards translated to a significant reduction of conductor-to-conductor spacing, which also reduced the PCBs residue tolerance. As a result, conductive contaminants that were allowed to stay on boards because cleaning had mostly stopped, caused failures and shortened life expectancy of the PCBs. Additionally, many manufacturers reinstated cleaning procedures, even on boards fabricated with no-clean flux and solder.

Common original equipment manufacturer (OEM) cleaning methods

Ultrasonic cleaning

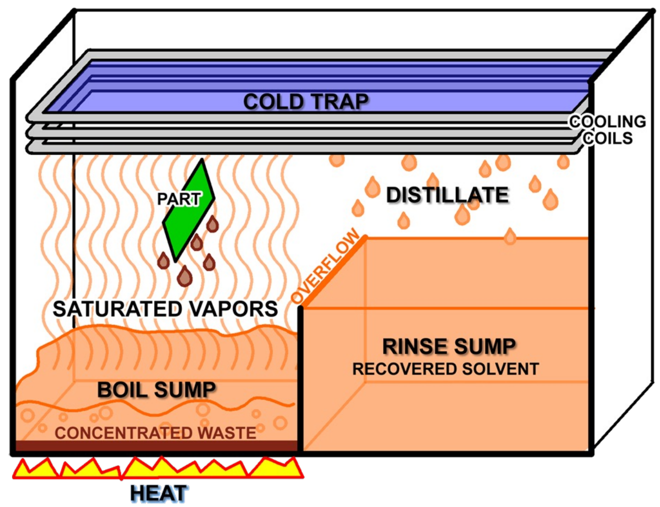
Ultrasonic cleaning utilizes a machine that emits high-frequency sound waves into a liquid bath filled with cleaning solution. This process creates billions of tiny bubbles that pop. As a result, they dislodge contaminates from the PCB – a process known as cavitation. For boards that can withstand this process, this is a good option to clean very dense or complex PCBs with many components because its tiny bubbles can reach every bit of exposed surface. Ultrasonic cleaners are also a great option for rigid metal parts, such as machine tooling, dies and engine parts.

Some manufacturers avoid the ultrasonic cleaning method because of the high frequencies' potential to damage components or connections. Components that cannot withstand the high frequencies tend to crack. As such, manufacturers that do utilize this method, ensure that all the soldered components can in fact tolerate exposure to a high vibration environment.

Following a disaster event, ultrasonic cleaners should not be utilized to address contaminated electronic assemblies. As a result of a justified rush to restore equipment to a pre-loss condition and in an effort to minimize business interruption, equipment restoration companies simply do not have time to thoroughly research if boards were manufactured to withstand the harsh ultrasonic environment. This statement is not intended to discount the expertise that restoration companies do possess. Given the number of different electronic assemblies found in a commercial business setting and considering that each assembly may contain multiple boards, ultrasonic cleaners should not be considered an option for electronics post loss, although utilized for rigid metal parts as noted above.

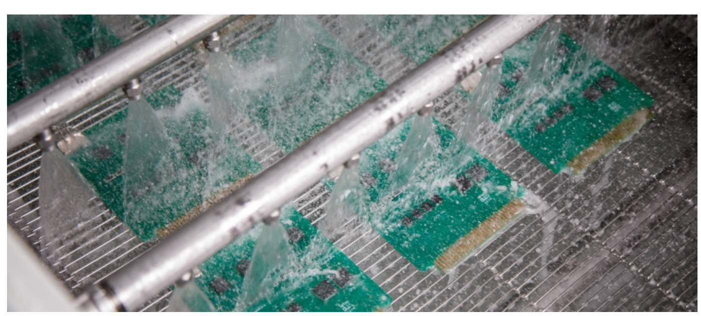
Vapor phase cleaning

Vapor phase cleaning or vapor degreasing is a process that boils a solvent in order to create steam. PCBs are lowered into this vapor, which condenses and dissolves contaminants left on the PCB. As the PCBs are lifted out of the vapor, the excess solvent drips back into the vapor sump (i.e., boil chamber)– carrying contaminants with it. The solvent is chosen based on the contaminants that need to be removed, the temperature at which the solvent boils, whether or not the solvent has flammable properties, and whether the solvent is considered to be environmentally friendly. The PCBs are then transferred to a second sump chamber called the rinse sump, where any residual dirt or grease are rinsed off with fresh solvent. Vapor phase cleaning is often the best choice for precision cleaning. The two-sump vapor phase process cleans more effectively than the single sump ultrasonic cleaning tub.



Deionized water wash

Deionized (DI) water is a safe and effective solution for removing water-soluble residue. Deionized water is water that has been treated to remove all ions, which typically means all dissolved mineral salts. Most water is therefore conductive because of these salts/ contaminants. Fresh water exhibits conductivity of between 0 and 1500 μS/cm, while sea water has a conductivity value of about 50,000 μS/cm.



For large PCB production throughputs and minimal component diversity, inline water-based cleaning machines are a time-efficient and cost-effective solution. In-line decontamination is a method of cleaning whereby PCBs are processed continuously on a conveyor system, and cleaning cycle times are controlled by the conveyor speed. PCB boards run automatically on a conveyor belt through individual process steps where DI water jets at an elevated temperature and pressure perform the cleaning – followed by DI water rinsing and then drying with a series of forced air jets.

Batch cleaning

Batch cleaning is a spray-in-air method utilized to decontaminate multiple PCBs, or 'batches of PCBs' as a group, in a single chamber spray system. The cleaning basically follows the principles employed in a dishwasher. All of the process steps are executed in the same process chamber. Cleaning chemistry is sprayed on PCBs through nozzle fittings or rotating spray arms. The cleaning is generally not achieved through spray jet pressure, as with the in-line method, but rather via the volume of cleaning chemistry passed over the PCBs.

Submersion

Electronic assemblies are designed to withstand varying environmental conditions as specified by the manufacturer. In most cases, environmental specifications are separated between those that apply when the assembly is in storage versus those that apply while the assembly is operating. As an example, Dell, the computer manufacturer, published technical specifications for the PowerEdge R740 server computer. A server is a computer that is dedicated to serve the needs of other computers. Those other computers, such as the laptop you may be using at the moment, are considered the "clients".

The reason two sets of specifications exist is because when a server operates, it produces heat. The temperature inside the server is generally controlled with fans that draw in cool air and hot air is exhausted. While in storage or during transit, the server is not operating and therefore does not need to be in a controlled environment. This does not mean the server can be placed into any environment, although the specifications are not as restrictive. As it relates to this commentary, the relative humidity (RH) specifications for the PowerEdge R740 state that during operation, "10% to 80% RH with 84.2°F (29°C) maximum dew point". While in storage, "5% to 95% RH with 91°F (33°C) maximum dew point." "The atmosphere must be non-condensing at all times". Other specifications detail allowable temperatures, vibration, shock, altitude, air filtration, conductive dust and corrosive dust. The PowerEdge R740 was therefore not designed to be submerged. In fact, most electronic assemblies are not intended for under water usage, and therefore not designed to withstand varying hydrostatic pressure levels (pressure that fluid in a confined space exerts).

Let's simplify this: During the 2011 monsoon season, multiple industrial parks outside of Bangkok, Thailand were flooded. Flood waters reached 11ft. Hydrostatic pressure at such depths is not necessarily high, although it's not negligible either. Compression characteristics of electronic components should be considered. Components can be affected because of their construction, packaging and operating principles. Pressure-tolerant electronic (PTE) components and systems are specifically manufactured to withstand submersion. As with most assemblies that are designed to operate in harsh environments, the cost to fabricate PTE components is undeniably higher.

Following a flood loss, electronic assemblies have to be evaluated to determine if they were designed to withstand hydrostatic pressure. It would not be unreasonable to assume that if an electronic assembly was part of equipment on the ground, it likely incorporates components that were not designed to withstand submersion. There's simply no need on the manufacturers part to incorporate components that cost far more for an environment that does not require them.

Post-loss equipment recovery since 1979

The cleaning methods discussed employ water-based cleaning agents. Rinsing is performed with deionized water. In 1979, Relectronic-Remech (Relectronic) was established as a joint venture between Siemens, the German industrial manufacturer, Allianz Insurance, an insurance carrier headquartered in Munich, Germany, and Munich Re, a Munich based reinsurer company.

Relectronic pioneered the concept of equipment decontamination in the field. With backing from two insurance companies, the primary goal was likely management of indemnity and business income loss payments, as equipment could be restored far quicker compared to lead times and costs for replacements. Let's dive deeper into this concept. We discussed above the deionized water wash process, which many manufacturers utilize inline machines to complete the cleaning. As noted, during this process PCB boards run automatically on a conveyor belt through individual steps where DI water jets at an elevated temperature and pressure perform the cleaning. This is followed by DI water rinsing and then drying with a series of forced air jets. These steps are performed in separate chambers.

Circuit boards that are able to pass through an inline cleaner are limited in size. Post-loss restorable equipment may contain circuitry and sub-assemblies that are far larger than what an inline machine can handle. As such, professional decontamination entities broke down this process such that equipment disassembly would take place in one area, cleaning and rinsing would take place in another, and drying would take place in a separate chamber or vacuum oven. In some cases, OEMs disassemble the equipment and hand the electronic circuitries to specialists who know how to professionally decontaminate them. Once dried, the circuitries are reinstalled and the OEMs test, perform repairs as needed and recalibrate the machine.

Post-loss professional decontamination has been successfully employed for over 40 years, even though many OEMs advise that they never heard of the service. There are quite a few companies that offer professional decontamination, and for the most part they complete the cleaning properly. However, the companies approach to a loss event is not uniform. Below are some key differences:

- Utilization of ultrasonic cleaning baths for electronic circuitries. We are cognizant that assemblies and/or components can sustain damage in a high frequency/vibration environment. Post-loss ultrasonic cleaning is only recommended for rigid metal parts or items that do not incorporate sensitive electronic components.
- Utilization of the deionized water wash process on everything. While this process will certainly clean circuitries properly, the process may be more than the assemblies require. Cleaning processes should depend on the extent of exposure. If dry decontamination will suffice, there is no need to wash the assembly, saving time and cost.
- Some companies elect to clean everything in the facility, simply because they do not have expertise to empirically quantify which areas were truly impacted. Clearly this is a waste of indemnity dollars.

Equipment assessment

Thus far we understand that the majority of circuit boards are cleaned as part of the normal manufacturing process, and throughout this commentary we also discussed utilization of deionized water. As a reminder, deionized water is water that has been treated to remove all ions, which typically means all dissolved mineral salts. Most water is therefore conductive because of these salts/contaminants. During a water loss event, equipment is normally exposed to water that contains a myriad of impurities. Additionally, during the initial manufacturing, circuitry is not powered on like it may be during a loss. How do these factors affect post-loss recovery?

The image shown exhibits a medical linear accelerator (LINAC). This machine is utilized to deliver radiation treatment to cancer patients. In front of the LINAC is a treatment couch and mounted from the ceiling are two monitors. Let’s assume this room was exposed to water because of a ruptured pipe above. Water will find its way through ceiling openings or cause tiles to saturate and fall. For the purpose of this exercise, we will assume that the majority of the water intruded directly above the LINAC.

The LINAC is an impressive machine. However, all we’re really seeing are the outer covers. This is also the case for other types of equipment. Sophisticated circuitry is protected inside. This does not mean the covers will keep all the water out, especially if there are ventilation holes, although quite a bit will find its way to the ground.

Water negotiates its way in through cover seams and exposes circuitry. When assessing the extent of exposure and determining potential recovery options, consider the following:

- Was the equipment powered on during the loss event?
- Was the equipment in operation or did it just have standby power?
- What was the orientation of the circuit boards, power supplies and anything else electronic that was exposed? Vertical boards sustain exposure although seldom accumulate water. Horizontal boards sustain exposure and could experience puddling (accumulation of water on portions of the board).
- Are the boards protected with conformal coating? Conformal coating is a polymeric film that protects circuit boards from environmental conditions. Such conditions include corrosive atmospheres, humidity, heat and airborne contaminants such as dust. A great deal of mass production boards are protected with conformal coating.
- Are there visible signs of electrical arcing?
- Is there visible oxidation/corrosion forming?
- What is the availability of replacement parts?

Collaboration with OEMs or third party service vendors that can test, repair and recalibrate the equipment is key. Equipment owners feel far more comfortable with the idea of restoration if their trusted vendors are part of the recovery.

This type of assignment usually ends with a post-assessment cost research. Cost of professional decontamination, cost to replace circuitry that sustained physical damage, cost to test, repair and recalibrate the equipment, and lead time to complete the restoration should be considered. These costs and lead times will be compared to wholesale replacement with like, kind and quality (LKQ). Equipment and building systems consulting experts perform these analyses, align all the necessary resources to complete the work, and monitor progression to ensure a timely recovery.

About EFI Global

EFI Global, part of Sedgwick, is a well-established brand with an excellent reputation in the Americas, Africa, Asia-Pacific and Europe as a market leader in environmental consulting, engineering failure analysis and origin-and-cause investigations. Each year, EFI Global completes more than 45,000 projects worldwide for a wide range of clients, such as commercial, industrial, institutional, insurance, government, risk managers, public and private entities. EFI Global is one of the world's most respected emergency response firms, capable of providing practical solutions to the most complex problems. Our multidisciplinary team of first responders, project managers, engineers, geologists and scientists are selected for their technical proficiency and in-depth industry knowledge to aid clients in resolving technical problems. For more, see **efiglobal.com**.

Get in touch with an expert

Michael Lilien, P.E., C.F.E.I.
As a forensic electrical engineer, Michael's range of engineering experience is wide and deep. He has worked as forensic engineer, managing projects as varied as home and vehicle fires to product testing, evaluation and investigation. He has spent considerable time at electric utilities working in construction project management, field and distribution operations, standards writing and design review. His experience in manufacturing includes leading engineering teams with troubleshooting product and testing issues and product research, development and design. For questions on this article or projects, contact **michael.lilien@efiglobal.com**.

Christopher C. Nail, P.E., ACTAR, CXLT
Christopher's experience as a senior forensic engineer encompasses 11 years of experience in mechanical engineering with nine years in HVAC and plumbing design, with an additional 20 years in construction experience. The range of his experiences includes: mechanical failure, all aspects of commercial and industrial HVAC systems, field of accident reconstruction and performing forensic work in various areas. For questions on this article or projects, contact **chris.nail@efiglobal.com**.

Resources and references

- P.J. Duchi, Anne-Marie Laügt, Marie Verdier, G. Abidh. Inventec Performance Chemicals. "Cleaning PCBs in electronics: Understanding today's needs".
- Michael Konrad. Aqueous Technologies. "Cleaning equipment & environmental guide". 2014
- Michael Konrad. Aqueous Technologies. "Defluxing Déjà vu". February 2008
- Dell Technologies. "Dell EMC PowerEdge R740 technical specifications". March 2022
- Michael Konrad. Aqueous Technologies. "Improving reliability".
- Pam Lucier. Numekevor & Associates. "Relectronic-Remech leading the way in relectronic restoration". July 2003
- Minh Tam Tran Nguyen. University of South Florida. "Reliability assessment of ion contamination residues on printed circuit board". March 2013
- Michael Konrad. Aqueous Technologies. "Reasons to clean circuit assemblies even when using no-clean flux".
- ACDi Technology. "Printed circuit board cleaning: An important step in the electronic manufacturing assembly process". February 2020
- Chemtronics. "Ultimate guide to cleaning electronics".
- Zestron. "Cleaning processes - Overview of the common cleaning mechanics applied in the electronics production".
- Bob Burns. Printed Circuits. "The history of PCBs". July 2021
- Tracy Riggan. IPC. "How cleaning PCBs helps you achieve zero defects". December 2020
- MicroCare. "Modern cleaning methods for modern PCBs". October 2021
- World Electronics. "Different PCB cleaning methods". July 2021
- Nic Bingham. Unmanned Underwater Technology. "Designing pressure-tolerant electronic systems". 2013

efi global

caring counts | efiglobal.com