



Fire Event Electronic and Mechanical System Damage Mechanisms *Is Acid Gas for Real?*

Irreparable damage to electronic equipment and mechanical systems away from the actual fire area is often attributed to the phenomenon of “acid gas” attack. Is acid gas real? Yes. Is it always produced after a fire involving plastics? No. Is it a high probability that acid gas will deposit directly on surfaces after a fire? Probably not. Read on to learn more!

Fire and smoke produce several different impacts that require evaluation during a damage assessment. For example, a fire produces thermal damage both from direct combustion of the materials involved with the event (i.e., the fire), as well as thermal damage to materials from the heat of the event (e.g., melting). The fire-fighting activities themselves can produce significant damage during a fire event, ranging from electrolytic corrosion of electrical and electronic systems through simply physical damage. These impacts may be separated among mechanical damage (e.g., disassembly or “axing” of materials to get to the fire), damage due to de-powering (e.g., loss of services or computer data), water damage (from direct spray, leakage from hoses, or water migration from the fire area) and damage from other extinguishing agents (e.g., corrosion from dry chemical or thermal stress from carbon dioxide). The final and most difficult category of fire and smoke damage to evaluate is widely known as non-thermal exposure.

Non-thermal exposure from a fire essentially is a combination of the direct and the indirect impact of the smoke and gases produced by the fire. The key here is to understand that exposure to products of combustion does not, necessarily equal damage. Deposited products of combustion may, in some cases, be as innocuous as common office dust and gases, just (usually) in a higher quantity. As such, the determination of actual damage to equipment from non-thermal exposure is highly dependent upon many variables, the most important of which are “what burned?”, “how much burned?”, and “at what temperature?”. These three key variables will determine the “products of combustion” within the smoke, as well as the chemical constituents of the contaminants that are released into the airborne environment and deposited or formed on the electronic equipment surfaces.

Non-thermal exposure may be classified into numerous categories and sub-categories, the most important of which, from a damage standpoint, are:

- Soot – may cause discoloration of surfaces, seizure of mechanical elements and may absorb any or all of the subsequently listed chemicals
 - Conductive Soot (graphitic) – may cause shorting of electrically insulated components

- Semi-conductive Soot (carbonaceous) – may cause an increase in thermal insulation
- Insulating Soot (organic) – may cause electrical isolation of conductors, connectors, and relays
- Metallic Soot (vaporized metal or oxides) – may cause environmental health and safety issues and may be conductive, causing shorting of electrically insulated components
- Inorganic Gases
 - Acidic (HCl, HBr, HF, etc.) – may cause direct corrosion of metallic surfaces or lead to the formation of hygroscopic salts
 - Sulfur Oxides (SO_x) – may produce hygroscopic salts
 - Hydrogen Sulfide (H₂S) – may produce an electrically insulating film on metal surfaces, particularly copper and silver
- Hygroscopic Salts (zinc chloride, ferric bromide, copper chloride, etc.) – may produce corrosion by absorbing moisture at ambient relative humidity levels, producing metal oxide, acid, and water in a continuous cycle
- Volatile Organic Compounds (VOCs) – may produce odors and lead to contact activation in electrical systems
- Semi-Volatile Organic Compounds (SVOCs) – may produce the “smoke odor” and lead to a tacky-oily film on surfaces
- Condensation – may lead to moisture damage (all products of combustion contain water, which is a primary by-product of the combustion process).

The principal damage concern with non-thermal exposure is acidic gases and the production of hygroscopic salts (literally “water absorbing”) on metal surfaces. Acidic gases are primarily associated with the combustion of plastics; most commonly PVC, fire retardant plastics (e.g., FR4 rated circuit board materials, fire retardant plastic sheeting or wood, etc.), and plenum-rated cable, which contain halogens (the category of chemical elements which contains chlorine, bromine, fluorine, and iodine). The combustion of PVC is the best example to illustrate the formation and impact of acidic gases.

The combustion of PVC produces a very large amount of the highly reactive hydrogen chloride gas - HCl_(g). Depending upon the formulation, the combustion of PVC may produce up to 58% of the resin weight as HCl_(g). When in the presence of moisture, this acidic gas reacts with metallic surfaces to produce hydrochloric acid. This product of combustion continues to react with the metal surface to produce a highly corrosive metal-chloride hygroscopic salt. The salt further reacts with moisture in the air, commonly at very low relative humidities, to consume the surface metal and reproduce hydrochloric acid in a continuous cycle that will cause irreparable damage to the surface and equipment involved. This chemical cycle continues to occur long after the fire event and corrodes deep into the metal, resulting in an inverted funnel shaped damage pattern. One example often used to illustrate this corrosion mechanism is a rust patch that is sometime found on a vintage automobile (when they were made of metal) that has been exposed to sea or road salts. The visible degree of rust on the surface, often starting at a nick in the paint, is very small in comparison to the amount of rust behind the surface.

Due to the corrosion mechanism involved, metallic surfaces that are exposed to high concentrations of acidic gases must be kept or placed in a very low relative humidity

environment within hours after a fire event. These surfaces must also be neutralized and thoroughly decontaminated as soon as possible after exposure to acidic gases. If exposed to a normal environment (i.e., relative humidity of > 20%) for more than a few hours after such an event, contaminated electronic equipment often is un-restorable (dependent upon the degree of contamination and “shielding” of the surfaces).

Metallic surfaces that are commonly damaged and produce hygroscopic salts from the combustion of PVC include: chromated zinc, galvanized steel, steel, zinc, silver, nickel, and copper. Zinc containing surfaces (including galvanized surfaces) are often the first to react with $\text{HCl}_{(g)}$, producing the hygroscopic salt zinc chloride. Zinc chloride, in a pure form, will begin absorb moisture from the air at <10% relative humidity. In most PVC combustion related events, this “critical relative humidity” is closer to 15-20% relative humidity. The affinity of zinc for adsorption and re-formation of HCl is the reason why pH sampling is often a good first indication of the presence or absence of acidic gas deposition after a fire. Another good indication of an acidic gas contamination event is that galvanized, chromated zinc and zinc surfaces will begin to form highly acidic moisture on their surfaces. This process is known as deliquescence.

In order to evaluate the potential extent of contamination and impact from smoke residue in either the particulate form or from acidic gases, as well as potentially from other ambient sources, numerous semi-quantitative measurements for chloride should be made during damage assessment of a facility. The semi-quantitative sampling of chloride concentrations can be measured using silver chromate chloride test strips with five levels of color indications corresponding to various concentrations of surface chlorides. Chloride test strip sampling is accomplished on metallic, painted, and plastic surfaces, as well as particulate deposits by first wetting the strip with deionized water and placing the dampened strip on the surface of interest. Readings of the chloride test strip color indications are taken at one minute after sampling and 30 minutes after sampling (readings of particulate matter often takes longer for an accurate color indication to develop).

To evaluate surface concentrations of chloride, they must be compared to values utilized by various industries in determining acceptability of new products, as well as contamination levels known to be restorable or known to be damaging. The military specification for highly reliable new electronics is <20 $\mu\text{g}/\text{in.}^2$ of chloride concentration.¹ The telecommunications industry uses a guideline of <50 $\mu\text{g}/\text{in.}^2$ of any single anionic compound as a guideline for long-term reliability concern for high density circuitry. Common accumulation rates for chlorides in an office, non-manufacturing environment has been shown to be 1-2 $\mu\text{g}/\text{in.}^2/\text{yr.}$ ² Common accumulation rates for manufacturing environments (excluding the use of PVC or chlorine gas in the manufacturing process) are estimated to be 2 to 4 times higher than within an office environment. Maximum chloride concentrations measured after three major fires involving the thermal decomposition of PVC range from 2700 to 6600 $\mu\text{g}/\text{in.}^2$.³

¹ Military Specification 28809A, October, 1981.

² Sinclair, J.D.; Psota-Kelty, L.A. and C.J. Weschler. (1985) “Indoor/Outdoor Concentrations and Indoor Surface Accumulations of Ionic Substances.” Journal of Atmospheric Environment, Vol. 19, No. 2, pp 315-323, 1985.

³ Krzyzanowski, M.E. (1990) "Applications of Ion Chromatography in the Disaster Recovery of Electronic Equipment," 41st Annual Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, N.Y., NY 3/90.

Of most significance to the determination of the potential for corrosive damage to equipment as a result of chlorides is found in Reagor 1992⁴. This article documents the expected salvageability of surfaces based upon chloride concentrations. The article lists $< 30 \mu\text{g} / \text{in.}^2$ as “normal background level”, $30 - 200 \mu\text{g} / \text{in.}^2$ as “easily reclaimed,” $200 - 600 \mu\text{g} / \text{in.}^2$ as “difficult to reclaim” and $>600 \mu\text{g} / \text{in.}^2$ as “cost effectiveness of restoration is questionable.”

However, the production and subsequent fate of $\text{HCl}_{(g)}$ after thermal decomposition of PVC is highly dependent upon the fire dynamics, ventilation rate, additional products that are involved in the fire and progression of the fire prior to being extinguished. In most instances involving high temperature, rapid combustion events with other organic materials involved (e.g., cardboard, wood, and other plastics), the highly reactive $\text{HCl}_{(g)}$ will tend to become adsorbed onto the surface of soot particles. This often eliminates the free (unbound) $\text{HCl}_{(g)}$ from the air prior to reaction with metallic surfaces located within the building, particularly if it is a large volume facility. We have seen this occur in numerous facilities, particularly manufacturing plants which are often of large volume and have a limited availability of fire-retardant plastics available for decomposition; i.e., the small or even moderate amount of acidic gases that are produced become bound within the soot, and thus do not directly attack metallic surfaces in the gas phase. Although removal of the chloride/bromide containing soot is still required to prevent the reliability concerns associated with hygroscopic dust, once the soot is removed, the structural surfaces, electronic and mechanical equipment should be considered as at a pre-loss or better reliability state in relation to corrosion rates and airborne contaminate failure mechanisms.

The most common contamination concern with fires in facilities that do not involve significant quantities of halogenated plastics (as is the case with many administrative, hotel/motel, school, and residential facilities) is soot, VOCs and SVOCs. Along with the materials that burn, the temperature and duration of the fire will determine the composition of the soot, and types of VOCs and SVOCs. A high temperature, rapid fire will tend to produce a more graphitic, fine mode particulate soot with less VOCs and SVOCs (i.e., very dry soot deposits with less odor). A low temperature, smoldering fire will tend to produce a more insulating, coarse mode particulate soot with higher degrees of VOCs and SVOCs (i.e., an oily to gooey soot deposition with significant, long-term smoke odor). Products of combustion from a smoldering fire are cleanable from electronic and electrical systems; however, such fires typically result in the need for more extensive restoration with detailed cleaning needs, often requiring the use of solvents.

Many trash, paper, wood, wall, and roof fires tend more towards high temperature, low smolder fires, producing a relatively dry fine and coarse mode soot and low amounts of VOCs and SVOCs, hence a low degree of odor. Although the amount of soot produced by such fires may be significant, once the particulate soot is removed, the remnant odor will be minimal or non-existent. This type of soot also is highly granular and of a small particulate size that tends to be more readily removed from surfaces through common cleaning methods.

Common VOCs that would be produced by rapid, high temperature fires are dependent on the materials that burn. For example, a roofing material fire would be expected to produce mainly long chain hydrocarbons and aromatic hydrocarbons such as benzene and styrene. Common SVOCs that would be produced by a roofing material fire would include: Poly-cyclic Aromatic

⁴ Reagor, B.T. (1992). “Smoke Corrosivity: Generation, Impact, Detection, and Protection.” J. Fire Sci., Vol. 10, April/May 1992.

Hydrocarbons (PAHs), partially oxidized hydrocarbons, high molecular weight aldehydes, ketones, organic acids, and saturated cyclic hydrocarbons. Although odiferous and somewhat more difficult to remove from equipment surfaces (i.e., requiring specialized cleaning methodologies), common VOCs and SVOCs do not affect most modern digital (i.e., sold-state) electronics since open wire-spring relays are no longer commonly used in this equipment.

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