

Control of Corrosive Gases to Avoid Electrical Equipment Failure

Christopher O. Muller
Technical Services Manager
Purafil, Inc., Doraville, GA, USA

ABSTRACT

Corrosive gases have been and continue to be a growing problem in the paper industry. The use of recycled fibre is increasing at the same time that electrical and electronic equipment is becoming more sophisticated and complex. Significant quantities of corrosive gases are being generated from the paper making process and the equipment required to maximize process efficiency is being adversely affected. Direct and indirect costs of failures due to corrosion run into many hundreds of thousands of Pounds a year in the UK alone. Corrosion is also an increasing safety concern, particularly on higher voltage systems.

Computer process and control systems need not be exposed to the threat of corrosive damage. Real-time air monitoring and gas-phase air filtration technology have developed to the point where corrosive gases can be measured in real-time and controlled both effectively and economically.

The paper summarizes:

- ▶ Causes of corrosion
- ▶ Signs of corrosion
- ▶ Standards for air quality
- ▶ Air monitoring tools and techniques
- ▶ Use silver corrosion to obtain a complete environmental assessment
- ▶ "Real-time" corrosion measurement
- ▶ Corrosion control technology.

INTRODUCTION

Electronic process control equipment - from small remote sensors and instruments to mill-wide distributed control systems - has made modern plants capable of higher production rates with increased quality and made them much more competitive in the world market. Chemical, physical, and environmental monitoring and control of processes in a paper mill, which historically have been performed manually or through simple control systems, are now accomplished in real-time via sensors and actuators linked by a sophisticated distributed control system (DCS). This type of high speed sensor/actuator/control network enables manufacturers to produce goods economically at high rates and with high quality.

The key to proper control is a properly functioning DCS.. This ensures proper sensor function, communications, and process control. Corrosive gases present in most paper mills will permeate into control rooms, DCS spaces, and computer facilities and most likely degrade and eventually incapacitate critical electronic equipment. This scenario may, in many cases, lead to catastrophic failure in critical control and safety systems.

CAUSES OF CORROSION

Corrosion of metals is actually a chemical reaction caused primarily by attack of gaseous contaminants and is accelerated by heat and moisture. Rapid shifts in either temperature or humidity cause small portions of circuits to fall below the dewpoint temperature, thereby facilitating condensation of contaminants. Relative humidity above 50% accelerates corrosion by forming conductive solutions on a small scale on electronic components. Microscopic pools of condensation then absorb contaminant gases to become electrolytes where crystal growth and electroplating occur. Above 80% RH, electronic corrosive damage will occur regardless of the levels of contamination.

In the context of electronic equipment, corrosion is defined as the deterioration of a base metal resulting from a reaction with its environment. More specifically, corrosive gases and water vapor coming into contact with a base metal result in the buildup of various chemical reaction products. As the chemical reactions continue, these corrosion products can form insulating layers on circuits which can lead to thermal failure or short-circuits. Pitting and metal loss can also occur.

Corrosive Gases

Specifically, we are only concerned with three types of gases, which are the prime culprits in the corrosion of electronics: acidic gases, such as hydrogen sulfide, sulfur and nitrogen oxides, chlorine, and hydrogen fluoride; caustic gases, such as ammonia; and oxidizing gases, such as ozone. Of the gases that can cause corrosion, the acidic gases are typically the most harmful. For instance, it takes only 10 parts per billion (ppb) of chlorine to inflict the same amount of damage as 25,000 ppb of ammonia.

Each site may have different combinations and concentration levels of corrosive gaseous contaminants. Performance degradation can occur rapidly or over many years, depending on the particular concentration levels and combinations present at a site. The following paragraphs describe how various pollutants contribute to equipment performance degradation.¹

Active sulfur compounds (H₂S). This group includes hydrogen sulfide (H₂S), elemental sulfur (S), and organic sulfur compounds such as the mercaptans (RSH). When present at low parts per billion levels, they rapidly attack copper, silver, aluminum, and iron alloys. The presence of moisture and small amounts of inorganic chlorine compounds and/or nitrogen oxides greatly accelerate sulfide corrosion. Note, however, that attack still occurs in low relative humidity environments. Active sulfurs rank with inorganic chlorides as the predominant cause of atmospheric corrosion in the process industries.

Sulfur oxides. Oxidized forms of sulfur (SO₂, SO₃) are generated as combustion products of sulfur-bearing fossil fuels. Low parts per billion levels of sulfur oxides can passivate reactive metals and thus retard corrosion. At higher levels, however, they will attack certain types of metals. The reaction with metals normally occurs when these gases dissolve in water to form sulfurous and sulfuric acid.

Nitrogen oxides (NO_x). NO_x compounds (NO, NO₂, N₂O₄) are formed as combustion products of fossil fuels and have a critical role in the formation of ozone in the atmosphere. They are also believed to have a catalytic effect on corrosion of base metals by chlorides and sulfides. In the presence of moisture, some of these gases form nitric acid which, in turn, attacks most common metals.

Inorganic chlorine compounds. This group includes chlorine (Cl₂), chlorine dioxide (ClO₂), hydrogen chloride (HCl), etc., and reactivity will depend upon the specific gas composition. In the presence of moisture, these gases generate chloride ions which react readily with copper, tin, silver, and iron alloys. These reactions are significant even when the gases are present at low parts per billion levels. At higher concentrations, many materials are oxidized by exposure to chlorinated gases. Particular care must be given to equipment which is exposed to atmospheres which contain chlorinated contaminants. Sources of chloride ions, such as bleaching operations, sea water, cooling tower vapors, and cleaning compounds, etc., should be considered when classifying industrial environments. They are seldom absent in major installations.

Hydrogen fluoride (HF). This compound is a member of the halogen family and reacts like inorganic chloride compounds.

Ammonia and derivatives. Reduced forms of nitrogen (ammonia (NH₃), amines, ammonium ions (NH₄⁺)) occur mainly in fertilizer plants, agricultural applications, and chemical plants. Copper and copper alloys are particularly susceptible to corrosion in ammonia environments.

Photochemical species. The atmosphere contains a wide variety of unstable, reactive species which are formed by the reaction of sunlight with moisture and other atmospheric constituents. Some have lifetimes measured in fractions of a second as they participate in rapid chain reactions. In addition to ozone (O₃), a list of examples would include the hydroxyl radical as well as radicals of hydrocarbons, oxygenated hydrocarbons, nitrogen oxides, sulfur oxides, and water. Because of the transient nature of most of these species, their primary effect is on outdoor installations and enclosures. In general, metals are only slightly susceptible to photochemical effects. However, ozone can function as a catalyst in sulfide and chloride corrosion of metals.

Strong oxidants. This includes ozone plus certain chlorinated gases (chlorine, chlorine dioxide). Ozone is an unstable form of oxygen which is formed from diatomic oxygen by electrical discharge or by solar radiation in the atmosphere. These gases are powerful oxidizing agents. Photochemical oxidation - the combined effect of oxidants and ultraviolet light (sunlight) - is particularly potent.

Hydrogen sulfide (H₂S) from pulping, sulfur dioxide (SO₂) from power plants, and active chlorine compounds (Cl₂, HCl, ClO₂) from bleaching operations and cooling towers, have all been shown to cause significant corrosion in electrical and electronic equipment at concentrations of just a few parts per billion in air. Even at levels that are not noticed by or harmful to humans, these gases can be deadly to electronic equipment. Most of the odor threshold levels are much higher than the levels at which corrosive damage will occur.

SIGNS OF CORROSION

With either copper, silver, or composite materials, the end result is the same: a disruption of the contact point. The severity of the environment (i.e., the types and levels of gases, humidity, and temperature) will determine the speed in which these films are created and the level of disruption of the flow of electrical current.

The Nature of Corrosion²

For the purposes of this paper, corrosion can be thought of as two distinct types: the first being "whisker growth" and the second type being the more conventional corrosive attack where the acid gases react with the metals themselves to form non-conductive salts.

"Whisker growth" in which microscopic metals crystals grow out of the surface of the conductive metals, is caused by the presence of sulfide molecules, e.g., silver sulfide on a silver surface, which can migrate freely over the metallic surface and collect at dendrite boundaries where nucleation takes place and sulfide crystals grow out of the surface of the metal. These "whiskers" can have diameters of around 20 μm and can grow up to 20 mm in length (FIGURE 1).

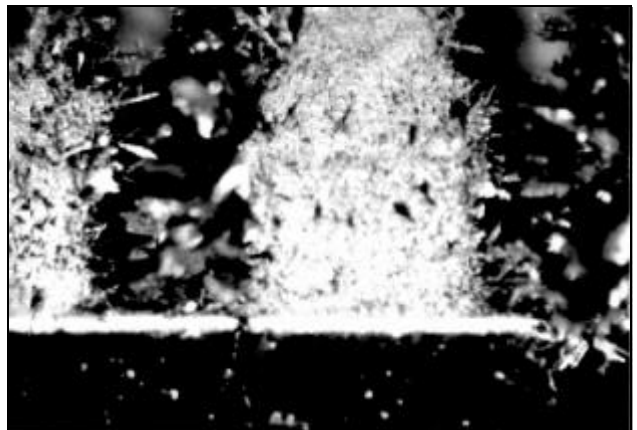


Figure 1 - "Whisker" growth on circuitry

Specific components which are particularly sensitive to corrosion attack include:

Edge Connectors. Contacts may be made solely of copper or gold-plated over a nickel-plated copper substrate, however, both susceptible to corrosion. In the latter, the conducting surface of the PCB is covered with a thin layer of gold plating which is provided to ensure that the electrical contact between the board and the connector is maintained with the highest integrity over a long period of time. Since gold is a noble metal, it is usually not attacked by ambient levels of corrosive gases. However, the gold layer is typically only between 4 and 8 μm thick and at these plating thicknesses is fairly porous. This permits the passage of adsorbed corrosive gases through the layer of gold which can then attack the underlying layers of nickel and/or copper.

The salts from the corrosion reaction form a higher volume than the pure metal and can "lift off" the gold plating or are forced back up through the pores onto the surface of the gold plating. In both cases the contact arm no longer rest on the conductive metal but rests on a high resistance coating.

In earlier generations of electronic equipment, with operating voltages in the region of 24, and sometimes 48 volts DC, equipment failures only occurred after many years of operation since the voltages were large enough to break down the thin high-resistance layers caused by salt formation.

The modern generation of electronics is, however, much more sensitive to this type of corrosion since the voltages are no longer high enough to break down these high resistance layers. Failure due to corrosion today is occurring much earlier in the lifetime of the equipment.

Pin Connectors. The problems experienced on pin connectors and IC plug-in sockets show the same problems as edge connectors. However, edge connectors appear to be more susceptible to corrosive attack and failures occur earlier than on pin connectors and IC sockets.

Wire-wrap Connections. Wire-wrap connection pins are particularly sensitive to corrosive attack because the wire forms a "smear" contact between the pin and the wire with up to four different metallic alloys being exposed

to the atmosphere. Corrosive attack can thus occur concurrently with electrolytic action which greatly increases the corrosive influence.

Electrical Systems. In heavy current systems, the build-up of corrosion by-products can cause overheating which result sin a reduction in equipment life or even explosions inside circuit breakers, contactors, motor starters, etc. It has also been found that corrosion of springs and thermal overload elements has led to malfunction of protection circuits.

Traditionally, substations and motor control centers have contained only heavy current equipment. Today, however, these rooms contain increasing numbers of electronic interlocking, protection, and signaling equipment. As such, the air purity required by these rooms is becoming the same as that required for electronics rooms.

How can mill personnel detect potential problems before serious damage occurs? Can the corrosive gases be measured to determine just how bad (or good) environmental conditions may be?

STANDARDS FOR AIR QUALITY

Standards are in place that provide specifications for proper control room design and give detailed information on the quality of air required for optimal performance of electronic equipment. In 1985, the Instrument Society of America (ISA) published a standard, ISA-S71.04-1985 "*Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*". This document was followed in 1987 by the International Electrotechnical Commission (IEC) Standard, IEC 60654-4 (1987-07) "*Operating Conditions for Industrial-Process Measurement and Control Equipment. Part 4: Corrosive and Erosive Influences*." Japan's standard, JEIDA-29-1990, was revised in 1990 and published as the Japan Electronic Industry Development Association's (JEIDA) "*Standard for Operating Conditions of Industrial Computer Control System*."

These standards define or characterize environments in terms of their overall corrosion potential. By the use of "reactivity monitoring," a quantitative measure of this potential can be established. Reactivity monitoring involves placing strips of specially prepared copper strips, called Corrosion Classification Coupons (CCCs, FIGURE 2), into an environment. The coupons are left in for a period of time, then analyzed in a qualified laboratory to determine how much copper corrosion film formation has occurred. The copper reactivity is a measurement in angstroms (ten billionths of a meter) of the thickness of corrosion film build-up normalized to a 30-day exposure. This analysis technique allows for the classification of the total corrosion film thickness, as well as the film thicknesses attributed to the exposure of individual corrosive gases.

The synergistic effects of the various combinations of gases makes the determination of severity levels complex. In addition to the contaminant gases themselves, the levels of temperature and humidity also have a major impact on the corrosion rates. Therefore, the easiest method of measurement has been through the use of CCCs according to the methods prescribed in ISA-S71.04-1985 and in IEC-654-4-1987. This data is then used to determine the severity level of the environment. This severity level in turn refers to the potential damage that corrosive gases in the air could cause to electronics and electrical equipment and, therefore, provides a method for determining equipment reliability.

Four levels of corrosion severity have been established by ISA-S71.04 (see TABLE 1). The optimum severity level is G1 - Mild. At this level, corrosion is not a factor in determining equipment reliability. As the corrosive potential of an environment increases, the severity level will be classified as G2, G3 and GX (the most severe). The effects of humidity and temperature are also quantified in this standard. High or variable relative humidity and elevated temperatures may cause the acceleration of corrosion by gaseous contaminants. Relative humidity of less than 50 percent is specified by the standard.

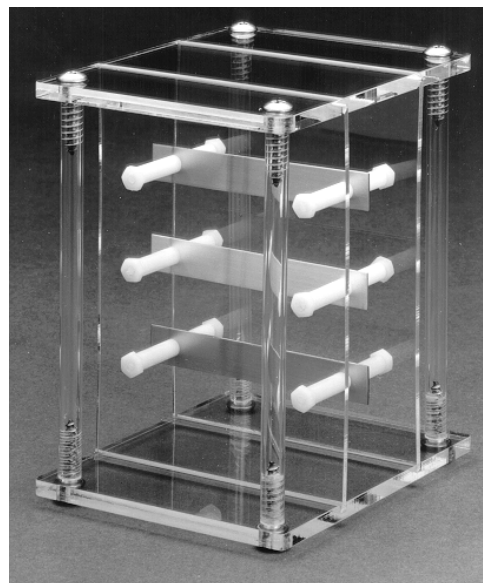


Figure 2 - Corrosion classification coupon

TABLE 1 - Copper Coupon Reactivities			
Class	Severity Level	Copper Reactivity	Comments
G1	Mild	<300Å	An environment sufficiently well-controlled such that corrosion is not a factor in determining equipment reliability.
G2	Moderate	<1000Å	An environment in which the effects of corrosion are measurable and corrosion may be a factor in determining equipment reliability.
G3	Harsh	<2000Å	An environment in which there is a high probability that corrosive attack will occur. These harsh levels should prompt further evaluation resulting in environmental controls or specially design and packaged equipment.
GX	Severe	>2000Å	An environment in which only specially designed and packaged equipment would be expected to survive. Specifications for equipment in this class are a matter of negotiation between user and supplier.

Purafil, Inc. has been performing corrosion testing for many years as a diagnostic tool in response to customers' needs and requests. During this time, more than 10,000 CCCs have been analyzed with more than 50% showing severity levels greater than those required for properly installed electronic equipment.

While CCCs are good for the measurement of average corrosion, it does not allow for the measurement of any variations that may have occurred during that period. It is possible that all of the corrosion occurred during only one day when there may have been a chemical spill or other upset condition as so often happens during normal manufacturing conditions. Therefore, the ability to measure the short term variations lasting less than a day or hours has not been available.

Long-term corrosion information, giving cumulative amounts of corrosion experienced by the electronic equipment, would be useful in predicting when failures will become a factor in the reliability of the equipment. The recent development of a real-time corrosion monitor that can electronically measure the cumulative, as well as the incremental, corrosion over time will eliminate the limitations associated with corrosion classification coupons.

Air Purity Requirements

The clean air requirements for gases required for the different types of equipment are:

- ▶ Process computer systems generally require **G1** conditions inside the computer room;
- ▶ Microprocessor-based process control or instrumentation systems generally require **G1** conditions inside the electronic equipment rack room and also inside the control room if there are significant quantities of electronics inside the control room;
- ▶ Discrete instrument type process control systems (i.e., with separate controllers, indicators and recorders) generally require at least **G2** conditions in the control room;
- ▶ Motor control centers (MCC) and substations which contain programmable logic controllers (PLCs), electronic control systems, thyristor drives, or uninterruptable power supplies (UPSs) generally require **G2** conditions;
- ▶ MCC and substations which contain *only* heavy current switchgear require conditions where the *average* concentrations of the gases are: SO₂ - 200 ppb, H₂S - 30 ppb, Cl₂ and reactive chlorine compounds - 10 ppb, and HF - 10 ppb.

AIR MONITORING TOOLS AND TECHNIQUES

Air monitoring is central to any environmental control program for achieving and maintaining air quality standards based on the presence (or absence) of gaseous air pollutants. Such monitoring can also provide the short-term data required to manage and mitigate contaminant-specific episodes.

Several characteristics of any measurement technique must be evaluated to determine its appropriateness for use in air quality monitoring. Among the more important characteristics are sensitivity, cost, and complexity.

Sensitivity is a particularly demanding parameter for environments where near-ambient levels of many pollutants may be encountered and control levels are in the low ppb range. Likewise, cost may be quite important when deciding on a measurement technique, particularly in large surveys. A final point of consideration is the complexity of the technique and the degree of skill and training required to obtain quality results. Other factors deserving consideration are selectivity and portability. Most measurement techniques are not optimized for all of these parameters, and one must weigh the various characteristics in order to best meet the desired goals. Often trade-offs will be necessary in selecting the techniques to be used for a specific study.

Direct Gas Monitoring

The biggest problem today is not whether specified levels of air quality can be reached, but whether they can be accurately measured to assure compliance with any standards or control criteria. Electronic devices designed for real-time gas monitoring respond to changes in the measured variable very quickly. They are capable of detecting pollutant levels in the low ppb range, and are available for a wide range of pollutants. Individually, chemical pollutants may be monitored using various analytical techniques to provide both the sensitivities and selectivities required to perform accurate low-level real-time monitoring. The major disadvantage to the use of real-time gas monitors is the relatively high cost when compared to other techniques. TABLE 2 lists a number of different pollutants and the levels which can be monitored with real-time monitors.

Pollutant	Concentration Range, ppb	Lower Detection Limit, ppb	Response time, sec	Selectivity	Susceptibility to Interferences
Ammonia	0-200	1.0	900	Medium	Low
Formaldehyde	0-1000	0.2	300	High	Low
Hydrochloric acid	0-200	1.0	900	Medium	High
Hydrogen sulfide	0-200	1.0	120	Medium	Low
Nitrogen oxides	0-200	0.1	90	NO-High, NO ₂ -Low	Low
Ozone	0-1500	1.0	50	High	Low
Sulfur dioxide	0-200	0.1	120	High	Low
TVOC	0-20,000	20.0	120	Low	Low

Reactivity Monitoring

A corrosion classification coupon test program offers the least expensive available indicator of probable corrosive damage. With zero capital investment and a monthly cost of less than one tenth of on-line gas analysis, it becomes practical to place coupons in a room every month to alert management to changes in the environment that may affect future computer performance and mill profit.

As previously mentioned, CCCs are passive monitoring devices typically exposed to the environment for a period of 30-90 days and then analyzed for the amount and type of corrosion which has formed. This can provide cumulative reactivity rates, an assessment of "average" environmental conditions over time, and an indication of the type(s) and relative level(s) of corrosive gaseous pollutants.

Silver Corrosion Monitoring For a Complete Environmental Assessment. Copper CCCs can be used to indicate the presence of many corrosive gases which can cause damage to electronics and electrical devices. CCCs originally used only copper reactivity to establish environmental classifications. However, it soon became apparent that copper was not sufficiently sensitive to all of the primary pollutants of concern in many industrial environments, e.g., SO₂, NO_x, O₃, and Cl₂. Further, copper coupons cannot detect the presence of environmental chlorine, a particularly dangerous contaminant to electrical equipment.

With this in mind, Purafil developed and pioneered the use of silver reactivity monitoring for industrial environments. Silver is more sensitive than copper to low levels of corrosive gases, sensitive to chlorine and, when used with copper reactivity monitoring, can be used detect changes in the levels of gaseous pollutants in the ambient environment as small as 1 ppb and differentiate between different classes of contaminants. Silver corrosion forms at a rate that is independent of humidity and can therefore provide a more accurate picture of the total reactivity level of the subject environment.

The corrosion reported from reactivity monitoring with CCCs is actually the sum of individual corrosion films. For copper coupons, sulfide and oxide films are most commonly produced and are reported as copper sulfide (Cu₂S)

and copper oxide (Cu_2O), respectively. For silver coupons, sulfide, chloride, and oxide films may be produced and are reported as silver sulfide (Ag_2S), silver chloride (AgCl), and silver oxide (Ag_2O), respectively. Each coupon is analyzed as to the type and amount of film present and its relative contribution to the total corrosion produced.^{3,4} In published research, Purafil was able to show that one could differentiate between corrosion caused by active sulfur compounds (H_2S) and sulfur oxides (SO_2) when both copper and silver corrosivity was monitored.^{5,6}

"REAL-TIME" CORROSION MEASUREMENT

One consideration faced in designing an air monitoring program is the choice of passive vs. active sampling. The immediate feedback of an active monitor is a most desirable aspect and is what often precludes the use of passive monitors. The main limitation in the use of CCCs is their inability to provide a continuous environmental classification. To address this, Purafil has taken reactivity monitoring a step farther through the development of a patented, real-time monitoring device employing metal-plated quartz crystal microbalances (QCM, FIGURE 3).^{7,8} The OnGuard™ 2000 Atmospheric Corrosion Monitor (FIGURE 4) is a microprocessor-controlled device able to measure the total environmental corrosion attributable to gaseous pollutants. The OnGuard 2000 can detect and record changes of 1 ppb in the concentrations of corrosive gases. This ability is regarded as one of the main requirements for any real-time monitoring protocol to be used in these environments.

The OnGuard 2000 is the only commercially available corrosion monitor employing copper and silver-plated QCMs which provides real-time information on the amount of corrosion occurring due to the presence of gaseous pollutants. It monitors corrosion on a continuous basis which allows for preventive action to be taken before serious damage has occurred. Appropriate reactivity and alarm levels for a particular application can be easily adjusted.

The OnGuard 2000 may be operated by independently, wired directly into a central computer system, or networked to relay information from multiple units to a central location. Monitoring data can be uploaded to a PC for viewing or graphing. By making use of the unit's ability to interface with computers, up-to-the-minute information on the levels of corrosive contaminants can be obtained. Environmental classification databases can be established and maintained to provide historical data.

CORROSION CONTROL TECHNOLOGY

The three methods of gaseous contaminant control most commonly employed in HVAC systems are source control, ventilation control, and removal control. Source control should always be the first strategy examined. Removing the sources of contaminants prevents them from becoming a problem in the first place. However, in these industrial environments, the source of gaseous contaminants are from the manufacturing processes themselves and cannot be easily removed. Process emissions have reduced over the last several years, but they are still a long ways from levels which would be considered safe for electronic equipment.

When source control is not an option, ventilation control should be the next option. Ventilation control involves the introduction of clean dilution air into the affected space. Contaminant levels can thus be reduced below acceptable threshold levels. However, as in source control, this is not a viable option in pulp and paper mills because the outside air does not meet the required criteria with regards to gaseous contaminants. Therefore, if this air were to be used for ventilation, one would simply be increasing the total contaminant load in the space.

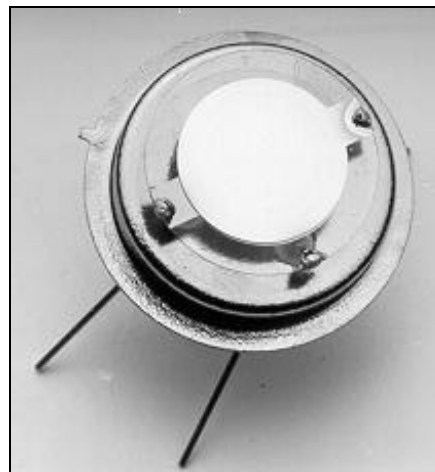


Figure 3 - Quartz crystal microbalance



Figure 4 - OnGuard 2000 Atmospheric Corrosion Monitor

When it is clear that neither source nor ventilation control will adequately control the levels of gaseous contaminants in the affected space, removal control should be employed. The use of a Purafil gas-phase air filtration system employing one or more dry-scrubbing media as an integral part of an HVAC system can effectively reduce gaseous contaminants to well below standard levels.

To better understand and appreciate the capabilities of air filtering systems, we must examine what contamination needs to be controlled. There are three types of airborne contaminants considered in ISA S71.04-1985: liquids, solids and gases. The two most common technologies available to deal with low-level airborne contamination are particle removal filtration, such as mechanical filters, for liquids and solids, and gas-phase, or dry-scrubbing, filtration for the latter.

Air filtration can effectively remove essentially all of the gaseous contaminants which could negatively impact electrical systems when the proper considerations are made in choosing the gas-phase (chemical) filters. A typical gas-phase air filtration device has three major sections. The first section would consist of a one- or two-stage particulate prefilter to remove dust and other particulate matter that could "coat" the chemical filter media. This would be followed by 2-3 stages of the appropriate chemical filtration media. This would be followed by a final filter section.

Purafil Gas-Phase Air Filtration Equipment/Systems

HVAC-Integrable Systems. Some Purafil systems are designed to be integrated into the overall HVAC system. This approach offers the confidence that all parts of the air purification/HVAC systems will work together. Integrated systems typically require there be sufficient space within the air handling unit (AHU) or mechanical or machine rooms in which they can be placed. Unless redundancy is designed into the original system, the Purafil system will only operate providing the central HVAC system is in operation. Common integrated systems include Purafil side access (PSA) and front access equipment which are very effective in treating low-to-medium concentrations of gaseous contaminants. Typical systems can offer a full range of options for prefilter selections, multiple media banks, and final filter selections.

Industrial Purafil Side Access Unit (IPSA) - Similar to front access units, the IPSA is a versatile system which can be designed to achieve virtually any efficiency rating desired. These units are used to filter low-to-medium concentrations of outside gaseous contaminants in less polluted areas of the manufacturing areas. If the IPSA is used to clean outside air in a very hostile environment, or process exhaust air, the life of the media will be shorter than that for a bulk-fill system.

Typical IPSAs are constructed of 14 gauge galvanized steel, and the housings offer a full range of size options for prefilter selections, multiple media banks, and final filter selections. These unit are non-powered and rely upon the HVAC system's blower system. Wide ranges of sizes are available according to airflow requirements.

Front Access System (FAS) - FASs are very effective in treating low-to-medium concentrations of gaseous contaminants. FASs are designed to be easily integrated and adapted into an existing air handling system.

FASs are usually installed as 1-3 built-up banks of 305 x 610 mm (1'x2') or 610 x 610 mm (2'x2') frames (cells) which can be stacked in virtually any size configuration to meet the specific space requirements of most systems. This modular system offers a wide combination of media bed depths, media types, and particulate filtration.

Typical Purafil FASs are constructed of 16 gauge steel frames coated with corrosion-resistant paint. Aluminum or stainless steel frames and special coatings are also available for use in particularly hostile environments.

In addition to outside air applications, FASs can be used for recirculation. As the incoming outside air will already have been filtered, FASs used for recirculation purposes can remove contaminants to very low levels to maintain the desired air quality. Because of the low contaminant challenge levels, FASs used for recirculation should have a long media life.

Self-Contained Systems. Purafil also offers systems consist of the housing to hold the media as well as a blower section to move the air through the system. These systems are totally separate from the HVAC system. Self-contained systems allow for easier retrofits, the use of standard air handlers, easier service of the system, and less complex air balancing. Additionally, some self-contained systems contain greater amounts of media, thus are able to handle higher gaseous challenge levels. Typical systems include a prefilter, one or two banks of dry-scrubbing media contained in either refillable or disposable modules, a blower section, and a final filter.

Positive Pressurization Units (PPU) - The ultimate control for any space requiring high air quality standards involves positive pressurization. The PPU is an all-in-one packaged air filtration machine for indoor use. Both particulate and chemical filtration are integrated into one unit, complete with a self-contained blower. It is used to filter low to medium concentrations of gaseous pollutants while providing continuous positive pressure within the space.

The PPU cabinet is constructed of seam-welded 14 gauge steel and includes a prefilter, two banks of dry-scrubbing media contained in either refillable or disposable modules, an optional 90% final filter, a blower section, and an adjustable damper for control of pressurization air. A maximum of 50% of the unit's total airflow capacity may be used for pressurization air.

Deep-Bed Scrubber (DBS) - A DBS is used to filter exhaust or outside air containing high concentrations of gaseous contaminants. DBSs are designed to sit outside the protected space and provide clean pressurization air. These units provide greater removal efficiency due to multiple, deep media beds and lower air velocities. By increasing the residence time of the contaminants in the system, these units are particularly effective against high gas challenge levels. The multiple beds in these units allow for the use of multiple dry-scrubbing media - each targeting a specific contaminant or group of contaminants.

Typical DBS's include a rain louver with birdscreen (optional), a blower section, two or more 305 mm (12") beds of dry-scrubbing media in series, and a (high efficiency) final filter. These units may be supplied in either a "blow through" or "draw through" configuration depending on whether the application is filtering air from the outside or exhausting air from a manufacturing process. Commercially available DBSs may be manufactured out of aluminum, fiberglass reinforced plastic (FRP), or stainless steel - depending on the nature of the chemical species to be removed.

Tub Scrubbers (TS) - Like the DBS, a TS is used to filter high concentrations of contaminant gases, particularly in catastrophic release applications. However, instead of employing multiple 305 mm (12"-deep) media beds (to handle different medias targeted at different specific gaseous contaminants), TSs feature a single bed of media (up to ~1 m [36"] in depth) to handle single-contaminant waste gas or exhaust streams. The TS can also be configured to be a single unit total recirculation and pressurization (TRAP) system.

Typical TS's include a rain louver with (optional) birdscreen, a blower system, a single media bed, and pre- and final filters. The unit can be constructed of aluminum, FRP, or stainless steel.

In addition to outside air applications, these systems can also be used for recirculation. As the incoming outside air will already have been filtered, systems used for recirculation purposes can remove contaminants to very low levels to maintain the desired level of corrosion control. Because of the low contaminant challenge levels, systems used for recirculation typically have long service lives.

Corrosive (Recirculating) Air Units (CA) - CAs are designed to sit inside the protected space and are air purification machines with recirculation as their primary function. CAs in service today come in various vertical and horizontal configurations with airflows (typically) ranging from 850- 6800 m³/hr (500-4000 cfm). These units are used to filter low to medium concentrations of gaseous contaminants to further filter and polish the room air in order to maintain very low gas contaminant levels. For larger rooms it is often necessary to use several CAs to fully recirculate all the air within the room. Typical CAs include a prefilter, one or two banks of dry-scrubbing media contained in either refillable or disposable modules, a blower section, and a final filter.

Media Filters

Purafil's dry-scrubbing air filtration media are available for use in a variety of filter designs - usually as packed-bed filters where the media is filled in the space between perforated metal or plastic screens. These include filters in which a variety of media bed types and depths are employed.⁹ Many of these type filters are used in tandem with particle removal filters for optimal filtration capabilities. These filters can be installed in front- or side-access housings or other standardized equipment. They can also be installed in some self-contained air cleaner units. These filters are available as refillable or disposable units.

The use of packed-bed media filters provide essentially 100% media particle-to-particle contact which allows virtually all of the contaminated air to contact the media before exiting the media bed(s). The filter one uses for a particular application will depend on a number of considerations including the required removal efficiency, the desired service life, the types and number of contaminants expected, the HVAC system airflow, and the available

pressure drop within the HVAC system. Packed-bed systems are most often used in industrial facilities due to the extremely high contaminant removal efficiencies and long service lives which can be attained.

Chemical Filtration Media

The heart of a gas-phase air filtration system is the dry-scrubbing chemical filtration media. Purafil offers a variety of dry-scrubbing media which are currently in wide use for treating contaminated airstreams due to their ability to attract and hold a variety of corrosive chemical contaminants. When the media are treated with various agents, or impregnants, these system's capabilities can be expanded to an even wider array of gaseous contaminants.

Gas-phase air filtration, as applied in mechanical ventilation systems, uses two main mechanisms to remove airborne gaseous contaminants. One, which is a reversible physical process, is known as adsorption. The other, which involves adsorption and irreversible chemical reaction(s), is termed chemisorption.

Adsorption is a physical process whereby gaseous contaminants are "captured" by the media. However, this is a reversible physical process in that gases once adsorbed can later desorb. The net rate of adsorption depends on the rate at which contaminant molecules reach the surface of the media, the percent of those making contact which are adsorbed, and the rate of desorption. However, many other factors can affect the removal of contaminants by physical adsorption. Among these are the media substrate, the resistance to airflow (ΔP), the media bed depth, the gas velocity through the bed, the characteristics of the contaminant(s) in the space around the media, and the removal efficiency required.

Chemisorption involves the reaction with various chemical species contained in (or on) the media which can convert the contaminants to (among others) carbon dioxide, water vapor, organic and inorganic salts, etc. This process is irreversible and essentially instantaneous. Chemisorption may be employed whenever physical adsorption by itself is inadequate or ineffective against a particular contaminant or group of contaminants. Desorption of target contaminants, once adsorbed and chemically reacted, does not occur. Many of the same factors which affect the removal of gases by adsorption also affect their removal by chemisorption.

Because of the demands placed on a gas-phase air filtration system designed for corrosion control, the use of two or more dry-scrubbing media may be indicated (TABLE 3). While it is preferred to use each media in a single filter, sometimes physical constraints may not allow the use of multiple filter beds. Because of this Purafil can offer blends of media in order to provide complete chemical contaminant control while meeting the restrictions of the mechanical system.

TABLE 3 - Breakthrough Capacity Test Results (typical) @ 99.5% Removal Efficiency ¹⁰		
Contaminant	Gas-Phase Air Filtration Media Tested*	Capacity, weight %
Ammonia	Purakol [®] AM media	5.83
Chlorine	Purakol [®] media	10.87
	Puracarb [®] media	9.82
Hydrogen chloride	Purafil [®] Select + Puracarb/Purakol media	4.00
Hydrogen fluoride	Purafil Select + Puracarb/Purakol media	3.50
Hydrogen sulfide	Purafil Select media	12.82
	Puracarb media	14.77
Nitrogen dioxide	Purakol media	6.61
Nitric oxide	Purafil Select media	4.28
Ozone	Purakol media	21.00
Sulfur Dioxide	Purafil Select media	6.18
	Puracarb media	7.98

*Purakol AM - activated carbon impregnated with phosphoric acid

Purakol - activated carbon

Puracarb - activated carbon + activated alumina impregnated with potassium hydroxide

Purafil Select - activated alumina impregnated with potassium permanganate

Purafil gas-phase air filtration systems used in pulp and paper mills typically have gas removal efficiencies $\geq 99.5\%$. To reach this level of efficiency, a system may employ multiple media beds - taking advantage of the strengths of one or more media to target specific gases. Generally, the ability of a gas-phase air filtration system

to capture chemical contaminants is directly related to the residence time of the airstream within the media bed, the type and concentration of contaminants, and the temperature and relative humidity of the airstream.

SUMMARY AND CONCLUSIONS

Most electrical systems used in the paper industry are protected against the potential threats posed by fire, power, ESD, shock, vibration, humidity, temperature and particulate contamination. Unfortunately, the potential damage to electronic equipment caused by the corrosive effects of gaseous contaminants has still not been fully recognized or addressed by many of the major paper manufacturers.

The first stages of corrosion may show up as untraceable alarms, as corrosion products grow and provide random circuit paths which clear themselves as soon as current flows through them. However, some information has already been lost. In the worst cases, mainframe computers have been totally destroyed, necessitating lengthy, expensive shutdowns to replace million-dollar control systems.

In electrical power systems, the build-up of corrosion products can cause overheating, leading to reduced equipment life or even to explosions of circuit breakers and motor starters. While the cost of the systems themselves are high, the production losses from moderately sized operations can quickly add up to exceed the costs of repairing or replacing the affected systems.

Corrosive failure of electronic equipment is particularly prevalent in the pulp and paper industries. Low concentrations, in the ppb range, of gaseous contaminants such as H_2S , SO_2 , NO_x , Cl_2 , mercaptans, or NH_3 in the air coming in contact with computer/electrical switching circuits will quickly react with most metals forming non-conducting layers of metal salts (Figure 5). As a result, substantial resistance to current flow is developed, variations in voltages occur, and the entire circuit may become useless due to changes in component value.

Recognizing the severity of the problem, most of the world's leading manufacturers of computer systems have placed in their site planning manuals references to the ISA, IEC or JEIDA standards for acceptable levels of airborne contaminants because they provide achievable and effective guidelines to protect their electronics and electrical equipment from the damaging effects of corrosive gases.

One consideration faced in designing an air monitoring program is the choice of passive vs. active sampling.

The (relatively) immediate feedback of an active monitor is a most desirable aspect and is what often precludes the use of passive monitors. Another consideration is the option of direct versus indirect monitoring techniques.

For environmental corrosion assessment, the ideal situation would be continuous, on-line, multiple gas monitoring. However, since the ambient concentrations are typically quite low, and different combinations of gases produce varying reactivity levels, this can become a difficult and expensive task. Therefore, alternate diagnostic methods have been developed.

Reactivity monitoring can characterize the destructive potential of an environment. The growth of various corrosion films on specially prepared copper and silver coupons provides an excellent indication of the type(s) and level(s) of essentially all corrosive chemical species present in the local environment.

The OnGuard 2000's measurements correlate, in real-time, directly to ISA S71.04-1985. Based upon the change within each 24-hour period, a determination is made of the corresponding 30-day severity level - G1, G2, G3, or GX. The monitor communicates at several levels providing vital information on corrosion severity level, temperature, and relative humidity. These devices can be networked into a host system for complete plant-wide monitoring.

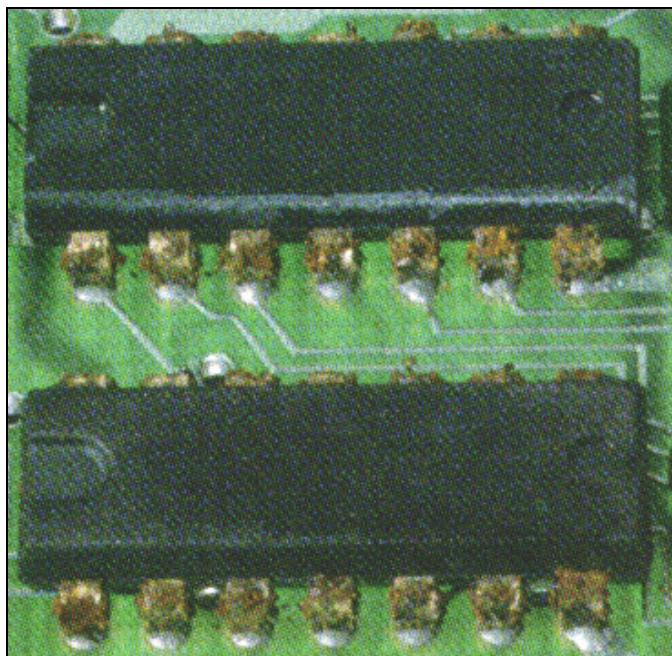


Figure 5 - Corrosion formed on the legs of IC

Real-time corrosion monitoring should be viewed as a critical component of any mill-wide preventive maintenance program. The damage to electronic controls not only puts the operation of the mill systems in jeopardy, with damage being repaired at an expense much greater than the preventive cost, but also has personnel safety implications.

Reactivity monitoring only indicates that a potential corrosion problem exists, but does nothing to eliminate that problem. Detecting corrosion is only the first step towards the goal of maintaining a corrosion-free environment. Preventive maintenance programs should include analysis of needs, installation of the proper air filtration system, technical support and problem solving, and timely service when repairs are required.

Purafil's gas-phase air filtration technology has developed over the past 25 years to protect crucial process control systems operating in harsh, industrial environments. Gaseous contaminants, both externally and internally generated, can be effectively removed down to the low parts per billion level to preclude any potential damage to electronic equipment.

The net result of corrosion in a process measurement and control systems is:

- System failure with the resulting high maintenance costs
- Misinformation or improper control
- Process shut-down

The latter is the ultimate cost - lost productivity or reduced quality.

An example of how Purafil gas-phase air filtration systems can reduce costs is shown graphically in FIGURE 6. This shows the frequency of monthly service calls for one of a European pulp mill's control rooms. The room had been initially built without air filtration. Over a period of several years, the electronics started deteriorating. Repair and replacement costs are reflected in the number of service calls.

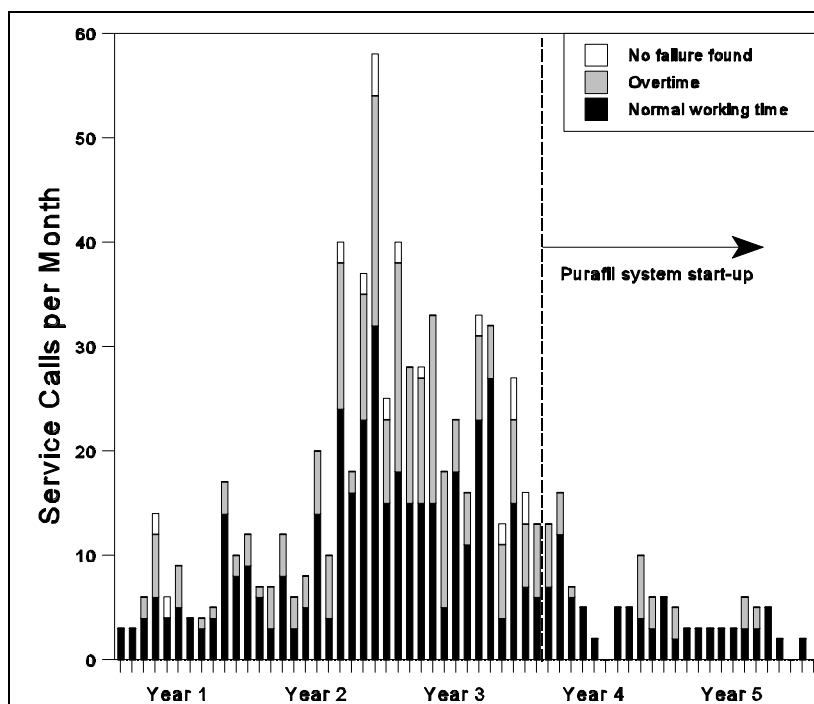


Figure 6 - Monthly service calls, European pulp mill

Note that the number of service calls are broken down by those required during normal working hours and on an overtime basis. Also shown are the number of times during a month that a problem was intermittent, and no problem was found during the service call.

Purafil systems were installed in August of the third year for which this information had been collected, as indicated by the dotted vertical line. After that time, there was an marked decrease in the service calls and the associated preventive maintenance costs required in this room. There were still some intermittent problems, probably associated with corrosion which had formed during the time before the Purafil systems were installed.

Ultimately, the successful implementation of a corrosion protection program requires:

- Knowledge and understanding that corrosion of electronic equipment is a serious problem.
- Commitment to a monitoring program to detect the potential for equipment failure before process controls are destroyed and costly production shutdowns occur.
- Commitment to an integrated contamination control system.
- Commitment to take corrective action whenever necessary

REFERENCES

1. Standard: ANSI/ISA S71.04-1985, "Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants," Instrument Society of America, Research Triangle Park, NC, 1985.
2. Boonzaier, W.G. "Acid Gas Corrosion Protection," *SA Measurement & Control*, pp. 5-9, July, 1986.
3. Abbott, W.H., "The Effects of Operating Environments on Electrical and Electronic Equipment Reliability in the Pulp and Paper Industry," *IEEE Conference Record*, Institute of Electrical and Electronic Engineers, Inc., New York, 1983.
4. Rice, D.W., et al., "Atmospheric Corrosion of Copper and Silver," *Electrochemical Society*, 128(2), pp 275-284, 1981.
5. Muller, C.O., "Combination Corrosion Coupon Testing Needed for Today's Control Equipment," *Pulp & Paper*, Vol. 64, No. 2, February, 1990, pp. 165-169.
6. Muller, C.O., et al., "Multiple Contaminant Gas Effects on Electronic Equipment Corrosion," Paper No. C90/225E, National Association of Corrosion Engineers Annual Conference, Las Vegas, Nevada, April, 1990.
7. England, W.G., et al., "Applications of a Real-Time Electronic Contact Corrosion Monitor," *Proceedings of Advances in Instrumentation and Control*, Vol 46: pp 929-955, Instrument Society of America, Anaheim, 1991.
8. Weiller, A.J., "Electronic Monitoring of Indoor Atmospheric Pollutants," *Proceedings of Healthy Buildings '94*, pp 241-243, National Coalition on Indoor Air Quality, 1994.
9. Godish, T., *Indoor Air Pollution Control*, Chelsea, MI, Lewis Publishers, pp. 282-306, 1989.
10. "Breakthrough Capacity Test Results (typical) at a 99.5% Efficiency - Final Report," Purafil, Inc., Doraville, GA, 1998.