Protecting Electrical/Electronic Systems in a Corrosive Treatment Plant Environment

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Introduction

Low-level corrosive gases commonly found at wastewater treatment plants can present a significant problem for electrical and electronic systems. Early intermittent corrosion failures of fine wires and contacts in electronic microcircuitry are difficult to identify and result in frequent maintenance, trouble-shooting and process control difficulties. With an increased reliance on such devices as computers, variable speed drives, and Supervisory Control and Data Acquisition (SCADA) systems, treatment plants are finding themselves at a greater risk of costly downtime and maintenance due to electrical and electronic system failures. For years, the Commissioners of Public Works (CPW) of the City of Charleston, South Carolina's Plum Island Water Pollution Control Facility experienced accelerated failure of an assortment of electrical and electronic systems. Research indicated that the accelerated failure was the result of corrosion. In 1998, in an effort to improve the reliability of the network communication switchgear, Plant personnel began to investigate methods for protecting critical electrical and electronic systems from corrosion. Through their investigation, the Plant was introduced to the Corrosion Technology Group at MeadWestvaco Corporation (formerly Westvaco Corporation). MeadWestvaco is a pulp and paper company headquartered in Covington, Virginia with a mill located in nearby North Charleston, South Carolina. Similar to wastewater treatment plants, low-level corrosive gasses associated with the production of paper products present a challenge to operating and maintaining electrical and electronic equipment at pulp and paper mills. To address this issue at their facilities, MeadWestvaco combined expertise in corrosion science, activated carbon technology and pulp and paper operations to develop a modular activated carbon adsorber that provides purified make-up air to protect instrumentation and electrical systems. Two products emerged from this development; the completely packaged, skid-mounted Vapor Adsorber, designed to protect control rooms and buildings, and the Cabinet Vapor Adsorber, developed to prevent corrosion in field-mounted electronic process control devices. In 2001, as part of a Plant wide HVAC system replacement, CPW installed seven (7) MeadWestvaco Vapor Adsorbers to provide corrosion protection to its Administration Building and all outlying motor control centers and electrical rooms. Subsequently, two additional Vapor Adsorbers have been installed and the Plant has standardized on Vapor Adsorber supplied make-up air for all conditioned spaces.

This paper begins with an overview of MeadWestvaco's development of Vapor Adsorber technology then discusses environmental monitoring using corrosion coupons. It continues with a historical look at CPW's project development and implementation and then concludes with a discussion on Vapor Adsorber performance results at the Plum Island Water Pollution Control Facility.

Vapor Adsorber Development

According to Brown, Lunn & Repik, corrosion induced failures in electronic process control equipment are of many different types. Examples are the braking of corroded copper wires, caused by acid condensates trapped under insulation, and the failure of electrical contacts caused by corrosion product creep following galvanic corrosion between precious metal overplates and copper nickel substrates. Microscopic analysis, performed by MeadWestvaco, of a typical corroded wire showed that detached scales were present on the wire surface and the corrosion reaction had consumed a great deal of the copper. Energy dispersive X-ray analysis of a cross-section of the corroded wire revealed that the scale was predominantly a sulfide. The fact that the sulfur content of the scale increased towards the outside of the scale suggested that the inner scale was a mixture of copper oxides and copper sulfides, while the outer layers were relatively pure copper sulfide.

A second failure mechanism is that of galvanic attack between gold and copper. Gold, which does not react with the environment, is used as an overplate on base metal substrates, such as copper and nickel, which react with the environment. Corrosion can occur where the gold overplate is porous, and the rate of attack is accelerated when the humidity is high. Corrosion products creep over the gold-plated surface, resulting in high electrical contact resistance and lead to a functional loss of electrical contact. Corrosion product creep is a rapid process, and in a simulated sulfur-containing environment, gold-plated surfaces were substantially covered with corrosion products in a few weeks.

Chemical substances found in paper mill environments, which are corrosive to electronic equipment and materials, may be gaseous or solid. The principal gaseous corrosives are the following: hydrogen sulfide, sulfur dioxide, the acid chlorine gases, and water vapor. Water vapor, sulfur dioxide and hydrogen sulfide influence the rate of both copper and silver corrosion.

In addition to corrosive gases, particulates in the environment may contribute to the corrosion. Hygroscopic dirt, such as sodium sulfate dust in a pulp mill chemical recovery area, attracts moisture and forms a corrosive solution. This can pose problems if the hygroscopic dirt becomes lodged between two conductors so as to attack one of them or cause a short circuit.

Electronic process control equipment can be protected from corrosion in several ways: The air in the control room can be purged of corrosive gases, the control equipment can be placed in an airtight cabinet, vapor phase inhibitors can be used, or more resistant but substantially more expensive materials may be specified. MeadWestvaco chose to tackle the corrosive problem by keeping corrosive gases out of the control room environments through the use of a modular filtration system using a deep bed of specialty activated carbon. This system works on the principle of supplying a purified air stream to pressurize the enclosed area to minimize the possibility of corrosive gas intrusion into the control room.

In order to achieve effective removal of gases such as hydrogen sulfide, sulfur oxides, chlorine and chlorine compounds, a specialty carbon was developed by the Westvaco Research Group. Solid particulates, primarily sodium sulfate and sodium carbonate, are removed by appropriate mechanical filters. In order to meet removal requirements and to minimize installation costs, a skid-mounted, modular filtration system was developed. A carbon adsorber using a deep carbon bed of a specialty carbon was specified to achieve a high degree of make-up air purity for a protection period of at least one year for most expected mill conditions.

Today, MeadWestvaco markets seven (7) commercially available Vapor Adsorber systems: The 100 Series, 500 Series, 1000 Series, 2000 Series, 3000 Series, 4000 Series and 6000 Series. The series number corresponds to the make-up air capacity of the Vapor Adsorber in cubic feet per minute (cfm). Each unit is a pre-engineered system that includes an air blower, pre- and post-filters and a deep-bed carbon adsorber, holding a special grade of activated carbon. The carbon bed is designed so that it can be easily removed to facilitate servicing. Fan motors range in size from 1.5 horsepower for the 100 Series to a 20 horsepower motor for the 6000 Series. Materials of construction for all Vapor Adsorbers are Fiber Glass Reinforced Plastic (FRP) and stainless steel; ideal for even the worse treatment plant environments.

In addition to the skid-mounted Vapor Adsorber systems, MeadWestvaco also markets the Cabinet Vapor Adsorber. The Cabinet Vapor Adsorber is a completely self-contained unit for the control of corrosive gases by activated carbon adsorption and chemical reaction. It is designed to stop the harmful effects of low concentrations of corrosive gases in electronic field cabinets. It provides highly purified make-up air to pressurized electronic enclosures which cannot be located in protected computer rooms. The purified air prevents the intrusion of contaminants, preventing corrosion of electronic equipment. The Cabinet Vapor Adsorber is manufactured of corrosion-resistant materials and mounts easily to the door or side of operating floor cabinets.

Environmental Monitoring

MeadWestvaco performs environmental monitoring using a minimum 90-day copper coupon test to evaluate the corrosivity of control equipment environments. A standard promulgated by the Instrument Society of America (ISA) implies that 30-day exposures may be used to characterize control equipment environments. Westvaco Laboratory performed research according to the method recommended by ISA for calculating equivalent annual corrosion,

$$x_1 = x\left(\frac{t_1}{t}\right)^A$$

where x_1 is the film thickness normalized to a 30-day exposure, x is the measured film thickness after time t days, t_1 is 30 days, and the exponent A is 0.3 for G1 environments, 0.5 for G2 environments, and 1 for GX environments. G environments represent contaminant severity levels as published by ISA.

According to W. B. A. Sharp of the Westvaco Research Laboratory, data shows that the accepted extrapolation methods using short-term coupon measurement did not predict the amount of corrosion after one year with any degree of accuracy. Sharp explains that part of the reason for the failure of the predictive equations is that they erroneously assume that the initial film thickness is zero. Additional discrepancies may arise if the composition (and corrosivity) of the atmosphere changes during the test, so that the corrosion film growth does not follow a single power law throughout the monitoring period. The effect of a change in atmospheric corrosivity will depend on the composition and thickness of the corrosion products at the time of the change. All these considerations favor the use of a single standardized monitoring period rather than the determination of annualized rates from a variety of monitoring periods. A 90-day exposure is considered long enough to give a representative measure of the corrosivity, yet short enough to be useful to plant personnel responsible for protecting control equipment.

Sharp, Falat and Krasowski conducted experiments at 86 control rooms in a single bleached kraft mill to predict failure rates based on atmospheric corrosivity. The atmospheric corrosivity in each of the 86 electrical rooms in the mill was measured during a 90-day period, using the coupon monitoring procedure described above. Corrosion-related failure histories of control equipment in these rooms were obtained from electrical maintenance staff. Table I summarizes the data, showing the minimum atmospheric corrosivity that caused different types of failure.

Table I. Failure data summary from electrical control rooms

Atmospheric corrosivity (micrometer per year)	*Type of failure*	*Time to failure (years)*
	Electrical equipment:	
>0.5	Contacts and wires	3
	Electronic equipment:	
>0.17	Intermittencies	---
>0.19	Circuit boards inoperative	3-4
>0.76	Circuit boards inoperative	2
>1.3	Circuit boards inoperative	1
>2.9	Microprocessor inoperative	1

According to Sharp, Falat and Krasowski, these results indicate that in order to eliminate premature corrosion failures in control rooms containing electrical equipment only (no electronic equipment), the atmosphere must produce less than 0.5 micrometer per year of corrosion product on the copper coupons. To eliminate premature failures of electronic equipment, the control room atmosphere must produce significantly less than 0.2 micrometer per year of corrosion product on the copper coupons. A guideline of 0.1 micrometer per year was chosen as a practical maximum corrosivity to safeguard electronic equipment.

Plum Island Project History

In January 1999, in an effort to improve the reliability of its network communications server, the Plum Island Water Pollution Control Facility began pilot testing the Cabinet Vapor Adsorber in its communications server cabinet. Pre-installation environmental monitoring was performed to determine corrosion levels inside the cabinet. Monitoring results showed a corrosion rate of 1.84 micrometer per year, exceeding the recommended guideline of 0.1 micrometer per year by a factor greater than 18 times. In June 1999, following a six month pilot test, environmental monitoring was again performed to determine the effectiveness of the Cabinet Vapor Adsorber. Results of the monitoring showed a corrosion rate of 0.04 micrometer per year; an outstanding 97.8% reduction in the corrosion rate and well below the recommended guideline of 0.1 micrometer per year. And, more importantly, no network communications server failures occurred during the pilot test period.

Although encouraged by the successful pilot test of the server cabinet, the plant was still experiencing significant corrosion related electrical/electronic failures in its Administration Building. The Administration Building is a two-story building containing administrative office space, male and female locker rooms, a testing laboratory, a conference room and the treatment plant's Operations Control Center. The building was environmentally controlled with central air conditioning and gas heating. Historically, strong hydrogen sulfide odors were prevalent in the building and it was well known that corrosion rates inside the building were significant. Weekly failures of personal computers were not uncommon and electronically recorded process control data was unreliable due to routine system failures.

Plant personnel decided to expand the environmental monitoring to representative areas throughout the Administrative Building to quantify actual corrosion rates in the building. Table II summarizes the results of the environmental monitoring.

Table II. Administration Building Pre-Monitoring

Date Analyzed: 6-29-1999 – 6-30-1999

ENVIRONMENTAL MONITORING PROGRAM
ANALYSIS OF CORROSION COUPONS

Coupon Number	Vapor Adsorber	Area Monitored	Time Days	Thickness Angstroms	Rate Micr/yr
20545	NA	XXXX OFFICE	133	13544	2.24
20543	NA	XXXX OFFICE	133	13866	2.29
20529	NA	XXXX OFFICE	133	13979	2.31
20549	NA	XXXX OFFICE	133	13785	2.28
20539	NA	XXXX CUBICLE	133	13905	2.30
20544	NA	CONFERENCE ROOM	133	13723	2.27

The environmental monitoring reported corrosion rates, on average, more than 20 times higher than recommended corrosion rates. Armed with this data, plant personnel began to evaluate methods for implementing Vapor Adsorber technology to the entire Administration Building. Initial efforts focused on installing a Vapor Adsorber system on the existing HVAC system. These efforts failed primarily due to the poor condition of the existing HVAC system and the patchwork of insufficiently sized air ducts that had resulted from multiple building additions throughout its 30-year history.

While efforts to install the Vapor Adsorber system began to stall, the condition of the existing HVAC system continued to deteriorate. In 2000, CPW contracted with an engineering consultant to provide design services for a new Administration Building HVAC system. During this same period, Plum Island completed installation of its plant-wide SCADA system and completed its conversion from direct drive motors to variable frequency drives (VFD). Plant management expressed deep concern over the long-term reliability of the SCADA system and the newly installed electronic equipment. Long known as a hostile environment for even the most robust of material, a significant toll had already been taken on the limited electronic equipment that had been previously installed at the plant. Based on a desire to protect the SCADA investment and to ensure system reliability, CPW expanded the HVAC project to provide conditioned air to all electrical rooms and motor control centers. Additionally, the decision was made to supply purified make-up air to each conditioned space utilizing MeadWestvaco Vapor Adsorbers.

Initial project development involved identifying potential locations to be conditioned spaces. Each potential location received pre-installation environmental monitoring conducted by MeadWestvaco. Table III summarize the locations and the results of the environmental monitoring.

Table III. Plant Wide Pre-Monitoring

Site	Corrosion Exposure Duration (days)	Equivalent Product Thickness (Å)	Annual Corrosion Rate (microns/year)	Protection Necessary (Y – Yes, N – No)	
				Electronic Equipment	Electrical Gear
A-Pump & Blower MCC	87	2153	(Inside Cabinet) 0.44	Y	Y
Sludge Handling-Upstairs	87	11993	2.45	Y	Y
Instrument Lab Shop	87	10678	2.18	Y	Y
B-Plant Primary Treatment	87	12506	2.56	Y	Y
Sludge Bldg. #1 MCC	87	11816	2.42	Y	Y
B-Pump & Blower MCC	87	13960	2.85	Y	Y
Sludge Handling CR	87	13522	2.76	Y	Y
Chemical Handling	87	10122	2.07	Y	Y

Design coordination efforts between MeadWestvaco and the consulting engineer focused on minimizing the required number of Vapor Adsorber systems, selecting locations for each system that would facilitate servicing, and sizing the systems to provide the recommended 2–5 air exchanges per hour. Properly sizing the systems proved to be the biggest challenge because of the existing conditions in many of the spaces. Ideally, buildings would be tightly sealed to prevent intrusion from the outside atmosphere and to facilitate sustainability of positive pressure inside the building. Most of the areas selected for conditioning were not originally designed as conditioned spaces. Many had a significant number of unsealed wall penetrations and poorly functioning windows and doors. Conservative estimates were used to perform size selection while at the same time attempts were made to minimize size in an effort to keep down costs. Table IV summarizes Vapor Adsorber selection by size and location and includes the design number of air exchanges per hour.

Table IV. Vapor Adsorber Sizes by Location

Application	Room Volume (ft^3)	Vapor Adsorber(s) cfm Capacity	Room Turnovers Capacity (turns/hour)
Mechanical Building	9,353	500	3.2
B Primary Building	9,376	500	3.1
Generator Building	9,197	500	3.3
Sludge Building	8,328	500	3.6
B Pump and Blower Building	15,400	500	1.19
A Pump and Blower Building	9,363	500	3.2
Harbor Tunnel Pump Station	7,200	500	4.2
Administration Building		4000	
Chemical Metering Pump Building	7,600	500	3.9

In January 2001, CPW entered into a Partnership Agreement with MeadWestvaco. The agreement included pre-negotiated pricing for the Vapor Adsorber systems, guaranteed pricing for replacement carbon and on-site services to be performed by a MeadWestvaco factory service representative. On-site services included quarterly service visits, corrosion rate monitoring, room pressurization monitoring, and detailed room sealing/design recommendations. As an additional service, MeadWestvaco agreed to perform Interim Bed Life Monitoring to accurately predict the carbon life for each system. Due to the variability in hydrogen sulfide concentration levels throughout the plant, it was expected that carbon life would vary from system to system.

In July 2002, in coordination with the startup of the new plant wide HVAC system, initial startup was performed on seven Vapor Adsorber systems. The immediate effects of the Vapor Adsorber systems were apparent in all locations, but most noticeable in the Administration Building where there was a total elimination of the hydrogen sulfide odors that had always been present in the building. What had once been an unpleasant work environment where employees often complained of headaches was now a fresh, clean atmosphere where employees felt comfortable to work.

While the new plant-wide HVAC system underwent initial startup pains, the Vapor Absorber systems performed without significant problems. In September 2002, a MeadWestvaco factory technician performed initial follow-up service, including environmental monitoring. Table V summarizes the results of the follow-up environmental monitoring and includes pre-installation environmental monitoring for comparison. Two areas that received Vapor Adsorber systems are not included in Table V because pre-monitoring data did not exist, not allowing for a comparison.

Table V. Follow-Up Monitoring Comparison

Application	Pre-Monitoring (microns/year)	Follow-Up Monitoring (microns/year)	Δ (microns/year)	Reduction (%)
Mechanical Building	1.26	0.02	-1.24	98.4
B Primary Building	2.56	1.49	-1.07	41.8
Sludge Building	2.76	1.71	-1.05	38.0
B Pump and Blower Building	2.85	1.42	-1.43	50.2
Administration Building	2.31	0.03	-2.28	98.7

Follow-up monitoring confirmed that dramatic improvements had occurred in the Administration Building with an unbelievable 98.7% reduction in the corrosion rate. An equally impressive 98.4% reduction was recorded in the HVAC system's Mechanical Building. While each area monitored reported improvements, not all were as significant as the Administration Building and the Mechanical Building. Nor were the results within the 0.1 micrometer per year recommended by MeadWestvaco.

The failure of some areas to achieve a greater reduction in the corrosion rate was not surprising. As previously discussed, these areas were plagued with numerous unsealed wall penetrations and poorly functioning windows and doors. Improvement plans have been implemented to seal wall penetrations and to replace the windows and doors in these locations. Window and door replacement has proved challenging in some areas because differential settling of buildings constructed on fill material have resulted in warped window frames and doorways.

Conclusion

The Plum Island Water Pollution Control Facility's Administration Building, outlying motor control centers and electrical rooms were highly corrosive environments with corrosion rates more than 20 times greater than recommended corrosion rates for the protection of electrical/electronic systems. The installation of MeadWestvaco Vapor Adsorber systems delivered dramatic corrosion rate improvement to the Administration Building and reduced corrosion rates in all plant-wide motor control centers and electrical rooms. However, the results of follow-up monitoring have shown that it can be difficult to achieve desirable corrosion rates in older buildings not originally designed as conditioned spaces. Plant personnel expect that with an aggressive room-sealing plan, a significant reduction in corrosions rates can be achieved in the poorer performing locations. Today, most process control functions at Plum Island are fully automated, along with data and record keeping, through the plant's SCADA system. SCADA system reliability is near 100% with no reported corrosion related electrical/electronic system failures. MeadWestvaco has proven to be a solid performer, partnering with CPW from initial design concept through project development, implementation and startup. MeadWestvaco continues to provide quarterly follow-up service and is responsive to all issues concerning the Vapor Adsorber systems. To protect its investment in automation and to ensure system integrity, CPW will continue to standardize on Vapor Adsorber supplied make-up air for all conditioned spaces at its Plum Island Water Pollution Control Facility.

References

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