RELIABILITY OF ELECTRONIC EQUIPMENT EXPOSED TO CHLORINE DIOXIDE USED FOR BIOLOGICAL DECONTAMINATION

G. E. Derkits [1], M. L. Mandich [1], W. D. Reents[1], J. P. Franey[1], C. Xu[1], D. Fleming[1], R.Kopf [2], and S. Ryan[3],
[1] Alcatel-Lucent Carrier Product Group, [2] Alcatel-Lucent Bell Laboratories, [3] U.S. Environmental Protection Agency National Homeland Security Research Center.
Address of Primary Contact: G. Derkits, Alcatel-Lucent, Room 1E-241, 600 Mountain Ave., Murray Hill, NJ, 07974, phone: 1-908-582-7050; fax: 1-908-582-7112; e-mail: Gus.Derkits@alcatel-lucent.com
Address of Second Contact: M. Mandich, , Alcatel-Lucent, Room 1E-347, phone: 1-908-582-3396; fax: 1-908-582-6228; e-mail: Mary.Mandich@alcatel-lucent.com

SUMMARY

We have studied the effects of chlorine dioxide fumigation on the reliability of electronic equipment using personal computers as examples of current commercial systems. Unit and subunit failure were objectively defined by standard commercial software. After the initial one-day exposures to the fumigation conditions, the systems were tested to assess impacts and retested monthly for six months. Cumulative failures of decontaminated systems were many times higher than unexposed systems and increased progressively for the harshest fumigation conditions. Failures occurred in electronic, mechanical, optoelectronic, and thermal subsystems. Failure mode and root-cause analyses were performed on a blind sample of systems. Corrosion of metals and degradation of organic materials were predominant causes of failure. Metal corrosion continued to progress well after the initial exposure. [*Keywords:* Decontamination, reliability, personal computer, chlorine dioxide, diagnostic software.]

INTRODUCTION

Chlorine dioxide gas was used to successfully decontaminate several major buildings in the U.S. following the anthrax letter attacks in 2001. The Department of Homeland Security and the Environmental Protection Agency are interested in generating specific data on the impact of chlorine dioxide (ClO_2) decontamination on electronic equipment, to better understand the usefulness and limitations of the decontamination technology. The current study was designed to provide information on electronic systems through the use of commercial personal computers as test vehicles. Personal computers have a variety of advantages in this application. Due to intense competition among suppliers, they are relatively low in cost and the technology they use is very current. They contain subsystems with a variety of technologies – electronic, electromechanical, optical, magneto-optical. They are highly standardized, with the result that commercial diagnostic software capable of giving precise diagnostic information of failure is available at low cost. They are small enough that several identical systems can be exposed to identical conditions simultaneously in a single chamber. Finally, they are easily disassembled for analysis. Pure metal coupons were placed inside the computers as precision corrosion monitors. The progression of failure was followed using diagnostic software over six months after the initial exposure.

METHOD

Test Vehicles and Standard Materials

The system test vehicles in this study were Dell OptiPlex® 745 mini-tower personal computers with Intel Core 2 Duo® E6400 Processors at 2.13 GHz with a single DIMM RAM card, running Windows XP. A 16X DVD-RW optical drive and a 3.5” floppy drive were included in the system configuration. Diagnosis of hardware faults was obtained using PC Doctor® Service Center 6, a commercial kit used by a number of large PC manufacturers for their final test and embedded diagnostics. This product has over 300 diagnostic tests, most of which can be run without operator intervention. Metal coupons of 99.999% copper, 99.99% aluminum, and 99.998% silver purchased to specification from Alfa Aesar were used as corrosion monitors. These coupons were weighed using a Mettler UMT2 microbalance accurate to 0.25ug. ClO_2 gas was generated by a ClorDysis® Solutions, Inc. gas generation system.

Exposure Conditions

All exposures were performed at the EPA National Homeland Security Center (NHSRC) in Research Triangle Park, NC. Three computers were exposed to the same conditions in each test cell (see Table 1). Immediately following the exposures, the systems were tested at NHSRC with PC Doctor®. Of the three computers in each cell, two were deployed for diagnostic testing. The remaining systems from each cell were submitted for in-depth, destructive, analysis. Computers to be destructively analyzed were then packed into shipping bags made of Static Intercept® material which preserved the state of the system during shipping and prevented toxic gases from entering the environment. Metal coupons from all systems were similarly packed and sent for analysis. The range of test conditions was designed to exercise the standard decontamination conditions, minimal exposure, and exposure to high humidity alone. Principle test variables included the power state of the computer, the concentration of ClO_2, the relative humidity, and the time duration of the fumigation. The matrix of test cell conditions is given in Table 1.

TABLE 1. MATRIX OF DECONTAMINATION TEST CONDITIONS

Cell	Pwr	Treatment	ClO_2 [ppmv]	RH [%]	Temp [°F]	Time [hrs]
1	On	High RH	3000	90	75	3
2	Off	Standard	3000	75	75	3
3	On	Standard	3000	75	75	3
4	On	Low ClO_2	75	75	75	12
5	On	Low ClO_2 & RH	75	40	75	12
6	On	No ClO_2 High RH	0	90	75	3
7	On	Ambient (Control)	0	40	75	--

Analysis

Analysis of a blind sample of test vehicles, one from each test cell, was performed at the Alcatel-Lucent Reliability Physics facility at Murray Hill, NJ. After the computers were received, they were unpackaged, placed in chemical hoods, and photographed with a high-resolution camera at a set of pre-determined sites to establish an immediate visual record. Additional photographs were taken at the discretion of the analysts. Photographs of some sites were taken multiple times in the course of the investigation to establish a visual record of progressive corrosion. An example of this is shown in Figure 1, in which progressive cut-edge corrosion of the steel frame is demonstrated.

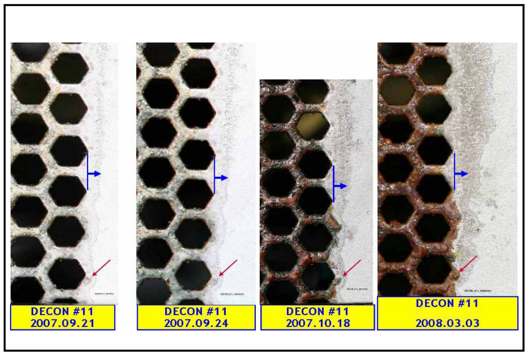

FIGURE 1. PROGRESSIVE CUT-EDGE CORROSION OF STEEL CASE OF PC.

PC Doctor was run on each system and the results recorded. Resistance readings were taken across predetermined test points on the motherboard and the systems were then subjected to destructive physical analysis.

RESULTS

Failure Progression

The relation between the harshness of decontamination conditions and system failure is illustrated in Figure 2. The red line with diamond symbols is the plot of the harshest conditions. The black line at the bottom is the control computer, which saw only ambient conditions. Note that the harshest conditions (3000 ppm, 90%RH) are outside of normal, target, ClO_2 use conditions, chosen to bracket decontamination application conditions.

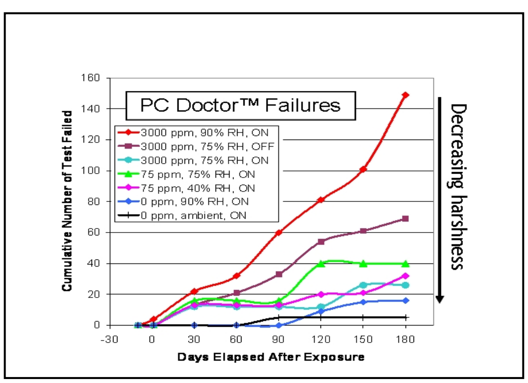

FIGURE 2. PROGRESSIVE FAILURES OF PCS THROUGH TIME AS GAUGED BY PC DOCTOR SOFTWARE, FOR VARIOUS DECONTAMINATION EXPOSURES.

Corrosion of Pure Metal Coupons

Figure 3 provides the weight gain of the pure metal coupons in the form of a bar chart overlaid with a line showing the average of all three metals. A figure of merit (FOM) representing the harshness of the decontamination process as the product of the concentration of ClO_2 times the duration of the exposure times the relative humidity (RH) is shown on the right-hand scale.

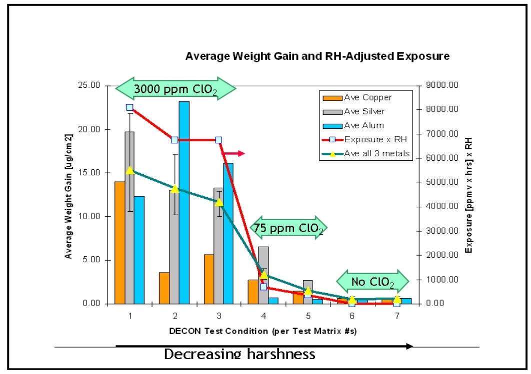

FIGURE 3. COMPARISON OF COUPON WEIGHT GAIN WITH HARSHNESS OF DECONTAMINATION PROCESS.

$$FOM = [ClO_2] \times time \times RH \qquad (1)$$

CONCLUSIONS

ClO_2 fumigation causes permanent and unrecoverable damage to a variety of material and subsystems in the test computers that progresses in time following the exposure. The extent of damage and its impact was a strong function of fumigation conditions. Material degradation included corrosion to metals including aluminum, steel, silver, nickel, and plated copper, and bleaching and discoloration of cable coatings. Subsystem damage included corrosion of gold plated connectors and catastrophic destruction of optical components in the CD/DVD drives.

Failures were detected by PC Doctor® in all computers, including the control (ambient), but the number of failures was significantly higher for the fumigated computers and they showed an increasing failure rate with time.

Novel aspects of this study include the use of personal computers as standard test vehicles, objective definition of failure by the use of independent standard commercial software, long-term (6 months) follow-through after initial fumigation, root-cause analysis of multiple subsystems down to the material level, application of pure metal coupons as standards in decontamination studies, and application of a standardized, repeatable set of target areas for high resolution photography in lieu of visual inspection.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Environmental Protection Agency and the U.S. Department of Homeland Security under contract number USMMM235W9 to LGS Innovations, LLC. We wish to thank Lance Brooks of USDHS for his help and support.