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CORROSION OF ELECTRONIC CONTROL SYSTEMS IN GAS TREATING ENVIRONMENTS

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ABSTRACT

The application of microelectronic computer control systems in field locations has developed rapidly over the last 15 years. These distributed control systems (DCS) are far more prone to corrosion damage than earlier control systems. Of particular concern are locations where sulfur species may be present such as hydrogen sulfide, sulfur dioxide, or elemental sulfur. Failures of critical components may occur in as little as three months in locations where humidity, temperature, and corrosive gasses are not adequately controlled. Temporary relief may be obtained by the use of vapor phase corrosion inhibitor (VCI) powders and sprays.* A more permanent solution is the installation and maintenance of an adequate air handling system that removes pollutants and controls humidity and temperature. This paper reports a number of different failures that occurred in one plant including general corrosion of circuit boards and a history module and corrosion fatigue of copper conductor wires on an electronics circuit board. Field data on different solutions to the problem are presented.

* Cortec VpCI-238, VpCI-111 Emitters

INTRODUCTION

Conventional analogue control systems used in the oil and gas processing industry have been somewhat insensitive to corrosion. Relatively heavy wall thicknesses of component parts compared to modern day microelectronic circuits meant that some minor corrosion could be tolerated with no significant detriment. Therefore, many years of satisfactory service could be obtained in older control rooms that had some air treatment but were not pressurized control rooms with sophisticated air handling systems. The thickness of electrical connectors on microelectronic distributed control system (DCS) circuit boards is much less, meaning that even the smallest amount of corrosion can cause board failure.

Although the importance of industrial corrosive atmospheres has been well recognized in some industries such as pulp and paper for some time,[1] only recently has its significance become more prevalent in the oil and gas industry. In the past, central control rooms may have been the only places equipped with temperature and environmental control systems; now a broader range of buildings such as remote process interface buildings must also be included. Field mounted control systems must be hermetically sealed to prevent ingress of corrosive atmospheres. In uncomplicated processing plants, even the central control room may not have adequate control systems. Conversion of older plants from conventional control systems to modern DCS systems can be a challenge. The scope of the project must include adequate funding to upgrade air handling systems.

Air quality is defined in the Instrument Society of America Standard ISA-S71.04-1985. A non-corrosive environment is described as G1 and is expected to contain less than

Gas	Concentration, ppb
H_2S	<3
SO_2 / SO_3	<10
Cl_2	<1
NO_x	<50

Table 1: ISA G1 requirements for specific gases

The provision of a G1 environment will result in corrosion having no significant effect on the life of circuit boards. In all the lesser categories, G2, G3, and GX, corrosion has an increasingly devastating effect.

Surveys of atmospheric corrosivity over a number of gas plants and refineries have found the most corrosive areas to be associated with sulfur handling areas and areas with H_2S and SO_2 emissions. In Kuwait, a broader study of atmospheric corrosion over most of the country found the highest atmospheric corrosion rates of copper to be associated with oil and gas producing areas, as shown in Figure 1.[2]

FAILURES OF HISTORY MODULE AND MONITORS

A series of repetitive failures occurred in various parts of the control system at a sulfur handling plant. Sulfur handling is the last part of the gas treating process. Hydrogen sulfide is removed from the sales gas in an amine unit and the resultant waste gases are fed to a Claus sulfur unit, followed by the sulfur pelletizer. Failures were reported in the sulfur peletizer plant's main control room components such as visual display monitors, printers, radios, and similar electronic equipment. Failures were also reported in the adjacent room that housed electronic racks, known as the LCN cabinet room, and marshalling area. In the cabinet room, the History Module was of great concern because failure times were as short as three months. The Communications Module also failed in approximately two years. Two separate lines of investigation were followed: an evaluation of the failed components and an evaluation of the atmosphere in the locations where the failure occurred.

Failure Analysis

The History Modules external electronic circuit board was badly affected by atmospheric corrosion caused by ingress of sulfur species from the plant. Electrical failure was attributed to corrosion by sulfur species.

Visual and stereomicroscope examination showed that many circuit board pads and connectors were badly tarnished (Figures 2, 3). Though heavy copper sulfide (Cu_2S) corrosion products were present on many conductor tracks and pads, the circuit board's gold-plated external connector pins were not corroded (Figure 3). The hard drive's vacuum seal was still intact. Further laboratory investigation of the problem included microscopy and energy dispersive microanalysis (EDS) of extracted corrosion products, which were removed using a replication technique.

Optical microscopy of the electronic module revealed radial growth of iridescent brown-black deposits on open connector pads (Figure 4). The deposits formed from corrosion of copper in a sulfur-bearing environment. These deposits appeared to be growing out from beneath the connector holes and coalescing with time, perhaps leading to a short circuit of related electronic components. The corrosion products were extracted onto acetate replica tape. EDS microanalysis (Figure 5) revealed primarily copper (Cu) and sulfur (S) in the corrosion products, corresponding to copper sulfide (Cu_2S).

Although the exact corrosive species were not identified in this part of the investigation, it is noted, for example, that wet elemental sulfur can be very corrosive to steels[2]. One proposed mechanism for steel corrosion is that elemental sulfur and distilled water can react to produce H_2S and sulfuric acid, to give a pH as low as 1.8. Although there was no direct evidence of sulfate corrosion products on the circuit board, even humidity and moisture can produce undesirable effects in electronics, such as causing electrical shorts and changes in electrical resistance[3].

Atmospheric Classification

Coupon tests were performed using copper, silver, and gold-plated coupon sets that provide copper corrosion product film growth data in accordance with Instrument Society of America classification ISA S71.04-1985.

This classification rates the corrosivity of the environment in four categories: mild, moderate, harsh, or severe. Mild or "G1" environments are usually specified for control rooms and DCS systems. In such an environment, no corrosion failures are expected. Moderate or "G2" environments predict that premature failure *may* occur in under five years. Harsh or "G3" environments expect that corrosion failures *will* occur in five years or less. Severe or "GX" environments are likely to cause rapid failure of electronic systems.

The coupon set also provides corrosion product film growth data for silver coupons. Silver coupons are more sensitive to low levels of contaminants and are particularly affected by sulfur compounds. The silver coupons are not formally addressed by the ISA standard.

The coupon set also provides a visual evaluation of gold plating damage.

In the current set of experiments, coupon sets were placed on top of a monitor in the control room and on top of the cabinets in the cabinet room, and on top of cabinets in a newly constructed sub-station. Coupons were exposed for 92 days.

The control room and cabinet room was found to be extremely corrosive. The copper corrosion product film thickness was rated moderately corrosive, G2. The silver corrosion rate was equivalent to severe, GX. The cabinet room adjacent to the control room was rated as harsh, G3, with respect to copper corrosion and silver corrosion. Figure 6 shows the cabinet room coupons.

Examination of mechanical air-handling equipment at the site found that there was no effective pressurization of the area. There was no chemical absorption of corrosive gases. There was only the most rudimentary control particulate matter and humidity.

Trials with VpCI Sprays

An experiment was performed with a temporary preservative to investigate the possibility of the obtaining some interim protection and provide an opportunity for the air handling system to be upgraded. The temporary preservative used was a thin film corrosion inhibitor with a vapor phase component that can be sprayed onto electronic components. An additional coupon set was sprayed with a temporary preservative, and placed on top of the monitor in the control room.

The silver corrosion product film thickness was reduced by a factor of fifteen from 3245Å (Angstroms = 10^{-8}m) to 217Å. The copper corrosion product film thickness was reduced from 610Å to 191Å, a factor of three. Figure 7 presents the coupon set.

	Copper Film Thickness Angstroms (10^{-8}m)	Silver Film Thickness Angstroms (10^{-8}m)	Copper Classification	Silver Classification
Without Inhibitor	610	3,245	G2	GX
With Inhibitor	191	217	G1	G1

Table 2: Effect of VpCI Spray

Benefits of a Well Designed Air Handling System

The atmospheric corrosion rates experienced in a newly constructed, adjacent substation were completely different from those experienced in the rest of the plant. The atmosphere was rated non-corrosive. Both copper and silver corrosion rates were classed as mild, G1, indicating that corrosion should not be an issue for this building, providing that the air conditioning system is adequately monitored and maintained. Figure 8 shows the coupons.

The measurements made in the newly constructed substation building clearly demonstrate the benefits of an air handling system designed to control contaminants and reduce humidity. The air-handling system with a coarse particulate filter, a fine bag filter system, chemical absorbents, and air conditioning to reduce humidity resulted in a G1 atmosphere. Nevertheless, it is also important to point out that the exact design of the air treatment system will affect the results. Light duty systems have thinner absorbent beds meaning that media changes must be performed much more frequently and periods of "breakthrough" are thereby increased. Heavier duty systems provide much more stable conditions and are more effective at removal of contaminants.

For effective corrosion control, the humidity must be reduced to less than 50 percent relative humidity. Pollutants such as sulfur compounds must be greatly reduced.

Maintenance and Continuous Monitoring Required

Over time, this absorbent will be consumed and need to be replaced with new absorbent to be effective again. The manufacturer's guidelines on the absorbent packs for this particular system design in this plant are that the media should be replaced every 6 to 24 months. This is a very general recommendation. It is therefore essential that on-line corrosion monitoring equipment be used to accurately determine when the media must be replaced. While grab-sample analysis of media beds may be used, such measurements can generate misleading data as consumption of the bed occurs progressively from the entry side of the bed, rather than uniformly throughout the bed. Therefore, results can vary greatly depending upon where exactly the sampling grab is taken. Corrosion monitoring equipment for electronic systems is available from a selection of vendors. Coupons can also be used for monitoring, but these require placement, retrieval and processing, which impedes the feedback of information. Some media vendors market tools to provide feedback on consumption of media using specially designed tools that can be withdrawn and reinserted in the bed.

CORROSION FATIGUE FAILURE[4]

Corrosion failures of electronic equipment also occurred in sealed field units at the same plant. The corrosive atmosphere migrated inside the sealed housing, and multiple repetitive failures resulted. The corrosive species involved in these failures were also sulfur compounds. The result was corrosion fatigue of copper conductor wires on an electronics circuit board. Time to failure was approximately one year. Following detailed evaluation, the failure mode of the transformer's copper conductor leads was confirmed to be corrosion fatigue. Vibration plus sulfur corrosion had promoted the transgranular fatigue cracking and some fine, secondary corrosion fatigue cracks were also found.

Failure Analysis

Several failed boards, showing transformer lead breaks, were examined (Figure 9). The fractures of these leads were studied on-site with a hand lens, which revealed that the leads showed a low ductility failure mode. Some leads and lead fractures were discolored, in some cases virtually blackened, and this was suspected to be a superficial corrosion product. Although the service life of these boards was not known precisely, an upper estimate was derived from the circuit board manufacturing date codes, found on the reverse side of the boards. More than ten failures have occurred, and failure after as little as about a year in service is strongly suspected.

The transformer lead wires had broken at a position close to the transformer coil (Figure 10). The blue arrows on the plan view of the four boards indicate the locations of the five broken transformer leads. Figure 10 shows a side view of one of the two broken leads on board 2; its location is marked on Figure 9. Several lead fractures were examined in the scanning electron microscope (SEM). The fracture surfaces of the all leads showed low ductility, flat fractures which were tarnished or blackened (Figure 11). After ultrasonic cleaning, two lead fractures (from boards 2 and 4) were examined at increasing magnifications. At 2000x magnification, a very flat fracture surface was apparent, with a hint of fatigue striations.

The lead failures were flat and non-ductile and showed characteristics of fatigue fracture at both a low and high magnification examination. Following fracture examination, longitudinal microsections were taken along the failed wires to include the fracture surfaces. Evidence of fine secondary microcracks was also found (Figure 12); these tiny cracks contained a dark-colored corrosion product. The microsection showed that the leads are made from tinned copper wire; the copper was fine grained and annealed. Finally, two blackened lead fracture surfaces were examined using a 15 kV electron gun potential in the SEM, to get an improved surface microanalysis. This clearly revealed that the corrosion product film comprised copper and sulfur, presumably as copper sulfide.

Following laboratory evaluation and a site visit, the failure mode of the transformer's copper conductor leads was indicated to be corrosion fatigue. Vibration plus corrosion by sulfur compounds had promoted the fatigue cracking and some fine, secondary corrosion fatigue cracks were also found.

Although the switch circuit board housing is sealed with an O-ring, sulfur ingress had caused corrosion on some component leads. By design, the pelletizer plant experiences significant vibration during unit operation, via the reciprocating motion of the shaker screen beneath the pelletizer hopper tank.

The lead failures occurred by vibration-induced fatigue damage, which was accelerated by sulfur corrosion. The exact corrosion mechanism and species is uncertain, although sulfide corrosion in electronics is often caused by ingress of gaseous hydrogen sulfide and failures have occurred below the odor threshold[5]. Although the circuit board housing was intentionally sealed with an O-ring, sulfur ingress presumably occurred from the process, possibly via the conduit thread. Two particular risk environments promoting sulfide corrosion have been reported to exist[5]: (1) from an external industrial source; (2) hydrogen sulfide generated by out-gassing or decomposition of organic materials containing sulfur, which can include seals or gaskets, depending upon the elastomers used. This article[5] also noted that: "Copper and silver are widely used in electronics because of their excellent electrical and thermal properties. Unfortunately both have very low activation energies towards the formation of sulfides with hydrogen sulfide. The sulfide corrosion product is porous so hydrogen sulfide continues to reach the metal surface. As long as the gas is present there is no mechanism to stop the corrosion process. In contrast tin, another metal commonly used in electronic assembly, forms an impervious sulfide layer, which prevents further reaction." Since the subject transformer copper wires were tinned, this may therefore have offered some initial protection. Once cracks started growing by fatigue, the thin tin layer would have been breached, leading to bare copper exposure to the corrosive sulfur environment.

The following recommendations are possible options to alleviate the problem of corrosion and fatigue:

1. Mount the electronics remotely.
2. Consider a more rugged construction, where the manufacturer encapsulates the circuit board in a resin, to minimize mechanical and other forms of damage, such as corrosion. A field alternative is to use a polymer spray on the boards to minimize corrosion, such as the vapor phase corrosion inhibitor spray tested in the control rooms discussed in the previous section.
3. Minimize or dampen the vibrations. Although vibration is inherent in this process, stiffening the hopper tank with ribs, etc., may effectively reduce the mechanical vibrations and modify any resonance.
4. Improve sealing of the housing to eliminate ingress of the corrosive atmosphere.

CONCLUSIONS

The expanding use of electronic control systems in potential corrosive plant environments requires detailed design of adequate corrosion control measures to avoid the liability of high downtime costs due to the failure of relatively small system components.

Two different series of failures have been discussed. The first involves the failures of component electronic boards in various control room systems due to inadequate control of the room environment. In this case, corrosion control can be achieved by temporary techniques such as the application of vapor phase corrosion inhibitors, applied as a spray coating specially formulated for electronic boards or more permanently, by the installation and maintenance of an adequate air handling system that includes fine particulate removal, chemical absorbance, and humidity control. The second series of failures involves the corrosion fatigue failure of board components for a remote field mounted control system. In this case failure can be prevented by reducing vibration, and eliminating the corrosive environment through the use of temporary VCI sprays, or the use of encapsulated circuit boards, or the use of more effective case seals.

Detailed analyses of several upstream and downstream oil and gas plants have found the most corrosive atmospheres are found in the waste gas treatment area, and in particular in the sulfur handling area.

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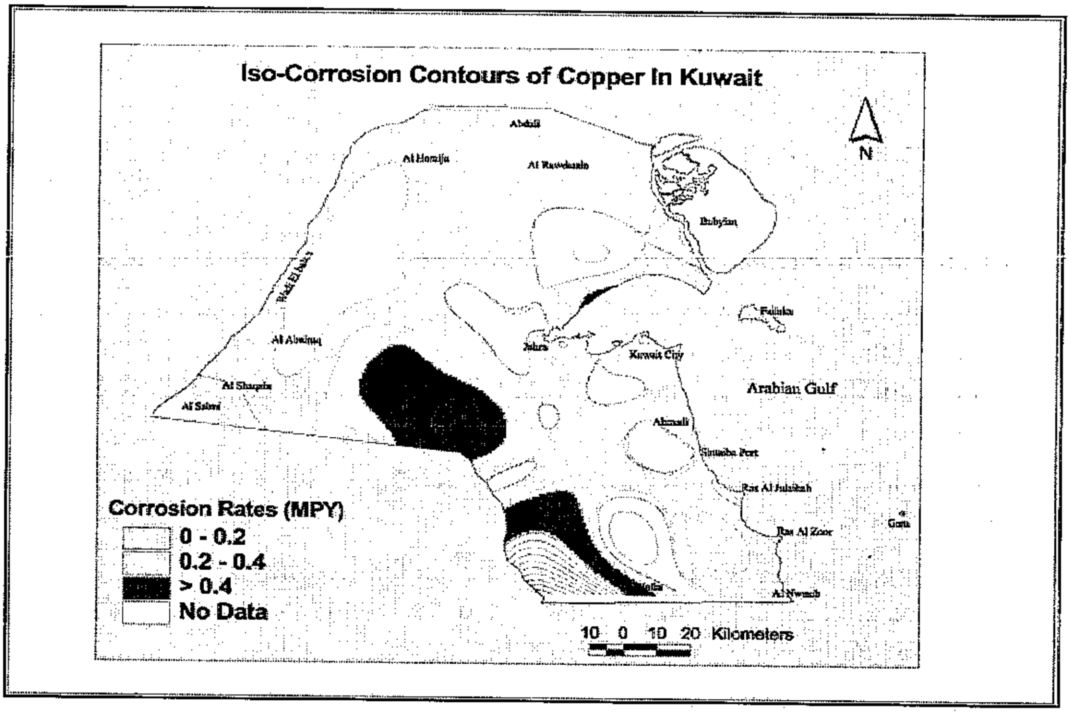


Figure 1: Atmospheric corrosion data for copper in Kuwait[2]

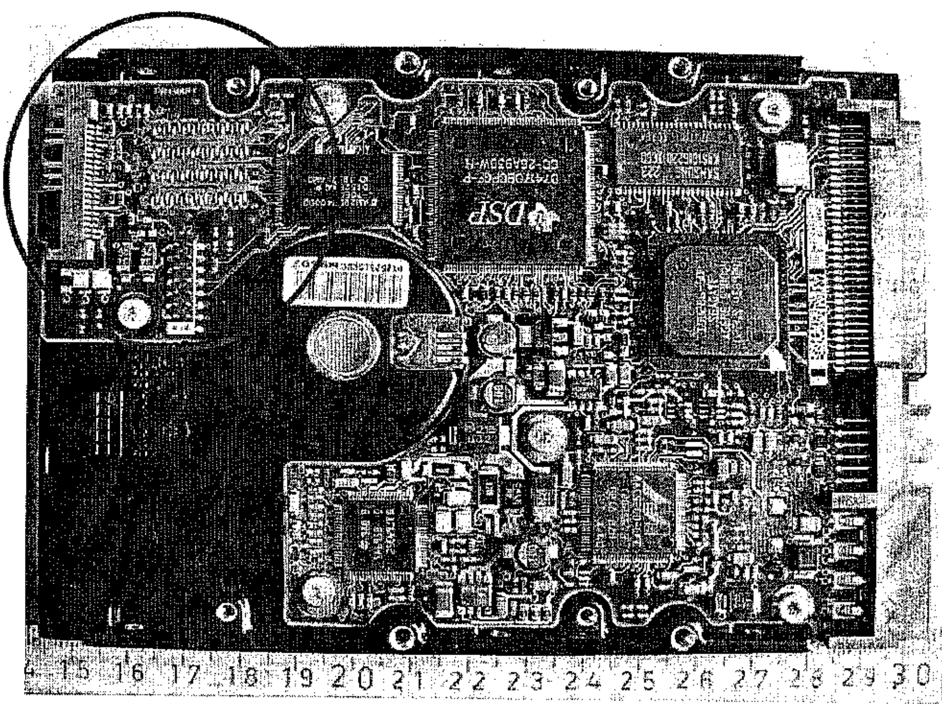


Figure 2: View of the module circuit board, after removal of external covers.

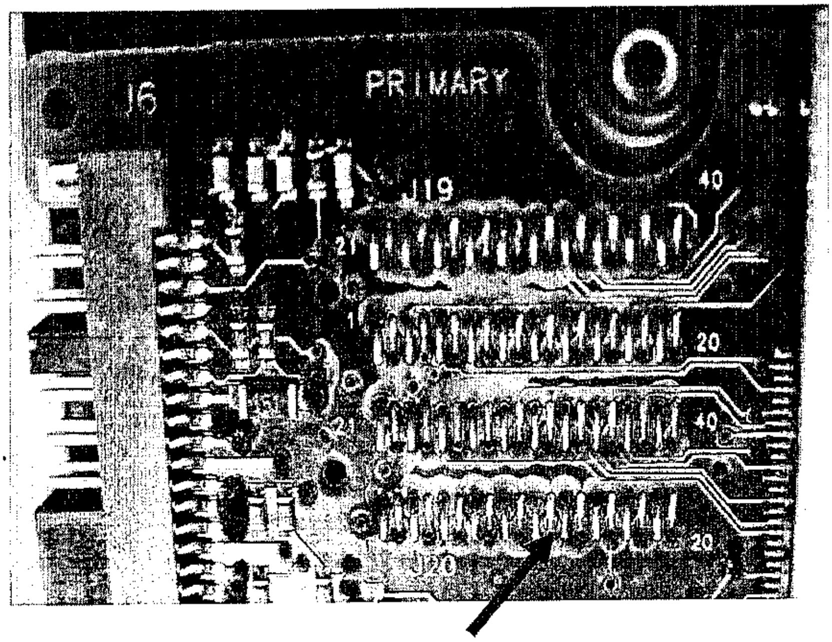


Figure 3: Detail view of circled area in Figure 1.
Note corroded pads (arrow) and uncorroded external contact pins (left)

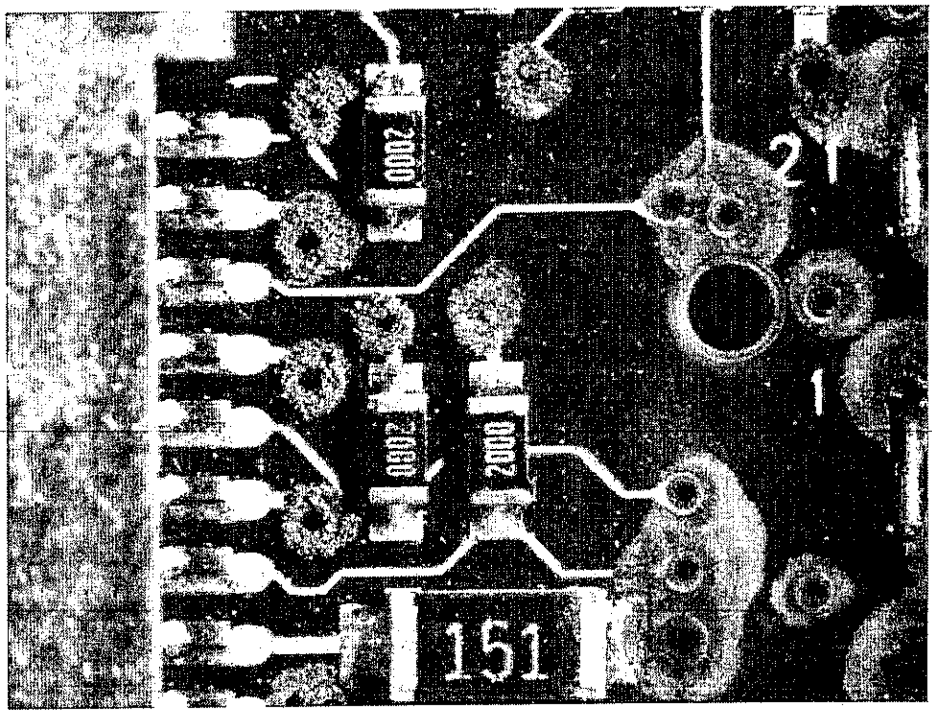
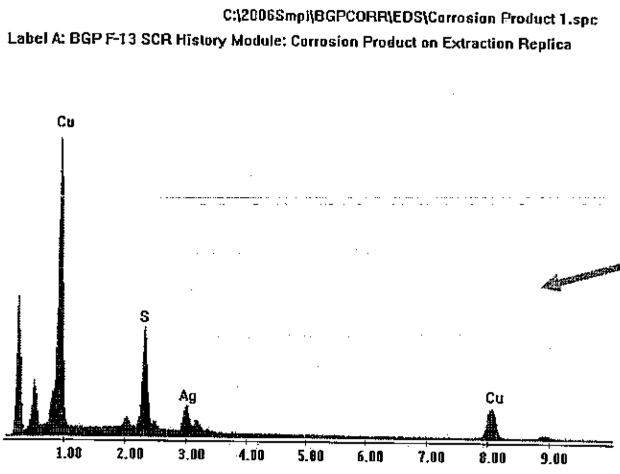


Figure 4: Optical image of corrosion product



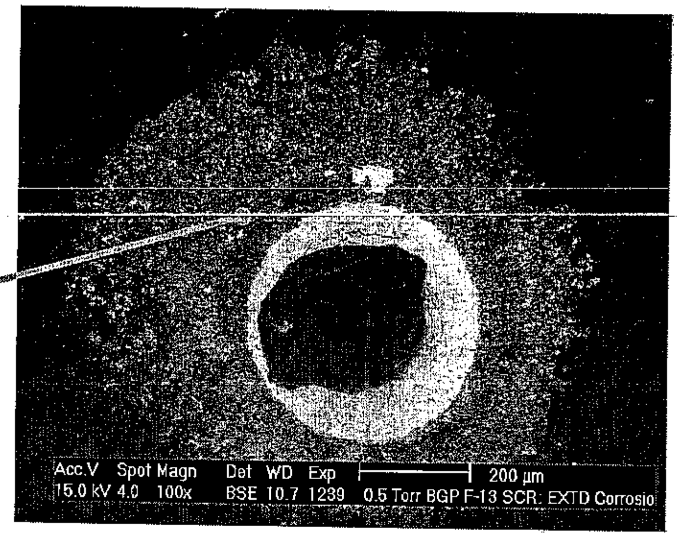


Figure 5: EDS X-ray microanalysis spectrum of corrosion product and corresponding BSE image in the scanning electron microscope

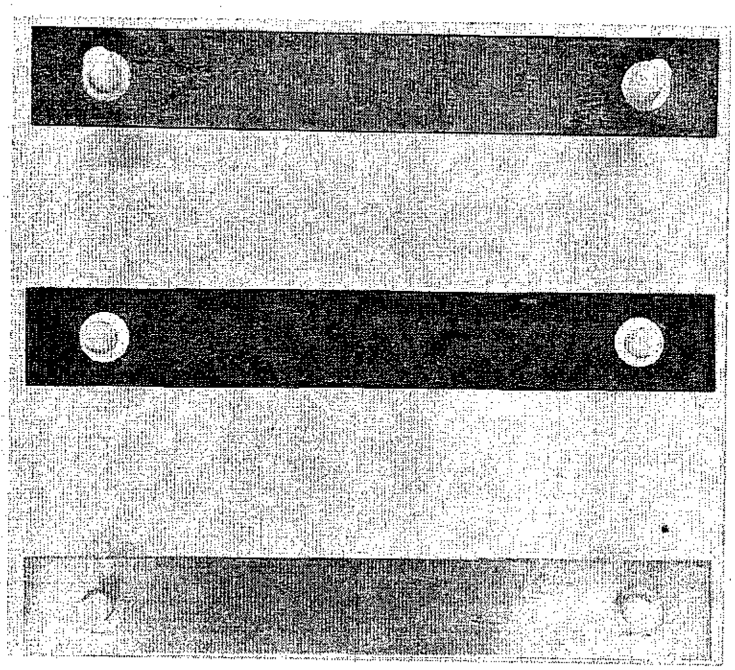


Figure 6: Cabinet room results

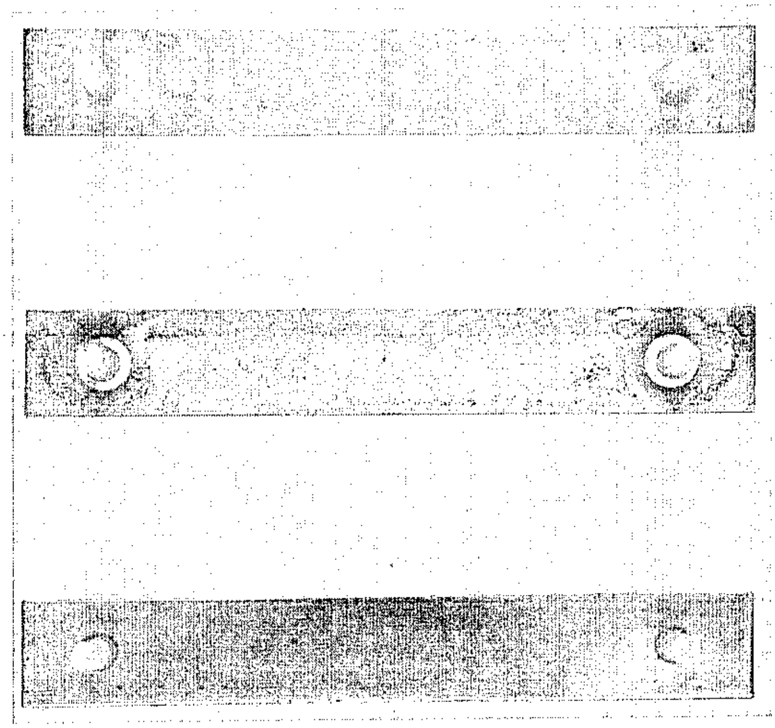


Figure 7: Control room exposure with inhibitor

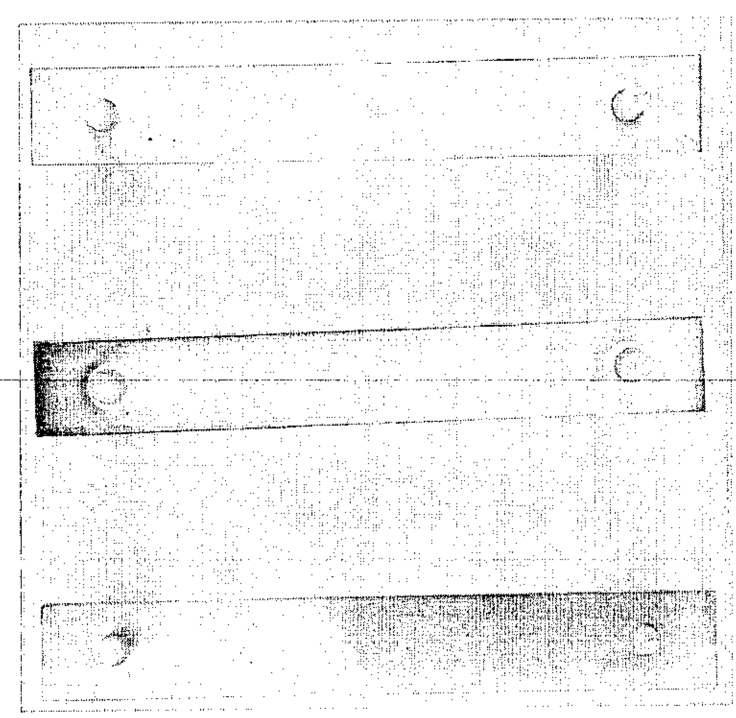


Figure 8: Newly constructed substation results

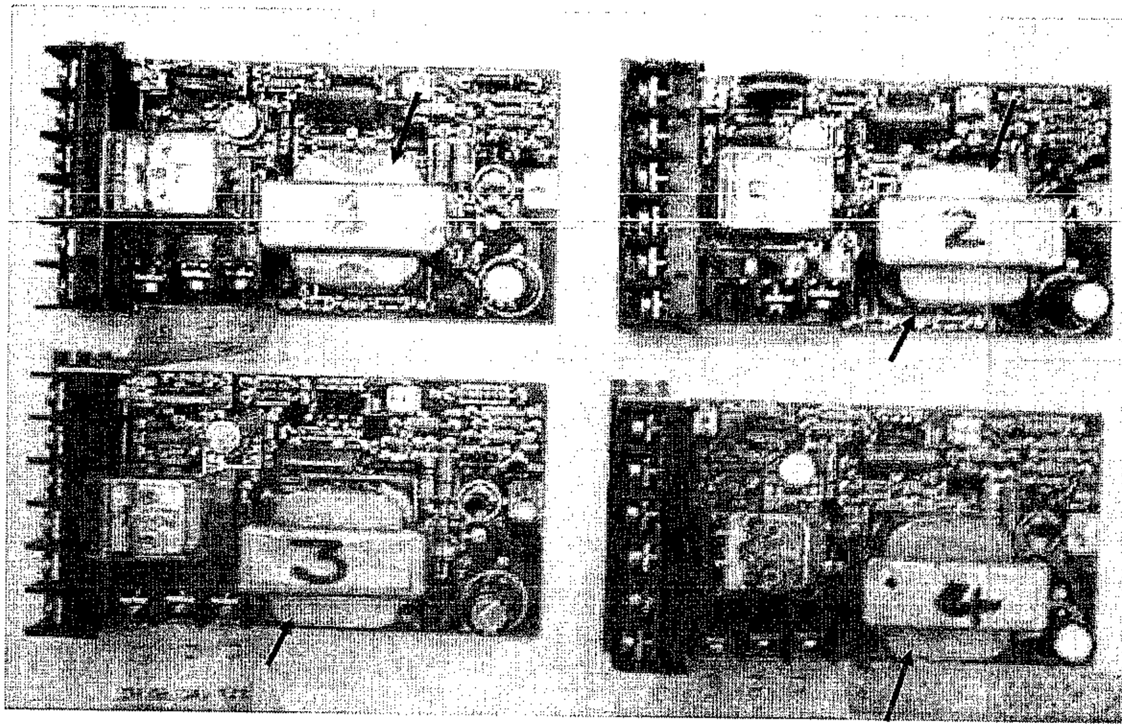


Figure 9: Plan view of four circuit boards, as received; arrows show locations of transformer lead failures.

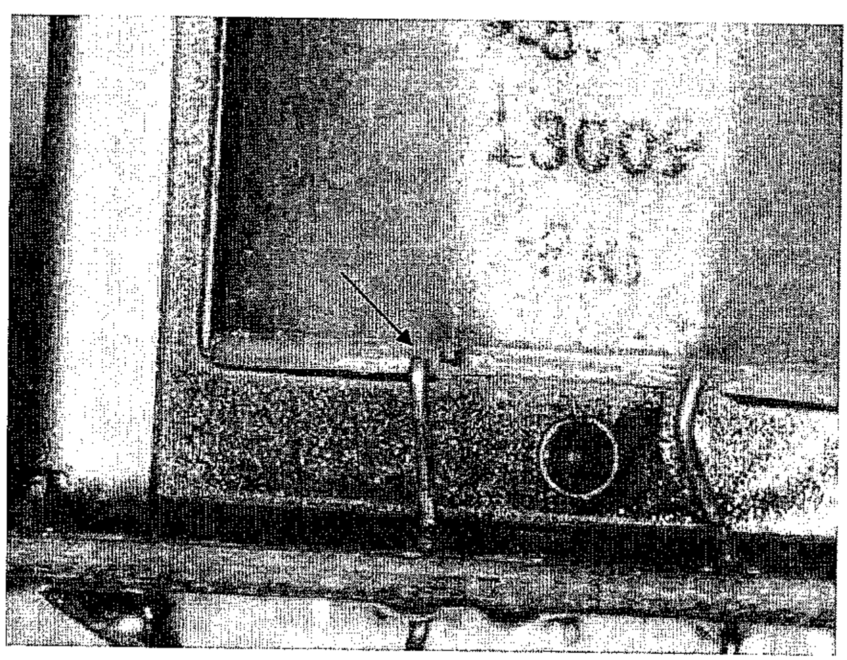


Figure 11: Side view of a broken transformer lead on Board # 2 (arrow), magnification approximately 2X

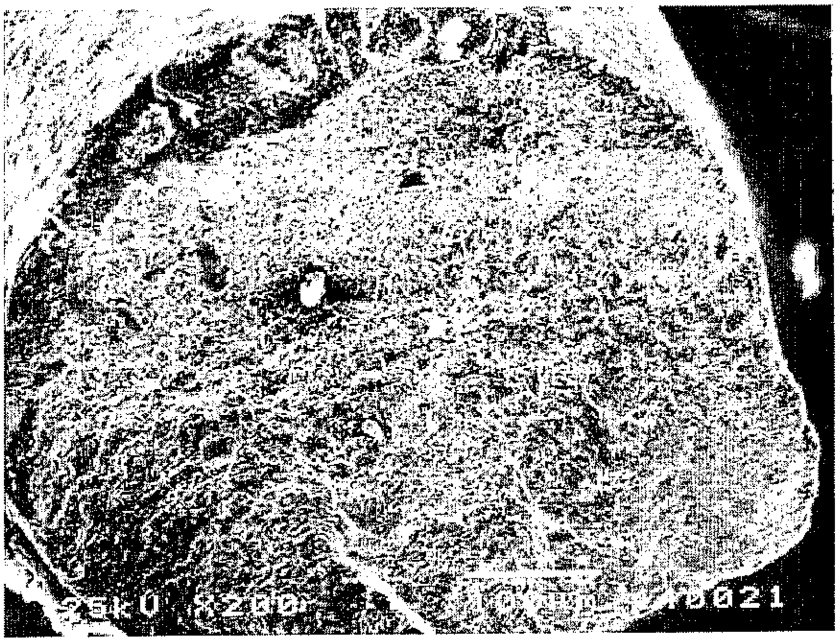


Figure 11: Fracture surface of broken lead, Board # 2
SEM micrograph, 200X

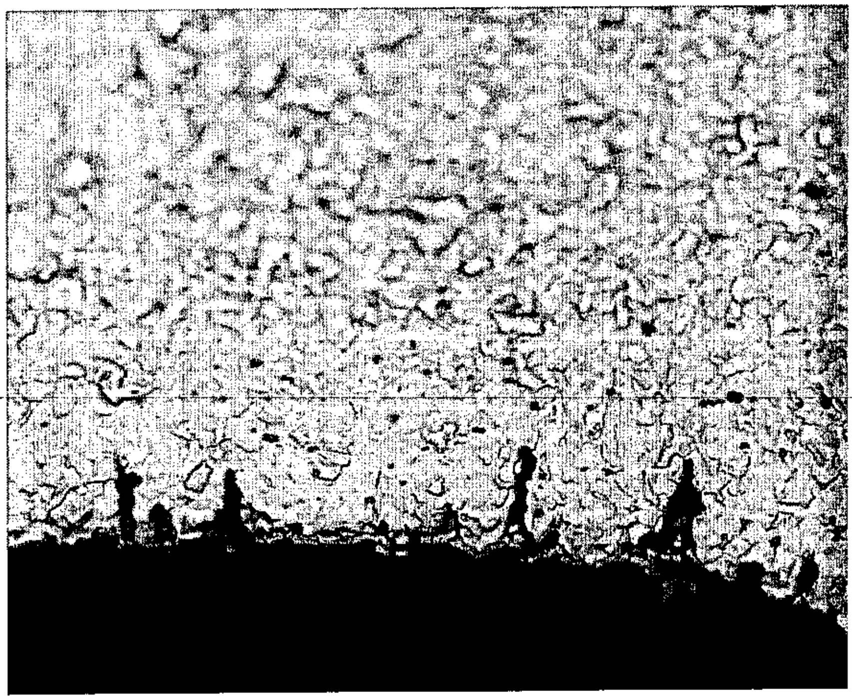


Figure 12: Microsection showing fine secondary cracks on broken transformer lead from Board # 2, etched 750X