DESTRUCTIVE CORROSION IN CATV DISTRIBUTION SYSTEM EQUIPMENT

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ABSTRACT

The term destructive corrosion is used here in the sense of corrosion which proceeds to the point of causing an item of equipment to fail, requiring that it be replaced. The principal adverse environments include marine locations and industrial areas with polluted atmospheres. For underground installations, adverse environments include polluted and corrosive drainage, flood and ground waters. The electrochemical nature of most corrosion is emphasized in a brief review of elementary corrosion theory. The various forms of corrosion likely to be encountered in CATV equipment are described, and typical causes are discussed. Sulfur dioxide and chlorides are pinpointed as the most corrosive of the atmospheric constituents. Various locations are compared in terms of severity of corrosion. Examples of equipment-related corrosion are illustrated and discussed. Corrosion testing and evaluation concepts are reviewed. Preventative design, testing, installation and operational principles are suggested.

INTRODUCTION

Corrosion can be a serious problem for CATV distribution system equipment, as it is for most types of equipment fabricated from metal which must operate out of doors in a wide range of uncontrolled environments. The overall magnitude of the metal corrosion problem is indicated by the fact that the cost of corrosion and of protection against it has been estimated recently by various authorities at from 6 to 20 billion dollars annually for the United States alone.

The phenomenon of corrosion has been defined in several ways. A good consensus definition might be:

> Corrosion is the destruction or deterioration of a metal or alloy by chemical or electrochemical reaction with its environment.

Most definitions exclude non-metals from the definition of corrosion; all exclude mechanical deterioration, such as erosion.

The subject of this paper is destructive corrosion of CATV distribution system equipment. Destructive corrosion is used here in the sense of corrosion which proceeds to the point of causing an item of equipment to fail in some manner, requiring that it be replaced or repaired. Corrosion which merely causes a deterioration of appearance will not be considered in any detail here, even though that is not necessarily a trivial consideration.

Corrosion can definitely cause failures in CATV distribution equipment of all types. The various forms of corrosion will be described, largely from a phenomenological rather than a theoretical standpoint, and some of the causes, mechanisms, and preventative design methods which apply to CATV equipment will be discussed.

CORROSION THEORY [1-8]

One common way of classifying corrosion is as either wet or dry. Wet corrosion occurs only when a liquid (including a condensed vapor) is present, while dry corrosion occurs in the absence of a liquid, usually at elevated temperatures. The overwhelming majority of corrosion problems in CATV equipment are of the wet variety - that is, a liquid must be present for corrosion to occur. Only wet corrosion will be discussed in any detail here.

Most wet corrosion processes are electrochemical in nature. The electrochemical nature of corrosion is illustrated in figures 1 and 2. Figure 1 shows how the flow of electric current from a dry cell battery (actually an ammonium chloride moist paste cell) is directly associated with the "corrosion" of the zinc case (the anode). An analogous electrochemical process occurs during the corrosion of a metal or alloy in contact with a conductive fluid, as illustrated in figure 2.

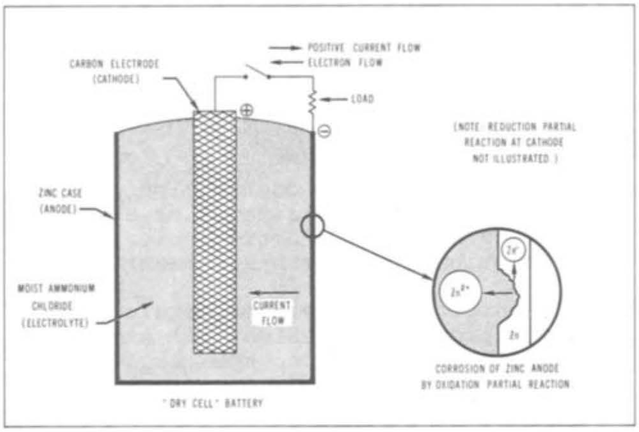


Figure 1. Illustration of electrochemical nature of corrosion - corrosion of zinc anode in dry cell battery.

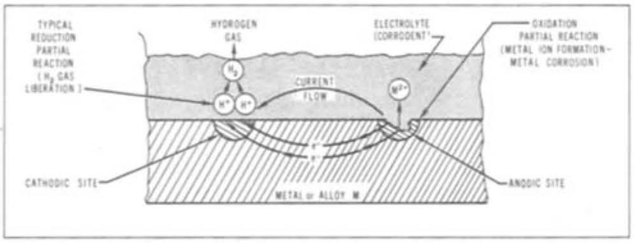


Figure 2. Illustration of electrochemical nature of corrosion - corrosion of single metal in contact with corrodent.

In order for electrochemical corrosion to occur in any metal or combination of metals, there must be a cathodic surface (cathode) and an anodic surface (anode) at different potentials in electrical contact with each other, and with both in contact with a conductive fluid (electrolyte). Direct current must flow between the cathode and anode. Within this electrochemical system an oxidation-reduction (redox) reaction occurs, with the oxidation reaction occurring at the anode and the reduction reaction occurring at the cathode. It should be noted that the anode and cathode can be any two metallic surfaces at differing potentials in electrical contact, ranging from two immediately adjacent surfaces of a single piece of metal (figure 2) to two separate and dissimilar pieces of metal connected by an electrical conductor and in contact with a common electrolyte (see figure 3 in the section on galvanic corrosion).

The anode is the area where current leaves the metal and enters the fluid, and that is where the principal corrosion occurs. The cathode is the area where (usually) no corrosion occurs and where current enters the metal from the fluid. Anodes and cathodes can form on a single piece of metal because of local differences either in the metal or in the electrolyte in contact with the metal.

Any overall oxidation-reduction reaction in electrochemical corrosion can be separated, for purposes of better understanding, into two or more partial reactions of oxidation and reduction. When viewed from the standpoint of partial processes of oxidation and reduction, all corrosion can be classified into a few generalized reactions.

The anodic reaction in every corrosion reaction is the oxidation of a metal to its ion. Letting M_a represent the chemical symbol for the anodic metal, the oxidation reaction can be written as

$$M_a \longrightarrow M_a{}^{+n} + ne \qquad (1)$$

when n represents the valence of the anodic element. For example

$$Al \longrightarrow Al^{+3} + 3e$$

$$Fe \longrightarrow Fe^{+2} + 2e$$

In these cases the anode metal ions leave the anode surface and go into solution in the electrolyte where they then usually combine with negative ions to form insoluble precipitates which becomes the corrosion product (for example, rust). These oxidation partial reactions are the destructive part of the oxidation-reduction pair. (In some cases, the liberation of hydrogen gas in a reduction partial reaction can damage the cathodic area.)

In the electrochemical corrosion process the rate of electron production by the oxidation partial reaction at the anode must be matched by an equal rate of electron consumption by the reduction partial reactions at the cathode since charge neutrality must be maintained. The reduction partial reactions can be more complex and varied than the oxidation partial reactions. Two examples of reduction partial reactions which commonly occur in an aqueous electrolyte are

$$2H^+ + 2e \longrightarrow H_2\uparrow \text{(hydrogen evolution)} \quad (2a)$$

$$O_2 + 2H_2O + 4e \longrightarrow 4\ OH^- \text{(oxygen reduction)} \quad (2b)$$

There are several other reduction partial reactions which commonly occur at the cathode, but reduction partial reactions occurring at the cathode will not be emphasized in this paper.

A simple example of the corrosion of a single metal in contact with a liquid is the corrosion of iron to form rust when in contact with aerated (oxygenated) water. The first (corrosive) stage of the process can be written as

$$2Fe + 2H_2O + O_2 \longrightarrow 2Fe^{+2} + 4OH^- \longrightarrow 2Fe(OH)_2\downarrow$$

where the precipitate $Fe(OH)_2$ is an unstable intermediate compound which eventually oxidizes further to form common rust.

In any given corrosion cell (metal + corrodent) the possibility of electrochemical corrosion occurring, and the rate and extent of its occurrence, are all governed by complex relationships involving such factors as electrolyte concentrations, pH values, electrode potentials, electrode film resistances, and electrode polarization tendencies as a function of corrosion current and time. Frequently, several different reduction reactions occur simultaneously at the cathodic surface. Electrode resistance and polarization effects tend to limit (often substantially) the rate at which corrosion actually occurs with various metal combinations, compared to that which would be expected from electrode potential values alone; that is particularly true for the stainless steels. All of these and related considerations form the subject matter for the study of electrochemical corrosion theory in greater depth, but for the most part that is beyond the scope of this paper.

Much can be accomplished in the way of corrosion control from a practical standpoint, however, without a detailed understanding of the more complex aspects of corrosion theory, provided that one is aware of the various forms which corrosion can take and of the more common causes and preventative measures for each form. That is the approach which will be emphasized in this paper.

FORMS OF CORROSION [1-22]

The effects of corrosive action take many different and distinct forms. The form of the corrosion, if it can be correctly recognized, will usually provide a strong clue as to its cause, its mechanisms, and the means that can be taken to prevent or minimize damage that it can cause.

There is no universal agreement among corrosion authorities on exactly how to categorize the various forms of corrosion, but the categories listed in Table 1 seem to represent a good consensus. Most of the categories listed in Table 1 can be broken down further into subcategories for more detailed consideration.

TABLE 1. FORMS OF CORROSION

*	1.	Uniform attack
*	2.	Galvanic (dissimilar metal, two-metal) corrosion
*	3.	Stress-corrosion cracking
*	4.	Intergranular corrosion
*	5.	Concentration cell (crevice) corrosion
*	6.	Pitting
*	7.	Stray-current corrosion
	8.	Dealloying (selective attack, selective leaching)
	9.	Erosion corrosion
	10.	High temperature (dry) corrosion

* Indicates a form of corrosion of concern in CATV distribution system equipment.

In Table 1 the first 7 categories are starred to indicate that they are of concern for CATV distribution system equipment.

Uniform Attack

In uniform attack the metal corrodes rather evenly over the entire exposed surface. It is the most common form of corrosion (the rusting of steel, for example) and it is usually the most obvious and most easily recognized form of corrosion. It usually occurs when a metal surface is exposed over a large part of its area to a fluid which is generally corrosive to that metal.

Galvanic Corrosion

Galvanic or dissimilar metal corrosion occurs when two dissimilar metal parts are in electrical contact with each other and both are in contact with a common body of conductive fluid (electrolyte - liquid, paste, or similar). The extent of galvanic corrosion damage can vary from negligible to extensive, depending on the various parameters. Galvanic corrosion is a rather common and well known effect, at least in principle, but it may not be so readily recognized or easily detected in practice because of the fact that the two (or more) dissimilar metals may be separated physically by quite a distance if they are connected together by a good electrical conductor and both make contact with the same body of conductive fluid. In any galvanic cell (two dissimilar metals in electrical contact with each other and with an electrolyte) one of the metals is anodic with respect to the other, and it is the more anodic of the two metals which is subject to extensive corrosion damage. Normally, the more cathodic of the two metals remains relatively undamaged. In fact, it is protected from even a normal degree of corrosion by the sacrificial action of the anodic metal, which can be destroyed very rapidly under unfavorable conditions. Galvanic corrosion concepts are illustrated in figures 3A and 3B.

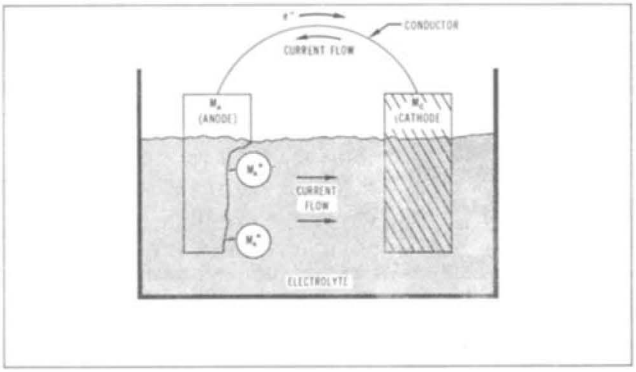


Figure 3A. Illustration of principle of galvanic (dissimilar metal) corrosion, showing the four key elements - anodic metal, cathodic metal, electrical contact or conductor, and electrolyte - which must be present for galvanic corrosion to occur.

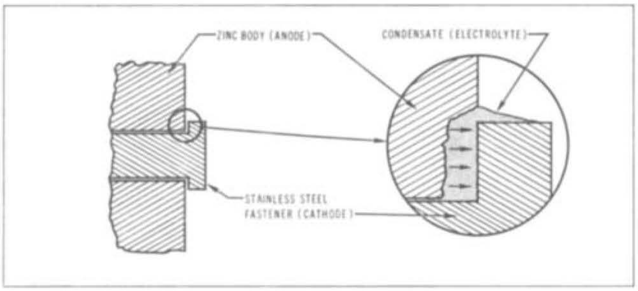


Figure 3B. One example of how galvanic corrosion could occur in practice.

The mass m of metal corroded away from the anode in steady galvanic corrosion in any given length of time is given by the expression

$$m \simeq k\, I_{galv}\, t_c, \text{ grams} \qquad (3)$$

where k = electrochemical equivalent constant for the anode metal, grams/coulomb

I_{galv} = galvanic corrosion current, amps

t_c = duration of corrosion, seconds

For non-steady corrosion current - the usual real-life case - the expression for the mass of metal corroded would be

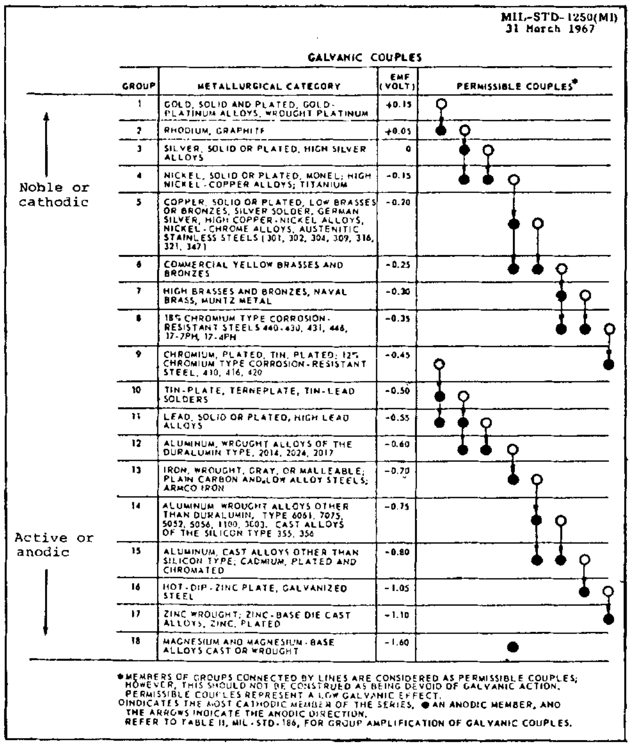
$$m \simeq k \int_0^{t_c} I_{galv}\, dt, \text{ grams} \qquad (4)$$

As an example, one ampere of corrosion current flowing for one year would result in the loss of 6.5 lbs. from an aluminum anode. The value of k for aluminum is 9.32×10^{-5} grams/coulomb; the values of k for other metals can be found in tables of electrochemical equivalents.

The open-circuit potential difference between the two dissimilar metals in any galvanic couple determines the direction of flow of the galvanic current. The polarization characteristics of the electrodes and electrolyte, in combination with the conductivity characteristics of the electrolyte, and the cathode-to-anode conduction path, determine the magnitude of the corrosion current. In a corrosion situation the corrosion current almost always varies with time. The magnitude of the corrosion current, and particularly the density of current at the anode-electrolyte interface (in amps/sq. in., say), determine the rate at which the anode is damaged. For example, if a given amount of corrosion current is forced to flow through a small exposed area of anode, such as the surface of a very small part, or a scratch in the protective coating on a large part, the small exposed surface can corrode away rather quickly and destroy the part in a short time.

The relative tendency for pairs of dissimilar metals to form galvanic couples in conductive solutions is often expressed for engineering design purposes in the form of galvanic series charts, which lists metals and alloys in descending order from the most cathodic (most noble) to the most anodic (most active) for a specific electrolyte. The practical application of such a series in equipment design and installation lies in avoiding the use of dissimilar metals which are not very close together in the series if there is any probability that they may be exposed to a conductive fluid. One limitation of a conventional galvanic series is that it is more qualitative than quantitative; another is that it does not always reflect the different degrees of polarization which occur in actual galvanic cells with corrosion current flowing.

In order to minimize those and other limitations, various types of galvanic couple compatibility charts have been developed from the basic galvanic series in order to aid the designer. One example of a compatibility chart is shown in Figure 4, reproduced (with slight modification) from MIL-STD-1250(MI) [16]. It is probably overly restrictive for all but aggressive environments. Other more elaborate charts with more gradations in degrees of compatibility and environment have also been published [1, 2(a), 33, 34, for example]. Each of the various methods of presentation has advantages and disadvantages. Probably the best way for a designer to make an important decision on compatibility of any pair of metals, if testing is not feasible, is to refer to as many reliable charts as are available to him.


MIL-STD-1250(MI)
31 March 1967

GALVANIC COUPLES

GROUP	METALLURGICAL CATEGORY	EMF (VOLT)	PERMISSIBLE COUPLES*
1	GOLD, SOLID AND PLATED, GOLD-PLATINUM ALLOYS, WROUGHT PLATINUM	+0.15	
2	RHODIUM, GRAPHITE	+0.05	
3	SILVER, SOLID OR PLATED, HIGH SILVER ALLOYS	0	
4	NICKEL, SOLID OR PLATED, MONEL; HIGH NICKEL-COPPER ALLOYS; TITANIUM	-0.15	
5	COPPER, SOLID OR PLATED, LOW BRASSES OR BRONZES, SILVER SOLDER, GERMAN SILVER, HIGH COPPER-NICKEL ALLOYS, NICKEL-CHROME ALLOYS, AUSTENITIC STAINLESS STEELS (301, 302, 304, 309, 316, 321, 347)	-0.20	
6	COMMERCIAL YELLOW BRASSES AND BRONZES	-0.25	
7	HIGH BRASSES AND BRONZES, NAVAL BRASS, MUNTZ METAL	-0.30	
8	18% CHROMIUM TYPE CORROSION-RESISTANT STEELS 440-430, 431, 446, 17-7PH, 17-4PH	-0.35	
9	CHROMIUM, PLATED, TIN, PLATED; 12% CHROMIUM TYPE CORROSION-RESISTANT STEEL, 410, 416, 420	-0.45	
10	TIN-PLATE, TERNEPLATE, TIN-LEAD SOLDERS	-0.50	
11	LEAD, SOLID OR PLATED, HIGH LEAD ALLOYS	-0.55	
12	ALUMINUM, WROUGHT ALLOYS OF THE DURALUMIN TYPE, 2014, 2024, 2017	-0.60	
13	IRON, WROUGHT, GRAY, OR MALLEABLE; PLAIN CARBON AND LOW ALLOY STEELS; ARMCO IRON	-0.70	
14	ALUMINUM WROUGHT ALLOYS OTHER THAN DURALUMIN, TYPE 6061, 7075, 5052, 5056, 1100, 3003. CAST ALLOYS OF THE SILICON TYPE 355, 356	-0.75	
15	ALUMINUM, CAST ALLOYS OTHER THAN SILICON TYPE; CADMIUM, PLATED AND CHROMATED	-0.80	
16	HOT-DIP-ZINC PLATE, GALVANIZED STEEL	-1.05	
17	ZINC WROUGHT; ZINC-BASE DIE CAST ALLOYS, ZINC, PLATED	-1.10	
18	MAGNESIUM AND MAGNESIUM-BASE ALLOYS CAST OR WROUGHT	-1.60	

*MEMBERS OF GROUPS CONNECTED BY LINES ARE CONSIDERED AS PERMISSIBLE COUPLES; HOWEVER, THIS SHOULD NOT BE CONSTRUED AS BEING DEVOID OF GALVANIC ACTION. PERMISSIBLE COUPLES REPRESENT A LOW GALVANIC EFFECT.

○ INDICATES THE MOST CATHODIC MEMBER OF THE SERIES, ● AN ANODIC MEMBER, AND THE ARROWS INDICATE THE ANODIC DIRECTION.

REFER TO TABLE II, MIL-STD-186, FOR GROUP AMPLIFICATION OF GALVANIC COUPLES.

Figure 4. One example of a simple dissimilar metal compatability chart. The basis of the chart is not specified in the source [16], but it appears to be based on a ΔEMF of 0.25 volts or less for compatibility (a criterion which is disputed by other sources).

At least two comments are worth making about galvanic series and galvanic couple compatibility charts. One is that published galvanic series charts - and the compatibility charts derived from them - are really based on a specific electrolyte, almost always seawater, a fact which the compatibility charts often neglect to mention. Other electrolytes can and do cause some differences in relative compatibilities, even to the point of reversing cathodes and anodes in a few instances. However, charts based on seawater as the electrolyte seem to be generally the most appropriate ones for most CATV purposes. Another point worth mentioning is that published compatibility charts do not always agree with each other with regard to the degree of compatibility of certain important pairs of metals. That alone is a good reason for referring to more than one reliable chart before making a decision.

To summarize the implications of galvanic corrosion briefly, it is not an uncommon occurrence on CATV equipment because all of the ingredients of galvanic cells are frequently present but not always recognized. Fortunately, not all galvanic corrosion actually renders the equipment inoperative, but enough does to make it a matter of serious concern.

Stress-Corrosion Cracking

Stress-corrosion cracking is defined as the spontaneous failure of a metal resulting from the combined effects of corrosion and stress. Stress-corrosion cracking is a particularly insidious form of destructive corrosion because it may develop as very fine intercrystalline cracks within the material, with little or no visible evidence of corrosion until failure occurs suddenly by destructive cracking of the material. Figure 5 illustrates a typical stress-corrosion cracking failure in an aluminum hose fitting.

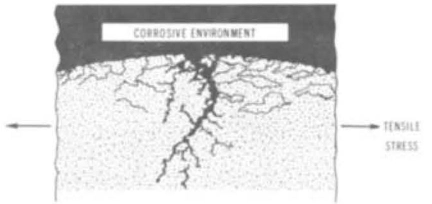


Figure 5. Sketch made from a photomicrograph showing the stress-corrosion cracking of a 2024-T351 aluminum alloy hose fitting loaded in hoop stress.

Like other forms of corrosion, stress-corrosion cracking occurs in specific metal alloys subjected to specific environmental conditions. One common denominator of stress-corrosion cracking is that it occurs only while the material is being subjected to a tensile stress of some minimum or threshold level which depends on the specific alloy and the specific corrodent. Therefore, the possibility of it occurring should be considered for all CATV equipment parts in which any of the material is stressed in tension. It should be noted that unrelieved residual internal stresses in a metal as a result of the fabrication process can create or contribute to the requisite tensile stresses just as readily as can externally applied stresses.

In CATV equipment there are probably only two areas in which the combination of stresses, materials and environments are likely to cause stress-corrosion cracking problems. They are (1) aluminum alloy coaxial cable connector hardware, but only with certain susceptible alloys, and (2) stainless steel fasteners, but again only with certain susceptible alloys. Several references on susceptibility [6, 9-14, 18-22] are available to assist the designer in avoiding the stress-corrosion-prone aluminum and stainless steel alloys. For aluminum, there should be no problem in selecting a non-susceptible alloy with all of the other desirable characteristics. For stainless steel, the otherwise desirable 300 series 18/8 austenitic types are known to be somewhat susceptible to stress-corrosion cracking in the presence of hot chloride solutions, but at atmospheric temperatures the susceptibility is believed to be quite low, permitting their use with low risk.

Certain types of protective coatings can also be effective in minimizing the stress-corrosion cracking tendencies of marginally-susceptible alloys [9].

Intergranular Corrosion

Intergranular corrosion is a form of localized subsurface attack in which a narrow path is corroded out preferentially along the grain boundaries of a metal. The mechanism is electrochemical and is usually caused by the presence of second-phase precipitates in the grain boundaries which differ in potential from the primary phase. In other words, grain boundary material of small area acts as anode in contact with large areas of grains acting as cathode. The attack is often rapid, penetrating deeply into the metal and sometimes causing catastrophic failures. Figure 6 is a sketch illustrating an occurrence of aluminum intergranular corrosion which had not progressed to the point of failure.

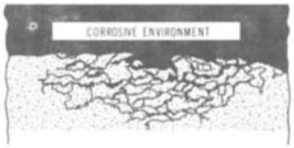


Figure 6. Sketch made from a photomicrograph showing intergranular corrosion in an aluminum alloy.

Improperly heat-treated austenitic stainless steels, most precipitation-hardening high strength aluminum alloys, and certain other aluminum alloys are susceptible to intergranular corrosion in varying degrees. Again references [6, 9-14, 17] are available which indicate the degree of susceptibility of the various alloys, and low-susceptibility alloys can easily be selected for CATV applications. Most copper-bearing aluminum alloys, both wrought and cast, should be avoided in order to minimize the risk of both intergranular corrosion and stress-corrosion cracking.

Concentration Cell Corrosion

Concentration cell or crevice corrosion is corrosion which results from the trapping or stagnation of electrolyte in holes and surface deposits, in crevices under bolt heads, washers, strand clamps and rivets, and in closely fitted regions, such as gasket surfaces, flange spaces and lap joints. In concentration cell corrosion there need not be any dissimilar metals, either on a microscopic or a macroscopic scale. Anodic and cathodic zones can be created on a perfectly uniform single-phase metal surface by local variations in oxygen or metal ion concentration which develop within the trapped, stagnant electrolyte. These variations in composition give rise to a flow of corrosion current, resulting in the corrosion of the anodic zones of the metal. The oxygen concentration form of concentration cell corrosion is illustrated in figure 7.

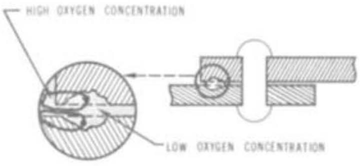


Figure 7. Sketch illustrating the occurrence of the oxygen concentrations form of concentration cell corrosion.

Concentration cell corrosion usually results in an open pitting of the corroded surfaces. Since it usually (but not always) occurs in very narrow crevices, it is almost never visible in a casual inspection of the equipment, only becoming apparent when the parts creating the crevice are disassembled. It can be destructive in CATV equipment, particularly at sealing surfaces.

Pitting

In addition to the formation of pits in crevices, there is a more general form of pitting corrosion to which certain metals are particularly susceptible. That type of pitting occurs most commonly on metals which develop their own protective surface film, under conditions in which the film is almost, but not completely, protective. The two metals most susceptible to pitting of those commonly used in CATV equipment are stainless steel alloys and aluminum alloys. The early stages of pitting corrosion of an aluminum alloy is illustrated in figure 8. In some circumstances, pitting is self-limiting; in other circumstances it continues until the wall is penetrated.

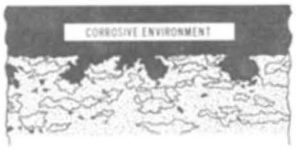


Figure 8. Sketch made from a photomicrograph showing a possibly early stage of pitting corrosion in an aluminum alloy.

Pitting is the result of electrochemical action in local cells on the surface of a metal. At the point of initiation, corrosion occurs at the local anodes, while the local cathode is the immediately surrounding metal surface. One reference [9], quoting a paper by Mears and Brown, lists 18 possible causes of local cell formation leading to pitting. Of those 18, local variations in metal composition due to the presence of either a second phase or impurities and local damage to the protective surface film on the metal from either chemical or mechanical effects are probably the two most important causes. Both stainless steel and aluminum are particularly susceptible to electrolytes containing chloride ions, such as seawater spray or condensate. Among the stainless steel alloys, molybdenum-bearing type 316 provides the maximum resistance to chloride-induced pitting.

Stray-Current Corrosion and Other Current-Induced Corrosion

Stray-current corrosion is corrosion resulting from the flow of current through paths other than the intended circuit of electrical conductors, in conjunction with the operation of electrically powered equipment. The stray current may be either alternating current, direct current, or one superimposed on the other. Destructive stray currents frequently occur in conjunction with multiply-grounded circuits. In such cases, only part of the return current flows through the ground return conductor, no matter how low its resistance, while the remaining current flows through unintended paths which may include structures. If a path through a structure involves a mechanically-connected joint, or a gap, in which an electrolyte is trapped, the metal in the area where the d.c. leaves the surface to enter the electrolyte is subject to stray current corrosion which can be severe if the level of stray current is high.

The amount of metal corroded by stray d.c. leaving the metal and entering the electrolyte is given approximately by

$$m \simeq k\, I_{stray}\, t_c, \text{ grams} \qquad (5)$$

where the variables are as previously defined (equation (3)), except that I_{galv} is replaced by I_{stray}.

As a general rule, stray a.c. causes substantially less damage to most metals than does stray d.c. of the same magnitude under otherwise identical circumstances, and the corrosion damage usually decreases with increasing frequency. For metals like steel, lead and copper, it is estimated that 60 Hz a.c. causes only about 1% of the damage of an equal level of d.c. [5]. For passive metals such as stainless steel and aluminum which develop their own protective films, however, there is recent evidence that 60 Hz a.c. can damage or destroy the protective film and cause much greater than 1% of the damage of the equivalent d.c. Alternating current damage levels of from 5 to 31% of the equivalent d.c. damage levels have been reported for an aluminum alloy under specific test conditions [5].

In CATV equipment, it is possible for both stray d.c. and stray 60 Hz a.c. to be present in ground loops. Damage by a.c. can be increased by partial or complete rectification to d.c. Earth soil often causes rectifier action and aggravates corrosion where a.c. ground loops are working. Corrosion products themselves could cause rectifier action and and corrosion rates could increase with time for situations involving a stray alternating potential, since an increasing percentage of the a.c. would be rectified to the more destructive d.c.

When stray-current corrosion situations occur they are usually both nonobvious and quite destructive. That suggests that some attention should be paid to the problem at or before the time of equipment installation, by both analysis and testing, to ensure that conditions conducive to stray current corrosion do not exist.

There is another potential form of corrosion which is related to stray-current corrosion and which should also be given proper attention, although it does not normally appear among the standard categories of corrosion. For lack of a better name known to the authors, it might be termed either non-stray-current corrosion or current-induced corrosion. It can occur along intended conduction paths at points where current flows through mechanical contacts between separate metal pieces. If the design is such that an electrolyte can accumulate around or between the contacts, current-induced corrosion of one or both contact surfaces is likely to occur.

Virtually all of the discussions concerning the effects of stray-current corrosion is equally applicable to non-stray-current corrosion.

Other Forms of Corrosion

The other forms of corrosion listed in Table 1 are generally not significant for CATV equipment and will not be discussed here.

CORROSIVITY OF VARIOUS ENVIRONMENTS FOR CATV EQUIPMENT [1-15,21-24]

CATV equipment must function in a variety of environments which generally range from mild and unpolluted to aggressive and/or badly polluted natural environments. Aerial installations of equipment are exposed to the full range of weather conditions and atmospheric environments. Underground installations are exposed to atmospheric environments as modified by the weather protection provided by the enclosures, plus - in some instances - to rain water, drainage waters, ground waters, and/or soils.

The general aggressiveness of the atmosphere varies over a wide range from one location and type of environment to another. In the more aggressive areas, it may even vary widely from one point to another within a small locality, depending on the proximity to sources of corrodents, the direction of the prevailing winds, the presence of sheltering terrain, and many similar factors. In short, it is really the micro-environment at each specific installation site which actually determines the general corrosivity of the atmosphere at that site.

The term general corrosivity as used here is convenient for discussion purposes but is actually an oversimplified concept. The concept of corrosivity can really only be applied to the effects of specific corrodents on specific metals and coatings, effects which vary from one type of material to another and from one form of corrosion to another. For example, one metal may be most susceptible to damaging pitting attack by a marine environment, while a different type may be most susceptible to damaging intergranular attack by a polluted industrial atmosphere.

If consideration is limited to the materials usually used externally in CATV equipment - principally aluminum casting alloys, coated mild steel alloys and stainless steel alloys for hardware, zinc casting alloys and cadmium coatings - then it is possible to rank in a very approximate way the various types of environments with respect to their general corrosivity toward those metals and coatings as a group. Table 2 provides such a rough ranking of atmospheric environments, based on the considerations discussed. Except for the urban and suburban examples, the examples cited in Table 2 are ASTM or similar corrosion test sites for which good comparative data are available. However, it should be recognized that comparisons such as Table 2, while useful for orientation purposes, tend to oversimplify a complex situation.

TABLE 2. RELATIVE SEVERITY OF VARIOUS ATMOSPHERIC ENVIRONMENTS TOWARD METALS AND COATING USED IN CATV EQUIPMENT

[9, 10, 11, 13, 21, 22]

Atmospheric Environment	Example	Relative Corrosivity
Severe industrial-marine		Most corrosive
Severe marine	La Jolla, Cal.	
Severe industrial	McCook, Ill.	
Moderate marine	Miami Beach, Fla.	
Moderate industrial	Detroit, Mich.	
Humid subtropical		decreasing corrosivity
Urban/semi-industrial	Los Angeles, Cal.	
Suburban	Anaheim, Cal.	
Rural	State College, Pa.	
Semi-arid	Phoenix, Ariz.	
Arid desert		Least corrosive

In all cases arid and semi-arid regions (such as Phoenix) cause the least corrosion, closely followed by most rural regions (except rural seacoasts). In many cases, heavy industrial areas at the seacoast can cause the worst corrosion.

In marine environments, the distance from the water, the elevation above sea level, the velocity and direction of the prevailing winds, the variations in dew point, the temperature cycles, and the prevalence of fog, spray and sea mist all strongly influence the rate of corrosion. For example, for some alloys the corrosion rate at 80 ft. from the water can be over 10 times the rate at 800 ft., as found in comparative tests at the ASTM corrosion test site at Kure Beach, N. C.

There is general agreement that, for the metals being considered, the two most aggressive corrosive agents in the atmosphere are (1) the sulfur compounds, principally sulphur dioxide and its acid derivatives, as found in industrial areas, and (2) the chlorine compounds, as found in both marine atmospheres, principally as chloride sea salts (NaCl, MgCl, etc.), and in industrial atmospheres, often as chlorine gas.

In the industrial areas sulfur dioxide is released to the atmosphere by fuel-burning power plants, chemical plants, refineries, diesel-powered vehicles and the like. Sulfur dioxide reacts with moisture in the atmosphere and condensate on equipment to form corrosive sulfurous and sulfuric acid solutions. Gaseous chlorine, also released by some chemical plants, reacts with moisture to form a corrosive combination of hypochlorous and hydrochloric acids.

For underground systems which come into contact with drainage water or ground water, there are any number of possible corrosive agents, including chemicals used for soil treatment. Factors which have a strong bearing on the pitting corrosivity of water toward certain aluminum alloys, for example, include the pH level, conductivity, dissolved oxygen content, and concentrations of sulfate, chloride carbonate and copper ions [9,22].

One potential corrodent which could affect both aerial installations and underground installations is the chloride salts (principally calcium chloride) used in many areas of the country to remove ice and snow from the streets in the winter. Snow plows undoubtedly throw salt-bearing ice and snow up onto aerial equipment installations, while melted ice and snow may drain into vaults.

CORROSION AS RELATED TO CATV EQUIPMENT

[25-28]

In an earlier section of the paper, corrosion was neatly separated into about 10 distinct forms for purposes of analysis and discussion. When corrosion actually occurs in CATV equipment, however, it is not always confined to a single clearly identifiable form, but is more likely to appear as an inseparable and almost unidentifiable mixture of several different forms of corrosion. The end result often is simply a badly corroded and functionally damaged item of equipment which must be replaced.

In the sections which follow, examples of how various types of corrosion may occur in and affect items of CATV equipment are described and discussed.

Investigation Of Corrosion Of Stainless Steel/Aluminum Couples In A Severe Marine Environment*

Although passivated austenitic stainless steel alloys (300 series) and aluminum casting alloys are rather widely separated in the galvanic series, the two materials are nevertheless commonly used in contact with each other in structures intended for outdoor exposure. They are used together because of generally favorable experience with them as a compatible couple in most environments. Stainless steel normally seems to act as a rather inefficient cathode in such couples, causing very little galvanic corrosion of the aluminum anode or itself. The explanations that have been suggested for this seemingly anomalous compatibility include a combination of (1) the presence of a high-electrical resistance oxide film on the surface of the stainless steel and (2) the tendency of the stainless steel cathode to readily polarize at the metal-electrolyte interface.

With regard to CATV equipment, Bell Telephone Laboratories Specification KS-19925, Issue 2 (1967), a specification for Cable Television equipment, requires the use of 304 or 305 stainless steel hardware on aluminum housings for aerial use.

Galvanic couple compatibility charts usually list these two types of materials as compatible in most environments, but urge caution in using them together in marine atmospheres. Since CATV equipment must function in marine as well as non-marine environments, however, it is necessary to know how such a commonly used pair actually performs in a severe marine environment.

In this section the results of exposing stainless steel alloy/aluminum alloy couples to such an environment, including the results of detailed examinations and analyses of the corrosion effects and corrosion products, are presented and discussed. The specimen couples investigated consisted of:

Specimen No. 1:	Type 304 passivated stainless steel clamped against type 356 aluminum alloy;
Specimen No. 2:	Type 302 non-passivated stainless steel clamped against type 356 aluminum alloy.

Both of these specimens were exposed simultaneously to a rather severe marine environment. After an extensive period the samples were removed from the test site for examination. Specimen No. 1 was sectioned for metallographic examination. The sectioned specimen is shown in figure 9. Figure 10 is a photomicrograph taken at 100X of one small zone of the corrosion products in the specimen shown in figure 9. The corrosion products completely fill the approximately 15 mil (.015 inch) gap between the dissimilar metals in that zone.

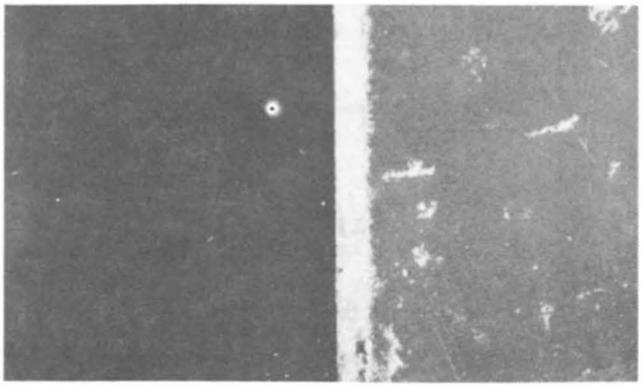


Figure 9. Sectioned view of Specimen No. 1-type 304 stainless steel in contact with type 356 aluminum alloy - showing buildup of corrosion products between the two materials.

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*This section has been based in part on work performed and documented by C. R. Halbach of ARTCOR, Irvine, California [25].

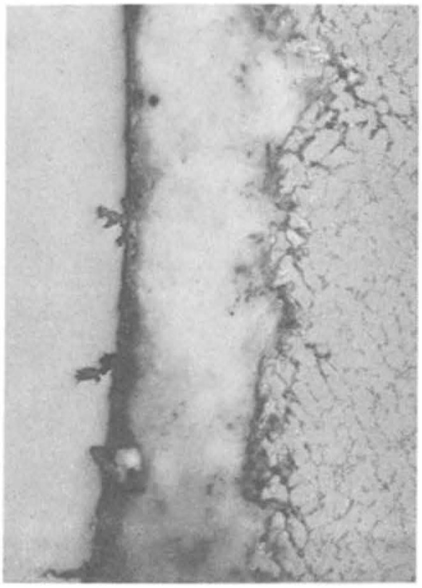

Figure 10. 100X photomicrograph of corrosion products in Specimen No. 1. At the right is the aluminum alloy which has undergone intergranular attack. The white mass in the center is the corrosion product (aluminum oxide + aluminum chloride). At the left is the stainless steel, with major pits visible [25].

The 100X magnification in figure 10 is particularly revealing in that it shows intergranular attack and subsequent dissolution of the grains of the 356 aluminum alloy, and it also shows pitting of the stainless steel.

Specimen No. 1 was then subjected to a scanning electron microscope and probe microanalysis examination of the corrosion products to identify the chemical elements present and their distribution within the region. The elements listed in Part I (A) of table 3 were found to be present in the corrosion products.

Iodine was one element specifically checked for in the scan of the corrosion products because of previous but unverified reports that iodine released into the atmosphere by kelp beds make certain marine areas especially corrosive, and this test site did have kelp beds nearby. No iodine was found, even though it would have been easy to detect with the instrument used.

In addition to the scanning electron probe micronanlysis of Specimen No. 1, arc emission spectrographic and X-ray diffraction analyses were conducted on the corrosion products found between the dissimilar metals in Specimen No. 2 to further document the chemistry of the corrosion products. The arc emission spectrographic analysis was used to identify elements present, while the X-ray diffraction analysis was used to identify compounds. The results of those analyses are shown in Parts I (B) and II respectively, of table 3. For the most part, the corrosion products found in Specimen No. 2 coincided with those found in Specimen No. 1.

TABLE 3. ELEMENTS AND COMPOUNDS IDENTIFIED IN STAINLESS STEEL/ALUMINUM ALLOY COUPLE CORROSION PRODUCTS BY ANALYTICAL INSTRUMENTS

[25]

I. Elements Identified in Corrosion Products by Scanning Electron Probe Microanalysis (S.E.P.) and Arc Emission Spectrographic (A.E.S.) Analysis:

Analysis of corrosion products			Presumed source
(A) Specimen No. 1 by S. E. P.	(B) Specimen No. 2 by A. E. S.		
Al	Al	>10%	356 aluminum alloy
Si	Si	> 1%	356 aluminum alloy
	Zn	< 1%	356 aluminum alloy
	Ti	< 1%	356 aluminum alloy
Fe			304 stainless st.
	Fe	< 1%	302 stainless st.
	Cr	> 1%	302 stainless st.
	Ni	< 1%	302 stainless st.
Cl	Cl	> 1%	sea water
Na	Na	< 1%	sea water
Mg	Mg	< 1%	sea water
S	S	< 1%	sea water
Ca			sea water
K			sea water

II. Compounds Identified in Corrosion Products in Specimen No. 2 by X-ray Diffraction:

1.	Aluminum oxide hydrate	$Al_2O_3 \cdot 5\ H_2O$
2.	Aluminum chloride	$AlCl_3$

The results of the examinations of the corroded specimens, including the chemical analysis results listed in table 3, demonstrated that dissimilar metal (galvanic) corrosion can occur when austenitic stainless steel/aluminum casting alloy couples are employed externally in a severe marine environment. It was concluded that the galvanic corrosion was induced by an accumulation of seawater electrolyte in the small clearance spaces and crevices between the dissimilar metals in contact, probably deposited by some combination of wind-blown spray, sea mist, fog, and moisture condensation at night. There had also been a significant amount of rain during the exposure, but it is not clear whether the net effect of the rain was to accelerate or retard the rate of corrosion. One might expect the rain to tend to wash the salt water electrolyte away and thus retard corrosion, but the net effect may not really be that straightforward.

The overall results of this project, a part of which is reported above, were subsequently applied in the materials selection and design of CATV distribution equipment.

Cracking of Cable Connectors* [26]

A number of coaxial cable connectors have cracked in field use because of corrosion and have had to be replaced. Typical cracks in the connectors are shown in the Figure 11 photograph. In each case the part which cracked was in hoop stress because of the method of assembly used in the connector, in which the part which cracked was assembled in the connector by press fitting over a mating silver-plated part. The material from which the cracked part was machined is 2011-T3 aluminum alloy, a free-machining alloy containing about 5.5% copper. It was reported that the connectors were removed from service near the seacoast, but additional details are lacking.

It can be concluded that each cracked segment of the connectors shown in Figure 11 was fabricated from a stress-corrosion-susceptible aluminum alloy (2011-T3 aluminum alloy) and then stressed in tension by press fitting during assembly of the connector, which loaded the cracked segment in hoop stress (a tensile stress). Finally, the connectors were installed in an area where the environment apparently provided a corrodent capable of causing stress-corrosion cracking. The result of all of those factors was stress-corrosion cracking of the connectors to the point of destruction, necessitating their replacement.

It is frequently found that chlorides are the corrodents responsible for stress-corrosion cracking, and in the case illustrated it is probable that chlorides present in a seacoast atmosphere were the culprits. However, it should not be assumed that this type of stress-corrosion cracking will only occur at the seacoast. Chlorides and other potential corrodents are also present in the atmosphere in most industrial areas, and the use of chlorides for snow removal is common in many areas of the country.

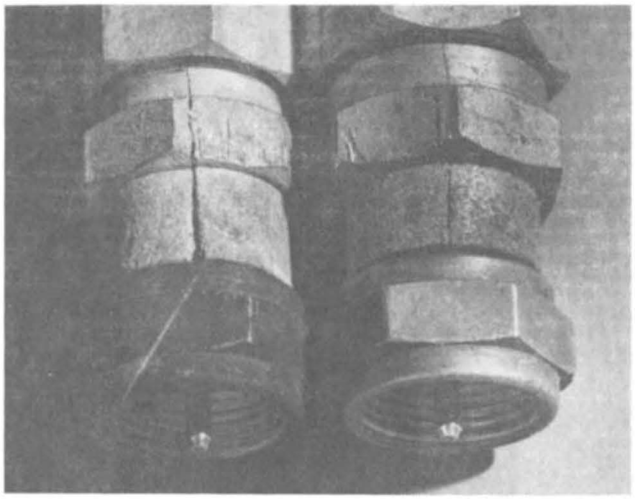

Figure 11. Photograph of two of the connectors removed from field installations near the seacoast after failing from stress-corrosion cracking. The cracks shown penetrate completely through the walls of the segments [26].

The safest procedure is to assume that the corrodents will be present, to fabricate equipment from low-susceptibility alloys, to minimize tensile stresses (including residual stresses) wherever possible, and, in the case of connectors, to install heat shrink boots over the connectors for maximum protection from the environment.

Corrosion Problems in EMI/RFI Gaskets

The necessity of using EMI/RFI gaskets for shielding in high signal level equipment creates a potential corrosion problem because the metal materials used in the gaskets are invariably different from the housing materials, but there must be metal-to-metal contact for the shielding to function effectively. That, of course, creates the potential for galvanic corrosion at the gasket, and corrosion can in fact occur in that area unless care is exercised in the selection of the gasket materials, in the design of the sealing area of the housing, and in the tightening of flange bolts in the field.

This subject is too specialized to discuss in more detail in this paper, but the interested reader is referred to the papers which have been previously published on this subject two of which are referenced [27,28].

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*Information for this section was provided by Mr. Robert Hayward of Gilbert Engineering Co., Inc., on connector models (now obsolete) which were not manufactured by Gilbert [26].

CORROSION TESTING AND EVALUATION

Corrosion Testing

The primary metals industry has been conducting extensive corrosion testing and evaluation for about a century, both in corrosion laboratories and in field test sites all over the world. Field corrosion tests of over 25 years duration are not uncommon. The results of most of this research is available in journals and books.

The CATV industry must rely primarily on this published data for guidance in the design of equipment. After a new design has been turned into hardware, however, there may be a need to check its ability to withstand severe field environments before releasing it for full-scale production. That requires corrosion testing by (or under the direction of) the CATV equipment manufactuer.

Corrosion testing in general includes both field testing and laboratory testing. Field testing, if carefully planned and conducted, provides the most accurate information on the corrosion resistance of any test specimen or item of equipment. Unfortunately, field testing doesn't usually provide much in the way of significant results for many months, or even years, a time scale not very useful in the rapidly progressing CATV industry. Given that situation, there is a natural tendency to rely on laboratory corrosion testing, particularly the so-called "accelerated" testing, to try to predict corrosion behavior in service.

Table 4 lists some of the more common forms of general corrosion testing which can be performed in a laboratory, together with various specifications used to standardize those tests.

The tests listed in Table 4 can be useful only if properly performed and, particularly, if properly interpreted. Unfortunately, there is some misunderstanding about the significance of such tests and how to interpret them.

For example, the salt fog (salt spray) tests are often regarded as representing an accelerated form of seacoast exposure; in that view, an item of equipment which survives X number of hours of normal or elevated temperature salt fog exposure with only limited corrosion and no destructive damage has been proved suitable for indefinite exposure in a severe marine environment.

TABLE 4. LABORATORY CORROSION TESTS

Type of Test	Typical Standard Test Specifications
I. Salt spray or salt fog	1. MIL-STD 810B, Method 509: Salt Fog.
	2. FED. TEST METHOD STD. NO. 151b, Method 812.1: Synthetic Sea Water Spray Test.
	3. ASTM B117: Method of Salt Spray (fog) Testing.
II. High humidity	1. MIL-STD 810B, Method 507: Humidity.
III. Immersion	
A. Total immersion	1. FED. TEST METHOD STD. NO. 151B, Method 821.1: Intergranular Corrosion Tests for Aluminum Alloys.
	2. NACE TM-01-69: Laboratory Corrosion Testing of Metals for the Process Industry.
	3. ASTM A279: Total Immersion Corrosion Testing of Stainless Steels.
B. Alternate immersion	1. FED. TEST METHOD STD. NO. 151b, Method 823: Stress-corrosion Test for Aluminum Alloy.
C. Partial immersion	--

While not totally wrong, that concept is a misinterpretation of the purpose and significance of salt fog testing. Those and similar tests are designed to be primarily accelerated quality control and acceptance tests, which first requires that meaningful criteria have to be established for passing the tests. Those tests are not life expectancy tests for some severe environment such as a marine environment, but instead are simply "pass - no pass" tests on materials, coatings, assemblies, etc. The reasons for these deficiencies and limitations in the applicability of the test results include the fact that the tests do not accurately duplicate all of the corrosive aspects of field conditions, and do not accelerate all forms of corrosion equally. Salt fog and similar laboratory tests on electrical/electronic equipment might, however, be made more realistic by supplying electrical power to the equipment during the test.

Although accelerated corrosion tests performed in a laboratory are not truly reliable for comparing the corrosion resistance of different materials, coatings, assemblies, etc. they are nevertheless commonly used for that purpose and can provide a reasonably good qualitative comparison most of the time if intelligently applied and interpreted. Two simple examples of such comparative testing, performed at Gilbert Engineering Company by R. Hayward [26] on different designs, materials and surface finishes for cable connectors, are shown in figures 12 through 15. One of the tests, illustrated in figures 12 and 13, was an alternate immersion test in which all of the connectors

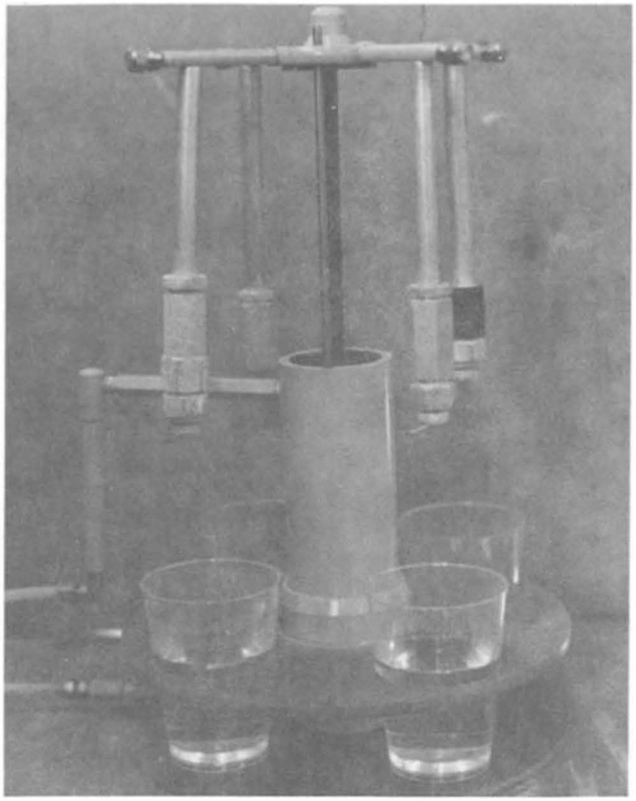

Figure 12. Photograph of alternate immersion test rig used for testing cable connectors of various materials and finishes in individual NaCl solutions [26].

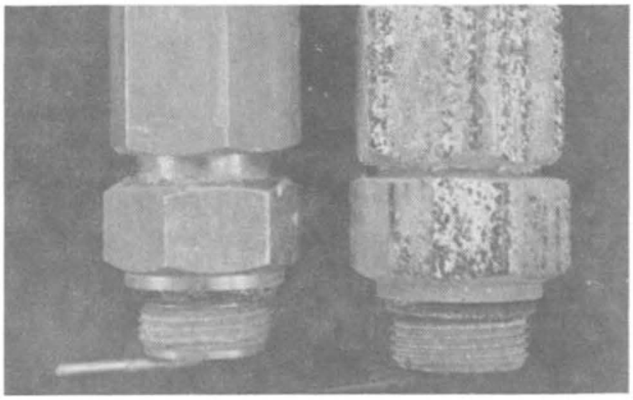

Figure 13. Comparison of appearance of two of the connectors tested in the alternate immersion test rig (figure 12) after 180 days of testing. The connector on the left was fabricated from 6262-T9 aluminum alloy and finished with a chromate conversion coating; the connector on the right was fabricated from 2011-T3 aluminum alloy and was not coated [26].

were submerged in concentrated (20%) NaCl solutions at room temperature for 1-1/2 minutes, then automatically withdrawn and exposed to room air for 1-1/2 minutes, with that cycle repeated continuously for 180 days in accordance with a procedure described in reference 1. The results (figure 13) demonstrated that one combination of aluminum alloy and coating - 6262-T9 alloy with chromate conversion coating - withstood this particular concentrated salt solution accelerated corrosion test with much less general corrosion than another alloy - 2011-T3 - without a coating.

The second test, illustrated in figures 14 and 15, was an alternate high humidity/condensation test performed in a closed glass vat with a small quantity of water in the bottom. This testing device was placed outdoors in the summertime in

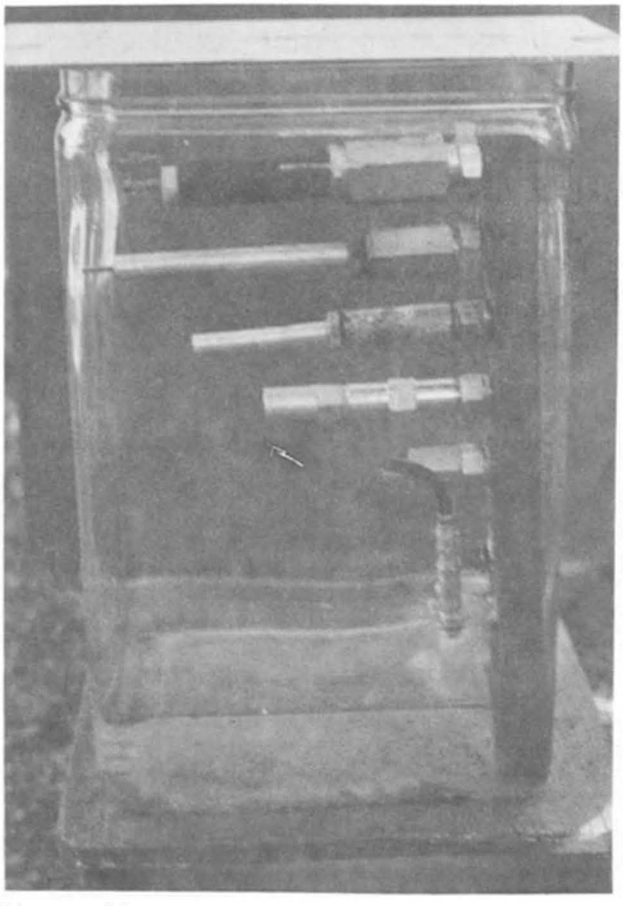

Figure 14. Closed test rig for testing of cable connectors of various materials and finishes in 24 hour cycles of alternating high temperature-high humidity (daytime) and reduced temperature-condensation (nighttime). The evaporating/condensing liquid was ordinary water. The heat source was the sun [26].

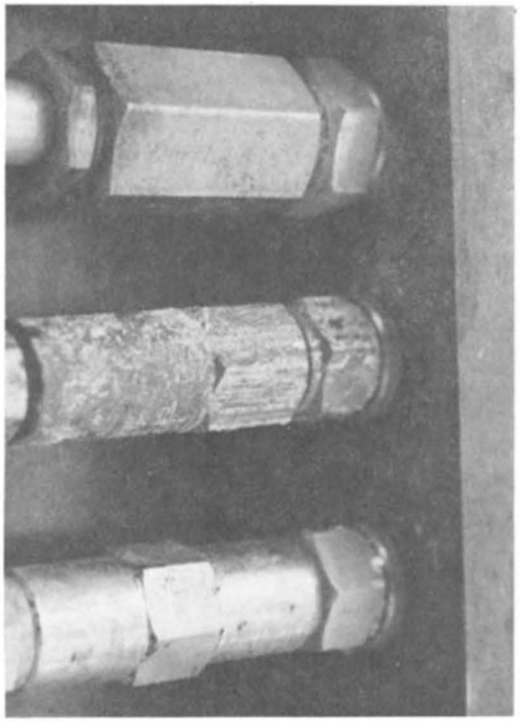

Figure 15. Appearance of three of the cable connectors after 90 days of high humidity/ condensation testing. Top: 6262-T9 with chromate conversion coating. Center: 2011-T3 with no coating. Bottom: Unspecified aluminum alloy with bright tin plating [26].

Phoenix and was heated by the sun to temperatures as high as 150°F, thereby producing both high relative and very high absolute humidities within the vat. Each night the vat would cool off and water would condense on the connectors. Figures 14 and 15 are photographs taken after 3 months of such testing. The results were at least qualitatively similar to those of the first test.

Overly simple corrosion tests can sometimes produce misleading results when there is inadequate control of test conditions or inadequate simulation of the controlling parameters. However, even very simple corrosion tests are usually better than no tests at all if they are interpreted with good judgment.

Evaluation Methods

There is only a limited amount of information which can be gained from a visual examination of corrosion-damaged items of equipment, and often it is impossible to accurately identify the true forms, mechanisms and causes of destructive corrosion without resorting to an analysis using laboratory analytical equipment, some of it rather sophisticated. Table 5 lists some of the analytical techniques which can be employed in order to identify such factors as the forms of corrosion and the compositions of the corrosion products and the corrodent residues, in order to determine and correct the real causes of the corrosion damage. Although such detailed analyses require the expenditure of both time and money, they are justified in many instances because of the danger that the wrong conclusions will be drawn from superficial examinations, resulting in ineffectual "corrective" action.

TABLE 5. EXAMPLES OF INSTRUMENTS USED IN THE ANALYSES OF CORRODED PARTS

[22]

Instrument or Technique	Uses and Advantages
1. X-ray diffraction	Principal use is in the identification of corrosion product oxides. Its major advantage is that it identifies compounds present, rather than just elements. It is capable of distinguishing between different oxides of a single metal.
2. X-ray fluorescence spectroscopy	Used in the identification of elements present in corrosion products, by analysis of the wavelengths emitted by irradiated products. Sensitive method for detecting elements present in amounts greater than 1%.
3. Scanning electron probe microanalysis	Also used in the identification of elements present in corrosion products. Irradiates specimen with electron beam finely focused to about 1 micrometer diameter. Used principally on sectioned and polished specimens to measure the variation in composition through the cross-section of a layer of corrosion. products.
4. Scanning electron microscope	Often used in conjunction with scanning electron probe microanalysis to obtain a high magnification graphical image of the corrosion products being analyzed by the probe. Superior in resolution and depth of field to optical microscopes.
5. Optical photomicrographic techniques	Usually used in the familiar high-magnification photography of sectioned and polished (or etched and polished) specimens for the visualization and study of the morphology of the corrosion effects. Illustrates the form of the metal-oxide interface and the homogeniety of the oxide itself. Permits identification and study of pitting, intergranular corrosion, stress-corrosion cracking, etc.

In an earlier section of the paper the typical use of several types of analytical equipment was described in connection with the investigation of stainless steel/ aluminum alloy galvanic couple specimens.

SUGGESTED PRINCIPLES FOR PREVENTION OF CORROSION IN CATV DISTRIBUTION SYSTEMS

Some specific conclusions which have been drawn regarding destructive corrosion and its prevention in CATV distribution system equipment can be catagorized and summarized as follows:

1. Environmental Effects

   a. For aerial installations, very corrosive environments may exist either near a seacoast or in a fume-polluted industrial area. A combination of the two may be even worse. Sulfur dioxide and the chlorides are the two most aggressive agents in the atmosphere. Concentration of corrosive agents may be highly localized because of local wind, spray or fume conditions, and degree of local sheltering.

   b. For underground vault installations without bell jar type protective covers (liners), any flooding of the vaults is likely to create corrosive conditions. The corrosivity of the flooding water toward aluminum (as an example) is a function of such factors as the pH of the water, the dissolved oxygen content, the conductivity, the concentrations of carbonate, sulfate, and chloride ions and the concentrations of copper and other heavy metal ions. The source of these constituents may be polluted or brackish ground water, or chemically-polluted drainage water.

2. Design Principles for Corrosion Resistance

   a. Equipment should be designed on the assumption that common corrodents will be present in an aggressive atmosphere.

   b. The use of incompatible dissimilar metals on exposed parts of equipment housings should be avoided if possible by referring to reliable galvanic couple compatibility charts.

   c. If incompatible dissimilar materials need to be used together in aggressive environments, the more cathodic material should be plated or otherwise coated with a metal compatible with the anodic material.

   d. The use of individual alloys which are not intended for outdoor exposure in severe environments should be avoided. Coatings should not be depended upon to protect unsuitable materials in aggressive environments - the coatings will corrode or deteriorate eventually.

   e. Caution should be exercised in coating the more anodic materials. Under some conditions it may cause serious pitting at porous sites in the coating and do more harm than good.

   f. Designs which permit stray-current corrosion conditions to exist should be avoided as much as possible.

   g. Unnecessary crevices should be eliminated in equipment designs.

   h. Stress-corrosion susceptible alloys should not be used for parts subjected to external or residual tensile stresses.

3. Corrosion Testing and Evaluation

   a. Maximum use should be made of the vast amount of corrosion research data available in journals and books in the selection of materials and in the design of equipment.

   b. Laboratory "accelerated" corrosion tests can be used - but with caution - to screen new equipment designs and materials for certain types of corrosion susceptibility. The tests must be selected, planned, executed and evaluated with a sound understanding of the deficiencies and limitations of such tests. They should not be construed as predicting life expectancy in a corrosive field environment, or as "proving" corrosion resistance.

   c. Consideration should be given to powering equipment during laboratory corrosion testing in order to simulate field conditions more realistically.

   d. A variety of sophisticated analytical instruments and procedures is available to aid in the identification of corrosion forms, mechanisms, products and agents. Effective use of those techniques should be made in the investigation of important corrosion problems.

   e. On-going efforts are needed to monitor corrosion problems in the field in order to obtain as much significant data as possible, and to try to correlate that data with the results of related laboratory tests.

4. Installation and Operation

a. Selection of equipment intended for installation in severe environmental areas (seacoasts, heavy industrial areas, etc.) should be limited to designs in which corrosion resistance has been seriously considered and emphasized, even though the first cost may necessarily be higher. Replacement of unsuitable equipment can be even more expensive.

b. For underground vault installations, equipment should be mounted inside of bell jar type plastic internal covers (liners) if possible, in order to keep the equipment dry in the event of flooding of the vaults. The installation of a liner of that type is illustrated in figure 16. The distribution equipment must be supported high in the vault in the trapped air pocket created by the internal cover.

c. All service technicians should be alerted to the importance of minimizing corrosion damage by properly installing and maintaining equipment and protective enclosures. The importance of properly torquing housing fasteners to maintain sealing integrity should be emphasized.

CONCLUSION

Destructive corrosion has been encountered in all types of CATV equipment installed in a wide variety of environments. It has been found in both aerial installations and underground installations, and it is almost certain that no equipment manufacturer has been immune to the problem.

There are definite costs associated with maintaining on-going corrosion-prevention programs, and in utilizing good practice in the selection of corrosion-resistant materials and designs. For the equipment manufacturer, it usually means incorporating more expensive materials, processes, and tests in the fabrication of his products. For the system operator, it may mean paying a higher first cost for such equipment and possibly also providing more protective but more expensive enclosures. On the other hand, there can be significant costs to both if a major error is made and a sizable number of corrosion-damaged items of equipment have to be replaced.

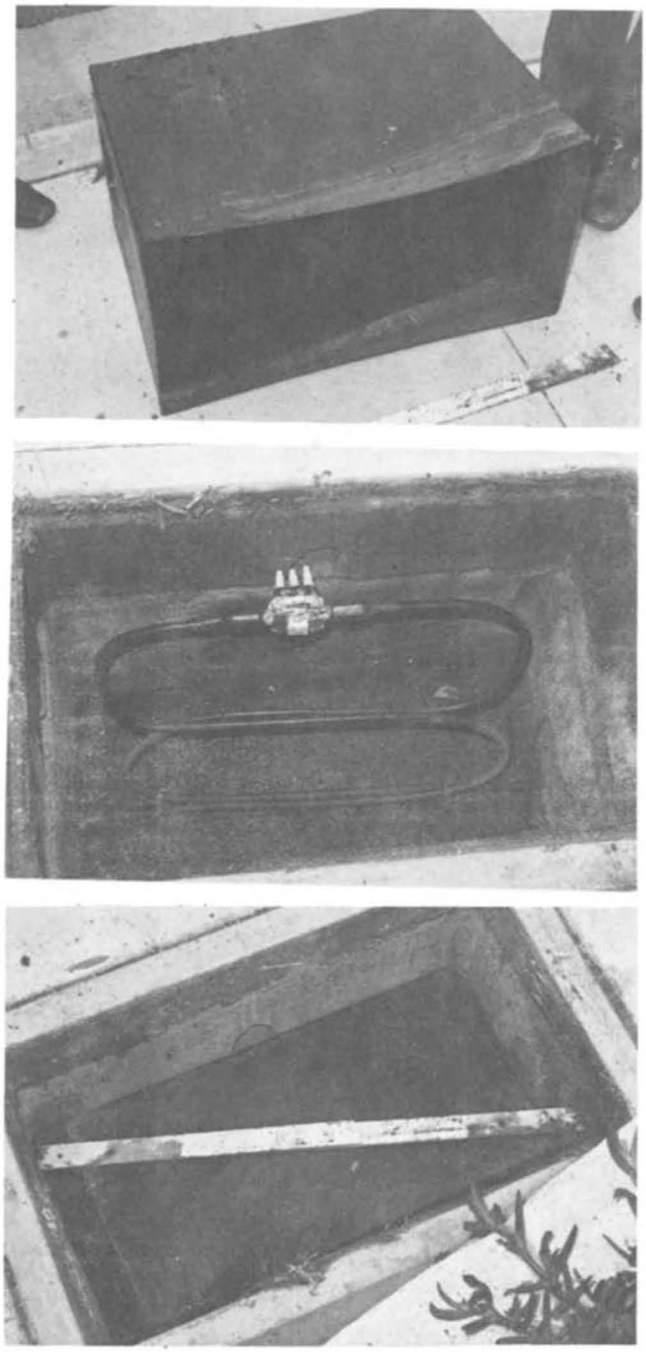

Figure 16. Use of liner in underground vault to provide air trap to protect distribution equipment from water.

Obviously, there is a need to avoid both gross overdesign and gross underdesign from the corrosion standpoint, but unfortunately the dividing line between overdesign and underdesign can vary considerably, depending on the intended location.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contribution of Mr. Carl Halbach of ARTCOR, Irvine, California, in conducting and documenting the investigation of some of the corrosion specimens. They are also indebted to Mr. Robert Hayward of Gilbert Engineering Company, Inc., Phoenix, Arizona, for supplying the previously unpublished information presented in this paper on field stress-corrosion problems and laboratory corrosion testing of coaxial cable connectors. Thanks are also due to Mr. Wayne Briggs of Chomerics, Inc., for supplying copies of both published and unpublished reports on EMI/RFI gaskets corrosion studies for reference.

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