

THE RELATION OF SOIL CHARACTERISTICS AND CHEMICAL CONSTITUENTS
OF SOIL SOLUTIONS TO THE SELF CORROSION
OF UNDERGROUND LEAD CABLE

THESIS

PRESENTED TO THE FACULTY OF THE DEPARTMENT OF CHEMISTRY
OF THE VIRGINIA POLYTECHNIC INSTITUTE
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

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INTRODUCTION

For a number of years the Bureau of Standards has been engaged in a general investigation on the subject of electrolysis and self-corrosion of underground systems in an effort to formulate some means to reduce or mitigate the damages caused by these agents.

In making these investigations, intense studies of the laws governing electrolysis and self-corrosion were made. The term "Electrolysis" is used to designate corrosion resulting from the discharge of an electric current which has entered the structure from an outside source. The term "Self-Corrosion" signifies corrosion caused by electric currents originating within the system itself or by direct chemical action. However, these two general classes of corrosion are not independent of each other, for the amount of damage that may be caused by either of these classes will be greatly increased by the presence of the other class.

While much study seems to have been made on both electrolytic corrosion and self-corrosion of these underground utility systems, very little investigation has been made to determine just how this corrosion is affected by different classes of soils and by the chemical constituents of the soil itself.

This paper is entirely devoted to the latter phase of this subject insofar as it is related to underground lead cable only. The work was carried on in a laboratory along four different lines of investigation, designated respectively as Parts I, II, III and IV. In Parts I and II the self-corrosion of lead was studied in various types of soils at

room temperature and at an elevated temperature respectively. In Part III, the corrosive effects of alkaline and acid solutions of various concentrations were studied, and in Part IV a review was made of an actual condition that existed in telephone cable in Philadelphia during 1924.

Lead-antimony alloy, consisting of 1% antimony, and lead-tin alloy, consisting of 3% tin, were used in these experiments because these two types of materials are used by the Bell Telephone System for cable sheathing. The samples were furnished by the Western Electric Company, through the agency of The Bell Telephone Company of Pennsylvania, and was sheathing that was actually stripped from cables.

The work was done in the laboratories of the Hahnemann Medical College and of the England, Walton Leather Company, both in the city of Philadelphia, and covered a period of approximately eleven months.

I

SELF CORROSION OF ALLOY LEAD CABLE SHEATH AT ORDINARY TEMPERATURE

The first part of this investigation consisted of a study of the soil and chemical corrosion of alloy cable sheath at ordinary temperature. The two kinds of alloys mentioned in the introductory paragraphs of this paper were used for these tests, and samples were prepared by cutting the sheathing into strips of about three inches long and half inch wide.

Five different series of soils were used. One was a muck, containing 28% organic matter, which was secured from dredgings from the Schuylkill River in Philadelphia, Pennsylvania. The second series consisted of a heavy clay containing 4.1% organic matter. The third and fourth series were prepared by mixing the first and second series in a ratio of 2 to 1 and 1 to 2 respectively. The fifth series consisted of natural soil secured from the surface of a well drained field. To each of these series were added various amounts of different chemicals so that the soil solutions would contain some of the most important constituents of natural soil waters. In this manner, ten different types of soils were prepared in each of the five series. The exact nature of each of these types is shown in the accompanying table.

Fifty pots were prepared from these soils and a sample of each of the two kinds of sheath used was placed in each pot. The antimony-alloy samples were bent into the shape of a horseshoe and the straight samples of the tin-alloy

were placed across the ends similarly as an armature rests on the poles of a magnet. This was done to enhance any local galvanic action which might be caused by a difference in e.m.f. between the two kinds of lead.

This experiment covered a period of about ten months, the pots being watered from time to time, whenever the moisture content fell below the desired value.

The observations made at the end of these tests are shown in Table I. Column 1 gives the pot number in each of the soil series; column 2 indicates the amount and kind of addition agent used in the respective pots; and the other columns show the nature of the corrosions observed on each kind of lead in each series. The abbreviations used are explained in the footnotes at the bottom of the table. For example, "V.S.W.*", in column 11, line 5, means that the tin sample in pot number 5 of Series III, containing 20% organic matter and 1.0% calcium acetate, was "very slightly" corroded in spots with the formation of a "white" corrosion product.

It was to be expected that results of experiments conducted as were these investigations, would not be as definite as might be desired, yet general facts may be concluded from a study of the results obtained. Just how much of this corrosion was effected by local galvanic action, is indeterminate from these tests, but reports from the American Committee on Electrolysis indicate that much corrosion is due to this condition. However, tests made by the Engineering Experiment Station of the Purdue University discredit this belief.

While these experiments did show a somewhat wide range of corrosive effects, resulting from the combination of so many conditions, such as moisture, temperature and chemical content, yet the following general conclusions may be derived as a result of the study.

1. In most cases the antimony-lead alloy was less resistant to corrosive action than was the tin alloy. This is probably due as much to the metallurgic property of this alloy as it is to its specific resistivity to chemical corrosion.
2. Acetate and silage (which forms acetic acid) in the soil had a very decided corrosive effect upon the lead sheath.
3. The results secured from the lime tests were very unsatisfactory. This was probably due to varying amounts of free acids that reacted with the lime to vary its alkaline effect. However, there are numerous references in literature to the corrosive action caused by concrete, gypsum and other calcareous compounds, and it is therefore thought that the recent recommendation of the National Cable Compound Company that crushed limestone be used to protect cable from the action of organic acids is of uncertain value.
4. Several references to the corrosive effect of sodium chloride on lead cable have been found in literature; but the tests conducted in this paper do not indicate that this salt has a very detrimental effect. It is probable that the effective agent here would be free chlorine, and under the conditions of these experiments it is not believed that this gas could have been present in the free state.
5. The appearances of the products of corrosion in spots is probably due to the concentration of the effective agent at those places, resulting from the lack of homogeneity in the mixture. However, it is possible that this is largely due to local galvanic action, as accredited by the American Committee on Electrolysis.
6. The compounds resulting from the corrosion were not analyzed, but they are probably very complicated in character. It is thought, however, that at least the following products would be found on analysis: - lead hydroxide, litharge, the sulphate and the carbonate.

TABLE I

Soil Corrosion of Alloy Lead Cable Sheath at Ordinary Temperature

Pot No.	Addition Agent	Series I			Series II			Series III			Series IV			Series V		
		R.	Sb	Sn	R.	Sb	Sn	R.	Sb	Sn	R.	Sb	Sn	R.	Sb	Sn
1	None	A	O	O	A	M	S	A	O	O	A	O	O	A	O	V.S.
2	0.3% CaCO ₃	A	O	O	A	V.S.	S	B	S	O	A	O	O	B	V.S.	V.S.
3	0.1% CaCO ₃	A	O	O	A	S	M.W*	A	V.S.	O	A	S	O	A	S	V.S.
4	0.5% Ca(C ₂ H ₃ O ₂) ₂	A	S.W.	O	A	M	M.B.	A	V.S.	S.B*	A	V.B.	M	N	V.W.	M
5	1.0% Ca(C ₂ H ₃ O ₂) ₂	A	S.W.	S.W.	A	M.B.	V.B.	A	S.W*	V.S.W*	A	M	M	B	V.B.	M
6	2.0% Ca(C ₂ H ₃ O ₂) ₂	B	?	?	A	V.B*W.	V.B*W	B	S.W*	B*W*	A	M	V.S.	B	V.B.W.	V.W.
7	1.0% NaCl	A	O	Bn*	A	O	O	A	O	O	A	O	O	N	S	S
8	0.5% NaCl	A	L	Bn*	A	S.B*	B*	A	O	O	A	O	O	A	V.S.	V.S.
9	1.0% Silage	A	S	Bn*	A	S.W.	S.Bn	A	S*	B	A	S	V.V.S.	A	S.W*	S.W*
10	0.5% Silage	A	S	Bn*	A	?	?	A	S	B	A	S	V.V.S.	A	M	M

Series I - Muck - 28% Organic Matter. No Line
 Series II - Clay - 4.1% Organic Matter. No Line
 Series III - Muck 1 - Clay 2 - 20% Organic Matter
 Series IV - Muck 2 - Clay 1 - 12% Organic Matter
 Series V - Natural Top Soil - 1.3% Organic Matter. No Line

Key:-

A - Acid
 B - Basic
 N - Neutral
 Sn - Tin Alloy
 Sb - Antimony Alloy

O - None
 S - Slight
 W - White Corrosion Product
 Bn - Brown Corrosion Product
 V - Very

M - Moderately Corroded (W)
 B - Black Corrosion Product
 ? - Result Unsatisfactory
 * - Spotted
 R - Reaction of Soil

II

SELF CORROSION OF ALLOY LEAD CABLE SHEATHS AT INCUBATOR TEMPERATURE

A study was made to determine the relation between temperature and the speed of corrosion of underground lead cable. The same kinds of alloy lead were used in this study as were used in the study conducted at ordinary temperature and the samples were prepared in the same way.

Five different types of soils were used in working out these tests; viz:- muck, sand, clay, cinders and a mixture of equal parts of sand, clay and muck. The muck and clay were of the same materials that were used correspondingly in Part I; the sand was ordinary building sand; and the cinders were ordinary coal ashes. Ten additional soil samples were prepared by adding different salts and organic acids to the samples of mixed soils. This preparation completed a series of fifteen types of soils.

Fifteen four-inch flower pots were prepared, each being filled with a soil of a different type, as indicated in Table II. One sample each of the antimony-lead alloy and the tin-lead alloy were placed in each pot. The pots were then saturated with water and were placed in an ordinary chicken incubator. The temperature was regulated to about 42 degrees Centigrade. These tests were allowed to run at this temperature for a period of one week, and at the middle of the period it became necessary to add more water to maintain the desired moisture content.

In preparing the soil samples that were used in this study, an effort was made to use such salts and organic acids as would be more likely found in soil solutions. While the author realizes that the effect of each chemical constituent may be widely affected by the presence of one or more of the others, yet the purpose of these tests was to determine what bearing each of these materials would have of itself, believing that once the individual effects are understood, the combined effects may be more or less calculated.

The results of these tests are shown in Table II. Of the natural soils used, cinders show the greatest corrosive effect. The author thinks that this is due entirely to galvanic action and that the carbon in the cinders acts analogously as a carbon plate in a primary battery. Muck with its large proportion of organic matter and moisture retention property, did not have the corrosive effect that might be expected. This may have been due to the lack of proper oxygen penetration, for while the lack of drainage or a high moisture content enhances corrosion, yet corrosion under these conditions seems to require a longer period of time. The results of the sand and clay tests were as might have been expected.

Benzoic acid, a solid organic compound, had no corrosive effect, while the corrosion caused by tartaric acid was very noticeable, especially on the antimony alloy. Acetic acid had a very decisive effect, as in the experiment conducted at ordinary temperature. Sodium chloride, magnesium chloride and sulphur had no noticeable effect, while potassium carbonate, ferrous sulphate, calcium carbonate and ferric hydroxide had slightly corrosive effect on the antimony alloy only.

As a general conclusion, it was noted that an increase in temperature had a greatly accelerated effect on the corrosion of lead cabling and that in all cases except clay a greater effect was noticed upon the antimony sample.

It is probable that the first products formed in these accelerated tests were the oxides which were hydrolyzed by the water present. These hydrolyzed compounds then reacted with the chemicals present to form complicated salts.

The following conclusions may be drawn from a study of the results obtained in these tests:

1. Where indecisive results were obtained, it is believed that the corrosive action was retarded by excessive moisture content, due to the slow rate at which the oxygen reached the surface of the samples.
2. The antimony-lead alloy was more corroded than the tin-lead sample.
3. The greater amount of corrosion caused by the addition of ferric hydroxide was probably due to catalysis and not to direct chemical action.
4. The corrosive power of the natural soils decreased in order - cinders, sand, clay and muck. However, it is believed that some unsuspected condition caused such poor results from the muck samples.
5. The solid organic acids were less corrosive than the liquid acids.

TABLE II

 SELF CORROSION OF ALLOY LEAD CABLE SHEATHS IN DIFFERENT TYPES
 OF SOILS AT INCUBATOR TEMPERATURE

Type of Soil	Pot No.	Reaction of Soil	Soil Analysis		Addition* Agent	Kind of Lead	Degree of Corrosion
			% CaCO ₃	% Org Mat.			
Muck # (Black Loam)	1	Acid	0	28	---	Sb	None
						Sn	None
Cinders	2	Neutral	0	0	---	Sb	Bad**
						Sn	Bad**
Sand (Bldg.)	3	Neutral	0	0	---	Sb	Little
						Sn	Little
Clay	4	Acid	0	4.1	---	Sb	None
						Sn	M
Mixed Soil §	5	Acid	0	11	---	Sb	None
						Sn	None
Mixed Soil §	6	Acid	0	11	MgCl ₂	Sb	None
						Sn	None
Mixed Soil §	7	Acid	0	11	FeSO ₄	Sb	S
						Sn	None
Mixed Soil §	8	Acid	0	11	Tartaric Acid	Sb	M
						Sn	S
Mixed Soil §	9	Acid	0	11	HC ₂ H ₃ O ₂	Sb	Bad
						Sn	Bad##
Mixed Soil §	10	Acid	0	11	Benzoic Acid	Sb	None
						Sn	None
Mixed Soil §	11	Acid	0	11	Fe(OH) ₃ §§	Sb	S
						Sn	None
Mixed Soil §	12	Acid	1	11	CaCO ₃	Sb	S
						Sn	None
Mixed Soil §	13	Acid	0	11	NaCl	Sb	None
						Sn	None
Mixed Soil §	14	Acid	0	11	S	Sb	None
						Sn	None
Mixed Soil §	15	Acid	0	11	K ₂ CO ₃	Sb	S
						Sn	None

S Slightly corroded.

Muck from bottom of Schuylkill River, Phila., Pa.

* Amt. of Chemical compound added was 1% in each case.

Corrosion worse on Sn sample.

** A white compound formed on sample, more on Sb sample.

§ Mixture of equal parts of muck, clay & sand.

§§ Freshly precipitated.

∅ Corroded in spots.

M Moderately corroded.

THE CORROSIVE ACTION OF ALKALINE AND ACID
SOLUTIONS ON LEAD CABLES

In this part of the study observations were made on the corrosive effects of a strong and weak acid, and also of a strong and a weak base in aqueous solutions on the two types of alloy cabling that were under tests. The corrosion of the lead was determined in its relation to the original concentration of the hydrogen ion in the various solutions. The concentration of the hydrogen ion in any solution is inversely proportional to its acidity and directly proportional to its alkalinity.

As stated in the introduction, two different types of lead alloy cabling were used in the experiments. The antimony alloy contained 1% antimony and the tin alloy contained 3% tin. Samples having a total area of exposed surface of approximately 25 square centimeters were prepared from each alloy. After cleaning the surfaces so that the pure lead alloy would be exposed, the samples were placed in bottles containing approximately 250 c.c. of solution. Tenth normal solutions of nitric and acetic acids and also of sodium and barium hydroxides were prepared. The nitric acid and sodium hydroxide solutions were diluted to normalities of 10^{-2} , 10^{-3} , 10^{-4} and 10^{-5} with both freshly boiled and singly distilled water. The acetic acid solution was diluted to two stages of normalities only, viz:- 10^{-2} and 10^{-3} , with both kinds of water. The barium hydroxide solution was diluted to the same strengths as were the nitric acid and sodium hydroxide solutions, but

with freshly boiled distilled water only. By using freshly boiled distilled water, solutions were prepared that were free from oxygen and carbon dioxide, while the solutions prepared with the unboiled water, contained both of these gases. The bottles containing the gas free solutions were stoppered.

Nitric acid being a strong acid, it was assumed to be completely ionized at the concentrations used. According to Lewis and Randall, the H-ion concentration of N/10 nitric acid is $10^{-1.102}$ and of a N/10⁻² solution is $10^{-2.050}$ etc. Since it was desired only to study the relative effects of solutions of different H-ion concentrations, these values for the five nitric acid solutions were taken to be 10^{-1} , 10^{-2} , 10^{-3} , 10^{-4} , and 10^{-5} , respectively. By the use of Goldberg and Waage's law of Mass Action, and taking the ionization constant of acetic acid as given by Getman to be 1.8×10^{-5} , and the H-ion concentration of water to be 10^{-7} , these values for the acetic acid solutions were found to be 1.45×10^{-2} , 1.14×10^{-3} and 1.3×10^{-3} respectively. In the hydroxide solutions, the H-ion concentrations were calculated to range from 10^{-13} in the strongest solution to 10^{-9} in the most dilute. These values were based on the principle of the constant ion product for water, this value always being equal to 10^{-14} . As the Hyd-ion concentration increases, the H-ion concentration decreases.

These solution tests were continued for a period of 35 days. Samples were drawn and tested at intervals as shown in the accompanying tables. The lead content was determined as explained by Thresh in the "Analyst", Volume 46, 1921, as follows:- ten c.c. samples of each solution were drawn and placed in test tubes. Sodium acetate and acetic acid were used to render these samples practically neutral to litmus. A small

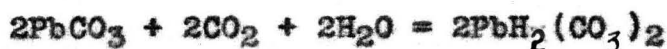
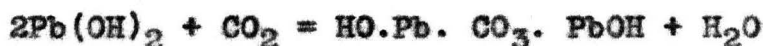
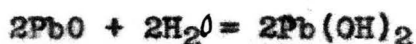
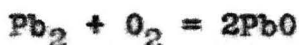
amount of a 1% solution of gelatine was added to each sample to act as a protective colloid, and H_2S was passed through the solution for a few seconds. The intensity of the color given to the solution was indicative of the quantity of lead present. These unknown solutions were compared with standard solutions made up in the same way. A series of ten standard solutions, containing from 0.3 to 1.25 mg. of lead per 10 c.c. was prepared. These standards had to be prepared freshly each time, since it was found that heat and light caused the color to change, due to the formation of colloidal opalescent particles.

Just as soon as the test showed that a solution contained 1.25 mg. of lead per 10 c.c., that particular test was stopped, since results so attained were sufficient to make the desired comparisons. The results of all these tests are shown in the accompanying tables.

Heap, in his article on the action of various kinds of water on lead, published in the Journal of the Society of Chemical Industry, 1913, states that the gases in the soil solutions have more corrosive effects on lead than the acids do. The gases referred to mostly in this article were oxygen and carbon dioxide. It is probably true that oxygen does play one of the most important roles in effecting this corrosion, because there is a certain amount of hydrogen ion in all waters. These hydrogen ions seem to adhere to the lead cable and act more or less as a protective coat; but when oxygen comes in contact with this hydrogen, it combines with it, removing this protection from the cable, thus causing more metallic lead to go into solution. Graham, Miller and Hoffman seem to think that CO_2 , if present in small quantities, also act as a protective agent, but this fact was not observed in the laboratory experiments just made.

However, in these experiments no particular attention was paid to the effect of gases that may have been present, except carbon dioxide in small amounts. And, of course, it is impossible to compare results of experiments in which special attention has been paid to the amount of gases dissolved in the solutions used with results of experiments where no account has been taken of these gases and other foreign matter. The results obtained from the soil tests are indicative of the effects of salts and other natural foreign matter that may be in the soil solutions.

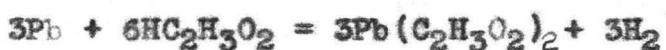
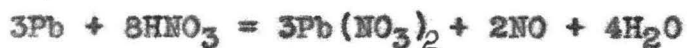
The following reactions will show the possible results of cable corrosion that may be caused by gases alone:



However, in acid solutions, it is believed that the dissolved lead is in the form of the salts of the acids present.

As indicated in the tables samples of both kinds of lead showed practically the same degree of corrosion in the nitric acid solutions. The rapidity with which corrosion took place in these solutions was probably due to the oxidizing effect of the acid itself. In the acetic acid solution, the tin sample seemed to be more resistant than the antimony sample.

As a general consideration of the action of the acid solutions on the lead, the difference shown by the two acids used in these experiments is probably due to the difference in the way that we would expect these acids to act. The following reactions represent a possible result of the corrosion:



It is observed from these reactions that it requires eight moles of nitric acid and only six moles of acetic acid to dissolve three moles of lead. This is probably one reason why the reaction proceeds more slowly in the latter solution.

Another possibility is offered by the ionization property of acetic acid. Just as fast as the H-ion in the solution is used up, by the oxygen present, more free hydrogen is formed by further ionization. For this reason the final results of corrosion in acetic acid solutions are not proportional to the H-ion concentration. This factor was not considered when the laboratory work was under observation.

The great plumbo-solvent action of nitric acid is attributed primarily to its oxidizing property. It is thought that complex reactions may cause the formation of hydrogen peroxide, which also gives a boost to the corrosion.

Spencer, in "Telephony," Vol. 17, 1909, states that even pure water containing free oxygen has a very noticeably corrosive action on underground lead cable, the result of the reaction being the hydrated oxide. The oxide is largely soluble in water and forms an alkaline solution. If this solution absorbs carbon dioxide or ammonium nitrate from the soil, the corrosive action is greatly intensified.

The trend of corrosion that took place in some of the hydroxide solutions is not completely understood. In the tests made with sodium hydroxide, the table shows that the $\text{N}/10^{-4}$ solution had a greater solvent effect upon the lead samples than the $\text{N}/10^{-3}$ solution. Even in most of the tests where less than 0.3 mg of lead were shown to be present in either solution, the weaker solution gave a more intense coloration.

These results may have been caused by some physical circumstance with which the author is not familiar, yet the heat and light conditions under which the experiments were conducted were the same in all instances. However, a comparison of the results indicates that the antimony is the more resistant of the two samples in both of the alkaline solutions.

A comparison of Tables III-C and III-D will show a greater corrosive action in the barium hydroxide solution than in the sodium hydroxide. Professor Anderegg, of the Purdue University, attributes this fact to the greater coagulating power of the divalent barium ion over that of the univalent sodium ion. When lead dissolves in alkaline solutions, lead hydroxide is ultimately formed, and this hydroxide often remains in solution to varying degrees of supersaturation. Because of the greater coagulating power of the barium ion, the lead hydroxide begins to precipitate out of this solution at a less degree of supersaturation than it does in the sodium solution. As this precipitation takes place, more lead is dissolved due to the alteration in the equilibria of the solution.

TABLE III-A

SPEED OF CORROSION OF ALLOY LEAD CABLE SHEATHS IN NITRIC ACID
OF VARIOUS CONCENTRATIONS

SOLUTION STRENGTH	N/10				N/10 ⁻²				N/10 ⁻³				N/10 ⁻⁴				N/10 ⁻⁵			
	A-1 ∅	A-2 ∅	T-1 ∅	T-2 ∅	A-3 ∅	A-4 ∅	T-3 ∅	T-4 ∅	A-5 ∅	A-6 ∅	T-5 ∅	T-6 ∅	A-7 ∅	A-8 ∅	T-7 ∅	T-8 ∅	A-9 ∅	A-10 ∅	T-9 ∅	T-10 ∅
1ST DAY	§	§	§	§	§	§	§	§	.6	.5	.6	.5	.5	.4	.5	.4	#	#	#	#
4TH DAY	-	-	-	-	-	-	-	-	§	§	§	§	1.25	1.25	1.25	1.25	#	#	#	#
7TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.3	.2	.3	.2
10TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.5	.3	.5	.3
13TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4
16TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4
20TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4
25TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4
30TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4
35TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6	.4	.6	.4

NOTES:-

- * - A and T denote antimony and tin samples.
Odd numbered samples contain CO₂ in solution.
Even numbered samples were free from CO₂.
- § - Denotes that sample contained more than 1.25 mg of lead in 10 c.c.
- # - Denotes that sample contained less than 0.3 mg of Pb in 10 c.c.
- ∅ - Corrosion expressed in mg of Pb in 10 c.c. of solution.

TABLE III-B

SPEED OF CORROSION OF ALLOY LEAD CABLE SHEATHS IN ACETIC
ACID SOLUTIONS OF VARIOUS CONCENTRATIONS

SOLUTION STRENGTH	N/10				N/10 ⁻²				N/10 ⁻³				
	JAR NO.*	A-11	A-12	T-11	T-12	A-13	A-14	T-13	T-14	A-15	A-16	T-15	T-16
	φ	φ	φ	φ	φ	φ	φ	φ	φ	φ	φ	φ	φ
1ST DAY	.6	.5	.5	.4	.5	.4	.5	.4	.4	.4	.4	.4	.4
4TH DAY	1.25	1.1	1.0	.8	.8	.7	.7	.6	.6	.6	.6	.5	.5
7TH DAY	-	§	§	1.1	1.1	1.0	.9	.8	.8	.7	.6	.6	.6
10TH DAY	-	-	-	-	-	1.25	1.1	1.1	1.0	.8	.7	.7	.7
13TH DAY	-	-	-	-	-	-	§	§	1.25	.8	.7	.7	.7
16TH DAY	-	-	-	-	-	-	-	-	-	1.0	.9	.8	.8
20TH DAY	-	-	-	-	-	-	-	-	-	1.20	1.0	.9	.9
25TH DAY	-	-	-	-	-	-	-	-	-	§	1.20	1.0	1.0
30TH DAY	-	-	-	-	-	-	-	-	-	-	§	1.20	1.20
35TH DAY	-	-	-	-	-	-	-	-	-	-	-	-	§

- - A and T denote antimony and tin samples.
Odd numbered samples contained CO₂ in solution.
Even numbered samples contained no CO₂ in solution.
- § - Denotes that sample contained more than 1.25 mg.
of Pb in 10 c.c. of solution.

TABLE III-C

SPEED OF CORROSION OF ALLOY LEAD CABLE SHEATHS IN SODIUM HYDROXIDE SOLUTIONS OF VARIOUS CONCENTRATIONS

SOLUTION STRENGTH	N/10				N/10 ⁻²				N/10 ⁻³				N/10 ⁻⁴				N/10 ⁻⁵				
	JAR NO. *	A-17	A-18	T-17	T-18	A-19	A-20	T-19	T-20	A-21	A-22	T-21	T-22	A-23	A-24	T-23	T-24	A-25	A-26	T-25	T-26
	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
1ST DAY	.8	.6	.6	.4	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
4TH DAY	§	§	§	§	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
7TH DAY	-	-	-	-	.3	.3	.3	.8	#	#	#	#	#	#	#	#	#	#	#	#	#
10TH DAY	-	-	-	-	.5	.4	.5	.3	#	#	#	#	#	#	#	#	#	#	#	#	#
13TH DAY	-	-	-	-	.7	.6	.7	.5	#	#	#	#	#	#	#	#	#	#	#	#	#
16TH DAY	-	-	-	-	.9	.8	.9	.8	#	#	#	#	#	#	#	.3	.3	#	#	#	#
20TH DAY	-	-	-	-	1.1	1.0	1.2	1.0	#	#	#	#	#	#	#	.3	.3	#	#	#	#
25TH DAY	-	-	-	-	1.25	1.2	§	1.25	#	#	#	#	#	.3	.3	.3	.3	#	#	#	#
30TH DAY	-	-	-	-	-	§	-	§	#	#	#	#	#	.3	.3	.4	.4	#	#	.3	.3
35TH DAY	-	-	-	-	-	-	-	-	#	#	#	#	#	.3	.3	.4	.4	.3	.3	.4	.4

ϕ - Corrosion expressed in mg of Pb in 10 C.C. of solution.

* - A and T denote antimony and tin samples.

Odd numbered samples contained CO₂ in solution.

Even numbered samples were free from CO₂.

§ - Denotes that sample contained more than 1.25 mg of Pb in 10 C.C.

- Denotes that sample contained less than 0.3 mg of Pb in 10 C.C. of solution.

TABLE III-D

SPEED OF CORROSION OF ALLOY LEAD CABLE SHEATHS IN BARIUM HYDROXIDE SOLUTIONS OF VARIOUS CONCENTRATIONS

SOLUTION STRENGTH	N/10		N/10 ⁻²		N/10 ⁻³		N/10 ⁻⁴		N/10 ⁻⁵	
	A-28	T-28	A-30	T-30	A-32	T-32	A-34	T-34	A-36	T-36
JAR NO.*	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø
1ST DAY	.4	.5	#	.2	#	#	#	#	#	#
4TH DAY	1.0	1.2	.2	.5	#	#	#	#	#	#
7TH DAY	§	§	.5	1.1	#	#	#	#	#	#
10TH DAY	-	-	.9	§	#	#	#	#	#	#
13TH DAY	-	-	1.25	-	#	#	#	#	#	#
16TH DAY	-	-	-	-	#	#	#	#	#	#
20TH DAY	-	-	-	-	#	#	#	#	#	#
25TH DAY	-	-	-	-	#	#	#	#	#	#
30TH DAY	-	-	-	-	#	#	#	#	#	#
35TH DAY	-	-	-	-	#	#	#	#	#	#

- ø - Corrosion expressed in mg of Pb in 10 c.c. of solution.
- * - A and T denote antimony and tin samples. No CO₂ in solution.
- § - Denotes that sample contained more than 1.25 mg of Pb in 10 c.c. of solution.
- # - Denotes that sample contained less than 0.3 mg of Pb in 10 c.c. of solution.

IV

EFFECT OF DRAINAGE WATERS ON THE CORROSION OF LEAD CABLE AS SHOWN BY FIELD TESTS

The last part of this paper is devoted to a review of a condition that was experienced by The Bell Telephone Company of Pennsylvania in the city of Philadelphia in the summer of 1923 and the winter of 1924. For some time past, the telephone cables in the vicinity of Thirteenth and Filbert Streets were frequently the cause of trouble in telephone communication in that section. Investigations showed that this trouble was due to corroded cable sheath, and yet, electrolysis tests indicated that the cable was negative to earth.

The corrosion of these cables was then attributed to Chemicals that may have been in the drainage waters. Samples of this water, together with samples of the corroded cable, were prepared for analysis in an effort to determine the cause of the corrosion. Composite and separate samples of the drainage water were taken on four different dates, each sample being appropriately marked. The analysis of this water is shown in Table IV.

The lead sheathing samples were analyzed also and it was found that lead carbonate, lead chloride, and lead sulphate were present, and yet, there seemed to be no chemical present in the drainage water in sufficient quantity to cause such chemical corrosion. It is true that free chlorine does attack lead to an appreciable extent, but it is improbable that the chlorine found in this water was in the free state.

It is the opinion of the present author that this corrosion was actually caused by either one of the following reasons, or both:-

First: Electrolysis, augmented by the presence of this drainage water, impregnated as it was with these Chemicals. This is probable, in spite of the fact that whenever electrolysis tests were made, the cable was negative to earth.

Second: By pure chemical corrosion, caused at intervals by wastes from industrial plants finding their way into the drainage waters in this vicinity.

From the results shown by these experiences, it seems clear that drainage waters are probable causes of lead cable corrosion, both because of the Chemicals that they may contain, and because they set up more favorable conditions for electrolytic action.

TABLE IV

ANALYSIS OF WATER TAKEN FROM MANHOLE
AT 13TH AND FILBERT STREETS, PHILADELPHIA, PENNA., 1924

SUBSTANCE	QUANTITY (GR. PER GAL.)
Total Solids	10.8
Organic Matter	4.0
Silica (SiO ₂)	0.8
Sulphuric Anhydride (SO ₃)	0.7
Chlorine (Radical)	1.2
Iron Oxide & Alumina (Fe ₂ O ₃ & Al ₂ O ₃)	0.2
Calcium Oxide (CaO)	2.7
Magnesium Oxide (MgO)	0.1
Sodium Oxide (Na ₂ O)	1.1
Potassium Oxide (K ₂ O)]	

NOTE:

It is probable that the following salts were present in molecular form in the solution:

NaCl; CaSO₄; CaCO₃; MgCO₃.

Much suspended matter was also present.

GENERAL SUMMARY

The experiments made in this study covered the investigation of the "self corrosion" of antimony and tin alloy lead cable sheath that was effected by various soil characteristics and by various classes of soil solutions. The study was made entirely with laboratory specimens and solutions and while it was difficult to attain the desired results, yet results of sufficiently distinctive character were secured in most cases to permit of an intelligent comparison and interpretation.

In general, the principal causes of soil corrosion of underground lead cable are the presence of organic matter and poor drainage. When organic matter decomposes the resulting organic acids, mainly acetic, attack the cable sheath with resulting corrosion products. Moisture, up to a certain point, is very detrimental, not only in aiding electrolysis, but by causing the formation of hydroxides. However, the presence of a great amount of water seems to retard corrosive action by making the approach of oxygen difficult. The presence of oxidizing agents, such as the nitrates, also enhances corrosion.

The nature of soil corrosion on cable sheath is usually that of a crater-like pitting of the surface. In these pits are found the corrosive products, probably lead salts in the form of carbonate or sulphate. The amount of corrosion varies over different parts of the surface, due to the non-uniform distribution of the agent causing the corrosion.

Just how much of this corrosion is effected by local galvanic action is indeterminable from this study, but the American Committee on Electrolysis holds this as a very important factor.

Alkalis, as well as acids, have detrimental corrosive effects on lead cable. This was shown very decisively in this study, and for these reasons, it is thought a bad policy to place non-protected cable in the vicinity of calcareous substances, such as concrete. In some cases where acids are probably present in drainage waters, limestone placed near the cable may have a neutralizing effect, but to what extent this principle should be practised is a matter for conjecture.

It is believed that the chief corrosive effect of salts is due to their aid to galvanic action. However, in many cases it is evident that they also effect corrosion products by chemical union with the cable sheath itself.

From this study it is evident that the whole matter of the corrosion of lead in the soil is very complicated. Not only does the peculiar amphoteric character of this metal enter into the problem, but also the physical character of the metal structure itself. These factors, combined with the complexities of the chemical content of the ground solutions, make the whole question of the soil corrosion of lead a matter for further and more intense study.

In conclusion, the author wishes to express his appreciation to Mr. D. S. Hilborn, Electrolysis Engineer of The Bell Telephone Company of Pennsylvania, and Professor F. O. Anderegg of the Chemistry Department of the Purdue University, for their advice and directions in the conduction of these experiments.

BIBLIOGRAPHY

1. Anon. Electrical Review and Western Electrician.
Vol. 63, 1913.
"Organic Acids Formed by the Action of Moisture on
Wooden Supports".
2. Burton McCullum, E.E. Bureau of Standards
Technologic Paper No. 26, December 1915.
"Earth Resistance and its Relation to Electrolysis
of Underground Structures".

Technologic Paper No. 15, January 1915.
"Surface Insulation of Pipes as a Means of Preventing
Electrolysis".
3. R. S. Dean, Journal of American Chemical Society,
Vol. 45, 1923.
"Some Experiments on the Metallography of the System,
Antimony - Lead".
4. R. H. Gaines, Engineering Record, Vol. 67, 1913.
"corrosive Action of Water on Pipes".
5. A. J. Hale and A. S. Foster, Journal of the Society of
Chemical Industry, Vol. 34, 1915.
"Corrosion of Lead in Contact with N/10 Solutions of
some Acids, Alkalies and Salts".
6. H. S. Hannum, Telephone Facts, Vol. 12, No. 10, 1922.
"Use of Limestone to Protect Lead Covered Cable from
the Action of Manure, Cinders and Made Ground".
7. H. Heap, Journal of the Society of Chemical Industry,
Vol. 32, 1923. "A Study of the Action of Various
Waters and Solutions on Lead".
8. Stephen Isom, "Data Compiled on Underground Cable With-
out the Use of Conduit". The National Cable Compound
Company, Mitchell, Ind., 1922.
9. Journal of the American Institute of Electrical Engineers.
Vol. 35, Part II.
10. Latest Report of the American Committee on Electrolysis,
published in 1921.
11. Preliminary Report of the American Committee on Elec-
trolysis, published in 1916.

12. E. B. Rosa, Chief Physicist, Bureau of Standards Technologic Paper No. 27, June 1913.
"Special Studies in Electrolysis Mitigation".
Technologic Paper No. 52, November 1918.
"Electrolysis and its Mitigation".
13. J. W. Shipley, Journal of the Society of Chemical Industry, Vol. 41, 1922.
"The Corrosion of Lead Pipes in Alkaline Soils".
14. T. G. Spencer, Telephony, Vol. 17, 1909.
"A Discussion of Electrolytic Corrosion and Self-Corrosion and Their Prevention".
15. L. A. Stenger, Chemical and Metallurgical Engineer, Vol. 22, 1920.
"Soil Waters Rapidly Corrode Lead Cable Sheath".
16. J. C. Thresh, Analyst, Vol. 46, 1921.
Vol. 47, 1922, Vol. 48, 1922.
"An Important Series of Papers on the Action of Natural Waters on Lead".
17. S. S. Wyer, Consulting Engineer, Columbus, Ohio.
"Digest of Publications of Bureaus of Standards on Electrolysis of Underground Structures Caused by the Disintegration of Stray Electric Currents from Electric Railways".
(January 1918)