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CORROSION AND PROTECTION OF UNDERGROUND TANKS AND BURIAL VAULTS

CONTENTS

I. INTRODUCTION

During recent years the Bureau of Standards has received increasing numbers of requests for information concerning the corrosion of underground tanks and burial vaults. To meet these requests in an efficient way it has seemed desirable to assemble such information as the Bureau has at hand which pertains to this subject. The Bureau of Standards has made no direct tests of the action of soils on buried containers but it has conducted extensive investigations of the corrosion of pipe materials and pipe lines together with studies of methods for reducing underground corrosion losses. Much of this information is pertinent to underground containers so far as they are affected by soils, although the application of the data is somewhat different from their use with respect to pipe lines.

As most of the inquiries come from people who may be unfamiliar with the technical features of corrosion, this paper will deal with its subject in a non technical way.

II. CAUSES AND CHARACTERISTICS OF CORROSION

Any lack of uniformity in the buried metal, in the soil which surrounds it, or in the contacts between the metal and the soil, is a potential cause of corrosion, although the importance of some of the differences may not be great. Soils differ greatly from place to place, as anyone who has had occasion to watch the laying of a pipe line has probably noticed. These differences occur in the texture of the soils, which ranges from gravel to very minute particles of clay. As great differences occur also in the chemical constituents of soils. Some soils contain acids resulting from the decay of vegetable matter and from poor drainage; others contain considerable quantities of salts or basic materials which are formed from the disintegration of rocks. Both types of soils may be corrosive for different reasons.

An important characteristic of underground corrosion is its uneven depth. A pit may puncture a sheet of steel before the sheet has lost more than a few percent of its weight. This is particularly important with respect to underground containers of fluids, since a leak may occur at one point while the metal at some nearby point is practically uncorroded. In this connection the Bureau of Standards data on the penetration of buried metals by pits are of special importance. They have three characteristics which may not be realized by casual readers of the reports on the Bureau's soil-corrosion investigation. One of these is that in most well drained soils the rates at which the pits deepen decrease with time. In some soils the pits may reach a limiting depth. The fact that for most soils the rate of corrosion decreases with the period of exposure has occasionally been misunderstood or its significance misinterpreted. It is of considerable importance in the interpretation of data for very short periods of exposure, i. e., periods of a few years or less, particularly if the soils are well aerated or well drained. After a few years the rate changes but slowly, and if the rate is based on an exposure of ten or more years the error made by assuming that the pit depth at some future time will be proportional to the age of the buried metal will probably not be larger than the uncertainty of the results, because of the lack of accuracy of the original data and the erratic nature of underground corrosion. Table 1 shows the estimated maximum pit depth on 0.4 square foot of wrought iron or steel for an exposure of 12 years. The estimate is based on observations of from 24 to 3[illegible] specimens. The table also shows the standard deviation of the estimate.

Table 1[1]

Estimated Depth of Deepest Pit on 0.4 sq ft of Steel Exposed for 12 Years.

Soil No. and Name	Location of Test Site	Pit Depth in Mils[2]	Standard Deviation
2- Bell clay	Dallas, Tex.	55.3	7.5
3- Cecil clay loam	Atlanta, Ga.	76.6	13.1
4- Chester loam	Jenkintown, Pa.	97.3	28.9
7- Fairmount silt loam	Cincinnati, O.	45.4	8.6
8- Fargo clay loam	Fargo, N.D.	90.9	19.9
11- Hagerstown loam	Baltimore, Md.	79.8	16.9
14- Hempstead silt loam	St. Paul, Minn.	108.2	29.2
16- Kalmia fine sandy loam	Mobile, Ala.	81.5	16.3
17- Keyport loam	Alexandria, Va.	46.7	5.0
18- Knox silt loam	Omaha, Neb.	61.6	25.3
19- Lindley silt loam	Des Moines, Ia.	69.3	11.5
22- Memphis silt loam	Memphis, Tenn.	64.3	6.2
25- Miami clay loam	Milwaukee, Wis.	53.4	9.9
28*-Montezuma clay adobe	San Diego, Calif.	175.3	32.4
30- Muscatine silt loam	Davenport, Ia.	64.4	17.8
32- Ontario loam	Rochester, N.Y.	63.9	12.7
36- Ruston sandy loam	Meridian, Miss.	53.2	7.0
37- St. Johns fine sand	Jacksonville, Fla.	79.0	20.3
39- Sassafras silt loam	Wilmington, Del.	69.3	66.6
40- Sharkey clay	New Orleans, La.	86.1	24.2
41- Summit silt loam	Kansas City, Mo.	79.1	11.3
42- Susquehanna clay	Meridian, Miss.	108.4	17.8
43- Tidal marsh	Elizabeth, N.J.	123.9	32.1
44- Wabash silt loam	Omaha, Neb.	69.6	13.2

1 From NBS J.Research 16, 449.
2 A mil is 0.001 inch.
* Specimens exposed for 10 years only.

The standard deviation indicates how much a single observation may be expected to differ from the average. If the data were normally distributed 95 percent of the observations should not differ from the average by more than twice the standard deviation. Actually data on maximum pit depths are not distributed normally and somewhat less than 95% of the observations of pit depths for certain soil conditions have been found to lie within the range of the average plus or minus twice the standard deviation.

Table 2 which gives the thickness of some of the sheet metals used in the construction of some underground tanks and grave vaults, will be of interest when table 1 is considered.

Table 2. Thickness of Sheet Metal Used in Underground Construction.

U.S. gage No.	Thickness in mils[1]
3	250
4	234
5	219
6	203
7	188
8	172
9	156
10	141
11	125
12	109
13	94
14	78
15	70
16	65
17	56
18	50

[1] A mil is 0.001 inch.

Another characteristic of soil corrosion is that on the average the deepest pit on a large area will be deeper than the deepest pit on a smaller area of the same metal exposed to the same soil conditions, i.e., there is a greater probability of a leak developing in a large tank than in a small one having the same wall thickness. The importance of this fact is somewhat reduced by the fact that usually large tanks are made of thicker material than small ones. However, if the Bureau's data* on maximum pit depths are to be used in estimating the pit depth on a grave vault or a 1000-gallon tank they should be increased by a factor of from 2 to 3 depending on soil conditions.

*See appendix for list of Bureau of Standards publications on underground corrosion.

The third important characteristic of soil corrosion data is that they are reproducible only within rather large limits. Two tanks subjected to apparently identical soil conditions may not serve for the same time.

While the average of a number of tests is reproducible to a satisfactory degree, the individual observations may differ widely and the average indicates only in a rough and general way what may happen in a single case. On this account some allowance as a factor of safety should be made when corrosion data are used to estimate the minimum expected life of a buried tank.

Corrosive and non-corrosive soils occur in almost all parts of the United States and often lie quite close to each other. Usually well drained soils are not corrosive, but this is not always the case. A number of tests have been developed by means of which the corrosiveness of a soil can be determined roughly. These tests, however, are only reliable when made and interpreted by one familiar with such work.

One who is seriously concerned with underground corrosion should therefore have tests made by an expert in soil corrosion or assume that the soils may be corrosive and protect his property accordingly. There are a large number of ways of avoiding corrosion losses, each of which has its place under some conditions and most of which are inadvisable under other conditions.

III. CORROSION RESISTANT MATERIALS

Perhaps the ideal way to avoid corrosion would be through the use of an inexpensive corrosion resistant material. Several inexpensive materials which are resistant to certain corrosive conditions are available. Unfortunately, different conditions require different materials. Copper-bearing steel is a particularly good example of this. When copper-bearing steel is exposed to atmospheric corrosion, a thin, dense coating of rust is formed which greatly retards further corrosion. The same material does not appear to be especially resistant to corrosion when exposed to water or to soils. Other examples could be cited. The problem is therefore to find a material suited to the conditions to which it will be exposed, and in the solution of this problem the wide range of soil properties must be kept in mind. A metal which resists one soil condition may be unsuitable for a different soil.

Commercially pure iron probably loses weight somewhat more slowly than ordinary steel, but the specimens of this material in the Bureau of Standards tests were not superior to other metals tested with respect to the depth of the deepest pits. The precision of these tests was insufficient to positively indicate that any one of the ferrous materials commonly used for pipes was superior to the others. Steels containing small percentages of chromium, copper, molybdenum, silicon or nickel do not differ greatly from steels without the alloying elements in their resistance to soil corrosion. There is some indication that phosphorus in steel tends to decrease the rate of pitting but the evidence is not conclusive.

High percentages of chromium alone are insufficient to prevent serious corrosion in soils containing chlorides. Stainless steel of the 18-8 variety is very resistant to most of the soils to which it was exposed. There is some indication that the surface finish and heat treatment of this material affects its resistance to corrosion.

Gray cast iron corrodes as fast as or faster than steel under most soil conditions. However, it is usually thicker than steel used for the same purpose and a larger part of the corrosion products remains in place. These combined with the impurities or alloys in cast iron tend to plug the pits and add somewhat to the strength of the remaining metal so that under favorable conditions badly corroded cast iron will continue to withstand moderate pressures.

White or chilled cast iron may be somewhat more resistant to corrosion than gray cast iron because of the reduction in the number and size of graphite flakes, since corrosion in gray iron seems to follow these graphite particles. The very limited data available on malleable iron indicate that it corrodes at about the same rate as steel.

Of the non-ferrous metals which have been tested by the Bureau, copper and alloys containing 80 or more percent of copper are the most generally resistant to soil action. Copper corrodes in soils containing large percentages of decaying organic matter. Yellow brass corrodes badly in some soils on account of dezincification. Very limited tests of aluminum and two of its alloys indicated that these materials were unsatisfactory in alkali soils.

Lead forms its own protective coating when subjected to well aerated soils containing carbonates or sulphates but there are a few soils in which lead pits rather badly. Zinc also pits deeply in some soils.

A very rough idea of the relative merits of some of the commonly used materials may be obtained from table 3. Only in rare cases will tanks be placed in muck or tidal marsh soils. Not all of the data are strictly comparable because of differences in the ages and dimensions of the specimens but the errors due to these causes are probably not very large. The pit depths recorded are the averages of the two deepest pits on each of ten specimens each having an area of about 20 square inches of surface or of a proportionately greater number of pits on larger areas. When the data are applied to larger areas they should be increased for reasons already explained. A method* for adjusting corrosion data to take account of the effects of time and area has been proposed for ferrous materials.

*K.H.Logan, S.P.Ewing, and I.A.Denison. Soil corrosion testing. A.S.T.M. Symposium on Corrosion Testing Procedures (1937).p.95.

Sufficient data are not available to establish the effect of time and area on the pit depths on non-ferrous materials. For some of them, at least, it seems probable that the rate of penetration is proportional to the period of exposure.

IV. PROTECTIVE COATINGS FOR BURIED METALS

All of the data referred to above are based on tests of the materials with no protective coatings except such as are formed in the course of their manufacture or by the action of the atmosphere or the soil to which they were exposed. While few metallic structures except pipe lines are exposed to soil without some protective coating, it seemed best to test metals and coatings separately in order that it might be possible to distinguish between the corrosion-resisting properties of the two classes of materials.

1. Metallic Coatings.

Metallic coatings may protect the metal to which they are applied in one or both of two ways. The metal of the coating may be more resistant to corrosion than the base metal or it may be more corrodible and protect the base metal because of the galvanic action set up when the base metal is exposed in spots.

If the coating is more noble in its nature and is punctured by pinholes or abrasion the resulting galvanic corrosion may accelerate the corrosion of the base metal.

A very good discussion of metallic coatings has been prepared by Rawdon* who describes methods of application and testing but presents only limited data on the behavior of coatings underground.

*H.S.Rawdon. Protective metallic coatings. The Chemical Catalog Co.

(a) Zinc.- Zinc applied by the hot-dip process is the most commonly used metal for a protective coating. Zinc corrodes less rapidly than steel in many soils and when the iron or steel is finally exposed galvanic action tends to prevent corrosion of

Table 3. Ten-year rates of pitting (1) of ferrous and non-ferrous materials in different types of soils.

Type of soil	Cast iron	Open hearth iron	Wrought iron	Bessemer steel	Copper bearing steel	Copper	Bronze	Brass (60-40)	Zinc (cast)	Lead (chemical)	Aluminum	Al-Mn alloy
Black alkali	17.8[2]		11.9[2]	19.3[2]	16.7[2]	M[3]	1.1	D[4]	7.0	1.7	f[5]	f
Muck	13.0	16.2	9.7	9.2	15.3	S[6]	5.5	P[7]	5.5	1.3	f	f
Clay	13.3	8.3	8.4	9.2	9.9	p	M	D	1.8	2.5	f	1.4
Tidal marsh	7.2	11.4	7.7	7.4	13.7	-	1.1	D	6.8	1.2	P	1.3
White alkali	19.9	14.6	11.5	11.9	15.2	p	3.1	D	9.8	1.8	f	1.9

1 - in mils per year
2 - these rates are based on 8-year-old specimens having larger areas.
3 - M = surface roughened - no definite pits.
4 - D = dezincified.
5 - f = specimen destroyed or punctured.
6 - S = severe surface corrosion, nearly uniform.
7 - P = pits too shallow to be measured.

the ferrous metal until the zinc immediately adjacent to the exposed point has been removed. The extent of this galvanic protection depends upon the thickness of the zinc and probably to some extent on the electrical conductivity of the soil solution. Opinions as to the effectiveness of zinc as a coating differ widely, partly because of the differences in soil conditions to which the galvanized materials were exposed and partly because of the differences in the weights of coatings tested.

The Bureau of Standards experiments do not show definitely what soil conditions are favorable or unfavorable to galvanized materials, but a coating of 2.8 oz per sq ft prevented the formation of measurable pits in all but one of the soils to which it was exposed for 10 years. This soil contained relatively large percentage of sulphates and was very corrosive with respect to iron and steel. In order to get a coating of this thickness on formed sheet metal it would probably be necessary to galvanize the container after it was formed since heavy coatings of zinc scale off when the metal is bent sharply.

(b) Lead.- The lead coatings applied to the pipes in the Bureau of Standards tests were, on the average, from 0.002 to 0.003 inch in thickness with spots which were much thinner. Some of the coatings probably contained pinholes also.

The tests referred to indicate that the lead coatings were inferior to the zinc coatings in the same tests. This may be due to pinholes, or because the lead corroded sufficiently to expose the steel to which it was applied. The galvanic action set up when the steel was exposed tended to accelerate the pitting. Nevertheless, on the average, the pits on the lead-coated specimens were fewer and shallower than on unprotected steel during the first ten years of exposure. The behavior of lead suggests that in many soils a heavy coating of lead free from pinholes might afford excellent protection to steel.

(c) Aluminum-Calorized (aluminum-coated) specimens were exposed to so few soils that the data are inconclusive. However, the indications are that calorizing as applied to the specimens tested is not altogether successful, though it appears to reduce materially the rate of penetration at least for 8 years.

The behavior of copper, stainless, steel, and steel high in nickel suggests that ply metal consisting of ordinary steel with a layer of the other metal on the outside might provide material for a corrosion-resistant tank. The base metal exposed at cut edges might be protected by the noble metal sprayed on. The Bureau has made no tests to support this suggestion.

Limited tests of oxide coatings such as foundry and mill scale indicate that these coatings tend to protect the metal beneath them but that it is difficult to maintain a continuous coating and where the coating is broken galvanic action tends to accelerate corrosion and to loosen more of the coating. The question of whether or not mill scale should be removed before another coating is applied is a controversial one. If mill scale is removed it is necessary to coat the metal immediately as rusting begins within a few hours if the atmosphere is damp. Slight rusting interferes with the adhesion of many protective coatings.

2. Non-Metallic Coatings.

(a) Paints, Lacquers, and other Thin Coatings.- The Bureau of Standards has exposed a large number of paints, lacquers, and other thin coatings of organic material and has found that with few exceptions such coatings contain pinholes and permit rust to develop beneath them within a few years. The general conclusion is that thin organic coatings do not offer complete protection to metal exposed to severely corrosive soils although many of them materially reduce the loss of weight during the first few years of their use. Additional tests are under way and it is of course possible that a satisfactory thin coating will be found. In several cases the pit depths on specimens protected by thin coatings have been deeper than those on the corresponding unprotected specimens. It is impossible to determine positively at this time whether such results are accidental. However, until the value of some thin coating has been definitely established it is safer to use a thick protective coating where soils are corrosive.

(b) Thick Bituminous Coatings.- Bituminous coating materials originate mostly from two sources, - the refining of petroleum and the manufacture of gas or coke from coal. The petroleum products are known as asphalts. They differ among themselves because of the differences in petroleums and because of refining processes and subsequent treatment. Coal tar pitches also differ greatly in several respects.

Other things being equal, coal tar pitch absorbs less moisture than does asphalt, is more brittle and more sensitive to changes in temperature. The hardness of each material depends partly upon its softening point which can be modified to a large extent by the manufacturer. If the bitumen is too hard it may crack and spall off when subjected to a sudden blow or change in temperature. If the softening point is too low the bitumen may flow under its own weight or under the pressure of the soil to which it is exposed. The properties of some bitumens are improved with respect to their use as protective coatings by the addition of inert material such as finely divided silica, mica, slate, or limestone. Such mixtures are frequently called enamels.

Both the asphalt base and the coal tar pitch base enamels have their strong and their weak characteristics and neither class can be said to be definitely superior to the other except perhaps under certain conditions.

Enamels may be further improved by incorporating in them a woven fabric or felt impregnated with bitumen. This practice permits the building up of a thicker protective coating. The fabric has little or no waterproofing value but it aids in keeping the bitumen in place and reduces the distortion due to the pressure of clods and stones. When soil conditions are especially severe a coating consisting of several successive layers of bitumen and fabric is frequently used. The bitumen is applied hot by several methods the choice of which depends largely on the structure to be protected and the conditions under which the coating must be applied.

Hot bitumen will not adhere to cold metal. It is necessary, therefore, either to heat the metal to approximately the softening point of the bitumen or to apply a priming coat consisting preferably of the bitumen dissolved in a volatile solvent.

Tests* made at the Bureau of Standards indicate that organic

*G.N.Scott and S.P.Ewing. Pipe line fabrics. American Dye Stuff Reporter 24, 669; Oil & Gas J. 34, 123.

fabrics, even when impregnated with bitumen or a disinfectant, rot when exposed to soils containing decaying organic matter and moisture.

Organic coatings have two serious weaknesses. It is difficult to apply them in the form of a continuous coat of uniform thickness, and they are easily injured in the handling of the structure. Since a single bare spot on a buried tank may result in a leak which will destroy its usefulness or necessitate its removal for repairs, it is desirable to test the coating for bare spots before the tank is installed. An apparatus for such tests has been developed.*

*G.W.Clarvoe. The detection of flaws in pipe line protective coatings before burial. Pipe Line News 5, #8, p.13.

After the tank has been buried the coating may fail and allow pits to develop. Since small leaks may allow the fluid to escape into the earth without the loss becoming evident on the surface of the ground, some means of following the deterioration of the coating is desirable.

If the coating has a high electrical resistance, as all organic coatings should have, the measurement of the resistance between the tank and a ground plate from time to time may indicate a change in the condition of the coating. Such measurements may, however, be affected by the resistance of the earth and they should, therefore, be made when the soil is moist.

(c) <u>Cement Coatings.</u>- A coating of one or two inches of cement mortar or concrete completely surrounding the tank will protect it against corrosion under most soil conditions. It is impracticable to apply such a coating to a tank before it is installed but the cement can be placed in the bottom of the excavation and more cement poured around the tank as soon as it has been placed in position. A mold of thin sheet metal properly supported will reduce the amount of cement or concrete required. Serious corrosion is not to be expected under most conditions even if small cracks develop in the cement or concrete since there is sufficient alkaline material in the cement to render such water as reaches the tank noncorrosive.

V. CONCLUSION

This paper was prepared chiefly to answer general inquiries concerning the corrosion of tanks and grave vaults. In such a paper it is not practicable to discuss corrosion in sufficient detail to permit readers to solve many specific problems. The purpose of the paper is rather to furnish generally useful information and to direct readers to papers from which detailed data applicable to their problems may be found. To this end references to outside publications have been made. An appendix is attached which lists the publications of the Bureau of Standards that deal with underground corrosion and its mitigation. In case the information in these papers is not clear or is incomplete, further information may be requested from the Bureau. Such requests should be specific and should furnish definite information on the problem under consideration if a helpful answer is expected.

Lack of time or data may, of course, prevent a complete answer but inquiries are always welcomed.

APPENDIX

NATIONAL BUREAU OF STANDARDS PUBLICATIONS DEALING WITH UNDERGROUND CORROSION

	Title	Price
Technologic Paper No. 368 - (NBS Tech. Papers 22, 447)	Bureau of Standard's Soil-Corrosion Studies. I. Soils, Materials and Results of Early Observations	$ .50
Research Paper No. 298 - (NBS J. Research 6, 683)	Pipe Line Currents and Soil Resistivity as Indicators of Local Corrosive Soil Areas	.15
Research Paper No. 329 - (NBS J. Research 7, 1)	Soil-Corrosion Studies, 1930 - Rates of Corrosion and Pitting of Bare Ferrous Specimens	.10
Research Paper No. 359 - (NBS J. Research 7, 585)	Soil-corrosion Studies - Nonferrous Metals and Alloys, Metallic Coatings and Specially Prepared Ferrous Pipes Removed in 1930	.10
Research Paper No. 363 - (NBS J. Research 7, 637)	Correlation of Certain Soil Characteristics with Pipe Line Corrosion	.05
Research Paper No. 539 - (NBS J. Research 10, 413)	Methods for Determining the Total Acidity of Soils	.05
Research Paper No. 638 - (NBS J. Research 12, 119)	Soil Corrosion Studies 1932	.05
Research Paper No. 696 - (NBS J. Research 13, 125).	Corrosion of Ferrous Metals in Acid Soils	.05

	Title	Price
Research Paper No.883 (NBS J.Research 16,431)	- Soil Corrosion Stufies 1934. Rates of Loss of Weight and Pitting of Ferrous Specimens..................................	Out of print
Research Paper No.918 (NBS J.Research 17,363)	- Electrolytic Measurement of the Corrosiveness of Soils......................	.05
Research Paper No.945 (NBS J.Research 17,781)	- Soil Corrosion Studies 1934. Rates of Loss of Weight and Penetration of Non-ferrous Materials........................	.10
Research Paper No.982 (NBS J.Research 18,361)	- Soil Corrosion Studies 1934. Field Tests of Non-bituminous Coatings for Underground Use.......................................	.10
Research Paper No.1058 (NBS J.Research 19,695)	- Soil Corrosion Studies 1934. Bituminous Coatings for Underground Service..........	.10

The above papers may be secured from the Superintendent of Documents, Government Printing Office, Washington, D.C., at the prices indicated, or may be consulted at most of the larger pollege and public libraries.

The following letter circulars may be secured by writing to the Bureau of Standards:

LC434 - Soil Corrosion Surveys.

LC480 - Tests for Non-metallic Protective Coatings for Underground Pipes.

LC510 - Protective coatings for Underground Pipe Systems.

LC518 - The Corrosivity of Soils.

LC519 - Cathodic Protection of Pipe Lines.

LC521 - Corrosion and Protection of Underground Tanks and Grave Vaults.