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DEPARTMENT OF COMMERCE  
BUREAU OF STANDARDS  
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SOIL CORROSION OF UNDERGROUND PIPING SYSTEMS

The following abstracts and summaries have been prepared from publications relating to soil corrosion of ferrous and non-ferrous metals and are intended to give a fairly complete outline of recent investigations in this field. They do not fully cover the various theories of corrosion, but apply more particularly to practical investigations under field conditions. Where more detailed information is desired, the unabridged articles should be consulted.

Bureau of Standards publications referred to may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C., at the following prices:

Bureau of Standards Soil Corrosion Studies. I. Soils, Materials and Results of Early Observations. K.H. Logan, S.P. Ewing, and C. D. Yeomans. Technologic Paper No. 368. 50 cents.

Soil Corrosion Studies, 1930 - Rates of Corrosion and Pitting of Bare Ferrous Specimens. K. H. Logan and V. A. Grodsky. Research Paper No. 329. 10 cents.

Soil Corrosion Studies, Nonferrous metals and alloys. K. H. Logan. Research Paper No. 359. 10 cents.

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1. The corrosion of cast iron and lead pipes in alkaline soils. J. W. Shipley (University of Manitoba). Jour. of the Society of Chemical Industry, 41, No. 18, p.311, September 30, 1922. - Summary on Corrosion of Cast Iron. (1) The corrosion of cast iron by soil salts is of the graphitic softening type. (2) Magnesium salts are the most corrosive of the soil salts, and magnesium sulphate is the most effective of the salts experimented with. (3) Local action induced by naturally occurring concentration cells may easily be a factor in the soil corrosion of cast iron pipes. (4) The presence of calcium



sulphate in a limy silt soil gives a slight acidity to the ground waters. (5) Autocorrosion of the cast iron is promoted by this acidity of the ground waters due to the stimulation provided to the graphite-iron galvanic couple by the presence of the hydrogen ion. Iron more readily displaces hydrogen when the latter is present in the ionic condition.

The soil corrosion of iron structures is thus seen to be an electrochemical process, complicated by its dependence upon several variables, of which the composition of the metal in the structure, the nature of the soil in contact with the metal, and the movements of the ground waters are the most important.

Summary on Corrosion of Lead. (1) Salt solutions attack lead, a carbonate of lead being the final product when exposed to the air. (2) Sodium carbonate was the most corrosive of the salts experimented with. (3) Lead cathodes exposing an area of 37.5 square centimeters are not attacked by currents of from 4 to 10 milliamperes. (4) "Coefficients of corrosion" are not applicable to electrochemical decomposition. (5) The presence of ammonium nitrate appears to inhibit corrosion by the formation of a protective coating of lead oxide over the surface. Such a protective coating may only be temporary. (6) The soils of the Winnipeg district have a decidedly corrosive action on lead, the nature of the corrosion being usually that of a crater-like pitting of the surface, with or without an adhering deposit of lead sulphate or carbonate. (7) Contact with a foreign substance localizes the corrosion. (8) The cause of the corrosion may be attributed to local galvanic action due to differences in the physical structure of the lead, to the presence of impurities lodged between the crystals of the lead, or to concentration cell effects.

2. Corrosion of iron in absence of oxygen. J.W.Shiple, I.R.McHaffie, and N. D. Clare (University of Manitoba). Industrial and Engineering Chemistry, 17, No.4, p.381, April, 1925. - The corrosion of iron in the absence of oxygen is proportional to the hydrogen-ion concentration down to a pH of 9.4, when hydrogen evolution and solution of iron cease.

The rate of corrosion in the absence of oxygen is determined by the hydrogen-ion concentration, and the continuance of the corrosion by the total available acidity. If the solution in contact with the iron is not buffered, corrosion will continue, but at a diminishing rate and diminishing hydrogen-ion concentration until a pH of 9.4 is reached.

Oxidation of iron requires a potential a little less than the potential required for the evolution of hydrogen. Consequently, in the presence of oxygen, hydrogen will not be evolved



at a H-ion concentration corresponding to the solubility of ferric hydroxide or lower.

The submerged corrosion of iron imbedded in impervious clay is due (1) to the buffer action of the clay at a H-ion concentration sufficiently acidic in the absence of oxygen to produce the evolution of hydrogen, and (2) to the lowering of hydrogen overvoltage by the thin film of solution on the extremely fine subdivision of the clay in contact with the metal.

The location of pits is determined by the constituents of the iron. When oxygen is present the migration of electrically charged colloidal particles of ferric hydroxide to cathodic areas on the metal perpetuates and enlarges these cathodic areas. The metal underneath becomes anodic. If the noncorrodible constituents are sufficiently cohesive, as is the case in gray cast iron, graphitic softening rather than pitting is produced, and no holing of the metal results.

3. Bureau of Standards Soil-Corrosion Studies. I. Soils, Materials and Results of Early Observations. K.H. Logan, S.P. Ewing and C.D. Yeomans. Bureau of Standards Technologic Paper No. 368, pp. 447-554, 1928. - This is the first report of an extensive investigation of soil corrosion which the Bureau of Standards started in 1922. At that time a large number of specimens of different commercial pipe materials were buried in 47 locations throughout the country representing a wide variety of soil types. A list and description of the materials under test is given as well as a technical description of the 47 soils.

At approximately two-year intervals representative samples have been removed and the extent of corrosion carefully determined. Examinations after 1, 2, and 4 years permit no definite conclusions to be drawn regarding the corrodibility of different metals of similar groups. The work thus far shows that the type of corrosion of a group is influenced by the nature of the soil. Most soils are but slightly corrosive. In many cases the corrosion rate and pitting rate fall off with time. Galvanized pipes are in general more resistant to corrosion than untreated pipe. The corrosiveness decreases with increasing weight of zinc coating. Some soils corrosive to steel cause the formation of a protective film on zinc which affords good protection. Thin bituminous coatings yield insufficient protection against severely corrosive soils, probably because of the poor methods available for application. Lead and zinc fail by pitting in some soils and aluminum is readily attacked. Copper and high-copper alloys are generally resistant in all soils. The investigation has not proceeded sufficiently far to warrant definite conclusions to be drawn regarding the relative merits of metals of the same type.

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4. Soil-corrosion studies, 1930 - Rates of corrosion and pitting of bare ferrous specimens. K.H.Logan and V.A.Grodsky. Bureau of Standards Journal of Research, 7, No.1, July, 1931: Research Paper No. 329. - This is a report of the Bureau of Standards soil corrosion studies based on the inspection of specimens which had been in the ground eight years. The results in general confirm the conclusions reached after previous inspections, as reported in Technologic Paper No. 368. Throughout the eight years during which the specimens have been exposed, characteristics of the soil rather than of the ferrous materials have controlled the kind and extent of the corrosion. Because there is a possibility that at later periods differences in the materials will result in appreciable differences in rates of corrosion, the Bureau believes that it should not make comparisons of materials at this time; moreover the data now available do not indicate that any one of these is best for all soil conditions. So far, materials which appear best under one soil condition have appeared inferior to some other material in a different soil.

A statistical study of the data shows that the standard error for the average performance of any one material in all soils is between 6 and 10 per cent. Considering the character of the investigation and the number of uncontrolled variables that influence the rates of corrosion, the precision of the data appears somewhat better than was expected. It should be remembered, however, that the data record only what has happened and not what will be the result at the conclusion of the work.

Rates of corrosion vary somewhat from year to year because of settling of the trench in which the specimens were buried and changes in the supply of moisture. There is no constant relation between the rate at which specimens lose weight and the rate at which the depth of pits increases. Some soils cause the materials to pit badly, although the pitting results in comparatively little loss of weight. In other soils the corrosion is more uniformly distributed over the surface of the material, and a considerable loss of weight occurs with a low rate of penetration. As, in most installations of pipe, much thicker material is used than is necessary to withstand the pressure of the fluid carried, the loss of weight is not of great importance if uniformly distributed, but the formation of even a few deep pits may be a serious matter.

Rate of pitting, therefore, rather than rate of loss of weight is frequently the best indication of the corrosiveness of a soil. While data to be secured later may indicate relative merits of materials, the data so far obtained are chiefly valuable in connection with the study of field methods for determining soil corrosivity. When these methods are further developed, it will be practicable to make a soil-corrosion survey, from the results of which the owner can tell whether he should use a corrosion-resistant pipe material or apply a protective coating to his line.





5. Soil-Corrosion Studies - Nonferrous metals and alloys, metallic coatings and specially prepared pipes removed in 1930. K. H. Logan. Bureau of Standards Journal of Research, 7, No.3, September, 1931. Research Paper No. 359.- The information concerning soils which has been obtained as the result of the bureau's soil-corrosion investigations makes it clear that the rate of corrosion of any metal exposed to soil can not be accurately expressed by a single figure or group of figures. On account of the variations found in all soils, the influence of the character of the soil differences in contact between the soil and the metal, changes in the supply of oxygen and moisture, and the effects of the corrosion products, the best that can be hoped for is an expression representing the average rate of loss of weight or pitting accompanied by a figure for the standard deviation, probable error, or some other expression indicating how much the behavior of any single specimen may be expected to differ from the behavior of the average of a representative group of specimens.

Average values sufficiently accurate to show small differences in the performance of competing materials can only be secured through the testing of a very large number of specimens. Since in any one case any material may prove considerably better or worse than the average, it is doubtful whether the drawing of fine distinctions between materials would be of practical value except for the consumers of very large quantities of materials. Attention should, therefore, be directed chiefly to the unmistakable differences between different kinds of materials rather than to possible small differences between nearly similar materials.

The most general conclusion to be drawn from the data is that for best results the material must be chosen to fit the soil in which it is to serve, since no one material is best for all soil conditions. Another general conclusion is that small differences in the data should not be considered significant, since it is improbable that a repetition of the test would yield identical results.

In nearly all soils copper and alloys high in copper resist corrosion well. Muntz metal shows at least slight dezincification after six years burial in half of the soils investigated and serious dezincification in a few of them.

In nearly all of the soils considered, lead corroded much less rapidly than iron or steel. The rates of pitting of commercial lead specimens were 3 mils per year or greater in 25 per cent of the soils. The lead containing antimony showed rates of pitting greater than 3 mils per year in nearly 50 per cent of the test locations.

The outer metallic ribbon of the parkway cable showed corrosion in most test locations. The inner ribbon was somewhat

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less corroded. Serious pitting of the lead sheath occurred only in the soil containing alkali carbonates.

All of the metallic coatings tested appeared to increase the life of the material to which they were applied. Comparison of the effectiveness of the metallic coatings is difficult because they differed in thickness. All coatings showed evidences of deterioration in several soils. In most of the soils, there was no evidence that the rate of penetration by pitting increased after the lead coating had been punctured. The possibility is suggested that the relative positions of lead and iron in the electrochemical series depends upon the soil in which specimens composed of lead and iron are placed. The precision of the data is insufficient to show at this time whether one base material is better than another for galvanized sheets to be used underground, but it appears that any difference which may exist is not great.

6. Copper pipe for gas distribution. Arthur F. Bridge and Frederic A. Hough. Gas Age Record, pp.503-512, April 23, 1932. - General Conclusions. (1) In many corrosive soils the rate of corrosion of copper is less than that of steel by an amount sufficient to justify its use for gas services and for two-inch and three-inch mains, provided internal corrosion is not a limiting factor. (2). If, in a given soil, copper does corrode rapidly, usually an alloy high in copper content can be found to which conclusion (1) applies. (3) Copper pipe is probably unsuited for underground pipe in areas where stray current electrolysis is severe. (4) Copper pipe should not be used to distribute gas containing as much as one grain of hydrogen sulphide per 100 cubic feet, unless the gas is dry. (5) Undehydrated oil gas as ordinarily purified, will corrode copper pipe. (6) The corrosion of copper pipe by purified but undehydrated oil gas, is more rapid than that due to many corrosive soils. (7) Dehydration greatly reduces the rate at which the corrosive gases, normally present in purified manufactured gas, attack copper. (8) From the standpoint of both mechanical strength and soil corrosion resistance, a wall thickness of .065 inch (No.16 gage) is sufficient for copper gas mains and services three inches in diameter and smaller. (9) Brazed joints are satisfactory for copper pipe in soils that do not tend to dezincify bronze. (10) Soldered copper-sleeve joints appear to be satisfactory for both mains and services in all soils. (11) When a reduction in pipe size is permissible, it is practical and economical to replace old mains and services by using them for conduits for copper pipe, thus avoiding much cutting of pavement and lawns. (12) Because of the low cost of installation, the use of copper pipe inside existing steel mains and services is fully justified, regardless of the rate at which the soil attacks steel.



(13) When chemical and physical conditions are such that copper pipe can be used, it is economically sound at now existing prices, to use it for two-inch and three-inch mains in soils where the life of wrapped steel mains is less than 19 years, and for services in locations where wrapped steel services have an expectancy less than 22 years. (14). If the mains and services are to be installed under expensive pavement, the required life for wrapped steel mains given in No.12 above, is increased to 22 years and that for services, to 25 years.





