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PREVENTION
OF THE
CORROSION OF LEAD SHEATHED CABLES
INSTALLED UNDERGROUND

A Thesis Submitted to
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of
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THESIS

INTRODUCTION

The underground distribution engineer, faced by the problem of preventing the corrosion of lead covered cables installed underground, is not so much concerned with the chemical theory by which to explain corrosion as he is in determining the extent and the methods of curbing it. A study of the literature reveals that there is some difference of opinion as to the exact mechanism operating to produce corrosion. It is not the purpose of this paper to enter this matter, but rather, to find a common ground on which to base satisfactory, practical methods of dealing with the problem of corrosion prevention.

The following statistics on cable failures, due to corrosion of the lead sheath, are taken from the report on Cable Operation in 1937, prepared by the Transmission and Distribution Committee of the Edison Electric Institute. The total number of cable failures on nearly 15,500 miles of cable, operated by 49 companies, was 7.1 per 100 miles of cable per year. 25.1% of these failures was attributed to corrosion of the lead sheath. The real significance of this figure may be better seen by comparison with some of the other causes of cable failure. For instance, deterioration of the insulation was the cause of 12.3% of all cable failures, while the largest single cause, next to corrosion, was mechanical damage of the sheath due to external causes, amounting to 15.8%. The latter is not under the control of the Utility and little can be done to reduce it. It would seem that, since corrosion is the major cause of lead sheathed, paper insulated, cable failures, it might well be the concern of the underground distribution engineer.

HISTORICAL REVIEW

The distribution of electric power by means of lead covered cables installed underground came into being shortly after the birth of the electric light and power industry. The streets and alleys of our large cities were already crowded with the overhead circuits of the telegraph and telephone companies, and, with a new utility looking for right-of-way it was apparent that this could only be found underground. The Edison Underground Tube System seemed the answer for a time but soon A.C., with its higher voltages and the need for better insulation, led to the only other economical solution - paper insulated, lead covered cables. Once the problems of right-of-way, and suitable cables to install therein, were solved another serious situation was uncovered - electrolysis. An interesting account of the difficulties encountered is contained in an address by Capt. Wm. Brophy, before the N.E.L.A. in 1896. Quoting in part:

"Having now been compelled, as we will assume, to go underground, what are the difficulties to be met with? After placing your wires underground, if there are no stray currents to disturb them, you are reasonably safe for a number of years; for the manufacture of insulated cables for underground work has now been brought to a very high state of perfection, and you can get almost any required degree of insulation. But unfortunately, in this country, where we want everything of the most approved type, and where, in order to get it, we will run almost any risk, we have, co-existing with the electric light, the single trolley electric railway system, which has done wonders in building up cities and towns, and in bringing people of small means within the reach of comfortable homes where they can get a reasonable amount of fresh air and God's sunlight. The horse, as a motive

power for propelling street cars, is fast disappearing. It is a pity that the rail of the electric street railway was adopted as a part of the circuit, and those who introduced it little knew what the consequences would be. - - - - - Owing to imperfect bonding, or to the lack of conductivity of one side of the circuit, these large currents sought and found the earth; in other words, the potential of the earth was raised at places distant from the station, and was lowered again within a radius of a half or quarter of a mile, more or less, depending largely on the state of the soil on which the station was built. The earth's potential there became lower than the cables; these lead covered cables affording a much easier path to the negative side of the dynamos than portions of the earth. Large volumes of current were conveyed through them. No difficulty occurs at the point where the current seeks the cable, but at the point where it seeks to leave the cable - where the earth's potential is lower - here the trouble begins.

"Electrolysis. What is it? Can it be prevented, and how? Electrolysis proceeds on the same line, and under somewhat similar conditions, as the well-known method of electroplating; the moist earth being an immense electro-plating bath of various resistances, while the lead covering of the cable, metal gas and water pipes, are the negative and positive poles. Corrosion of metals, due to the electrolytic current, goes on as surely as fate. There is a difference, and perhaps a wide one, between the working effects of an electro-plating bath and the destructive corrosion of iron and lead pipes and lead covered cables. All currents of electricity flowing into the earth seek the best conducting medium, and cause the destruction of the latter at the point where they seek the earth again.

"The corrosion of metals is due to the following conditions:- A thin

film of water surrounds these metals, and it is decomposed into oxygen and hydrogen by the electric current. Oxygen, when freely released, is always intensely active in combining with any metal present. The lead covering of the electric conductor within the ducts, or buried in the earth is, as a rule, covered with a thin film of water, and it is not infrequently the case that the ducts and manholes are filled with water. In every case, the lead takes the place of the positive and negative plates in the electro-plating bath. If the current of electricity, after touching along the surface of the lead, leaves it to seek a point where the earth's potential is lower than that of the lead, water is decomposed, and the free, nascent oxygen immediately enters into combination with the lead surface to produce lead oxide in the forms of paste, and iron oxide or rust in iron. The crust of oxide being permeable by water, a fresh surface of the metal is in contact and presented to the moisture; and the process is continued indefinitely until the lead covering is destroyed. The amount of metal thus decomposed depends on the amount of current flowing from metal to the ground. - - - - -

"What is the remedy? The only real remedy is to cease using the rail as a part of the circuit and to use a metallic circuit. But to bring about this condition of affairs is a task not easy of accomplishment. The Courts have already decided that the electric railways have a perfect right to use the earth if they see fit. Now that we have the electric railway with us - and we would not part with it under any circumstances - let us do what we can under these present conditions to reduce the evil".

The references given to the literature take up the problem of elec-

trolytic corrosion at this point and bring it up-to-date in a thorough fashion. However, to the writer's knowledge, the patent field has not been covered and a brief review of some of the more interesting patents will now be made.

Robt. Berry. #132,746. November 5, 1872.

Improvement in Coating Lead Pipes.

"To carry out my invention, I employ a solution of chromate or bi-chromate of potassa, acidulated or not, as the case may be, and bringing it in contact with the lead to be protected by any of the processes known. In this manner an insoluble chromate of lead will be formed on the surface of the lead to be protected".

Arthur E. Colgate. Assignor to Western Electric Company.

#403,418. May 14, 1889.

Method of protecting the Lead Pipe of Telegraph-Cables from Corrosion.

Method consists of forcing sulphureted hydrogen into the ducts containing cables. The resulting lead sulphide formed is supposed to prevent corrosion.

Lucien I. Blake. #661,165. November 6, 1900.

Protecting Underground Metallic Structures from Effects of Electrolysis.

"It is well known that a current which leaves a metallic surface by a conducting path which is non-ionizable or not chemically decomposable will produce no electrolytic effect on that surface, and I have taken advantage of this fact in carrying out my plan of protecting underground metallic structures against electrolytic corrosion by interposing between the metallic surfaces and the surrounding soil an electrically-conducting

medium which is non-ionizable and which will prevent access to such surfaces of the products of electro-decomposition of any solution which may be present in the soil. The protective medium may be composed of one or more of a large number of materials and may be applied in many ways. I may, for example, employ carbon in any suitable form, preferably a mixture of graphite with some binding material by means of which it may be applied and fixed to the surface of the metallic structure which it is designed to protect. I have found, for example, that a mixture of graphite and paraffin is well adapted for this purpose.

"It is not essential that the substance of the protective medium should be itself a conductor of electricity, provided only it permit the passage through it when applied for use of the current while preventing the access to the metal surface of the products of decomposition. Such substances are now well known and have been employed as non-perous electrolytic diaphragms in galvanic batteries and electro-decomposition cells. Among such substances may be mentioned precipitated chalk, pulverized anthracite coal, gelatinized compounds of silica and the like which when used in layers of sufficient thickness, and moistened if by nature they are dry, permit the ready passage of current, but prevent the recombination of the products of electro-decomposition.

"The protective medium may be applied to the metallic structures in any convenient manner. It may be applied in a thin layer with brushes or suitable tools, or it may be deposited in larger amounts in a trench and the metal structure embedded in it".

Rob't M. Burns. #1,903,976. March 16, 1929.

Process of Making Concrete.

"This invention relates to concrete ducts which are used for protecting lead cable sheath, and to the process of making the same.

"The object of this invention is to provide a cable duct in which the corrosive effect of lime on the lead cable sheath is prevented or retarded.

"Applicant discovered that certain substances tend to protect lead or lead alloy cable sheath from corrosive attack and that this effect is due to the presence of the silicate ion, that it is induced by so low a concentration as is afforded by a saturated calcium silicate solution and that it is effective within a relatively wide range of hydrogen ion concentration. Applicant further discovered that the corrosion of lead cable sheath resulted in the formation of red crystalline lead monoxide which crystallizes from saturated solutions of lime or alkali plumbites or plumbates. The alkali responsible for corrosion may be produced by a solution of lime or alkali salt, sodium chloride or ordinary table salt which is used to thaw out street car switches in winter and occasionally finds its way into cable ducts where it is converted into caustic soda at the surface of the cable sheath as a result of current flow from earth to the sheath. This type of corrosion also occurs in newly manufactured concrete ducts owing to the presence of free lime in the concrete. Applicant further discovered that distilled water exposed to air readily corrodes cable sheath alloys and that this corrosive action may be prevented by the introduction of solid silicate or by the addition of finely divided silica flour.

"According to this invention concrete cable ducts are constructed by introducing a certain quantity of soluble silicate as water glass silica

or silicious slag in the concrete mixture while constructing the cable duct. The silicate has the property of neutralizing or preventing the corrosive effect of lime on the cable sheath through the formation of a silicate film on the surface of the cable sheath. Cable ducts after being constructed or laid may be impregnated with a solution of soluble silica or coated on the inside duct surface with soluble silica. However, in the case where soluble silicate is introduced in the concrete mixture, the concrete should be of such composition that water permeating through it or forming a solution by contact with it should have silicate ion content of not less than that of saturated calcium silicate; hydrogen ion content of not less than 1×10^{-11} grams per liter of solution.

"What is claimed is;

1. The method of preventing the corrosion of lead alloy cable sheath enclosed in concrete ducts which consists in producing a saturated silicate condition adjacent the lead sheath which forms or causes to be formed a coating of an insoluble film on the lead sheath.
2. The method of preventing the corrosion of lead alloy cable sheath enclosed in concrete ducts which consists in producing a saturated silicate condition adjacent the lead sheath which forms or causes to be formed a coating of lead silicate on the sheath".

Henri Benit. #1,944,778. May 7, 1931.

Method of Protecting Lead Against Corrosion.

"The method consists in rendering the lead unattackable by destructive agents by creating on its surface, chemically, a protective layer formed by a very stable lead salt which resists chemical changes. The lead salt

thus produced will form a very thin layer protected mechanically by the usual covering which might now be tar or other inexpensive material which will not be chemically neutral. There will be no longer any liability of corrosion of the lead in case of cracking of the waterproof covering even if corrosive products are present in this coating because the lead salt formed on the surface of the lead will prevent attack by the latter.

"The lead salt which forms the protective coating should be very stable and be easily and cheaply formed. Lead sulphide fulfills these conditions; it is insoluble in water and is unattackable or almost unattackable by acids and mineral and organic salts. It is formed easily from pure sulphur or from natural or artificial sulphide derivatives in contact with lead, the reaction being very rapid with the aid of heat.

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"For example, there may be applied to the lead directly at a temperature a little above 100°C. a layer of ordinary tar mixed with pure sulphur in a proportion greater than 3%. Under these conditions there will be formed instantaneously on the lead a film-like coating of lead sulphide and the reaction will cease of its own accord leaving an excess of sulphur in the tar. - - - - -

"Where the protective covering of the lead consists of concrete or cement another form of the invention consists in incorporating in the cement during the preparation of the mortar a small proportion of sodium sulphide. It will be understood, from what has been stated above, that the lead will thus be protected against attack of the most highly basic cements".

Vladimir Grodsky. #2,007,969. Patented July 16, 1935.

Filed October 14, 1933.

Method of Protecting Underground Pipes and Conduits.

- - - - - "This is accomplished preferably by mixing a portion of the soil removed from the trench or excavation with a proper percentage of an inhibiting compound usually an alkali, whereby the acidity is neutralized in the case of acid soils, and the potential acidity is balanced in the case of alkaline soils. The soil as conditioned will comprise a small percentage of the total earth removed from the trench or excavation and is returned in its loose absorbent condition to the trench in the usual manner to fill the same and cover the pipe.

"I find it desirable and economical to isolate the portion of the soil so conditioned and returned to the trench for two reasons. First, by isolating the conditioned soil from the remainder of the adjacent soil it is possible to maintain a substantially constant mixture. Again, by isolating or confining the conditioned soil with positive means, I prevent any possibility of the leaching out of the neutralizing agent due to the presence of excess water.

"The means which I employ to accomplish this isolation will preferably comprise a waterproof material, such as textile or paper fabric, providing a liner in the lower portion of the trench, and in some cases forming an envelope to completely isolate the pipe and conditioned soil.

"Instead of conditioning the soil by mixing a neutralizing agent therewith, I in some cases provide the pipe or conduit with a surrounding layer of the neutralizing or inhibiting agent, and preferably enclose the loose absorbent mass in an envelope of the lining material. - - - -

"The soil having been removed and its nature determined, I add thereto one or more of a group of corrosion inhibiting compounds selected from the oxides, hydroxides and carbonates of the alkali metals.

or alkali earth metals. I prefer to use calcium hydroxide but sodium hydroxide and potassium hydroxide may be employed, as well as calcium oxide, barium oxide, calcium and barium bicarbonate, and in some cases, sodium carbonate. Phosphorous and chromium compounds may also be employed".

THEORIES OF CORROSION

At first the corrosion of lead (other than by electrolysis) was supposed to take place entirely by chemical action. There are a whole series of lead oxides beginning with the suboxide Pb_2O , followed by lead monoxide or litharge PbO . Then comes lead sesquioxide Pb_2O_3 , formed when lead hydroxide, in an alkaline solution, makes contact with an oxidizing agent. It sometimes happens that the cable sheath may become negative to its surroundings and at the same time sodium chloride, NaCl , may find its way into the duct, usually at street intersections where salt and sand are spread when the streets are icy, or near street car switches which are kept from freezing through the use of salt. The result of the action of the negative potential is to decompose the sodium chloride, releasing nascent chlorine which is an excellent corroding agent. The following reaction is believed to take place under such conditions - $2\text{PbO} + \text{NaOCl} \rightarrow \text{NaCl} + \text{Pb}_2\text{O}_3$. There is also red lead which appears to be Pb_3O_4 + $n\text{PbO}$ or has an approximate formula Pb_4O_5 . Now here arises a peculiar situation; the chemist describes these oxides of lead as amphoteric oxides; that is to say, that lead monoxide, for example, may act either as a base or an acid. Lead monoxide reacts with potassium hydroxide to form potassium plumbite, $\text{Pb}(\text{OK})_2$, or with an acid to form a lead salt. In the same way lead sesquioxide, Pb_2O_3 , appears to be lead metaplumbate, Pb_2PbO_3 , and red lead similarly appears to be lead artho-

plumbate, Pb_2PbO_4 . This dual role that lead plays was used to explain why lead was attacked by weak acids, particularly acetic, and also by alkalies.

The older, or as it may well be called 'Chemical Theory of Corrosion', served very well for some time; however, as corrosion became a more serious problem and greater attention was given to its causes there were cases that could not be satisfactorily explained. In time sufficient evidence was produced, both experimentally and in the field, to support an electro-chemical theory of corrosion. Oliver P. Watts, writing on, 'Voltaic Couples and Corrosion', (page 235, Electrical Chemical Society, Volume 47, 1935), states, "the electro-chemical theory of corrosion now seems to have been adopted as agreeing better with the known facts of corrosion than any of the theories previously proposed. Whether corrosion of metal takes place in a solution of NaCl , NH_4Cl , sea water, H_2SO_4 , or alkali, or the metal dissolves as a double salt, these experiments disclose no difference in the nature of the corrosion process. As far as can be detected with the naked eye, removal of air prevents corrosion. In these particular cases, either for a single metal or a couple of two or more metals in contact, corrosion appears to depend on the ability of the metal to displace hydrogen from the electrolyte".

In reply, Benough and Wormwell wrote:- "It is probable that a choice between these alternatives cannot be made with certainty until it is possible to experiment on an atomic scale, since differences on such a scale may start corrosion".

Experimentation on such a scale was approached by Frink and Kenny. (The Passivity Produced by Chromic Acid on 18-8 Chromium-Nickel Alloy. Transactions Electro-Chemical Society, Vol. 60, page 235, 1931). "The

actual elimination of point to point galvanic couples, or, in other words, the equipotentialization of the metal surface was demonstrated by direct potential measurement for the first time. This equipotentializing principle may be of general application to other metals and alloys, no metal or alloy being corrosion proof without the elimination from its surface of point to point galvanic couples". (The capillary electrode had an area of cross-section of 0.012 sq. mm.).

Wm. Blum. Transactions Electro Chemical Society. Volt. 52, page 432, 1927. "According to the electrolytic theory there can be no corrosion except as there is a difference in potential between two parts of the surface, due either to initial difference in composition, in physical condition or in the surrounding mediums".

W. H. Hatfield. Transactions Electro Chemical Society. Vol. 64, page 123, 1933. "Acceptance of the electro chemical theory in regard to corrosion of a specimen in a uniform aqueous electrolyte necessitates, in my opinion, the assumption of the existence of some variation in the potential across the metal surface".

Considering for the moment purely electrolytic corrosion we imagine that the stray current flowing from the cable sheath to ground causes the ionization of the electrolyte adjacent to the sheath, releases ions some of which attack the lead. The electromotive force causing this electrolytic corrosion was assumed to be derived from the street railway tracks. One day someone asked, "why must the electric current come from some outside source?" "Why, if cables are installed in ducts and we know that moisture is present, cannot the necessary potential be generated locally by cell action?" An experiment to prove this point was conducted in the laboratory. A lead specimen, supported on a glass rod in a dilute

solution of sodium chloride, was found to corrode at the point of contact with the glass rod. The problem was, then, to discover how the potential was generated. One theory is that the glass rod tends to exclude the dissolved oxygen from the point of contact with the lead, thereby making it positive to the remainder of the specimen. This potential may, under proper conditions, amount to as much as 0.1 volt. Due to the small physical dimensions of the field the resistance is low and electrolysis may readily take place. There are many possible ways in which corrosion, due to cell action, may take place, but they all have a common characteristic - inhomogeneity of field. A few illustrative examples are: a cable only partly submerged in water; the sheath of a cable in contact with solutions of two different concentrations or, in the case of cable buried in direct contact with the soil; the natural difference in soil particles has been shown to cause corrosion.

There appears, then, to be two very general classifications of lead corrosion, viz., by direct chemical reaction which is rather complicated by the amphoteric nature of lead, and electrolytic corrosion, due to self-generated electromotive force through cell action.

STATEMENT OF PRESENT PROBLEM

One is finally forced to conclude that lead, instead of being a very stable element and one not easily destroyed may, under unfavorable circumstances, become the very opposite. For a long time all corrosion of lead underground was blamed on stray current electrolysis. When it was recognized that there were other causes and a theory involving the electrochemical corrosion of lead was proposed it became apparent that stray currents may have had a beneficial effect. It has been shown that in order for cell action to take place a small portion of the lead must become positive. Now, when stray currents are present, it is necessary to

install drainage cables in order to keep the sheaths negative. This appears to prevent, to a large degree, the formation of corrosion cells. Now, with gasoline driven busses replacing the street cars, the protection afforded through keeping cable sheaths negative to their surroundings by control of stray currents is disappearing. Furthermore, it is not economically feasible, except in very special cases, to maintain the cable sheath negative to ground. Where the cables are remote from all other underground structures it is entirely possible to provide facilities in the form of rectifiers, motor generator sets, or other sources of D.C. to maintain the sheath at a potential of not more than 0.2 volts.

The present problem, then, consists of recognizing that the sheaths of underground cables, whether pulled into ducts or buried direct in the ground, may be attacked by corrosion due to stray current or produced by cell action or by direct chemical action. McCallum and Logan, of the Bureau of Standards, in Technical paper #355, have presented a comprehensive view of electrolysis testing. Bureau of Standards Technical Paper #368, by Logan, Ewing and Yeomans, Soil Corrosion Studies, discusses the damage likely to occur to cables buried directly in the soil. I. A. Denison reports on Electrolytic Measurement of the Corrosiveness of Soils - Bureau of Standards Research Paper #RP918.

Since the electro-chemical theory of corrosion has come to play such an important part in explaining the causes of sheath damage it is only logical that electro-chemical means should be used in locating corroded areas. One such method that shows great promise is described in U.S. Patent #1,865,004, granted to H. E. Haring of the Bell Telephone Laboratories. A non-polarizable electrode, or half cell, is pulled through a vacant duct and the variation in potential between the cable sheaths and

1. The first step in the process of the development of a new product is the identification of a market need. This is often done through market research, which can be conducted in a number of ways, including surveys, focus groups, and interviews with potential customers. The goal of market research is to gather information about the needs and preferences of the target market, as well as to identify any gaps in the current market.
2. Once a market need has been identified, the next step is to develop a concept for a new product that meets that need. This involves brainstorming ideas and creating a prototype of the product. The prototype is used to test the concept and to gather feedback from potential customers.
3. The third step in the process is to conduct a feasibility study. This study is used to determine whether the product is viable in the market. It involves analyzing the market, the competition, and the costs of production. The goal of the feasibility study is to determine whether the product is likely to be successful in the market.
4. If the feasibility study is positive, the next step is to develop a business plan for the product. This plan outlines the marketing strategy, the production process, and the financial projections for the product. The business plan is used to secure funding for the product and to guide the development of the product.
5. The final step in the process is to launch the product in the market. This involves creating a marketing campaign to promote the product and to attract customers. The goal of the launch is to establish the product in the market and to generate sales.

the electrode at regular intervals is noted. Field experience has shown that marked variations in potential indicate areas of corrosive attack. The electrode may take several different forms. The British Post Office uses a copper-sulphate half cell, while the Bell Telephone Laboratories have used a lead chloride half cell. A modification of the latter, as used by the writer, is described in the appendix.

When the non-polarizable electrode, or half cell, is pulled into a vacant duct and the electrical circuit completed through a potential indicating instrument the equivalent of an electro-chemical cell is set up with the lead cable sheaths as one pole and the non-polarizing electrode as the other; hence, its name - half cell. The material separating the two poles consists of the duct material and, in some cases, may be of rather high resistance. In addition, any attempt to draw current from the non-polarizing electrode will tend to change its normal voltage and lead to erroneous results. Therefore, a potentiometer or vacuum tube voltmeter is recommended for use in the field. These instruments have certain drawbacks, however, and the writer has used a voltmeter designed to make hydrogen ion determinations. The meter is readily portable and has a resistance of two megohms/volt. Considerable skill, apparently, is necessary in interpreting the results and for that reason several tests were conducted under known conditions. First of all, a section of conduit was surveyed which, it was quite certain, was located in a non-corrosive location. The curve A (page 25), plotted from the readings obtained, seemed to verify the assumption inasmuch as there were no marked changes in potential. The next test was conducted on a conduit in which two cable failures, attributed to chemical corrosion, had occurred. Furthermore, the conduit section was located in an alley and it was quite certain that

sodium chloride was not a factor, nor was it likely that stray currents were present (see page 26, Curve D). Cable A failed at Point #1 and was replaced four years before the test was made and Cable B failed at Point #2 only two years before. The remaining cables have been installed in this location for eight to ten years without failing. Cable A was severely corroded for several feet each side of the fault, the remaining portion being in good condition; Cable B, however, was badly corroded for 217 feet. This much was scrapped because of the condition of the sheath. The condition of the sheath of the four remaining cables is not known, but the potential from the 240 ft. point to the manhole would indicate serious corrosion. The reason that failures did not occur in this region, it is supposed, is due to the fact that the corrosion was not highly localized as the potentials at the 70 and 150 ft. points would indicate. The potentials obtained after the cable sheaths had been treated with a corrosion inhibiting gel, Curve E, will be discussed later. Turning now to the curves on page 25, Curve B shows the potentials existing when street cars are operating on a track adjacent to the conduit. The readings taken were the average value as the potentials varied quite widely due to the stray current. Curve C shows the conditions existing some time later after street car service had been discontinued. The potentials, of course, did not fluctuate and the values are those actually indicated. This set of curves shows that stray current, if controlled, may be an actual aid in preventing corrosion by maintaining cable sheaths negative to earth. While, in all probability, the cable sheaths are not dangerously positive to earth after the removal of street car service, nevertheless the conditions are definitely less desirable from the standpoint of possible sheath corrosion due to chemicals in contact with the lead, or cell action. Finally, Curve F, page 26, shows the potentials exist-

ing on a section of cable in a residential section where corrosion due to any cause would be least expected. Examination of the physical surroundings showed a sewer adjacent to the thirty foot point. The general contour of the duct section rose from the 0 foot point to the end of the duct section. Further investigation disclosed that the sewer had backed up on previous occasions undoubtedly discharging highly corrosive material into the lower end of the conduit section. The condition of the half cell upon removal from the lower end showed the presence of decayed matter.

So far as the writer is aware the half cell method of exploring a vacant duct is the only way to determine the presence of corrosion in situ. The other methods commonly used depend upon chemical analysis or microscopic examination of the products of corrosion. One such method involves the use of a 5% solution of tetramethyldiaminodiphenylmethane containing dilute acetic acid. When this indicator is dropped on the corroded area a blue color is produced in the presence of lead peroxide. Some authorities question the reliability of this test and for this reason it must be used with discretion. Photograph No. 1 shows a typical case of stray current electrolysis. The oval, sharp edged pits are typical of this form of corrosion. Photograph No. 2 shows another case of stray current electrolysis but here the cable sheath was cathodic. The presence of sodium chloride in the duct was shown and it seems probable that the redeposit of lead was due to the wide difference in conductivity of the electrolyte at several points along the duct. Differential aeration is a cause of corrosion in some localities and may be identified by the symmetry of the affected areas. In some cases the damage may at first be attributed to foreign material in the ducts scoring the sheath when the cable was installed, so regular is the region of attack. Some-

times, it is true, mechanical damage may be a contributing factor through changing the crystal structure, thus leading to concentration cells in the presence of an electrolyte.

METHODS OF PREVENTING CORROSION

The most logical way to prevent corrosion of lead sheathed cable is, of course, to isolate the cable from all corroding media by means of a protective covering of some impervious material. Jute wrappings impregnated with asphalt have long been used for cable buried directly in the ground and, for the most part, when conscientiously applied have withstood the test of time. Armored cable, made of alternate wrappings of jute and steel wire, are generally used in crossing streams, lakes or other bodies of water. What is desired is an inexpensive covering that will protect the cable sheath from corrosion under the average conditions of installation. The practice of pipe line companies has been followed with some degree of success. The flexibility of cable as compared with rigid pipe must be considered and bitumastic enamels or other brittle coatings are to be avoided. Rubber or rubberized fabrics, sold under a variety of trade names, have been advocated. A series of tests conducted on a number of such coverings produced by several different manufacturers revealed that the average life of the coatings in submerged ducts was approximately five years. Some of these coverings represented an additional cost of between 5% to 20% of that of the cable. If these cables were to be buried directly in the ground some form of mechanical protection would be required. Photograph No. 3 shows one form of protection, a cathedral tile, which seems very promising both as regards cost and protection. More commonly, concrete or wood slabs are placed over the buried cable. One method of protecting buried cable that has several

advantages consists of laying tar paper on the bottom of the trench to keep the cable out of contact with the soil, both while the protective coating is being applied and after the installation is completed. The cable is pulled into the trench and supported out of contact with the tar paper by means of pieces of old crossarms or other suitable support. If the trench is narrow and deep the cable may be supported above the trench while the coating is applied. One coating, now under test, consists of a grease, about the consistency of cup grease, in which is incorporated sodium silicate (1 gallon), and sodium bichromate (1 lb.) to 10 gallons of grease. The function of the two chemicals will be discussed under the action of inhibitors. The grease was applied up to a thickness of 1/16 of an inch. Grease can be applied by unskilled labor and with close supervision a satisfactory coating is obtained with a minimum of expense. The cable is then covered with cathedral tile. Where the ground is not likely to be flooded this covering is considered satisfactory. Another coating under test consists of emulsified asphalt, (clay type), in which has been incorporated 1% each of sodium silicate and sodium bichromate. For use in cold weather alcohol must be added to keep the emulsion from freezing. The advantage of asphalt over grease lies in its drying to a comparatively moisture resistant state. Cathedral tile is again used for mechanical protection. The costs of these types of coating are approximately equal and will be found to be considerably less than that of most other types. Examination of one installation, after it had gone through the winter and spring seasons, revealed that the tile, when properly laid with little or no gaps between adjacent sections, had prevented the ingress of loose soil.

The value of inhibitors for the control of corrosion is well

established in practice. Their protective action has been attributed to rendering the metal passive or, according to some experimenters, to the polarization of the anodic or cathodic areas. R. M. Burns, of the Bell Telephone Laboratories, in a technical publication, Monograph B-912, The Corrosion of Metals - I, discusses the subject from the electro-chemical point of view. He states the case for the use of silicate as a means of controlling the corrosion of lead in these words, " - - - - - the highly protective film of silicate which presumably forms upon lead and lead rich alloys when immersed in water or soil solutions containing as little as ten parts per million of silicate. As is well known, distilled water is corrosive to these metallic materials. Were it not for this fortunate effect of silicates upon lead it is doubtful that it or its alloys could be used for cable sheathing in the present type of underground construction which permits exposure to soil surface waters at times".

The British Post Office has taken advantage of this fact and has incorporated sodium silicate in the pulling grease used when telephone cables are installed in corrosive locations. Cables so coated are undoubtedly less subject to chemical attack, but when sodium silicate is emulsified in a grease the electrical resistance of the resulting mixture when applied as a film to a lead covered cable may be decreased. If this be so, then the cable is subjected to stray current. An effort was made to find a suitable grease that would not only protect lead against chemical attack but also reduce the hazard from stray currents. It was discovered that sodium bichromate had a beneficial effect and has been used with sodium silicate as a pulling grease for cables installed in ducts and, emulsified in grease or asphalt, as a coating for buried

cables. Under the action of stray current a protective layer of lead chromate is quickly formed. This layer of lead chromate adheres so firmly that patches of it have been found even after the cable sheath had been sand blasted. Specimens of lead sheathed cable coated with a silicate-chromate-grease have been installed in ducts flooded with a saturated solution of sodium chloride and maintained at a potential of 6 volts, some positive and some negative to ground, for a period of six months without showing appreciable signs of attack. Such protection can be afforded to cables only at the time of installation and is not applicable to cables already in service. Therefore, a search was begun for some method that would permit the use of silicate and chromate on cables already operating in ducts.

The following process has been developed over a period of several years and about 1,000 feet of cable have already been treated as an experiment. Because it can be applied to operating cables and because of the gratifying way it has withstood accelerated tests under highly corrosive conditions seems to merit description. The process is based on the formation of a silica gel through the action of sulphuric acid on a water solution of sodium silicate. Sodium bichromate is added to the acid to secure the beneficial action of this chemical as an inhibiting agent. The process is carried out as follows. The duct, containing the cable to be protected, is plugged at the lower end and vented to the atmosphere through a small flexible tube. A rubber hose is inserted at the high end of the duct and carried to the surface of the street where it terminates in a funnel. The duct is then filled with a solution of water, sodium silicate, sulphuric acid and sodium bichromate. The ratio of the constituent parts of the solution is not critical but is usually as follows:-

water - 20 gallons; sodium silicate - 1 gallon, (20° Baume^s); sulphuric acid, 1/8 pint (1400 Sp. gr.); sodium bichromate, one pound. This solution gels in about 15 minutes at ordinary temperatures. Some concern was felt as to the difficulty that might be encountered should it become necessary to remove a treated cable. Trial has shown that the pulling stress is not increased by the presence of the gel. Furthermore, the gel is easily converted back into a liquid so that any of it carried into a manhole may be readily removed. The effect of syneresis, loss of water by the gel, has not been fully determined. The high thermal conductivity and thermal capacity of the gel are an aid in increasing the KVA rating of cables protected.

Cathodic protection of underground pipe lines has been discussed in the literature and its application to lead covered cables is clearly indicated. The chief difficulty in the case of the latter, however, is that cables are usually installed in urban areas, which means that the effect of the protective potential on other underground structures cannot be ignored. Where cathodic potentials may be applied without jeopardizing other property, great care must be exercised to control the magnitude and gradient of the voltage applied to the sheath. Should the sheath become appreciably more than 0.2 V. negative to earth cathodic corrosion may take place, especially if there are chloride ions present. At potentials of much less than 0.2 V. the voltage developed by local cell action may not be neutralized.

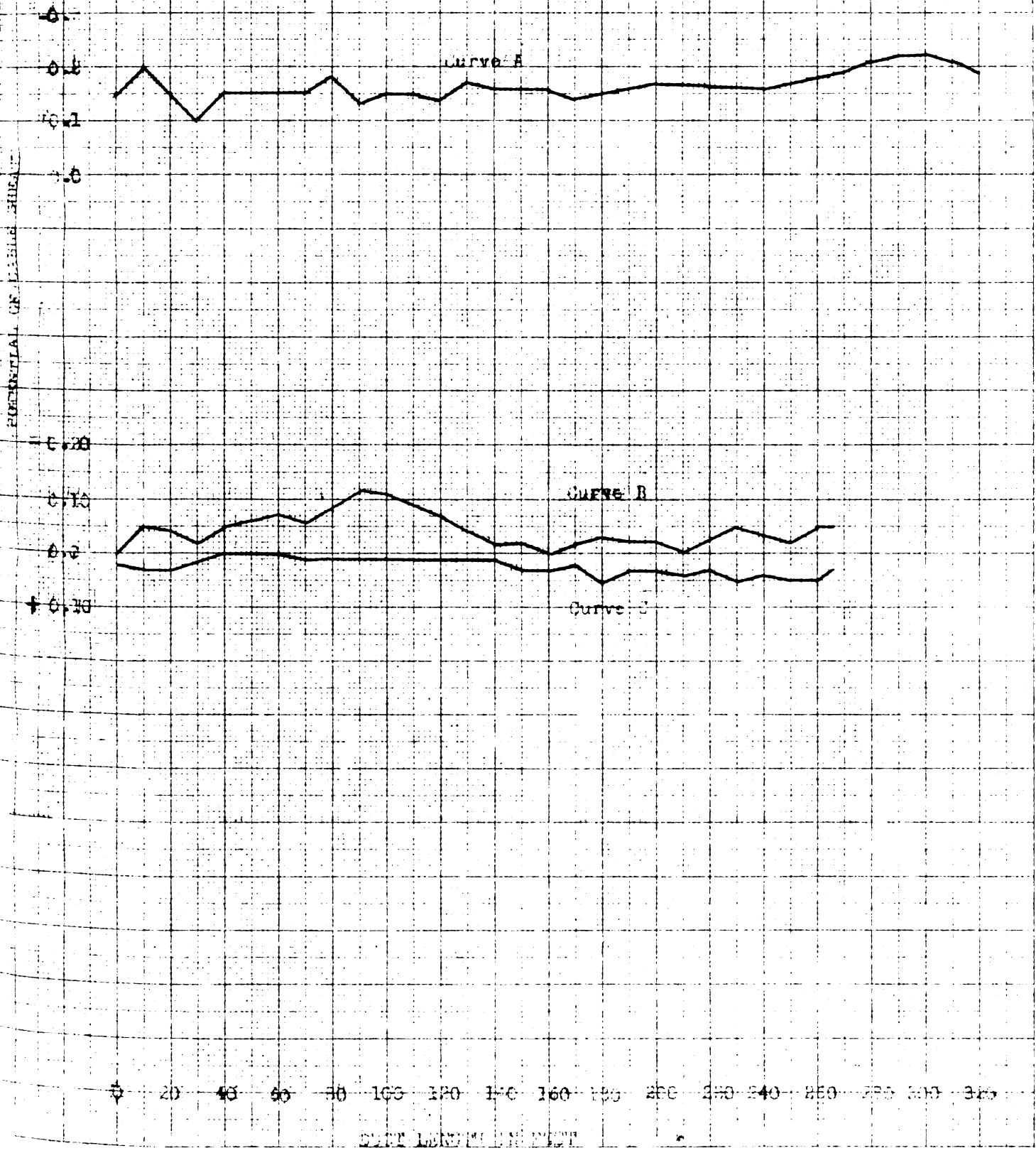
CONCLUSION

A study of the cable operation record of a typical Utility operating approximately 2,000 miles of lead covered cable reveals that for the 10 year period, 1927 to 1936 inclusive, the rate of cable failures due to all

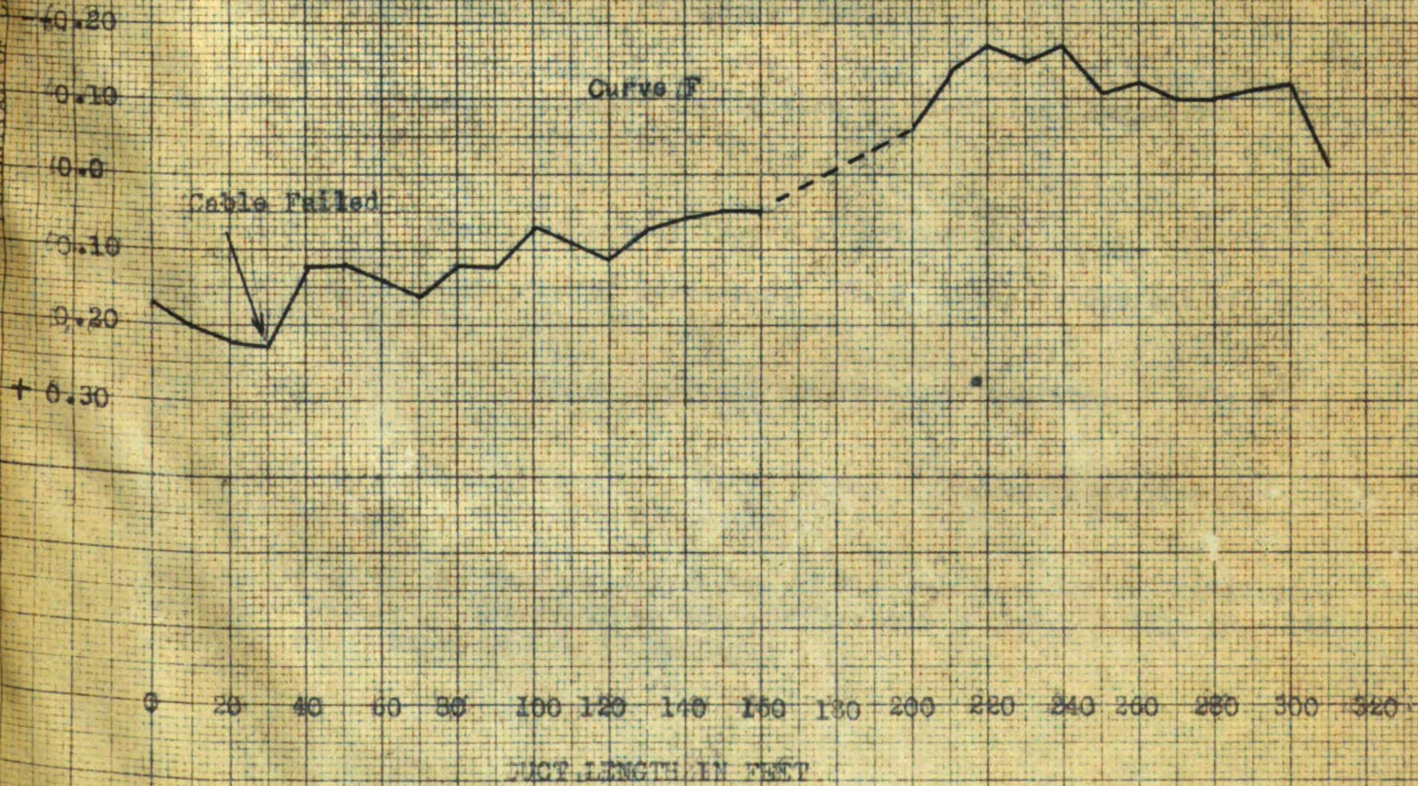
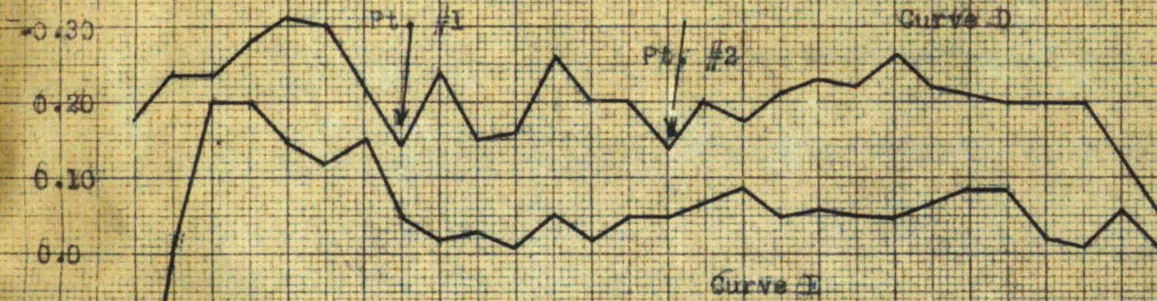
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causes was 6.5 failures per 100 miles per year. Of this total figure 0.76 failures per 100 miles per year were attributed to stray current electrolysis and 0.47 to corrosion. The figures for 1936 were: 5.35, 0.23, and 0.41. The reduction in electrolysis failures from 0.76 to 0.23 per 100 miles of cable per year shows what can be done through the cooperative efforts of a Committee on Electrolysis. On the other hand, the total number of failures dropped from 6.5 to 5.35, while the corrosion failures remained practically unchanged. The writer believes that these figures show the advisability of taking steps to curb the losses due to corrosion.

CORROSION SURVEY



CORROSION SURVEY



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APPENDIX

Construction of the Corrosion Testing Cell

The actual physical dimensions of the cell are unimportant, but the following conditions must obtain.

1. The cell must be mechanically strong.
2. The shell must be chemically inert.
3. The lead slug which acts as the electrode must be well insulated from ground.
4. It is highly desirable to provide a means of cleaning the cell in the field. The cell under description is cleaned by screwing the end plug into the shell, thereby compressing the Agar Agar and forcing it out through the small radial holes.

HERCOLITE was chosen as best fulfilling the first two requirements. A long leakage path was provided for the lead slug by cutting deep threads in the shell and casting the slug in place. The end was then sealed with De Kohtinsky's cement.

The steps in filling the cell are as follows:

1. Clean surface of lead slug.
2. Cover it with a paste consisting of KCl , $PbCl_2$, a small amount of distilled water, and a few drops of glycerin.
3. Dissolve 2 grams $PbCl_2$ in 100 c.c. of distilled water, then add 38 grams KCl and dissolve; heat the solution to the boiling point and add 5 grams of Agar Agar; finally add 40 c.c. of glycerine.
4. When the mixture starts to cool its viscosity increases and at about $70^{\circ}C.$ may be poured into the shell without danger of the solution running out of the radial holes.

The solution dries out readily and so the cell should be kept immersed in distilled water when not in use. Erratic readings will be obtained unless the potential of the cell is regularly checked.

Photograph No. 1



Photograph No. 2



Photograph No. 3



Finished Installation

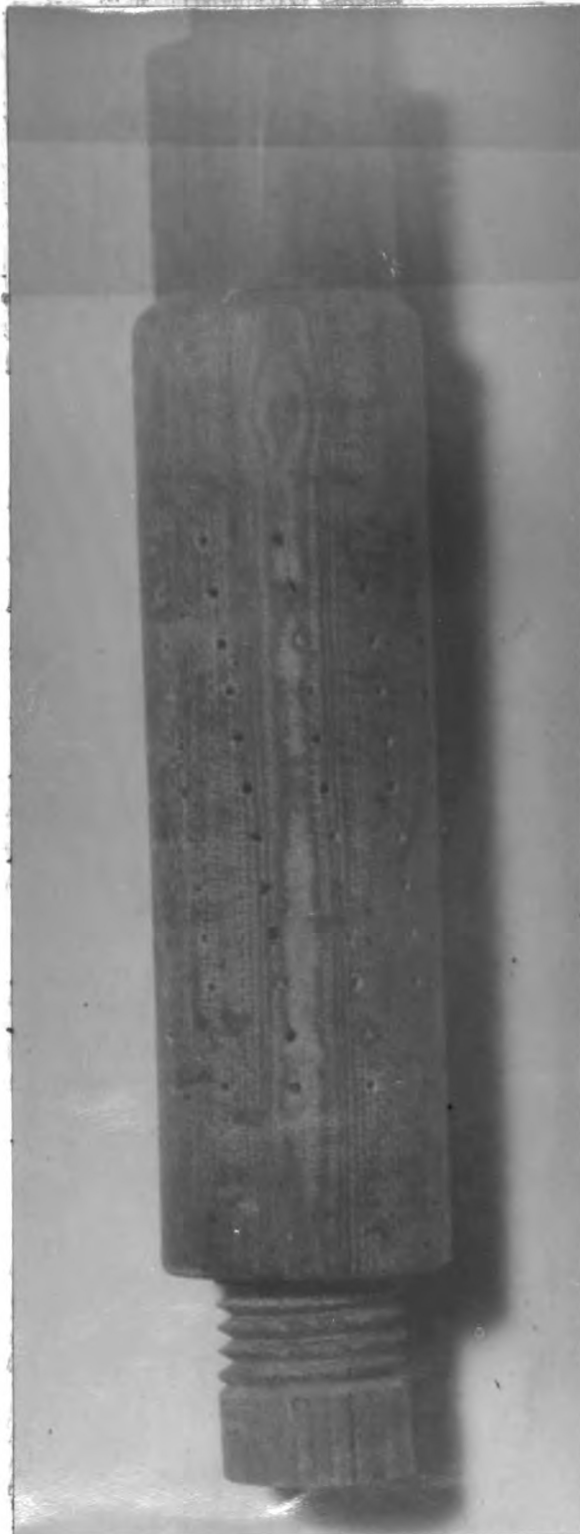


Applying Coating



**Photographs Courtesy
Clark L. Bassett**

Corrosion Cell



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