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CATHODIC PROTECTION OF UNDERGROUND STRUCTURES
Abstracts of Publications

Contents

Preface

From time to time the National Bureau of Standards receives requests for information regarding the application of cathodic protection. The Bureau has conducted only a limited amount of research on this subject. The application of cathodic protection to underground structures is comparatively a new art and there is considerable disagreement among authorities regarding methods of application and criteria for protection. On account of these conditions it seems best to refer inquirers to literature on the subject and it is believed that brief abstracts of articles on cathodic protection will enable the reader to decide which articles should receive his attention. In making selections the reader is advised to consider when possible, the reputation of the author, his opportunities to obtain data and his probable purpose in preparing the article.

The abstracts are subdivided according to the topics which they discuss, but many of the articles cover more than one topic. In such cases the entire article has been abstracted under one heading, but cross references to the more important multiple topic papers have been placed under appropriate headings.

The length of the abstract is not an indication of the importance of an abstracted article. Some articles contain tables of data which cannot be satisfactorily abstracted and it has been necessary merely to indicate the nature of the article. In some cases the length of the abstract has been governed by the probable accessibility of the magazine which contained the article as indicated by its circulation. The Bureau is not prepared to furnish copies of the abstracted articles; however, several technical libraries are prepared to furnish photostatic copies of articles at reasonable rates.

I. THEORY

1. Observations on the behavior of steel corroding under cathodic control in soils. I. A. Denison and R. B. Darnielle. Trans. Electrochemical Soc. 76, 199 (1939).

Corrosion cells were specially designed, using glass through which the development of corrosion products in soils could be observed. The formation of a dense membrane of iron oxide between the anode and cathode appeared to be related to the rate of corrosion, such membranes forming at some distance from the anode in corrosive soils, and in close contact with the anode in mildly corrosive soils.

Tests made on the behavior of steel corroding under cathodic control indicate that the potential of the cathode tended to approach the potential of the oxygen electrode for the particular environment.

2. Applications of electrochemistry to cathodic protection. S. P. Ewing. Petroleum Industry Electrical Assn. Electrical News (May 1939).

By application of electrochemical principles and methods, the cathodic protection engineer could improve the accuracy and interpretation of his measurements. The error introduced by liquid junction potentials is discussed. Construction of reliable and reproducible reference electrodes is described and a diagram of such an electrode is given. A table of standard electrode potentials is used to help explain the causes of galvanic currents in a pipe line.

3. Cathodic protection of pipe lines from soil corrosion. S. P. Ewing. Natural Gas, 16, No. 3, 5 and 16, No. 4, 16 (1935).

This is a report of the Subcommittee on Pipe Coatings and Corrosion of the American Gas Association and is a compilation and extension of the more important literature on cathodic protection which appeared prior to 1935. On this account this letter circular will not review articles prior to 1935.

The fundamental principle involved is that a metal will not corrode if, at all points, it is cathodic with respect to the adjacent soil. Cathodic protection deals with methods of establishing and maintaining this condition through the imposition of electric current between the pipe and anode in the soil. Mathematical formulae are given for the fundamental relations between current, voltage and resistance for different conditions.

It is important that the line to be protected be free from insulating or high-resistance joints and free from accidental contacts with other lines. It is desirable that the line be coated with a meterial of low conductance. Rectifiers and drainage points should usually be located near the center of the corroding section. The required drainage current can be predetermined by temporarily connecting a number of storage batteries between the line and the anode and noting the voltage required to make the pipe 0.85 volt negative with respect to a copper-sulfate electrode. If the protection is to be applied to a newly coated line sufficient power should be provided to take account of any decrease in the resistance of the coating as it absorbs moisture. It is preferable that the preliminary tests be made after time has been allowed for the backfill in the tranch to become stable. A smaple calculation is made to show how the equations previously referred to can be used to estimate the resistance of the coating and the safe distance between drainage stations.

Since a large part of the voltage in the cathod protection circuit is consumed at the anode, it is important that the resistance of the contact between the anode and the earth be as small as economically practicable. The use of coke around the anode will tend to reduce the resistance of the circuit and the corrosion of the anode.

There are several satisfactory sources of potential for cathodic protection. The most commonly used are Tungar and Rectox rectifiers. A full-wave rather than a half-wave set is preferable. It is not essential that current be supplied continuously since polarization effects will afford protection to the pipe line for several hours or days if the current is interrupted. It is not advisable to apply cathodic protection to cement or concrete coated lines.

High voltage at the cathode may destroy the bond between asphalt coatings and the pipe. Coal-tar base coatings are practically moisture-proof so long as they remain continuous.

It is desirable to determine the extent to which currents other than the one intentionally imposed affect the pipe line. To facilitate testing, test wires should be brought out from the pipe at intervals of between 500 feet and 1500 feet. The wire should be brazed to the pipe and the end brought to the surface and attached to a short creosoted wooden stub or buried close to the surface in a well marked spot. The wire connecting the rectifier to the pipe should not be used as a potential lead.

Potential profiles should be made to determine whether the line is in a safe condition. The condition of the line may also be followed by burying adjacent to the line at critical points two test coupons of the same material as the pipe, one being connected to the pipe by a wire. After about a year these coupons are removed and examined. If the pipe is positive to the soil part of the time the coupon attached to the pipe will lose weight.

Three appendices give the mathematical development of the formulae used.

4. Soil corrosion and pipe protection. T. H. Gilbert. Petroleum Engineer 17, No. 2, 82 (1945).

The paper is a general discussion of pipe line corrosion from the standpoint of four causes:

1. Stray electric currents from street railways.
2. Natural differences in soil potentials.
3. Galvanic potentials arising from disimilar metals connected together.
4. Potentials arising from concentration cells in the soil.

The author discusses the different kinds and types of coatings, their advantages and disadvantages, and the use to which they are put.

A cathodic protective system to be effective must maintain the pipe to be protected at a mainimum of 0.2 volt negative to the soil.

5. Determining minimum current required to provide adequate cathodic protection. D. Harrell and M. Clerc. Pet. Eng. <u>11</u>, No. 1, 38 (1939) and 11, No. 4, 64 (1940).

The factor most vitally affecting the economics of cathodic protection is the minimum safe limit of protective potential, i. e. the potential at which all corrosion ceases and any excess energy only results in the generation of hydrogen. By using a mathematical derivation it is concluded that the protective potential is -0.2853 plus a temperature correction (in degrees F) of -0.00053 (t-77). The protective potential was then determined experimentally and found to agree with the theoretical value. The circuit diagram used in the laboratory experiment is given.

6. Developing magnesium for cathodic protection. Porter Hart and Y. W. Titterington. Corrosion <u>1</u>, No. 2, 59 (1945).

Efficiency and life of a magnesium anode largely depends upon three factors:

1. Composition

2. Backfill

3. Current density.

The percentage of iron, nickel and copper above a definite maximum tends to accelerate the local cell corrosion of the anode.

The selection of back-fill material is particularly important because therein lies the opportunity of reducing local cell corrosion of the anode surface. Chromates in the absence of chlorides give excessive polarization and seriously restrict the current output.

At a current density of 200 milliamperes per sq. ft. the current efficiency is 50 percent (approximately). A program was started to determine the effect of various electrolytes and fillers on the current efficiency of magnesium anodes when connected to a large non-polarizable structure.

Cathodic protection of two pipe lines is described in detail. There are included two tables of performance of the anodes, figures showing methods of installation and photographs of the anodes. Also included is a table of costs of different types of cathodic protection installations, as well as a table of composition of magnesium alloy and commercially pure magnesium.

7. Electrolytic methods for the prevention of corrosion. D. S. McKinney. Trans. Electrochemical Soc. 75, 31 (1939).

This paper discusses the use of zinc slabs in connection with electrolytic methods for the prevention of corrosion. The application has generally proved unsuccessful because of the limited electromotive force of the couple, the difficulty of maintaining metallic contact between the zinc and the metal to be protected, and the rapid consumption of the zinc. Further, it was found that the protective action to iron was appreciable over an area of only about fifty square feet surrounding each zinc slab. Mr. McKinney is of the opinion that generated electricity offers two advantages over the use of zinc; (1) the potential applied can be controlled, hence the effect of poor contacts may be overcome; (2) the anodes used may be made of noncorrodible materials, hence they do not require close attention or frequent replacement.

8. Methods of determining extent of cathodic protection. R. B. Mears and R. H. Brown. Gas, 20, No. 12, 35 (1944).

This paper was compiled from one presented before the 5th Annual U. S. Bureau of Standards Soil Corrosion Conference, St. Louis, Mo., and outlines four methods of locating corroding areas and determining complete cathodic protection. It refers to Pearson's "null" method employing a d-c and a-c bridge, whereby the polarization curves and the film resistance of the corroding objects can be determined. The authors believe the "null" method has the advantage that buried structures can be investigated without disturbing the structures.

9. Corrosion of buried metals and cathodic protection. M. C. Miller. Pet. Eng. 15, No. 6, 208, 15, No. 7, 101, 15, No. 8, 57, and 15, No. 9, 103 (1944).

This is a non-technical presentation of the principles of soil corrosion. It includes a discussion of galvanic corrosion, electrolysis, mill-scale and instruments for making various tests relative to corrosion of underground structures.

10. Control of pipe-line corrosion. O. C. Mudd. Corrosion, 1, No. 4, 192 (1945) and 2, No. 1, 25 (1946).

This manual sets forth the theory of corrosion, methods of corrosion investigation, and methods and economics of corrosion control. Many informative diagrams, photographs, and graphs are included.

The data have been collected by the Shell Pipe Line Corporation since 1933.

11. The effect of cathodic reactions on the corrosion of metals from the viewpoint of the local cell theory. W. J. Müller. Trans. Electrochemical Soc. 76, 167 (1939).

An explanation of the corrosion problem is given in this discussion of the local surface cell theory. The author considers the surface film of a corroding metal plate as having a very large number of pores, $10^{10}/cm^2$, and therefore about as many local galvanic couples. In his development of the theory of local surface cells, film polarization is taken into account. The potential displacement which occurs as the resistance increases at the exposed areas of the metal surface is termed "film polarization", and increases as the exposed area decreases.

The local cell current equation is derived and the measured potential of corroding metal plates is interpreted. A direct experimental determination of the electric current components of the local cells on a metal plate while corrosion is in progress, is represented in a series of equations. The anode potential of the local cell anodes corresponds to the Nernst potential, as determined by the concentration of metal ions in the layer of solution adjacent to the anodes.

The cathodic process can consist either in the evolution of hydrogen or in the depolarization by oxidizing agents, or under certain conditions both. When hydrogen is evolved, the local cell cathode potential is determined by the pH of the solution and by the overvoltage of those points of the corroding metal which show the lowest overvoltage. The cathodic depolarization by oxidizing agents has practically no effect on the cathode potential as long as the oxidizing agent is quantitatively used up during the depolarization process.

Numerous experimental data were used as bases for the theoretical conclusions in the development of which thirty-nine equations were used. Graphs illustrate the results of tests. A list of symbols and their definitions is included.

12. Control of pipe line corrosion. G. R. Olson. Pet. Eng. 14, No. 12, 96 (1943).

The author gives a simplified discussion of the corrosion problem in which he considers the theory of galvanic corrosion, corrosion due to stray currents or to dissimilar metals. He also gives his views on the theory and practices of cathodic protection as well as of ground beds and power units used therewith. One-hundred percent protection to the pipe line is not achieved until pipe to soil potential is maintained at 0.8 volt or larger.

13. Method of studying anodic, cathodic areas under cathodic protection. O. C. Roddey and L. R. Sheppard. Pet. Eng. 15, No. 12, 174 (1944).

This paper describes the results obtained from an experimental section of a pipe line set aside for the prime purpose of studying various methods of the application of cathodic protection. It points out the importance of soil surveys in conjunction with soil analyses in determining the so-called "hot spots". Various types of anodes and methods of distribution are discussed. Several methods of supplying power were tested. Costs of installation and maintenance are cited.

14. Electrical protection and use of light weight pipe in pipe-line construction. Walter F. Rogers. Pet. Eng. 13, No. 6, 71 (1942).

Mr. Rogers points out that the weight of pipe used in cross-country pipe lines could be reduced by the use of a joint coating-electrical protection program. Formulae are given to substantiate the author's reasoning.

15. Pipe to soil potentials in cathodic protection systems. Walter F. Rogers. Pet. Eng. 11, No. 13, 33 (1940).

The aim of cathodic protection is discussed in this paper. The author considers the minimum protective pipe potential to be 0.799 volt. The pipe to soil potential depends upon condition of pipe acting as a cathode. The potential of pipe to soil and of the $CuSO_4$ electrode is calculated.

Pipe to soil potentials can result in readings which are difficult to interpret.

16. Relationship of current density to cathodic protection. Walter F. Rogers. Pet. Eng. 12, No. 1, 156 (1940).

Field tests using test coupons 2" x 3" x 1/8" cold-rolled low-carbon steel gave the following information: current density varied from 3.65 to 8.20 milliamperes per sq. ft. which gave 76.2 to 100 percent protection.

The author suggests that this percentage protection data be used as a sign post rather than pipe to soil potential measurements.

17. Calculating current and potential distribution. Walter F. Rogers. Pet. Eng. 12, No. 3, 66 (1940).

16 ma per sq. ft. of pipe surface will give 99 percent protection. The usual procedure is to use 4 ma per sq. ft. with 63.5 to 71.5 percent protection.

The author gives equations for:

a. Voltage drop along the pipe
b. Voltage of the pipe
c. Value of current flow on the pipe.

These equations are for well coated pipe but are later developed to apply to bare lines.

18. Protecting buried metals against corrosion. Starr Thayer. Oil and Gas J. 40, No. 47, 37 (1942).

The author states that underground structures, such as pipe lines, suffer a corrosion loss of upward of $100,000,000 yearly.

Protective coatings constitute a long step toward elimination of pipe-line corrosion, when applied to new pipe. Older lines can be protected by cathodic protection, based on correcting the galvanic differences in potential between small sections of the pipe wall, or changes in soil conditions. Proper ground beds are very important.

It is not likely that all corrosion can be eliminated; however, most corrosion troubles can at least be mitigated, and considerable savings made.

19. Constancy of application is important factor in cathodic protection. Neil Williams. Oil and Gas J. 39, No. 30, 53 (1940).

Conclusions of the writer were based on results of work done by the Houston Pipe Line Company over a period of several years. In the application of cathodic protection for its line, one of the most important factors in the success or failure of protecting pipe from corrosion is the constancy with which the protective potential is maintained.

The author describes his experiences with wind chargers which use supplementary storage batteries that function automatically when the wind fails.

Also refer to Section II, #4
III, #1, 5, 6
V, #1, 4
VI, #9, 14.

II. INTERFERENCE

1. Use of forced-drainage systems in stray current areas. Eric G. Carlson. Corrosion, 1, No. 1, 31 (1945).

Controlled forced drainage systems have operating characteristics similar to normal drainage systems. The effect of such systems on other substructures is given consideration. The location of an anode must be selected with care to prevent interference with other underground structures. A method of controlling difficult anodic areas is discussed.

2. Interference on telephone lines caused by cathodic units. Paul F. Marx. Pet. Eng. 15, No. 2, 124 (Part I), and 15, No. 3, 86 (Part II), (1943).

Remedial steps taken to solve the interference problem on telephone lines caused by cathodic protection units are given. The equipment and circuits used are described in detail.

3. Cathodic protection co-ordination. G. R. Olson. P.I.E.A. Elec. News, 13, No. 2, 25 (1943).

It is believed that the cathodic protection interference problem in any given area should be attacked and solved with a viewpoint similar to that which would be used if all underground structures were operated under one management. In December 1940, the writer and Mr. Koenig prepared the "General Rules for Handling Joint Installations". These rules have been helpful in a number of installations. A copy of them is included in Mr. Olson's paper.

4. Control of stray currents from cathodic protection installations. G. R. Olson. Gas, 21, No. 2, 39 (1945).

This paper deals briefly with practical methods of handling problems arising from the application of cathodic protection to pipe lines lying in close proximity to other unprotected buried metallic structures.

5. Concepts and methods of cathodic protection. J. M. Pearson. Pet. Eng. 15, No. 6, 216 (Part I) and 15, No. 7, 199 (Part II), (1944).

The author gives a study of the theory of polarization, soil corrosion and electrode potential. The methods of measuring cathodic potentials are given in great detail. Instruments used for these measurements are described and circuit diagrams are included.

6. Co-operative problems involved in cathodic protection. L. F. Scherer. Oil & Gas J. 38, No. 27, 179 (1939).

The author points out many dangers inherent in cathodically protecting underground structures. Mr. Scherer suggests an organization to consider all cathod installations.

7. An analysis of certain circuits in cathodic protection. G. N. Scott. Proc. Am. Petroleum Institute, 23, No. 4, 36 (1942).

This paper deals with a solution to the problem of cathodic interference, i.e. the unintended imposition of an electric current on a structure not a part of a primary cathodic protection circuit.

Graphs are shown which are helpful in determining the potentiometric reading, the saturation current, and the limiting resistance.

The method developed is applicable to the measurement of pipe-to-soil potential by means of low resistance meters which are usually considered unsuited to this purpose.

Equations are derived for use in the solution of cathodic protection problems and an example of the use of the equations and graphs is given.

8. Cathodic protection interference. A. V. Smith. Am. Gas Assn. Monthly, 25, 421 (1943).

Mr. Smith discusses the importance of the relation of cathodic protection on one structure to an unprotected structure.

Regulation of interference currents by moving the anode to the best possible balance point is described and two cases are given as illustrations. The use of insulating joints should be avoided except where the anode has been moved to the best possible balance point. An enormous amount of interference current will be found on foreign structures in city networks if the anode is more than a few pipe diameters away from the protected structure. If interference is to be prevented, it is essential to have an understanding of superposition of current. Contacts between structures must be removed as each contact that exists will increase enormously the amount of current required for cathodic protection.

This paper shows that cathodic interference can be avoided by proper engineering.

Also refer to Section I, Theory
III, #4
VI, #22.

III. CURRENT

1. Determination of the current required for cathodic protection. S. P. Ewing. Proc. Am. Gas Assn. 613 (1940).

This paper gives data and conclusions drawn from laboratory investigations of the potential behavior of steel electrodes in soil to which cathodic currents are applied.

Among other things the author concludes that:

1. The potential of the metal with respect to a reference electrode taken alone is no criterion of the rate at which the metal is corroding.

2. The protective current always causes alkali to accumulate on the cathode surface. If there is sufficient oxygen, this alkali causes an oxide film to form and hence causes the potential to become more positive. If there is no oxygen the accumulation of alkali causes the potential to shift in the negative direction.

2. Current density related to current distribution. Harry C. Gear. Gas, 21, No. 10, 51 (1945); also Pet. Eng. 14, No. 10, 182 (1943), and P. I. E. A. Elec. News, 13, No. 59, 9 (1943).

The current distribution on a pipe line exposed to a system of forced electrical drainage decays exponentially with the distance from the point of drainage.

A graphic solution of the observed data gathered by reading IR drops on a pipe line exposed to a system of forced electrical drainage indicates soil boundaries or changes in the character of the soil by a change in slope of the current distribution curve.

The current density at any point on a section of pipe line exposed to a system of forced electrical drainage is directly proportional to the current drained, the slope of the current distribution curve and the distance from the point of drainage.

Curves are submitted showing the graphic relation between the IR drops and distance from the negative return.

3. Laboratory tests of cathodic protection in soils. W. Ryland Hill. Pet. Eng. 12, No. 6, 69 (1941).

This paper presents the results of tests made to determine which factors are most important in cathodic protection and to devise a practical method to determine the effectiveness of a cathodic installation.

Four soils differing in corrosivity were used in the experiments which are described. The current density was kept constant during the tests rather than the potential difference between the soil and metal because it was felt this more nearly corresponded to actual conditions. Results of the tests are given graphically.

4. The determination of the current required for cathodic protection. K. H. Logan et al. Pet. Eng. 14, No. 10, 168 (1943).

Several methods for determining the amount of current required to protect an underground structure against corrosion are in use. Most of these are based on rule of thumb or on experience. Scientific methods have been developed and are described in this paper along with the apparatus necessary for application of this procedure. Results of different methods for determining the protective current are compared. Circuit diagrams for the methods described are given.

5. Null methods applied to corrosion measurements. J. M. Pearson. Trans. Electrochemical Soc. 81, 485 (1942).

The author defines the null method and, in the appendix gives an analysis of the null circuit with an evaluation of the sources of error. Null methods become indispensable in the study of the corrosion of extensive buried structures. The general problem includes not only the "local action current" but also an external current component which flows from an external circuit through the boundary between electrode and electrolyte.

In measurement, the observations must be independent of the external current, yet give the relation between electrode potential and the total current density. Null methods are used to eliminate IR drops from measurements of electrode potential in the presence of polarizing current. Polarization potentials are measured to the outside of "electrode boundary" by using a.c. When increments of d.c. are used the effects of film resistance are nullified. Local action current may be calculated from polarization and film resistance curves.

6. A rational approach to cathodic protection problems. Gordon N. Scott. Pet. Eng. 12, No. 8, 27 (Part I), 12, No. 9, 59 (Part II), and 12, No. 11, 74 (Part III), (1941).

In this article the author develops a function for use in the measurement of radial currents entering or leaving a pipe line through the soil and also for use in the measurement of the conductance of pipe coatings. This function may be used in calculating the current needed for cathodic protection of a pipe line instead of the usual practice of using a "reading" of a certain value that has been established as protective more or less through rule of thumb.

This derivation is limited to the case of a single pipe line and for use in the case of multiple pipe lines may become exceedingly complex and unwieldy. The basic equation derived is $V_r = V_a + \frac{ip}{2\pi} \ln\frac{r}{a}$ where V_r = the general galvanic potential reading in mv; V_a = that observed at the pipe coating or surface, i = the galvanic current, p = the resistivity of the soil, r = the radial distance from the pipe center to a point in the test plane, and a = the physical radius of the pipe line. Applications of this equation are discussed.

7. What about cathodic protection? W. T. Smith and T. C. Marshall. Gas Age, 85, 49 (May 9, 1940).

This paper gives a general review of the recent history of cathodic protection and a list of the various sections of the country where zinc anodes have been installed using the distributed anode system. It also gives the design and equipment for installing protection using wind driven generator. A discussion of instruments and advantages of the distributed anode system is also given.

8. Induced current along pipe lines retards corrosion. Starr Thayer. Oil and Gas J. 35, No. 19, 91 (1936).

The Rectox cell is described. The writer's company has operated 16 cathodic protection stations with these rectifiers with no losses due to their failure. Their advantages are low cost and upkeep, flexibility and ease of installation. The chief disadvantage is the power supply. Under favorable conditions current for cathodic protection may be supplied by windmills. The author has operated a windmill with a 14-foot propeller and a 70-ampere generator using a 40-foot tower. A control on the generator was found unnecessary. The author is also experimenting with a gasoline-driven generator.

Also refer to Section I, #5
VI, #10.

IV. COSTS

1. Cathodic protection of Montana Power Company's lines. C. R. Davis. Oil & Gas J. 40, No. 21, 45 (1941).

This paper gives details of the installation of a West gas line system in Butte, Mont., and surrounding towns, as well as an East gas line system serving Red Lodge, Roberts, Columbus and others. The paper gives the cost of protecting the lines based on equivalent 3-inch main.

2. Careful cost study leads gas company to selection of cathodic protection. H. C. Gear. Pet. Eng. 11, No. 12, 29 (1940).

Author gives specific data comparing cost of cathodic protection with cost of pipe line repair.

3. Practical design and economics of a cathodic unit as applied in the refinery. D. Holsteyn. P.I.E.A. Elec. News, 13, No. 3, 9 (1943).

Due to the different equipment used and variable soil conditions throughout a refinery, many problems are encountered in applying cathodic protection. The author is of the opinion that complete protection is achieved only when a potential difference measured in volts between the pipe and a copper sulfate electrode in contact with the soil adjacent to the pipe measures .85 volt negative, exists all around the pipe. This conclusion is based on four sets of tests. It is stated that protection may also be based on current densities, but this is not as easily and accurately determined as the soil-to-pipe potentials due to the complicated layout of the ground bed. On the basis of certain assumptions as to pipe life and costs, the author shows that a cathodic protection installation protecting 10,000 square feet of pipe will pay for itself in 10.6 months.

4. Comparing equipment costs in cathodic protection. W. R. Schneider. Gas 15, No. 6, 31 (1939).

The author gives a summary of costs of cathodic protection equipment, calculated from the records contributed by six pipe-owning utilities.

5. The application and economics of electrical protection of pipe lines. Starr Thayer. Am. Petroleum Inst. Proc. 17, No. 4, 33 (1936).

Where cheap power is available Rectox rectifiers are usually the most economical means of furnishing current for cathodic protection. Windmills are more economical where sufficient wind prevails. One such installation develops 70 amperes with a 12-mile-per-hour wind. The generator is not regulated but has a thermal cutout which operates when the windings get dangerously hot.

The author estimates that his company has saved from $8 to $10 of reconditioning costs for each dollar spent for cathodic protection. Under favorable conditions 12 miles of line may be protected by one station but under unfavorable conditions less than a mile of 8-inch line may be so protected.

6. Cathodic protection on distribution systems. R. M. Wainright. P.I.E.A. Elec. News 12, No. 1, 33 (May 1942).

The economics of installing cathodic protection to an hypothetical distribution system are discussed. Equations are derived which show the cost of protection per year under various assumed conditions.

7. Cathodic protection - What does it cost? Stanley Wright. Gas 21, No. 5 (1945).

This paper is a brief discussion and summary of operating costs for five years, of eight cathodic protection units.

A table is included giving operating data and annual costs.

Also refer to Section I, #6, 10
V, #4,
VI, #5, 8, 20, 24.

V. ANODES

1. Use of carbon anodes in cathodic protection. M. J. Dorcas. Gas 21, No. 6, 6 (1945).

Anodes represent a substantial replacement item in the maintenance of a cathodic protection system. In addition to scrap steel, various other materials are used as anodes. These include cast iron, copper, zinc, magnesium, and carbon in the form of amorphous carbon or as graphite. Carbon and graphite seem to have special advantages in that they have high electrical conductivity and great resistance to oxidation and corrosion, resulting in long life and low cost operation. Carbon ground rods have been found universally applicable, but in externally excited systems only.

The consumption of iron when used as an anode may be calculated and is found to be more than 20 pounds per ampere year of current. If the oxygen generated at the carbon anode combined with the carbon to form carbon dioxide, the consumption of carbon would be 1.5 pounds per ampere year. Thus, it is said, that the same weight of carbon will be expected to last fifteen times as long as the same weight and original surface area as iron anodes.

2. Ground connections - construction and measurements. J. R. Eaton. P.I.E.A. Elec. News 14, No. 2, 5 (1944).

Material used as anodes must be spread over a considerable ground area to be effective. Figures are given comparing the conductance of a single rod to that of many rods and showing that pipe driven to a considerable depth is more effective than the same length of pipe used as closely spaced short lengths.

The liberation of heat due to the passage of current through the soil tends to cause the soil to dry out. A temporary anode may be used to predict the distribution of current flow to a pipe before permanent installation is made. The ground resistance of anodes after installation should be made at regular intervals to observe any changes which may occur. The resistance may be measured by such standard methods as the ammeter-voltmeter method or by the Megger Ground Resistance Tester, a direct reading instrument.

3. The behavior of zinc-iron couples in carbonate soils. T. H. Gilbert and Guy Corfield. Corrosion 1, No. 4, 187 (1945), and Gas 20, No. 10, 32 (1944).

This paper gives the results of a test using Zn-Fe couples buried 546 days in a carbonate soil. It also contains curves showing current developed at various periods after burial. A modification of the zero-volt-loss circuit by Denison and Darnielle is discussed.

4. Zinc anodes for preventing corrosion of distribution mains. C. L. Morgan. Pet. Eng. 16, No. 13, 196 (1945).

This paper relates experiences in the application of zinc anodes to steel gas distribution mains in Houston, Texas. The mains ranged in diameter between 6 and 10 inches and were coated with asphalt. 2400 feet of mains were protected by lowering their potentials, referred to a remote $CuSO_4$ electrode, to -.85 volt or .25 to .4 volt below adjacent water mains. One leak has occurred since the application of protection.

Four or five plates of 1/2" x 3" x 36", 99.9% pure zinc were placed one above the other in holes 4" in diameter and 20 ft. deep. The holes were back filled with a mixture of gypsum and clay. Ten plates were connected in parallel. Leads from the plates were brought up to terminal boxes so that the current could be measured. Each plate furnished from 13 to 26 milliamperes, depending on soil and other conditions. The average current required to lower the potential of a well insulated pipe 0.25 volt was 0.21 milliamperes per sq. ft.

The resistivity of the soil ranged from 500 to 1000 ohm-cm. The resistance to ground of a group of plates was about 1.5 ohms.

The paper gives detailed description of the anodes and also costs.

5. Experiences with zinc anodes. O. C. Mudd. P.I.E.A. Elec. News, 13, No. 1, 11 (1943).

The author reviews briefly the history of cathodic protection and initial measures for mitigation of underground corrosion. Mr. Mudd discusses the preliminary tests, using zinc for anodes, such as specing, relationship of area to resistance, and effect of depth of burial on current density. A number of illustrations showing method of installation and tables of electrical measurements are given. Records show that economic returns can be realized from zinc anode installations. Locating the anodes near the pipe line in corroding areas will reduce the cost of the installation and increase their effectiveness. The paper also points out that inactive or partially consumed anodes may be reactivated by removing the products of corrosion from the surface and reinstalling with added chemicals.

Zinc is limited in the amount of current it can produce in combination with iron in the soil. The author concludes that zinc is a suitable anode in most soils and at locations where the required current is not too great.

6. Progress report on the behavior of zinc-iron couples in soils. Melvin Romanoff. Corrosion 1, No. 2, 95 (1945).

In 1941 the National Bureau of Standards buried Zn-Fe couples at eight test sites to study the effectiveness of zinc anodes for the protection of iron. Current and potential measurements were made at the time of installations and at inspection periods. At one site corrosion was materially reduced but protection was not adequate. At the other site the iron was protected galvanically during the exposure period of 3.14 years.

7. Cathodic protection of pipe lines may create large market for magnesium. Staff Report. Chem. & Eng. News 23, No. 11, 984 (1945).

The value of magnesium in cathodic protection installation is attributed to its position in the electromotive series. Magnesium has an electrochemical equivalent of 1,000 ampere-hours per pound, while zinc has 372 ampere-hours per pound. The solution potential of magnesium to a $CuSO_4$ electrode is 1.7 to 1.8 volts, while that of zinc is approximately 1.1 volts. Magnesium is said to show little or no tendency to polarize with time, although this effect is noted frequently with zinc. Three factors upon which the efficiency and life of a magnesium anode depends are the electrolyte surrounding the anode, the composition of the metal used and the current density at which the anode operates.

8. Investigation of soil resistivity. H. F. White. P.I.E.A. Elec. News 13, No. 10, 13 (1944).

The action of carbon anodes in four soils is described in this paper. Anode current fell rapidly due to Na_2CO_3 and Na_2SO_4 in one soil. The addition of $CaCl_2$ restored the current permanently.

Also refer to Section III, #7
VI, #5, 11, 14, 25.

VI. INSTALLATIONS

1. Cathodic protection on high pressure mains. K. B. Anderson. Gas 21, No. 7, 37 (July 1945).

This article deals with cathodic protection of two steel, high-pressure mains. One is a 10-inch main and the other is a 6-inch main. Both were treated with single wrap tar and felt paper. The soil is principally Dublin Clay Adobe. The lines were electrically insulated into three sections. Corrosion eliminators were installed; one for the 10-inch main and one for the 6-inch main. Both were a-c rectifier type.

Tables showing the weight losses of test coupons are included.

2. Cathodic protection of oil storage tank bottoms. D. H. Bond. Pet. Eng. 11, No. 6, 100 (1940).

Cathodic protection of 45 55000-gal. storage tanks is described in this paper. Each tank is maintained 0.8 volt negative to a $CuSO_4$ electrode. Four motor generator sets of 15 volts, 90 - 72 amperes each, provide the current. The ground bed is composed of 300 ft. of 8-inch pipe buried horizontally and 10 sections of 6-inch pipe buried vertically 10 ft. on 10 ft. centers. The system uses 00 copper cable for connections.

3. Cathodic protection and applications of selenium rectifiers. W. F. Bonner. Elec. Communication 22, No. 2, 130 (1944).

The author briefly reviews the principles of galvanic corrosion. It has been found that the most efficient and economic method of countering the corroding current is to cause a direct current to flow from an outside source in the opposite direction.

The advantages of using selenium rectifiers as a source of direct current are: 1 - their operation is substantially uniform over the wide temperature fluctuations encountered in outdoor use. 2 - the efficiency remains practically constant through comparatively large load variations. 3 - they may be enclosed in light, compact, easily portable units which are suitable for pole mounting. 4 - the absence of moving parts obviates the necessity of frequent maintenance check-ups.

The saving which may be afforded by the use of cathodic protection is shown in the example of a refining company in Michigan where units were installed in 1938 to protect the submerged condenser coils. At the time reported, 1941, the coils were still in good condition. Prior to this installation the coils had to be replaced at intervals of eight to nine months. Many applications of the use of cathodic protection units using selenium rectifiers are given.

4. Cathodic protection of tank farms. R. A. Brannon. P.I.E.A. Elec. News 12, No. 6, 11 (1942).

This paper deals with the application of cathodic protection to a large tank farm in the Gulf Coast area of Texas. The installation was completed and placed in operation in May 1941. A survey of the results of operation of the system was made during February 1942. A long time will be required to determine the effect upon the tank bottoms, but results are already apparent on the tank farm lines. Pit hole leaks had occurred on these lines at an average rate of six a month since 1938. During the six months following the installation, twelve pit hole leaks occurred, or an average of two a month. This means a reduction of leaks of 66 2/3 percent. It is to be expected that leaks will be reduced further after the pipe which was extremely badly pitted before protection was started fails and is repaired.

There are sixty-three 55,000-barrel tanks on the farm and a total of more than 28 miles of connecting oil line varying from 2 to 16 inches in diameter. The cost of operation of the cathodic protection system has been very reasonable so far, the power consumption being about 10,000 kwhr per month. The preliminary survey and methods of installation are described.

5. A practical application of zinc anode protection to an 18-inch pipeline. C. L. Brockschmidt. P.I.E.A. Elec News 11, No. 10, 31 (1942).

This article describes the installation of cathodic protection units using electrolytic zinc anodes 1.375 in O.D. and 48 inches long. These anodes had a 1/4-inch round iron core which gave enough rigidity so that they could be driven into the ground, thus packing the soil around the anode, insuring a good electrical contact and excluding air. From the experience acquired during this installation, some procedures to be followed in new installations have been worked out. A table of costs is included although the figures are nominal, based on the use of improved machinery for laying ground wire and tamping in the zinc anodes.

6. Rectifiers, all types, comparison and operation. R. T. Fryer. P.I.E.A. Elec. News 14, No. 1, 17 (1944).

The author considers the copper-oxide type of rectifier outstanding for use in cathodic protection installations. The basic element consists of a copper disc, on which a layer of Cuprous Oxide (Cu_2O) has been formed on one side. A chart is given showing its construction. The larger capacity elements are made of copper plates ranging from 10 to 50 square inches, oxidized on both sides to prevent warping. This produces a desirable effect in that it doubles the active rectifying surface and reduces the amount of copper used. Further detailed data concerning the operation, regulation and application of copper-oxide rectifiers are given. This paper also contains information about other rectifiers but recommends the copper-oxide type.

7. Improved operation of wind chargers for cathodic protection of pipe lines. Dave Harrell. Pet. Eng. 9, No. 6, 76 (1938).

Pipe to soil potentials were measured by means of a recording vacuum tube voltmeter. At a site selected, one 32-volt wind charger protects 1000 ft. of 18-inch pipe. The charger is mounted on 40-ft. pole, capacity 25 amp maximum and 5 amp minimum (three-mph wind). Earth resistance is 1 ohm. This protected the line 46.38 percent of the time in November. The line returns to positive condition in 18-1/2 hours after charger stops. The method of installing two wind chargers with two 120-amp-hr batteries in parallel to give continuous protection is described.

Two curves showing operation of vacuum-tube voltmeter and 5 photographs of installations are included.

8. Operation of cathodic protection units on high pressure gas lines. Dave Harrell. Pet. Eng. 10, No. 12, 88 (1939).

The effective rate of a small rectifier unit is about 4 cents per kwhr and operation is almost trouble free. More attention is required by motor generator sets but the effective rate is about the same as for rectifier units. However, more power output is obtained. On lines virtually devoid of any coating, 4 ma per sq ft of pipe is used. On well protected lines 0.1 ma per sq ft is used.

To check the results of installations, ground potentials are measured with a vacuum-tube voltmeter. Soil to pipe potential should be 0.24 volt.

Cathodic protection to be practicable must be continuously maintained.

9. Cathodic protection to prevent corrosion of gas well casing. W. E. Huddleston. Oil and Gas J. 39, No. 52, 59 (1940).

This paper begins with the theory of corrosion and continues with the principle and application of cathodic protection for gas-well casing.

After a number of field tests made on bare lines the author maintains that adequate protection is obtained when a rising potential gradient is existent along the full length of the casing, beginning at the bottom of the well and terminating at the point where the negative battery cable is connected to the casing. Specially made contactors were used to contact the casing at various points within the well. Mr. Huddleston describes the method used for testing.

The most serious problem arising in the design of a cathodic protective system for gas-well casing is in securing the source of energy for operating the protective equipment. Other problems arise in the manner of determining the necessary load requirements for a given string of casing and the fabrication of a suitable low-resistance anode in locations having adverse soil conditions. The author suggests insulating new wells as they are completed.

10. Current and voltage needs for cathodic protection of steel submarine pipe lines. H. J. Keeling. Gas 15, No. 9, 31 (1939).

The current density required for protection of bare steel in sea water is about 15 ma per sq ft average. This may vary from 7 ma to 25 ma per square foot.

11. Corrosion protection for transcontinental cable west of Salt Lake City, Utah. T. J. Maitland. Corrosion 1, No. 2, 47 (1945).

The author describes the installation of zinc anodes to protect buried telephone cable protected by lead sheath. Conclusions are as follows:

1. Requires a low-resistance ground.
2. Zinc may become passive requiring frequent treatment.
3. A comparatively well insulated covering is necessary over the cable sheath to insure effective results over an appreciable distance.

12. Practical application of electrolysis on pipe lines in compressor stations. Paul F. Marx. Pet. Eng. 11, No. 4, 48, and 11, No. 5, 51 (1940).

The author discusses bonding and effective length of pipe line which can be protected with one cathodic protection unit. The installations of ground beds is described. Control plates are used to indicate effectiveness of the protection provided to the pipe line. Changes to be made in ignition systems of engines used in compression stations are discussed.

Definitions of terms to be used on field inspection sheets, suggested forms for pipe line surveys and methods of making pipe line surveys are given.

13. Coupling bonding on natural gas pipe lines. F. J. McElhatton. Pet. Eng. 15, No. 12, 114 (1944).

The author of this paper outlines three bond requirements: (1) the bond should be of extremely low resistance, (2) it should be applied to the pipe line in such a manner that it will not fail and will remain in good condition throughout the life of the pipe line, and (3) the cost of the bond should not be excessive. Cost is, of course, determined by the size of the bond and the method of manufacture.

Five types of bonds used successfully are mentioned, as well as methods of construction and application. Tables are given showing results obtained in over-all ohmic resistance; all tests were conducted on 24-in. O.D. seamless pipe. The measurements were taken with a wheatstone bridge.

14. Cathodic protection of aluminum equipment. R. B. Mears and H.J. Fahrney. Trans. Inst. Chem. Engrs. 37, No. 6, 911 (1941).

Aluminum is extensively used for certain types of chemical equipment because it has a high thermal conductivity, a low specific gravity and is not toxic to living organisms. In some cases the chemicals which are being processed or the waters used for heating or cooling purposes, may attack aluminum and in many such cases it is feasible to protect the aluminum equipment cathodically by means of zinc attachments.

Since aluminum is an amphoteric metal, excess cathodic current densities may cause special attack. It has been found safer to employ zinc to cathodically protect aluminum equipment rather than to use an inert anode and currents from an outside source. Aluminum being higher than zinc in the electromotive series, it might be predicted that zinc would be cathodic, not anodic, to aluminum. However, it should be pointed out that, while many calculations of fundamental importance are based on the electromotive series, this series has no great value in predicting the corrosion behavior of couples of dissimilar metals under service conditions.

In service, the solutions employed are different from the special solutions used in preparing the electromotive series. Since the solution potential of each metal depends on the composition of the liquid to which it is exposed (as well as on other factors such as temperature, degree of agitation, gas pressure, etc.,) it is not surprising that the solution potentials of the metals are quite different under service conditions from what they are under the carefully controlled arbitrary conditions employed while making measurements for the electromotive series.

Thus, in neutral solutions containing chlorides at room temperature, zinc usually has a solution potential which is about 0.2 volt anodic to that of commercially pure aluminum; however, the relative potentials of these metals may alter as the conditions of exposure are changed.

The authors cite five examples descriptive of service applications. Potential difference between zinc and aluminum in various solutions is given.

15. Cathodic protection of open tank condensers. N. A. Miller. Oil & Gas J. 40, No. 2, 66 (1940).

Cathodic protection as a means of combating corrosion is not new, but a comparatively small amount of data is available on its application to open-tank condensers. The same general principles of cathodic protection which have been applied widely and successfully to pipe lines apply equally well to the protection of open-tank condensers.

The author cites the service record of several installations including those at the Naph-Sol Refining Company and the Richfield Oil Corporation.

16. Cathodic protection installation carefully engineered. Chas. F. Ofner. Pet. Eng. 13, No. 6, 99 (1942).

This paper describes installation of cathodic protection on 54 miles of 10-inch line. Copper-oxide rectifiers are used in conjunction with a transformer rated at 115/230 volts on the primary side. Provision is made to give a range up to 50 per cent of the normal output on the secondary side.

Ground beds are of scrap iron pieces and are varied in size so that 40 amperes will flow when 12 volts are impressed. This current is the same at all rectifier installations.

Distance between units varies from 0.9 to 4.7 miles. Energy consumption is nearly the same for each unit.

Some data are given on an older cathodic protection installation.

17. Electrical bonding of pipe line couplings for cathodic protection. G. R. Olson. Am. Gas Assn. Monthly 23, No. 3, 86 (1941).

One of the many problems involved in the application of cathodic protection to a coupled gas line is that of electrically bonding the couplings to provide a continuous low-resistance metallic path in the pipe for the d.c. return current.

The experiences of the United Gas Pipe Line Company in soldering, brazing and welding copper cable directly to the pipe are cited.

Another method involves brazing the copper cable to small steel coupons which in turn are welded to the pipe. In the case of large cathodic protection units such as are frequently installed on poorly coated lines to protect several miles of pipe, a 4/0 copper equivalent bond or larger is frequently desirable.

A bond developed with the assistance of several engineers, shows promise of being a distinct advantage over anything tried to date. This bond consists of a 3/16-inch copper strip with 2 x 2 x 1/4-inch steel terminal plates which are curved to fit the curvature of the pipe. The steel copper juncture is welded in the factory in such a manner as to give a uniformly good joint. A 3/16-inch steel wire is also welded to the terminals in parallel with the copper strip. This steel wire can be bent and welded to any part of the coupling such as the center ring and/or follower rings.

Reference is made to Dr. Ewing's paper on "Electrical bonding for cathodic protection of pipe lines" in which he describes his "silver soldering method".

18. Recent developments in cathodic protection of bare pipe lines. G. R. Olson. P.I.E.A. Elec. News 12, No. 7, 17 (1942),

Study was initiated to determine if several older relatively short sections of bare lines could be effectively protected cathodically at a reasonable cost.

An electric power line was built parallel to the pipe line, with a separation of 25 ft. Ten 35-ft poles were used per mile of line. A single 2300-volt conductor was mounted on a pole-top insulator and a single 110-volt conductor was attached to the side of the pole. The pipe line was used as a common return for both primary and secondary. At 1-1/2 mile intervals small standard distribution-type transformers were used to step down the supply voltage from 2300 volts to 110 volts. A small rectifier unit was mounted on each pole and an anode consisting of a single joint of junk pipe was used. The rectifier units were especially designed to obtain low cost and flexibility in adjustment of output ratings to suit actual field requirements.

19. Cathodic protection in peat bogs. W. T. Pyott. P.I.E.A. Elec. News 11, No. 10, 61 (1942).

Cathodic protection will prove satisfactory in peat bogs whether or not anaerobic bacterial corrosion is present since it is known that anaerobic bacteria do not flourish if the pH of the soil is greater than 8.5, and tests on soil removed from the immediate vicinity of the pipe reveal pH values in excess of 9.0 after protection has been in effect several weeks.

20. Two unusual installations of cathodic protection of pipe lines. G. I. Rhodes. Proc. Am. Petroleum Inst. 17, No. 4, 21 (1936).

This paper contains an amount of specific data on cathodic protection which justifies the recommendation that those who are about to install a system of cathodic protection should study the original paper.

The first installation was applied to an enamel-coated gas line laid in Louisiana in 1926. Forty-six miles of the line were of 22-inch Dresser-coupled pipe. Approximately 33 miles of the line were of 12 to 14-inch pipe with screw-coupled or welded joints. Corrosion on certain sections of the line became serious within a few years after installation. A table of costs is given for the protection of 12 and 14-inch coated line.

Carbon-anode installations are described as well as copper-oxide rectifiers.

The second installation discussed was applied to a very poorly insulated pipe line in Colorado. On account of the cost of commercial power, zinc anodes were used as a source of emf. In laboratory tests it was found that "zinc provides cathodic protection with current densities far less than half of those required when power was applied as in Louisiana." An explanation is offered.

The anodes in the Colorado installation were rods of zinc 4 feet long and either 1 sq inch or 1-3/8 sq inches in cross section. Zinc of high purity must be used. The electrodes were installed at various intervals depending on the diameter of the pipe to be protected. The interval for 2-1/2-inch pipe was 25 feet and that for 22-inch pipe 4 feet. The initial open-circuit voltage between anode and pipe was 0.5 volt to 0.6 volt depending on the condition of the pipe. After the connection between the anodes and the pipe had been established for a few weeks this voltage was less than 0.3 volt for wet soils and more for dry soils. In the experimental installation the current generated by a zinc bar was approximately 0.025 ampere. The cost of the installation per anode varied between $3.08 and $3.21 per rod. The cost of protection of a 12-inch bare line for 20 years is estimated at $2120 per mile.

A series of curves indicates that the cost of protecting bare welded pipe lines by means of zinc is considerably less than by purchased power at 1.5 cents per kilowatt-hour.

21. Method of designing cathodic protection installations. W. F. Rogers. Pet. Eng. 12, No. 4, 42 (1941).

This article gives design data for protection of coated and bare lines. It points out that current density of 0.004 amp per sq ft will give 75 percent protection.

Total potential of 0.80 volt measured to a $CuSO_4$ electrode will give complete protection to a well coated pipe. It states that ground beds are made up of 400 feet of 6-inch pipe and generally lasted 4 years. The author gives data on pipe diameters to be used in ground bed and spacing between individual pipes in ground bed.

Protection systems for bare or coated pipe can be designed with equal accuracy.

22. Corrosion of steel and its mitigation. W. R. Schneider. J. Am. Water Works Assn. 37, No. 3, 245 (1945).

This paper discusses the application of cathodic protection to control corrosion due to electric currents, of steel pipe under water or in the soil.

Suggestions are given for procedures to avoid damaging other structures.

23. Cathodic protection - its application to a pipe line. L. C. Secrest. Oil & Gas J. 43, No. 3, 82 (1944); P.I.E.A. Elec. News 14, No. 1, 35 (1944).

In a nontechnical discussion, the author of this paper presents a few of the problems encountered in installing cathodic protection on one of the Continental Oil Company's pipe lines in Colorado and Wyoming.

Information is given as to the manner in which the pipe was prepared before cathodic protection was applied. The writer is of the opinion that if the pipe could be maintained at a minimum of 0.3 volt (0.85 volt using copper-sulfate electrode) to soil there would be no corrosion. The spacing of the cathodic units was based on this voltage at overlap points between the units.

Wind-electric units were decided upon and an average of 25 to 30 amperes output of the unit was estimated. Groundbed installations are described.

Total maintenance cost from November 1939 to date of writing, for the 28 wind-electric units has been $6.08 per year per unit. This figure covers replacement material only.

Installation varied from 7 to 21 miles. Inspection holes were opened and tests were made to determine if the pipe line had been cathodically protected. The author recommends the use of coupons connected electrically and unconnected to determine the amount of corrosion which may be expected along the pipe line.

A recording millivoltmeter was connected to various of these wind-electric units; and over a period of 4 months the results showed full protecting current from 60 to 65 percent of the time, 25 to 30 percent of the time overprotected, and 35 to 40 percent of the time practically no protection.

24. Problems in connection with cathodic protection of bare pipe. W. H. Stewart. Oil & Gas J. 42, No. 3, 68 (1943).

This paper discusses available power for cathodic protection installations. Several methods of transmission of power along the right-of-way, varying from standard cross-arm construction down to single feeder with pipe-line return, are in use.

The method of providing protection to the common metallic telephone circuit is discussed. The circuit diagram is shown.

In conducting tests on a 10-inch bare line the following spacing and size of units were decided upon: unit spacing, 1,750 feet; unit size, 8 volts, 24 amperes; ground bed (approx) 100 feet from line. Rectifiers were consecutively spaced approximately 1/3 mile apart.

An analysis of the power cost over a 12-month period reveals a cost of $0.013 per foot per year, or an average cost of $5.73 per month per mile. On the basis of these figures and knowledge of reconditioning costs, the initial installation cost of electrical protection, plus power cost, will take approximately 21 years to equal that of a complete reconditioning job.

25. Use of zinc for cathodic protection. H. W. Wahlquist. Corrosion 1, No. 3, 119 (1945).

When soil conditions are favorable, the use of zinc as a current source has a number of advantages. Installation and maintenance costs are less in general than the cost of the more usual types of sources. In addition there are no off-time periods when zinc anodes are used. They are efficient when used on either bare or coated pipe and are practical in locations remote from power lines. Problems of interference are eliminated as is the problem of providing and maintaining extensive ground beds.

Information is lacking as to the long-time performance of zinc in various types of soil. The high resistivity of some soils, or the formation of a high resistance film may limit the current output to values below those required for protection of the lines.

Data are given on the zinc-anode installations of the Colorado Interstate Gas Company's gas pipe lines which indicate a stability in the performance of the zinc over an 8-year period.

26. Investigate abnormal conditions to improve cathodic protection. Harris White. Oil & Gas J. 40, No. 19, 106 (1941).

The author describes a series of six tests made to ascertain the cause of a gradual increase in soil resistance after the soil had been subjected to current flow at regular time intervals. It was found that the addition of $CaCl_2$ to the anode kept the soil resistance down thereby increasing the effectiveness of the cathodic protection unit. A detailed description of the ground bed installation is given.

Also refer to Section IV, #1
V, #4.