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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC519

(March 16, 1938)

CATHODIC PROTECTION OF PIPE LINES

In response to a number of requests for information concerning the protection of pipe lines by superimposing electric currents on them, the following letter circular has been prepared. It consists of a review of some of the more important articles on this subject. Those who are about to undertake the installation of a system of cathodic protection for the first time should consult the complete papers, since it is impracticable to make the reviews sufficiently detailed to provide a satisfactory basis for the design of such a system.

The Bureau of Standards has published no papers dealing with the cathodic protection of pipe lines, but some of the data in Technologic Paper 355, Electrolysis Testing, are applicable. This paper may be consulted in many of the larger public libraries or purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C., for 30 cents per copy.

1. S. P. Ewing. Cathodic protection of pipe lines from soil corrosion. Natural Gas 16, #3, p.5, #4, p.16 (1935). Gas Age Record 74, 179.

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 an 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 material 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 trench to become stable. A sample 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 cathodic 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 Rextox 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.

2. G. C. Gabler and O. C. Mudd. Determination of corrosion on underground pipe lines and methods used in mitigation of the problem. Oil & Gas Jour. 34, #24, p.54 (1935).

The larger part of this paper deals with the causes of corrosion and methods of locating corroding areas. Line currents are found to be the best indication of pipe line conditions. The last page of the article discusses cathodic protection chiefly through the use of zinc anodes.

If oxide-film rectifiers are operated at about 50 percent of their rated capacity the replacements will be practically nil. The requirements of current for protection can be determined through the use of a portable source of direct current such as a gasoline-driven welding generator. Forced drainage should be applied at least 72 hours before values are observed to determine the extent of the drainage. It is practicable to provide protection by means of zinc anodes where other methods are impracticable. The potential of such installations is about 0.6 volt and the extent of the protection by a single anode is very limited. After considerable experimentation the Shell Pipe Line Corporation adopted the following procedure. The anode is a hollow cylinder of zinc 36 inches long, 7 inches inside diameter, and having a wall thickness of 5/16 inch. The weight of the anode is 56 pounds. Four anodes spaced 25 feet apart on a line parallel to the pipe line and 75 feet distant are used as standard practice. The anodes are connected to the pipe with a 2/0 rubber-covered copper wire. A 10-inch hole is dug to a depth of 6 or 7 feet. Two gallons of water are poured into the hole and a mixture of salt and soil is added and churned with the soil auger to a thick paste. Fifty pounds of salt are used in each hole. The anode is forced to the bottom of the hole. After installation the average value of the current tends to increase while the voltage decreases. The average value of the current per cylinder is about 0.25 ampere. It has been found necessary to apply coatings to certain sections of a line where current discharge to soil continued after cathodic protection was established. Coatings used with cathodic protection must have a high value of insulation and a minimum tendency to absorb water.

A chart is given showing the effects of applying cathodic protection to a section of pipe line.

3. G. I. Rhodes. Cathodic protection or electric drainage of bare pipe lines. Monograph, Natural Gas Dept., American Gas Association, 1935.

Some laboratory tests made in corrosive soil in 1934 indicate that 4 amperes per mile per inch diameter of pipe will protect a bare pipe against soil corrosion. It would then appear that 0.25 volt between pipe and earth will afford protection. In the measurement of voltages between pipe and soil special precautions must be taken. The author has devised a potentiometer-voltmeter method for this purpose. When steel is made a cathode, it develops a back emf of 0.26 volt after a minimum known protective current has flowed for 1000 hours.

If a bare pipe line is to be given cathodic protection without excessive wasted current, there must be many drainage points fairly close together or a means must be found to produce an equivalent result. The author obtains this result by multiple anodes placed in a line parallel to the pipe line and on the same right-of-way where practicable.

The author concludes with a discussion of costs similar to the data in his paper "Two unusual installations of cathodic protection," reviewed elsewhere in this letter circular. (See No. 8).

4. V. L. Nealy. General considerations on the mitigation of electrical corrosion of pipe lines. Oil & Gas Jour. 34, #23, p.85 (1935).

After discussing the making of corrosion surveys the author concludes his article with some data on windmills as sources of power for cathodic protection. A curve shows that the output of a windmill generator installed near Port Arthur, Texas, ranged from about 20 amperes for a wind velocity of 4 miles per hour to 66 amperes for a wind velocity of 8 miles per hour. A set of curves shows the potential of the pipe with respect to earth at several distances from the generator for wind velocities up to 10 miles per hour. At a distance of 5 1/4 miles from the generator the pipe was maintained at a potential of about 0.72 volt with wind velocities between 3 and 10 miles per hour. Polarization tends to maintain the condition of the pipe line during periods of no wind.

5. W. R. Schneider. Improvements in electrical pipe protection equipment. Gas 12, #5, p.22 (1936).

A corrosion eliminator consisting of a transformer, watthour meter and copper-oxide discs is used as a source of direct current.

The apparatus is enclosed in a single case. The eliminator supplies from 10 to 50 amperes at 8 volts.

To determine the current and potential required to protect a pipe line one or more electrodes are driven at the point to be protected and a storage battery and resistance connected between the pipe and ground. The soil-to-pipe potential is measured with a high-resistance voltmeter and $CuSO_4$ electrode. The current is adjusted to give a reading of 0.9 volt which is sufficient to afford protection. It is desirable to take readings after the current has flowed 24-48 hours to take account of polarization effects. The tests are usually made in the rainy season.

The d-c potential to be supplied is found by adding

1. Pipe-to-soil potential at the eliminator with optimum compensating current.

2. Drop of potential in leads and connections.

3. Ground electrode and pipe polarization potential having an approximate value of 1 volt.

4. The back potential of 1 volt if a carbon ground is used.

5. The drop of potential at the ground electrode.

The electrode to ground resistance can be found from the soil resistivity and a chart which is given. Horizontal electrodes are preferable, laid in a straight line at a depth of 5 feet or more. The resistance of parallel ground pipes is increased if the spacing is increased up to 100 feet or more. On a horizontal ground in service discharging 0.1 amp per sq ft the average loss of metal over a 5-year period was 3 1/2 pounds per amp yr.

Cast iron pipes are used for electrodes. Vertical ground connections consisting of drilled holes filled with coke will have a higher resistance than pipe grounds.

6. R. J. Kuhn. Cathodic protection of pipe lines in city and country. Oil & Gas Jour. 36, #18, p.201 (Sept. 1937).

The subject of galvanic currents on pipe lines was investigated by the author in 1926 and reported on in 1928. Cathodic protection was installed in a high-pressure gas line in the vicinity of New Orleans nearly 10 years prior to the publication of the article here reviewed. Cathodic protection of a pipe network in a city has proven practicable but special precautions must be taken to prevent injury to adjacent structures. Several cases have been observed in which underground structures adjacent to installations of cathodic protection have been adversely affected. Country installations of cathodic protection require different treatment from those in cities. The problem of securing electric power may be serious.

In an installation by the author, power is secured from a 13,000-volt transmission line stepped down to 120 volts and then to 20 volts before being rectified. In another installation, power is secured from 15 wind-electric plants. Difficulties due to the uncertainty and variability of the wind are compensated for by the persistence of polarization effects. With wind-electric units the maximum generating capacity must be three or four times the capacity of a steady unit.

The requirements for different installations may differ greatly and it is advisable to employ an engineer of wide experience to install a system of cathodic protection.

7. Starr Thayer. Induced current along pipe lines retards corrosion. Oil & Gas Jour. 35, #19, p.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.

8. G. I. Rhodes. Two unusual installations of cathodic protection of pipe lines. Am. Petroleum Inst. Proc. 17, (4), p.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. The following table indicates the extent of the installation.

	Number	Unit Cost
50-amp rectifier units	47	$275 each
25-amp " "	26	$200 "
Coupling bonds	13,071	$3.65 "
Coke and carbon electrodes	3,297	$5.00 "
Miles of power circuit wire	51.49	$275 per mile
" " feeder " "	41.83	$390 " "
" " anode connecting wire	49.5	$4.50 per 100 ft

Power required, 8.6 kw. Conversion efficiency 40%.

The power was transmitted along the line at 2300 volts. Carbon anodes surrounded by coke were used. In cases of single line these were usually placed in rows on one side of the line. Where there were two parallel lines two rows of anodes on opposite sides of the right-of-way were used. The anodes were connected to the 5-volt power feeder through resistances. Details as to the construction of the anodes and the feeder circuits are given.

The anodes were made from arc furnace electrodes approximately 6 feet long and 2 inches in diameter. These were placed in 10-foot holes 6 inches in diameter and surrounded by approximately 80 pounds of coke. It is estimated that the coke will be consumed at the rate of 4 or 5 pounds per year. These electrodes produce a counter emf of 1.6 volts which must be overcome in addition to the IR drop of the circuit.

Copper-oxide rectifiers were used to supply 5 volts to the direct-current feeders. In a period of 22 months 30 out of 480 stacks of rectifier discs developed defects, which were easily repaired.

A description is given of the test electrodes, instruments and circuits used in determining the potential of the pipe with respect to the earth. This was modified by the adjustment of the anode resistances until the pipe was 0.4 volt negative to the adjacent soil. It is thought this voltage may be higher than necessary. Curves are shown for the relation between the impressed current and the resulting potential of the coated pipe with respect to the adjacent earth. The voltage is roughly proportional to the cube of the current.

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 in. or 1 3/8 sq in. 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.

In the case of the Louisiana installation, the initial cost of cathodic protection was less than 20 percent of the estimated cost of reconditioning the line. In the Colorado installation the cost was less than half the estimated cost of reconditioning the line.

9. Starr Thayer. The application and economics of electrical protection of pipe lines. Am. Petroleum Inst. Proc. 17, (4), p.33 (1936).

Where cheap power is available Rectox rectifiers are 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.

10. G. I. Rhodes. Electric pipe line drainage with cost data. Elec. Jour. 33, 91, (Feb. 1936).

The paper first describes the principles involved in cathodic protection.

It was found experimentally that doubling the voltage between pipe and adjacent ground increased the current flow 8 or 10-fold. Curves are given for the current-voltage relation for bare 22-inch pipe. After the current has flowed for 1000 hours the current is roughly proportional to the third power of the voltage. Indications are that a line maintained 0.2 volt negative to adjacent soil will be protected against corrosion. On this basis a 22-inch bare line would require 30 amperes per mile of pipe. Requirements for a coated line are much less. For an enamel coated line in wet ground it was found that approximately 5 amperes maintained the pipe negative to the earth by 0.3 volt.

If a bare line needs reconditioning it is well established that 4 amperes per mile per inch of diameter will provide necessary protection. A 10.75-inch line would on this basis require 43 amperes. The total cost of supplying this current will vary from $2500 to $3400 per mile. Other cost data are given.

11. A. V. Smith. Theory and use of cathodic protection. Proc. A.G.A. 1937. (?)

This paper was presented at the 1937 Distribution Conference of the American Gas Association and at the time of abstracting had not been published. It is a very good elementary discussion of the electrical principles involved in soil corrosion and cathodic protection and is prepared primarily for the non-technical reader. The paper makes extensive use of diagrams and for this reason cannot be satisfactorily abstracted.