Does My Pressure Pipeline Need Cathodic Protection?

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ABSTRACT

When do water pipelines need cathodic protection (CP)? Under what circumstances should CP be considered for a pipeline? This decision must be based on the type of pipe product to be used in the proposed system, such as concrete pressure, ductile iron, or steel pipe, their various inherent corrosion-resistant properties, the corrosivity of the surrounding soil, and other important factors. This paper will examine and discuss these various factors and make recommendations as to when and when not to specify CP on a new pipeline. In addition, the advantages and disadvantages of galvanic CP and impressed current CP systems will be examined. The expertise and experience required to design a CP system will be summarized.

INTRODUCTION

CP is a method to protect ferrous metals from corrosion. When do water pipelines need CP? It seems a very simple question and a simple answer is “When it is expected to corrode” but there does not seem to be universal agreement in the water industry with that answer. How is that determined? How do we know when and under what conditions a pipeline will start to corrode?

CP of Oil and Gas Pipelines. Almost all oil and gas pipelines in the United States (and in many other parts of the world) are governmentally mandated to be cathodically protected. Why? To protect life, resources, and the environment. They are mandated because almost all metallic oil and gas pipelines are made from steel and steel corrodes in soil and water. Oil and gas steel pipelines are almost always coated with a high electrical resistant, organic-based coating such as fusion bonded epoxy (FBE), coal tar enamels, coal tar epoxies, epoxies in general, and polyethylene-based tapes as the primary corrosion control. CP is then used to protect exposed steel at flaws, cracks, and pinholes in the coating from corroding through the steel pipe wall and causing leaks. Leaking oil and natural gas due to corrosion have caused loss of life, and severe harm to people, resources, and the environment.

CP of Water Pipelines. So why aren’t all metallic water pipelines being cathodically protected? Are lives, resources, and the environment being harmed from water pipeline leaks? Resources certainly are being compromised. Several of these resources are the time, money, and material required to repair or replace a pipeline. The repair and replacement process, in and of itself, uses resources that can be better employed elsewhere as well as shuts down highways and roads that produces longer commute times and economic disruptions to adjacent businesses.

Lives have been lost, water has been wasted, homes, businesses, and infrastructure have been destroyed, and the environment has been harmed in water pipeline leaks and ruptures.

WHEN TO USE CP

Under what circumstances should CP be considered for a pipeline? This decision must be based on the type of pipe product to be used in the proposed system, such as concrete pressure, ductile iron, or steel pipe, their various inherent corrosion-resistant properties, the corrosivity of the surrounding soil, and other important factors.

Concrete Pressure Pipe (CPP) – AWWA C301 and C303. CP is rarely needed on CPP due to the inherent corrosion inhibiting properties of the high pH of the portland cement mortar and concrete that encases the steel. This high pH environment passivates the steel and protects it from corrosion in most soil and groundwater conditions. The typical ¾- to 1-inch thick mortar coating also acts as a barrier to soil and groundwater requiring many years to decades for chloride ions to penetrate through the mortar coating to the steel surface.

Under most conditions, properly installed mortar-coated pipe should last 100 years without additional protection besides the mortar coating and properly mortared joints. Some conditions will require supplemental protection for the pipe to last 100 years trouble-free.

Although CP is rarely needed on CPP, CP can be useful in the following conditions:

- When damage has occurred to the pipeline that exposes the steel to the surrounding soil and water. The damage may have occurred during transportation or installation of the pipe, improper operation of the pipeline, or due to third party damage.
- Prolonged exposure to high levels of stray current (direct current - DC) discharge (interference). CP is not required on CPP installed near or under AC power lines since the extremely high current densities required to cause DC discharge are not present.
- Connections to steel or DIP lines, or to appurtenances, that are not encased in portland cement mortar or concrete. Only the non-encased steel or DIP line or appurtenances need CP.
- When corrosion monitoring indicates that corrosion is occurring. This may occur when the chloride ion content in the soil or groundwater exceeds 400 mg/kg or 400 mg/l, respectively (ACPPA 2011). This may also occur where the pipeline is subjected to concentration of chloride ions due to wetting and drying cycles. This may occur when the chloride ion concentration exceeds 150 mg/kg or 150 mg/l. The chloride ions diffuse through the mortar coating or concrete to the steel surface where it may cause corrosion when the level of chloride ions at the steel surface reaches a level to depassivate steel. Chloride ion diffusion and the concentration of chloride ions at the steel surface is typically a slow process and can take decades.

As such, CP is rarely needed on new CPP lines and, if CP is used, it only needs to be used at the location of corrosion or stray current discharge as discussed above. Non-corroding or stray current pickup locations do not need CP.

Steel Pipe – AWWA C205

Mortar-coated steel pipeline. Steel pipelines can be produced with either a mortar coating or a dielectric coating such as polyurethane or tape. The mortar coating on steel pipe has the same inherent corrosion inhibiting properties as that on CPP. However, steel water pipe is a flexible pipe and the mortar coating may crack if enough support using slings to reduce bending is not provided during transportation and if enough support during backfilling to reduce deflection is not provided. Cracks are a convenient location of entry of chloride ions to the steel surface which can depassivate steel and initiate corrosion at the crack. If cracks and high chloride ions in the soil or groundwater are present and monitoring indicates corrosion is occurring, then the pipeline should be cathodically protected.

Bonded coatings. Dielectric coatings (also called bonded coatings), such as those used on steel pipelines in the oil and gas industry, have flaws and pinholes exposing the steel. Corrosion can occur at these exposed steel sites and cause leaks. In addition, these small areas of coating imperfections provide a location for stray current discharge from DC sources and extremely high current densities from AC sources (such as AC powerlines) to develop which can initiate and produce corrosion at a rapid rate resulting in pinhole leaks through the pipe wall. As such, CP should be applied to new and existing steel pipelines to control corrosion and stray current discharge at coating flaws and pinholes.

Ductile-Iron Pipe (DIP) – AWWA C151. Most buried DIP is supplied as-manufactured with approximately 1.0 milli-inch (0.025 mm) standard asphaltic coating with no supplemental protection. The asphaltic coating offers protection from corrosion during transportation and storage. The coating is not intended for long-term protection in soils, for stray current, or to reduce CP current requirement.

In some soils, DIP may last 100 years. Cast iron pipe (CIP) has in some soils, but it has a thicker wall. DIP that has a thinner wall than CIP will likely have a shorter life without encasement or CP. Even with encasement, DIP could be viewed in the same manner as steel with a dielectric coating, and may need CP.

A variety of systems exists to determine when DIP needs supplemental protection (NACE 2013). A 10-point system given in Appendix A of ANSI/AWWA C105/A21.5-10, Standard for Polyethylene Encasement for Ductile-Iron Pipe Systems (AWWA 2018) is the most commonly used. The standard covers the soil-survey tests, observations, and interpretations that comprise the 10-point system. The evaluation procedure is based on the results of the following five soil tests and certain observations: (1) soil resistivity, (2) pH, (3) oxidation-reduction (redox) potential, (4) sulfides, and (5) moisture. For a given soil sample, each result is evaluated and assigned points according to its contribution to corrosivity. The points from all five criteria are totaled. If the sum exceeds 10, the soil is considered corrosive to gray-iron or ductile-iron pipe, and corrosion will likely occur unless protective measures are taken.

The protective measure in AWWA C151 consists of encasing DIP with a thin tube or sheet of polyethylene (PE) during installation. PE encasement can be torn or damaged during wrapping of the pipe and backfilling unless precautions are taken. As such, CP should be applied to new and existing DIP lines to control corrosion and stray current discharge at the tears or damaged areas of PE encasement and on as-manufactured DIP lines without PE.

WHAT TYPE OF CP SYSTEM TO USE

Two types of CP systems can be employed:

- Galvanic (sacrificial) CP and
- Impressed current CP (ICCP).

The two CP systems are depicted in Figures 1 and 2.

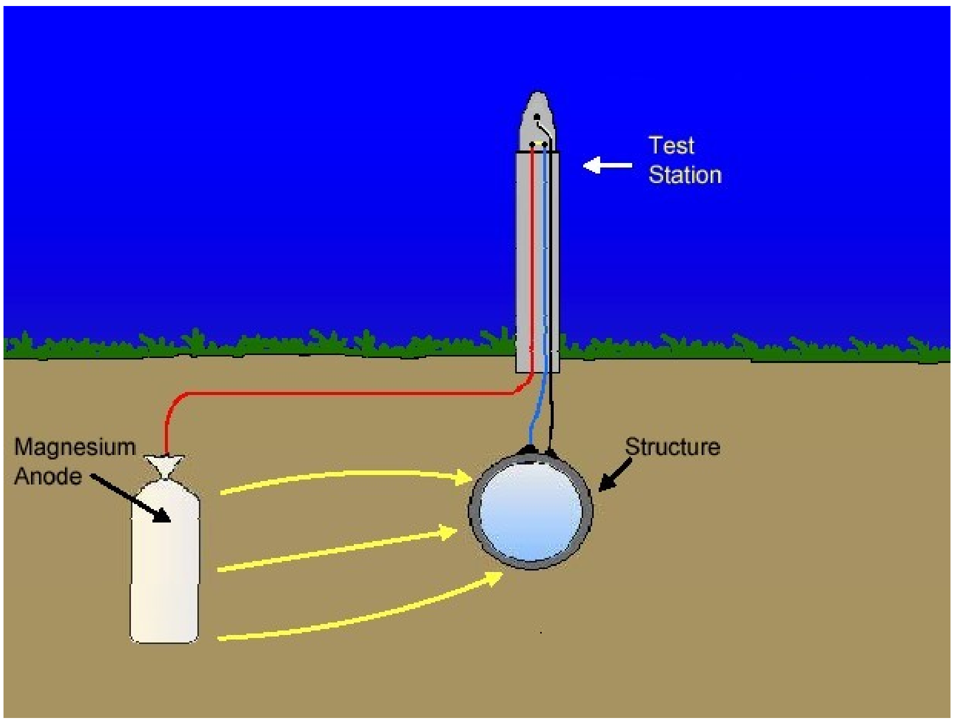

Figure 1. Galvanic CP system.

Pressure pipe discussed in the previous section can be protected with either type of system. A variety of advantages and disadvantages can be enumerated for each type of CP system. However, it is usually economic factors that determine which CP system is utilized to protect pipelines. The following are some of the factors:

- Length and diameter of pipeline – The longer and larger diameter the pipeline the less expensive the ICCP system is compared to a galvanic system because fewer anodes, anode beds, and connections to the pipeline are required.

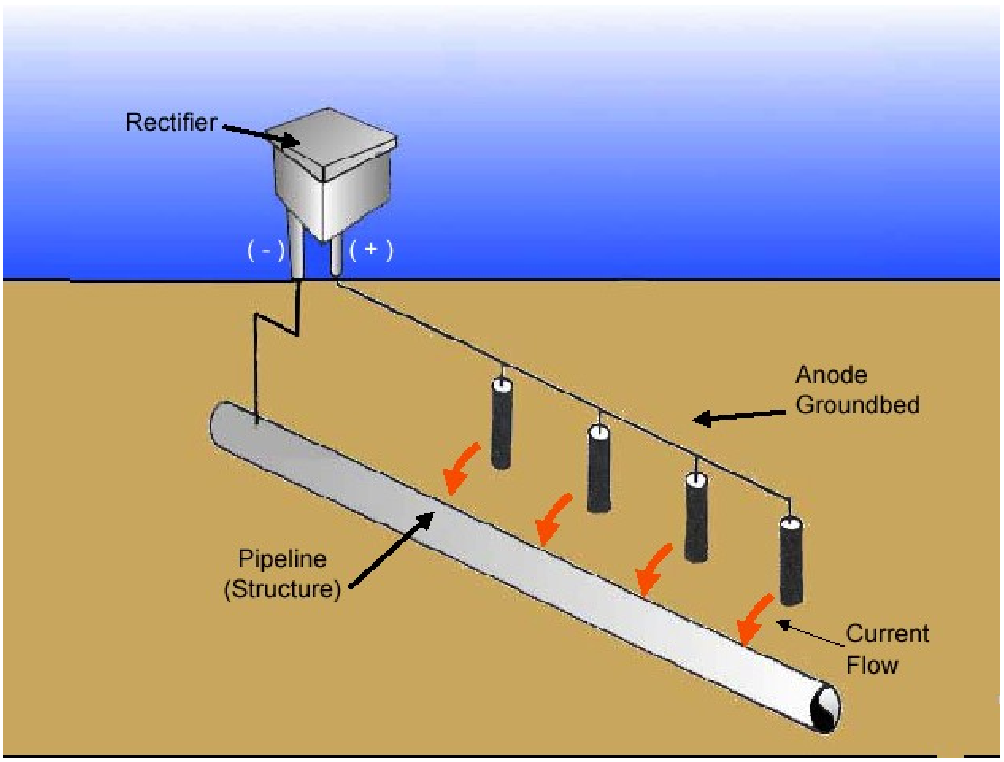

Figure 2. ICCP system.

- Access to electrical power for power supply – ICCP systems require a source of DC power that is usually from AC power lines using rectifiers. In some circumstances, AC power is not easily accessible. This usually means it is too expensive to run the power cable to the site. Other forms of AC or DC power can come from fossil fuel consuming generators, solar cells, wind, or other environmentally friendly power production systems. Galvanic CP systems do not require electrical power, but the number of sacrificial anodes needed may make ICCP cost effective.
- Maintenance – ICCP systems can be more expensive to maintain. This is primarily associated with the power supply (rectifier) that should be inspected more frequently to ensure its continual operation than galvanic systems.
- Width of right-of-way – If the right-of-way is narrow, ICCP may be required since the cost to obtain additional land to provide area for the anode beds can be cost prohibited.

After the decision has been made that CP is required, a cost analysis of each CP system for the specific pipe types should be undertaken. The lowest cost CP system should be selected.

HOW MUCH CP TO USE

The amount of CP to use is based on the amount of current required to attain a specified potential (voltage) criterion. The amount of current required varies depending on pipe type, soil or groundwater corrosivity (i.e. resistivity, pH, chloride content, Redox potential, etc. as discussed in an earlier section), potential criteria, as well as other factors. Several potential (voltage) criteria are used in the corrosion control industry. The following are the more commonly used criteria for specific pipe types:

- **Minimum 100 mV depolarization or polarization shift –** This CP potential criterion is commonly used in the reinforced concrete structure industry. It is one of the criteria in NACE International SP0100 "Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water and Waste Water Service" (NACE 2019). It requires the natural corrosion potential of the pipeline be shifted at least 100 mV in the more negative direction by the current produced from the CP system.

- **More negative than -850 $mV_{(CSE)}$** – This CP potential criterion is one of several criteria in NACE SP0169 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (NACE 2013). This CP potential criterion is the most widely used criteria for steel pipelines with bonded coatings in the oil and gas industry and in the water and waste water industry. NACE Publication 10A292 "Corrosion and Corrosion Control for Buried Cast- and Ductile-Iron Pipe" (NACE 2013) also referenced the use of NACE SP0169 criteria for DIP lines. It requires that the potential of the pipeline be shifted to at least -850 mV or more negative versus a copper-copper sulfate reference electrode (CSE).

- **Less negative than -1000 $mV_{(CSE)}$ for AWWA C301 CPP** – This CP potential criterion is a "maximum" criterion for prestressed concrete cylinder pipe (PCCP). The CP potential should not be more negative than -1000 mV to prevent hydrogen generation on the surface of the high-strength prestressing wire. Modern wire used for PCCP is manufactured and tested to resist embrittlement by hydrogen. Even so, maintaining CP potentials less negative than -1000 mV assures that the CP system will not be a cause of hydrogen production. It is one of the criteria in NACE International SP0100 "Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water and Waste Water Service" (NACE 2019).

The 100 mV shift and -850 $mV_{(CSE)}$ criteria can be used for all pipe types. However, the 100 mV shift criterion is typically used on CPP lines and the -850 mV criterion is typically used for steel pipelines with bonded coatings and DIP lines.

WHO DESIGNS CP SYSTEMS

CP systems should be designed by a NACE International Cathodic Protection Specialist (CP4), a corrosion engineer or NACE International Corrosion Specialist experienced in the design of CP systems for the specific pipe type under consideration, or equivalent.

SUMMARY AND RECOMMENDATIONS

1. CP is a method to protect ferrous metals from corrosion. It should be used when the pipeline is expected to corrode to prevent leaks and ruptures.

2. Lives have been lost, resources have been wasted, and the environment has been harmed by water pipeline leaks and ruptures.
3. CP should be considered for a pipeline based on the type of pipe product, such as concrete pressure, ductile iron, or steel pipe, their various inherent corrosion-resistant properties, the corrosivity of the surrounding soil, and other important factors.
    a. CP is rarely needed on CPP due to the inherent corrosion inhibiting properties of the high pH of the portland cement mortar and concrete that encases the steel. If corrosion or stray current discharge is found, CP needs to be used only where corrosion is occurring, or prolonged high stray current is discharging. Non-corroding or stray current pickup locations do not need to be cathodically protected.
    b. CP is rarely needed on mortar-coated steel pipe due to its inherent corrosion inhibiting properties of the high pH of the cement mortar coating. However, steel pipe is regarded as a flexible pipe and the mortar coating can be cracked if sufficient support is not provided. If mortar coating cracks and high chloride ions in the soil or groundwater are present and monitoring indicates corrosion is occurring, then the pipeline should be cathodically protected but only in the areas of corrosion. CP also needs to be used at the location of prolonged, high stray current discharge.
    c. CP should be applied to new and existing steel pipelines with bonded coatings to control corrosion at coating flaws and pinholes.
    d. CP should be applied to new and existing DIP lines to control corrosion on as-manufactured pipe or at tears and damaged areas in PE encasement.
4. Pressure pipe can be protected using either a galvanic CP or ICCP system. A cost analysis should be conducted to determine which CP system should be selected.
5. Several potential (voltage) criteria are used in the corrosion control industry depending on the pipe type.
6. CP systems should be designed by a corrosion engineer experienced in the design of CP systems for the specific pipe type under consideration, a NACE International Cathodic Protection Specialist (CP4), or equivalent.

REFERENCES

ACPPA. (2011). *External Protection of Concrete Cylinder Pipe – Guidelines of Supplemental Protection of Pipelines in Adverse Environments for Owners and Specifiers.* American Concrete Pressure Pipe Assoc (ACPPA), Hayden, ID.

ANSI/AWWA. (2014). *AWWA C301 Prestressed Concrete Pressure Pipe, Steel-Cylinder Type*, Standard C301. AWWA, Denver, CO.

ANSI/AWWA. (2017). *AWWA C151 Ductile-Iron Pipe, Centrifugally Cast,* Standard C151/A21.51-17. AWWA, Denver, CO.

ANSI/AWWA. (2017). *AWWA C303 Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type*, Standard C303. AWWA, Denver, CO.

ANSI/AWWA. (2018). *AWWA C105 Polyethylene Encasement for Ductile-Iron Pipe Systems*, Standard C105/A21.5-10. AWWA, Denver, CO.

ANSI/AWWA. (2018). *AWWA C205 Cement-Mortar Protective Lining and Coating for Steel Water Pipe 4-in. (100 mm) and Larger – Shop Applied*, Standard C205. AWWA, Denver, CO.

NACE International. (2013). *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, Standard Practice SP0169. NACE International, Houston, TX.

NACE International. (2013). *Corrosion and Corrosion Control for Buried Cast- and Ductile-Iron Pipe*, Publication 10A292. NACE International, Houston, TX.

NACE International. (2019). *Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water and Waste Water Service*, Standard Practice SP0100. NACE International, Houston, TX.