“Impressed Current Cathodic protection System for water pipeline internal surfaces”

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ABSTRACT

As the water pipelines are getting older, the internal surfaces of pipeline experience corrosion issues as coating/painting deteriorate and conventional corrosion prevention system are no longer effective. Specially Designed Linear Anode System with access fitting for internal pipeline cathodic protection (CP) is the only impressed current, linear anode system for cathodic protection of internal pipeline surfaces to prevent corrosion and increase the life of water pipelines. Used for water and salt water pipelines, the system features entrance fittings spaced as far as two hundred feet apart. Other methods for cathodic protection of large diameter pipeline internal surfaces require closely spaced probe anodes. This paper will also discuss design, materials and installation requirements of Impressed Current cathodic protection System for water pipeline internal surfaces.

Key words: Cathodic Protection (CP), Pipe to soil/water potential (PSP), Direct Current (DC), Electrical Resistance, Mixed Metal Oxide (MMO), Non destructive Method (NDT), Impressed current cathodic protection (ICCP).
INTRODUCTION

Pipelines are among the most efficient and important transportation medium which is used continually to carry and deliver large quantities of water from sources to users. Pipelines are secure mode of transportation and also economical and environment friendly as compared to other transports such as water tankers & rail wagons.

These pipelines are considered more significant not only for petrochemical, oil, and gas industries but also for drinking water and other transport industries such as mining, steel, chemical & fertilizer.

Flow accelerated corrosion of steel pipeline is one of the most predominant reasons of pipeline failures in water industry and responsible for losses either as direct or indirect losses due to the presence of saline water, severe flow, sands particles, etc.

Flow induced corrosion of pipeline is a major problem in many water pipelines. It may frequently lead to pipeline failure during fluid transportation and is costing a huge amount of money to mitigate and manage the corrosion problems. Flow Accelerated Corrosion (FAC) occurs due to the synergistic effect of electrochemical reaction and relative movement of fluids over the materials internal surface.

Some of the commonly used methods to prevent corrosion are galvanizing, painting and replacement of steel with costlier metals. Galvanizing and painting are extremely useful to protect pipelines when their sizes are small and above ground or are easily accessible for maintenance work. In the case of pipelines of large dimensions buried under ground or under water and carrying water, the above methods are not practicable or economical. Pipes carrying water need to be protected against corrosion. At high pressures, it is not economical to keep a larger factor of safety for plate thickness. This could lead to loss of revenue, increased maintenance cost and plant outages. In such cases, cathodic protection along with coating may prove the most economical solution.

In several cases, natural waters are sufficiently corrosive therefore require the use of protective coatings and cathodic protection for corrosion control inside the pipelines carrying water. Protective coatings and cathodic protection are synergestic, with the combination of the two methods providing a greater degree of corrosion protection than either method used alone. Properly designed and maintained, cathodic protection systems can extend the useful life of water pipelines. It is feasible to design a cathodic protection system to provide complete protection for internal uncoated submerged surfaces of steel pipelines. For existing steel pipelines with submerged surfaces that are internally not coated or that have coating in poor condition, it may be economical to rely entirely on cathodic protection.
INTERNAL CORROSION

Internal corrosion refers to corrosion occurring on the inside of a pipeline.

Steel pipe surfaces submerged in water are subject to corrosion. Internal corrosion often results from the presence of carbon dioxide (CO2), hydrogen sulfide (H2S), water, chlorides, organic acids and others. Typically, these elements react with the internal pipe surface through anodic and cathodic reactions. The product of these reactions may deposit within the pipe, creating a protective layer that may inhibits further corrosion. In other cases, the products do not precipitate and facilitate high rates of corrosion. Internal corrosion can also be caused by microorganisms. The rate of internal corrosion depends on the concentration of these corrosive species, the temperature, the flow velocity and the surface material and many other factors. Please refer Figure 1: Corrosion on pipe internal surfaces.

CATHODIC PROTECTION

Cathodic Protection can be defined as:

- A technique to control the corrosion of metal surface by making that surface the cathode of an electrochemical cell.
- A means of rendering the metal a degree of immunity from corrosion attack by causing the direct current to flow from its electrolytic environment into the entire metal surface.
- Cathodic Protection is a process for reducing corrosion on a metallic structure in contact with a corrosive electrolyte, by introducing an electrolytic action greater in strength and opposite in direction to the existing electrolytic activity (corrosion).

In almost all cases, natural waters are sufficiently corrosive to require the use of protective coatings and cathodic protection for corrosion control. Protective coatings and cathodic protection are synergistic, with the combination of the two methods providing a greater degree of corrosion protection than either method used alone. Properly designed and maintained, cathodic protection systems can extend the useful life of water pipelines. It is feasible to design a cathodic protection system to provide complete protection for uncoated submerged surfaces of steel pipelines. For existing steel pipelines with submerged surfaces that are not internally coated or that have coating in poor condition, it may be economical to rely entirely on cathodic protection.

It is the objective of this paper to show that Internal surfaces of large diameter water pipelines can be cathodically protected using either galvanic anodes or impressed current anodes.

Cathodic Protection Criteria:

A negative polarized pipe to water potential of at least -850 mV related to a saturated copper/copper sulphate reference electrode (CSE) or

A minimum of 100 mV of Cathodic Polarization between the pipe surface and a stable reference electrode contacting the electrode. The formation or decay of polarization can be measured to satisfy this criteria.
Cautionary Note: Cathodic Protection of internally well coated pipe should only be designed, installed and energized under the direction of a corrosion engineer with coating and cathodic protection experience. The coating system must be compatible with cathodic protection and must demonstrate resistance to cathodic disbondment. In some cases, coating damage, have been observed at polarized potentials more negative than -1.1 V CSE.

It is also suggested to consider automatic regulation of cathodic protection current to maintain a preselected pipe to water potential, this is due to several variables like water level, coating deterioration over time, temperature, water velocity etc.

GALVANIC ANODE CP SYSTEM FOR WATER PIPELINE INTERNAL SURFACE

For Galvanic anode CP system either Magnesium and Zinc alloy anodes may be used. The anodes have to be welded inside the pipeline at regular intervals. As shown in Figure 2 for this case and for the CP system to work the pipeline needs to be filled with water most of the time, else the CP system may not be fully effective. Sacrificial anodes will deliver CP current when there is water in contact with anodes.

Health and safety must be considered while considering a Galvanic anode CP system, another precaution is compliance with local and national regulations.

IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM FOR WATER PIPELINE INTERNAL SURFACE

ICCP system can be provided using mixed metal oxide coated on titanium anodes. Specially developed MMO linear Anode System for internal pipeline cathodic protection (CP) is the better linear anode system for cathodic protection of internal pipeline surfaces. Used for water and salt water pipelines, the system features entrance fittings spaced as far as two hundred feet apart. Other methods for cathodic protection of large diameter pipeline internal surfaces require closely spaced probe anodes. Please refer Figure 3: Typical scheme for impressed current cathodic protection system.

IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM COMPONENTS.

This section outlines the elements that should be considered when designing impressed current cathodic protection system for submerged surfaces of water pipeline internal surfaces.

- **Direct Current Power source**: Impressed current cathodic protection system requires DC power. It is commonly obtained from transformer-rectifier units that step down AC power and convert it to DC power. However, DC power may be available from other sources such as solar cells and others. Units should be designed and manufactured to provide continuous dependable power for design life, which can be 20 years. Proper protective and monitoring devices, including disconnect switches, circuit breakers, output voltmeters, output ammeters and surge, lightning and over load protection should be provided. Units should be either manually or automatically controlled over the full voltage output range.
• **Impressed current anodes:** There are two types of anodes that can be considered for ICCP systems. Probe type anodes are generally good for small diameter pipes and Mixed Metal Oxide (MMO) wire based linear anodes are good for large diameter pipelines. Flowing water is a depolarizing factor and limits the anode current “throw”. Typically, probe anodes are designed based on 2-3 pipe diameters, as the distance between probe anodes. Linear anode is located along the entire length of pipeline and nominally centered in the pipeline.

• The Internal Linear Anode is a complete system that consists of one or more MMO linear anode assemblies and fittings depending on the pipe configuration and final design. Each anode assembly includes:
  - **Anode:** MMO wire linear anode is designed specifically for each unique system with a made-to-length assembly and entrance fittings on each end.
  - **Entrance & Exit Fittings:** Fitting consists of a carbon steel or stainless steel pipe section ready to weld to the water pipeline, PVC flange set, entrance fittings.
  - **Reference Electrodes:** Permanent reference electrode lead wires should be brought to the rectifier location to facilitate readings. Reference cell wiring shall not be routed through the same conduit used for system DC wiring. Probe type, silver-silver chloride reference electrodes can be installed into the pipeline for measuring Water to pipe potential.
  - **Cabling:** Positive & negative cabling is required to complete the system circuit.
  - **Junction Boxes:** Positive and Negative junction boxes shall be required to terminate the anode cables and cathode cables into the respective JB’s.
  - **Miscellaneous Components:** Other items necessary to complete the installation.

Please refer Figure 4: Typical layout of ICCP system for pipe internal surfaces indication various components.

**LINEAR ANODE SYSTEM FOR WATER PIPELINE INTERNAL SURFACES.**

Internal linear anode system utilizes a mixed metal oxide coated on titanium wire impressed current anodes. Made to specific lengths with unique fittings, the anodes run between two entrance fittings inside of the pipe. A series of anodes, each up to 200 feet in length, work together to prevent corrosion on the adjacent internal surface of the pipeline. The pressure entrance fittings are welded to the pipeline. The Internal linear anode system requires monitoring reference electrodes and a cathodic protection rectifier. Anode replacement is possible while keeping the permanent entrance fittings. Please refer Figure 5: Internal anode with access fitting.

The Internal linear anode consists of a mixed metal oxide (MMO) coated titanium wire anode that is connected to an HMWPE/Kynar internal header cable at regular and extends the length of the anode segment. The entire anode assembly is housed in a flexible high density polyethylene (HDPE) housing that provides mechanical protection to the anode and cable assembly.

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The anode assembly is installed in the pipeline through entrance and exit fittings that are welded into the pipe and allow the anode segments to be suspended along the length of the pipeline. The anode cable extends outside the pipe through the patented pressure fitting assembly and is connected externally to the system power supply.

The Internal linear anode utilizes a dual power feed design with the internal header cable feeding from both ends of the anode assembly and multiple anode to cable connections assures that any single failure point does not render the anode assembly inoperable.

**ADVANTAGES OF ICCP SYSTEM OVER GALVANIC ANODE FOR WATER PIPELINE INTERNAL SURFACES.**

<table>
<thead>
<tr>
<th>SN</th>
<th>Impressed Current CP System</th>
<th>Galvanic anode CP system</th>
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<tbody>
<tr>
<td>1</td>
<td>Longer Design Life (25+ Yrs.)</td>
<td>Short Design Life in comparison to ICCP anode.</td>
</tr>
<tr>
<td>2</td>
<td>Once installed only requires annual system checks.</td>
<td>Disruptive - repeating repair cycle. Replacement of anodes costly.</td>
</tr>
<tr>
<td>3</td>
<td>External power source required.</td>
<td>No external power source required</td>
</tr>
<tr>
<td>4</td>
<td>Impressed current Ti/MMO anodes are capable of operating at significantly higher current density discharge rates – up to 100 A/m²; however, in most cases the operating levels are much lower.</td>
<td>Galvanic anodes are typically designed to operate at much lower current densities.</td>
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<tr>
<td>5</td>
<td>Current is controlled &amp; variable</td>
<td>Cannot control limited current</td>
</tr>
<tr>
<td>6</td>
<td>High (5-25V) &amp; variable driving force</td>
<td>Low (&lt;1v) &amp; fixed driving force</td>
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<tr>
<td>7</td>
<td>Works with any resistivity electrolyte</td>
<td>Requires low resistivity electrolyte</td>
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<tr>
<td>8</td>
<td>Proactive &amp; Sustainable</td>
<td>Reactive</td>
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<tr>
<td>9</td>
<td>Today’s standard for impressed current cathodic protection applications is typically a Titanium anode with a Mixed Metal Oxide coating (Ti/MMO). These anodes have extremely long service life and very low consumption rate measured in the 1-2 mg/amp-year.</td>
<td>Zinc and Magnesium anodes are typically used in galvanic systems and they have a nominal consumption rate of approximately 11.24 Kg/Amp-Yr. for Zinc and 7.9 Kg/amp-Yr. for Magnesium.</td>
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EXAMPLE DESIGN OF WATER PIPELINE INTERNAL SURFACE CATHODIC PROTECTION SYSTEM.

Have considered two parallel pipelines carrying sea water for a power plant project, each pipeline having 3.55m dia. Preliminary design of CP will be as under:

Cathodic Protection Current Density 260 mA/m². (Flowing Sea Water)
Cathodic Protection life 20 years.
Internal Coating efficiency @ 20 years' life considered 75%. (Specified by Client)
Current Density @75% coating efficiency 65 mA/m²
Surface Area 11.15 m²/m
CP Current required 725 mA/m

Total Current for 3000 m pipe 2175 Amps.
Length of each anode segment 75 m
Current output per 75 m anode segment 54.3 Amps. (725mA/m x 75m = 54.3 Amps)
Current output per 75 m segment with 20% design margin 65.2 Amps. (54.3 Amps x 1.2 = 65.2 amps)
Diameter of MMO wire anode 0.125” (nominally 3mm)
Cable size piggyback connected to MMO wire anode #4 AWG
Sea Water Resistivity 50 Ohm Cms. (Low resistivity indicates high CP current requirement and lower circuit resistance)

CP Materials Required based on above Design:

- 80 Sets of 75m long SPL-INT- Anode with access fittings suitable to deliver 65.2 amps for 20 years' life.
- 20 Nos of 20V/300A output oil cooled transformer rectifier unit
- Probe type reference electrodes 84 Nos.
- Anode Junction Box 20 Nos.
- Cathode Junction Box Cum Test Station 20 Nos.
- Required cabling.

Please refer Figure 6: Overall layout of ICCP system components for a section of pipeline.

Installation of Internal Linear anodes.

1. Cut holes from the steel piping surface for the entrance fittings.
2. Weld the steel fitting to the pipeline.
3. Pull the anode assembly through the pipeline with cable puller.
4. Finish installation of the entrance fittings to create a waterproof seal.
5. Install the probe reference electrode(s).
6. Install the rectifier and junction box with the cabling as required.
Figure 1: Corrosion on Pipe internal surface.

Typical scheme for sacrificial anode cathodic protection system.

Sacrificial Anode (Typ.)

Welding

Pipeline

Figure 2: Sacrificial anodes on pipe internal surface.

TYPICAL SCHEME FOR ICCP SYSTEM.
Figure 3: Typical Scheme for ICCP System

Figure 4: Internal anode with access fitting.

Figure 5: Typical layout of ICCP system for pipe internal.
Figure 6: Overall layout of ICCP system components for a section of pipeline.
BENEFITS OF INTERNAL ICCP SYSTEM

- Reduces corrosion on internal surfaces of pipeline and extends the life of pipeline.
- Reduces maintenance costs, reduces costs for emergency breakdown related to corrosion issues with pipeline internal surfaces.
- When using Linear anodes for ICCP of internal pipeline surfaces, least number of entrance fittings are required.
- Linear anodes provide uniform current distribution to all internal submerged surfaces of pipeline as compared to probe anodes provided for cathodic protection of internal surfaces of pipelines.

PROJECT REFERENCE

Impressed Current cathodic Protection system using MMO wire based linear anodes was recently installed on a two parallel 16” sea water intake/outlet pipelines at a power plant project in Chile. The system consisted of 60 each anode segments, each anode segment length being 105 mtrs. The Plant was commissioned in 2016 and author’s are awaiting performance data of the CP system.

An earlier version of MMO wire based linear anode system was installed in a pilot water treatment facility in DENMARK. The facility reported successful operation of CP system for three years prior to the facility being sold.

CONCLUSION

Cathodic Protection is a proven technology to reduce corrosion of steel in water and has been successfully used for protecting steel in contact with natural waters for several years. Galvanic anodes and Impressed current CP systems can be used in conjunction with coating for reducing corrosion on internal surfaces of pipelines. It is worth noting that ICCP system is technically possible to apply for the protection of internal surface of large diameter of water pipelines. Cathodic protection may be considered to reduce corrosion on internal surfaces of large diameter water pipelines. There may be areas in the pipe line where the thickness of the coating is less than the prescribed norms and the quality of the coating is poor and so Cathodic protection can be used on bare pipelines as well.

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