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PIPELINE CORROSION – CAUSES AND MITIGATION

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ABSTRACT
When designing a steel pipeline, it is essential to consider the possibility that corrosion will occur and may cause irreparable damage to the pipeline and other infrastructure as a result. This chapter will examine some of the causes of pipeline corrosion and possible methods of mitigating the risk of corrosion to increase the expected life of the asset.

1. INTRODUCTION

With every advance made by mankind comes an associated challenge and with the advent of steel pipelines after the development of the Bessemer process in the mid 1800's, one of the major challenges identified was that of corrosion.

Corrosion can be defined as "the undesirable deterioration of a metal as a result of its reaction with its environment".

Corrosion is a wide ranging and complex subject that affects our lives almost daily, and steel pipeline corrosion is a very significant contributor. The deleterious effects of corrosion span all sectors of life, including economic, environmental and responsible use.

Some of the effects of corrosion include:

Economic

- Direct costs of material losses attributable to the wasting away (corrosion) of piping, tanks, ships' hulls, etc.
- Costs due to loss of products or production
- Costs as a result of damage caused by pollution, fire or other consequences of a corrosion leak.

Conservation of Resources

- Replacement of corroded items indicates a duplication of the use of material and human resources in the design and production of replacements

Environmental

- Production of one tonne of steel consumes in excess of 200 000 Production of one tonne of steel consumes in exess of 200 000 litres of water and generates 1.8 tonnes of carbon dioxide.

- Air pollution and contamination by other hazardous materials released into the environment due to corrosion are also of concern.

2. BASIC UNDERSTANDING OF CORROSION

In order to understand some of the causes of corrosion and its mitigation, it is important to have a basic understanding of the electrochemical nature of corrosion. While corrosion of metals may manifest in different ways and can be identified in many forms, the basic method of attack in an aqueous environment is essentially the same.

The corrosion process is electrochemical in nature and is affected by the chemistry of the reactions as well as influenced by the environmental conditions.

There are four components in the corrosion process:

- A chemical reaction where the metal is changed into a charged metal ion which goes into solution. This results in actual metal loss and is termed the anodic reaction. Electrons are released by the anodic reaction.
$$\mathrm{Fe} \; {-}{>} \; \mathrm{Fe2}^{+} + 2\mathrm{e}^{-}$$
- The electrons released at the anode flow through the steel. This electron flow can be measured as corrosion current.

- The electrons are used in one of the cathodic reactions, such as the reduction of oxygen or the formation of hydrogen gas (in acidic solutions).

- To complete the circuit, there must be current flow through the electrolyte, and this is achieved by movement of the ions in the electrolyte.

Electrochemical corrosion only occurs when all four elements are present.

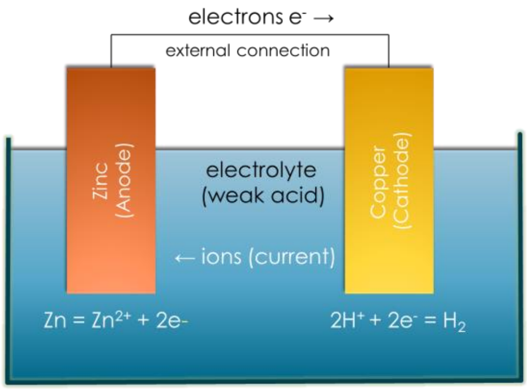


Figure 1: Schematic of Corrosion Cell

It is worth emphasising that only the anode corrodes. The cathode does not corrode and in fact is protected from corrosion by the corrosion of the anode. The electrolyte is any liquid that conducts electricity and that is in contact with the anode and cathode simultaneously. The metallic path is an electrical conductor that connects the anode and the cathode.

Removal or modification of any ONE of the four elements in the corrosion cell will result in a reduction or cessation of the corrosion process.

In the case of a pipeline, the anode and the cathode are integral within the pipeline surface itself, because at any moment in time, some areas of the surface of the pipeline are at slightly different potentials to each other. The more positive areas are called anodic and the more negative regions are called cathodic. Additional sources of corrosion cells on pipelines include: differential aeration, water table, chemical pollution/contamination and external electric fields.

By virtue of its design, a pipeline can corrode from the inside as well as from the outside. The forms of corrosion will be determined by the pipeline material of construction as well as the environment to which the pipe surface is exposed. Some methods of controlling corrosion may include material selection, modification of the environment, design changes, coatings and cathodic protection.

3. INTERNAL CORROSION OF A PIPELINE

A pipeline is a vessel, used to carry fluids. The type of fluid being transported may well cause corrosion or damage to the internal surface of the pipeline. The process of transportation often dictates the most suitable method of mitigation.

Internal corrosion of pipe

Causes

Some of the causes of corrosion to internal surfaces of a pipeline include:

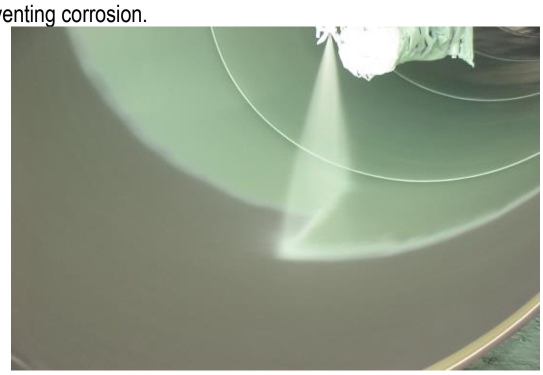
- Aggressive solutions being carried by the pipe. In the case of waters, these may be process waters with high acidity, etc.
- Microbial induced corrosion from waters "infested" with bacteria capable of damaging the steel.
- Different metals used within the same pipeline which may result in the formation of galvanic corrosion cells.

Mitigation

Mitigating the corrosion from the inside of the pipe is often determined by (a) the type of pipeline in use , i.e. a circulating system or a single pass system. In addition, in the case of water transportation, the treatment of the water may be determined by the use of the water. Water treatment is often dictated by "fitness for purpose".

Epoxy lined valve

In the event of high volumes of water passing through a pipeline, it is usually not economically feasible to treat the water in any significant way to reduce its corrosivity. These pipelines are usually lined with a suitable lining material such as epoxy or cement mortar lining. These linings effectively isolate the steel surfaces from the electrolyte, thereby preventing corrosion.



Internal Epoxy lining application

In a closed circuit, such as boiler water, it may be possible to dose the water with appropriate anti-corrosion agents. This "water conditioning" effectively alters the properties of the water. Examples include neutralisation of acidic waters using lime and clarifying waters with high solids.

Addition of biocides can effectively prevent microbially induced corrosion and selection of additional corrosion inhibitors may also be indicated. Water chemistry is a complex subject and the specific dosing requirements and types of chemicals required should be addressed by a specialist water chemist.

4. EXTERNAL CORROSION OF A PIPELINE

Pipes can corrode externally due to exposure to the environment. If the pipes are aboveground they will require a suitable barrier coating to prevent atmospheric corrosion.

When pipelines are buried, corrosion may primarily be attributed to the soil conditions and the presence of microbes. The presence of stray interference currents from other sources (including DC rail systems and nearby high voltage AC powerlines) can also contribute to the external corrosion of a pipeline and needs to be evaluated.

Pipe failure due to corrosion

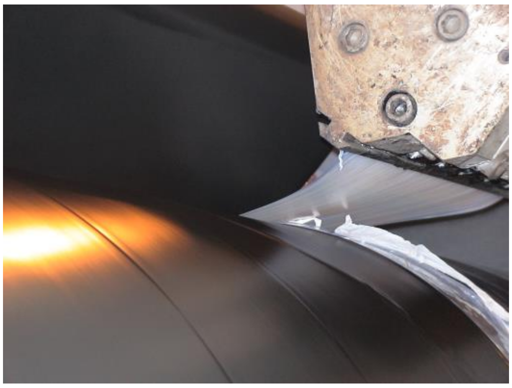
Mitigation of external corrosion of buried steel pipelines is achieved by two principal methods:

Coating

Pipeline coatings provide a physical barrier between the pipeline and the soil and provide the primary source of corrosion mitigation for pipelines. Adequate surface preparation and the appropriate selection of the coating and its method of application are critical. Epoxy, polyurethane, polyethylene and bitumen are some examples of external coating materials for pipelines.

Degraded coating

The variety and efficacy of coatings is a vast and specialised topic on its own. Suffice to say that care should be taken to consider all aspects of the pipeline including the material being transported, environmental conditions, pipe diameter, expected life and many others, when selecting the coating, It is important to remember that whilst coating A may be the preferred coating for Pipeline 1, the different conditions which will be experienced by Pipeline 2 may well result in the selection of a completely different coating system.



Application of a multi-layer coating system

Cathodic Protection

Cathodic protection (CP) is a proven, successful and widely used electro-chemical method of protecting buried or submerged steel as well as the reinforcing steel in concrete against corrosion. Cathodic protection was first described in 1824 by Sir Humphry Davy after he noted a significant decrease in the corrosion of copper hulls of ships to which iron ingots had been attached. However, it took more than 100 years before cathodic protection was used to any great extent on pipelines.
By applying a D.C. voltage between a specially provided electrode (the anode) and the steel structure or pipeline (the cathode) the resultant current flow prevents the loss of metal from the steel surface and protection against corrosion is achieved.

In general, the combination of coating + cathodic protection is more economical than either alone. In such instances, the coating protects the majority of the pipeline and the cathodic protection current only flows to and protects the exposed steel at any defects in the coating.

Cathodic protection is appropriate for protection in all soils and natural waters, including brackish and sea water. It can also be applied in a variety of chemicals and solutions, although consultation with a CP Design Specialist is recommended.

For any CP system to operate successfully, the following are essential:

- The pipeline must be buried (submerged) in an electrolyte.
- The pipeline must be electrically continuous.
- The pipeline must be electrically isolated from other metallic structures – usually by means of insulating flanges.
- The pipeline must be electrically insulated from civil structures such as the walls of valve chambers, pumpstations and reservoirs.
- Test facilities should be installed at regular intervals along the pipeline to allow easy access to monitor the level of protection.

It is generally accepted that at structure-to-soil potentials more negative than -0.85V_{CSE}, steel is cathodic and will not corrode. Thus, simply measuring the potential of the structure will demonstrate whether complete protection is being achieved.

Consultation with a CP Design Engineer will also ensure optimal construction practice for peripherals including valve chambers and actuators, flow meters, earthing systems, reservoirs and pump stations. The latter two are particularly important with respect to the location of insulating flanges.

Cathodic Protection is not generally used in the following instances:

- For protection against atmospheric corrosion or corrosion due to condensation.
- In acid solutions.
- For protection against steam or fumes.
- In situations with a complicated geometry such as a bundle of condenser tubes, or in cramped environments such as the inside of a small diameter pipeline.

In practice, Cathodic Protection is applied to a structure by one of two different methods.

Sacrificial Anode CP

The protective current required is obtained by creating a cell or 'battery' between the pipeline (cathode) and a more active metal - such as magnesium (the anode). In this cell, the anodic metal is corroded away to provide the power. This is known as 'Sacrificial Anode' Cathodic Protection (SACP).

When any metal is placed in an electrolyte (water or ground) a potential is developed across the metal/electrolyte interface. This is termed the "electrode potential" and every metal has its own specific value. Some values are shown below (measured w.r.t. a copper/copper sulphate electrode):

Metal	Potential (V)
Gold	+0.6V
Copper	-0.2V
Iron / Steel	-0.6V
Zinc / Aluminium	-1.1V
Magnesium	-1.6V

Table 1: Portion of Galvanic Series

When any two metals in the series are connected, the metal with the more negative potential becomes the anode and is corroded while the other metal becomes the cathode and is protected.

Sacrificial Anode Bracelets

Thus iron can be used as an anode to protect copper, while zinc, magnesium or aluminium can be used as anodes to protect iron or steel. The anodes in such instances are referred to as sacrificial.

A typical sacrificial anode installation for a coated, buried steel pipeline consists of 2 or more magnesium anodes (7,7 Kg each) buried 3m from the pipe, every 50 – 100m along the pipeline route. The anodes are connected to the pipe via a copper cable. The number of anodes is determined by the pipeline diameter and the characteristics of the coating system and the environment.

Some advantages of SACP include:

- SACP generates its own electricity and the system does not require external power.
- Once installed, SACP requires virtually no maintenance and is very reliable.
- SACP is relatively easy to install.

- It is impossible to accidentally reverse polarity.
- Typical life of 10-15 years depending on design

However, as with all systems, there are disadvantages. Some of these include:

- Installations are expensive.
- Performance (current output) depends on soil resistivity.
- Driving voltage is generally insufficient to overcome voltages from stray currents.
- Complete replacement is required at end of life.

Impressed Current CP

In an `Impressed Current Cathodic Protection System' (ICCP), the power required is obtained from the main AC supply, transformed to a lower voltage and rectified to DC. The DC output is connected between the structure and an external anode. The anode is constructed of a material made to last as long as possible under anodic conditions.

This technique utilises 230V or 400V AC to feed a step down transformer and rectifier bridge to produce, typically, 50V 20A DC. The negative terminal is connected to the pipeline requiring protection and the positive terminal is connected to the anode. Some form of output control is required, particularly in stray current environments.

The anode is often remote from the structure (>100m distance) and may comprise a series of individual anodes in a continuous coke bed, termed a groundbed. These may be installed in a horizontal or vertical configuration, although horizontal groundbeds are more common in South Africa. The individual anodes are constructed from special non-corrodible materials such as silicon iron or activated titanium.

ICCP Installation

Some advantages of ICCP include:

- A single installation can protect >15km of pipe
- ICCP can counter the effects of stray currents from DC rail and other CP systems.
- ICCP can be effective in all soil types.
- Typical life of 20 - 25 years.
- ICCP is effective for bare and coated structures.

Some of the disadvantages of ICCP systems include

- The system requires an external source of power
- Care must be taken to ensure the correct polarity or catastrophic corrosion of the pipeline will occur.
- The rectifier must be routinely maintained.
- Poor location of ICCP systems can result in interference corrosion to other buried pipelines in close proximity.

5. AC CORROSION

With the increasing use of common corridors for high voltage power and pipeline services, as well as the increasing use of high insulation value coatings on pipelines, increases in AC induced corrosion effects have been observed.

Multi-User Corridor

Acceptable codes and practices are still being developed both in South Africa and other countries but in general the three factors which are considered to a greater or lesser extent are:

- Conductive coupling during a fault. When a fault–to-earth occurs on an electric powerline, the current leaving the powerline will return to earth by all available paths, including a buried pipeline in close proximity (through its coating). Although the occurrence is fairly low, the risk of electric shock hazard is high and mitigation is usually by means of additional earthing around above-ground appurtances.

- Capacitive or electrostatic coupling is greatest risk during construction and is easily mitigated by temporary earthing of the above ground pipe segment(s)

- Electromagnetic induction between the high voltage powerline and the pipeline in close proximity can lead to inductive coupling and induced currents on the pipeline. Mitigation is quantified by mathematical modeling and usually achieved by means of zinc ribbon installed in the pipe trench and connected to the pipeline via solid state decoupler devices.

6. CONCLUSION

New pipelines are expected to be constructed with a design life of 50 years. Failure of a pipeline within a few years of installation is unacceptable and unnecessary.

Pipeline corrosion can be prevented or at least dramatically reduced, with the aid of careful material selection, the specification of suitable coatings and, where necessary, the customised design and installation of cathodic protection and AC mitigation systems. The additional cost of these measures generally only represents 5% of the capital cost of the pipeline.

Peace of mind is cheap at this price!

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