National Physical Laboratory

Guides to Good Practice in Corrosion Control No. 4

Corrosion Control for Buried Pipelines

Corrosion Research and Testing

For more information on corrosion research and testing contact Gareth.hinds@npl.co.uk
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National Corrosion Service

The National Corrosion Service (NCS) is operated by NPL on behalf of the National Measurement System to provide a gateway to corrosion and materials expertise for UK users. By acting as a focal point for corrosion enquiries the NCS can make the UK's entire base of experts available to solve problems or can use in-house expertise or teams to carry out consultancy. The NCS also raises awareness of corrosion problems and methods of control.

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A free advice service is available to UK Residents and Companies on materials and general corrosion related matters.

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Acknowledgements

This is an update of a DTI publication first issued in 1982. This revised version has been prepared by Mr D W Harvey, CEng, FICorr, of CathPro Consult Ltd, Chairman of BSI Committee GEL/603 Cathodic Protection, on behalf of NPL for the Department of Business, Energy and Industrial Strategy. Edited by Dr. A. Turnbull and Dr. G. Hinds, NPL.

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1. Introduction

Although many older installations of thick-walled cast or spun iron pipe have a long history of service before corrosion to failure, the cost of repairs when corrosion does occur is very high. In contrast, the cost of effective corrosion control is about 1-2% of the total cost of laying a pipeline and is recovered many times over by the consequent extension of the life of the pipe and/or by the savings in not having to provide a corrosion allowance in the form of increased pipe-wall thickness. Accordingly the current practice of using thinner-walled steel or ductile-iron pipe and applying protection against corrosion is economically sound.

This Guide describes the causes of corrosion of underground pipelines and the methods of retarding the rate of corrosion to a very low value.

The Guide is concerned with the external surfaces of metal pipes made of iron or steel. Pipes made of other metals are not considered here.

2. Identifying the problem

The principal influences affecting the rate of corrosion of any buried pipeline are:

i. The nature of the soil
ii. The composition of the groundwater
iii. Any external electrical influences (stray currents)
iv. The effectiveness of the protective system

The following questions should be asked when a new pipeline is being planned:

- Has a survey been made to determine the possible corrosivity of the soil?
- Have similar pipelines in the area corroded?
- Have other pipeline materials been considered – for example, polyethylene, pre-stressed concrete and glass-reinforced plastic?
- Is it proposed to apply coating, wrapping or sleeving to the pipe?
- Should the pipe be cathodically protected?
- Is there provision for inspecting the integrity of the coating and the quality of the backfill during construction?
- Are stray currents possible from other pipeline cathodic protection systems, electric railway systems, leaks from substations, or induced currents from overhead high-tension power lines parallel to the route?

On existing pipelines, increasingly costly repairs may show the need for better protection for the replacement pipe or for retrospective cathodic protection to be applied to the entire pipe or ‘corrosive hotspots’ or for action to avoid stray currents from new or ‘overlooked’ sources.

3. Causes of Corrosion

3.1 Mechanism of corrosion

Corrosion is an electrochemical process in which a metal reacts with its environment to form an oxide, or other compound, analogous to the ore from which it was extracted, resulting in its progressive degradation or destruction. The cell causing this process, known as a ‘corrosion cell’, consists of an anodic area where the metal is corroded, a cathodic area that is not consumed (protected) in the corrosion process, a metallic connection between the anodic and cathodic areas and an electrolyte in which the anodic and cathodic areas are immersed, i.e. the corrosive medium (soil or water in the present context). A direct analogy to the corrosion cell is the dry cell battery creating current passing through the electrolyte between the zinc casing and the graphite electrode when an external metallic circuit is connected. The cathode may be a second (more noble) metal in contact with the corroding metal or it may be an area on the same metal surface. Anodes and cathodes on a single piece of metal may arise from differences in metallurgical condition from place to place, from variations in natural or protective coatings on the surface, or they may be created by variations in the electrolyte as soils are far from homogeneous.

The cathodic reaction in almost neutral solutions involves the consumption of oxygen. On a continuous pipeline different levels of availability of oxygen give rise to two opposing effects; in well-oxygenated soils the metal becomes cathodic and in poorly oxygenated soils the metal becomes anodic:

a) *Local effect:* In well-oxygenated soil the cathodic reaction of reduction of oxygen can proceed easily, stimulating anodic dissolution of metal in adjacent areas. In general in poorly oxygenated areas the cathodic reaction is stifled so corrosion of anodic areas may be correspondingly slow.
b) *Long-distance differential aeration effect (‘long-line corrosion'):* A large area of a pipe in well-oxygenated soil can act as a cathode and remain stable. Coupling of this region of the pipe to a more distant poorly oxygenated area can cause current flow along the pipe, in some cases over several kilometers, with the consequence that the poorly oxygenated area becomes anodic and corrodes.

The conductivity of the soil/water also plays a significant role. Corrosion current flows more easily through soils of low resistance than of high resistance (the return path through the metal being of low resistance in all circumstances - see Section 6.1). In addition, differential aeration/concentration cell effects can occur on a pipe that passes through soils of different compositions caused naturally or by the construction processes.

The explanation of what happens in practice can be complex and prediction can be difficult.

3.2 Practical illustration

Figure 1 is a section showing a pipeline laid from a hill across a valley:

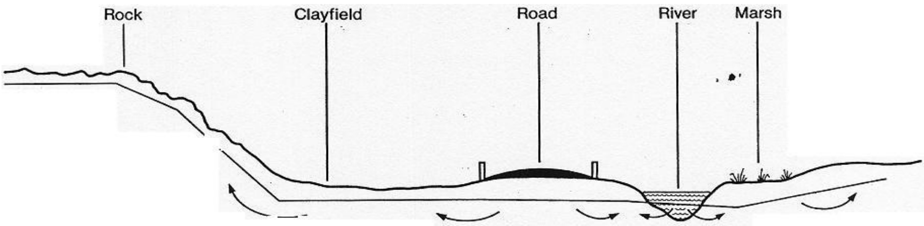

Figure 1. *Corrosion generated from soil and environmental changes.*

The following effects can be expected:

i. *Rocky area:* corrosion rate is low because well drained, well-aerated soil has high resistivity/low conductivity. The whole area of the pipe tends to be cathodic.

ii. *Clay area (poorly oxygenated):* local corrosion cells are stifled, but the corrosion rate is high because the whole area of the pipe is anodic to that in the rocky hillside and resistivity is low. Corrosion may possibly be assisted by local anaerobic bacterial activity.

iii. *Clay area near road:* corrosion rate is low because the area is made cathodic by current flow from the poorly aerated section under the road.

iv. *Road area (even less aerated than the adjacent clay area):* local corrosion cells are stifled, but the corrosion rate is high because the area is anodic to the adjacent clay area.

v. *River:* corrosion rate is high because of active local corrosion cells in well-oxygenated water. This may lead to differential-aeration protection of areas of the pipe in the ground nearby. If part of the pipe is enclosed in concrete, accelerated corrosion may occur a few inches away from the emergence because a steel/concrete interface becomes very cathodic to a steel/soil or a steel/water interface.

vi. *Marsh area:* local cells are stifled, but the corrosion rate may be high because the area is continuously wetted and is probably acidic (low pH), becoming anodic to the well-oxygenated area of pipe under the next hillside.

3.3 Bacterial corrosion

The cathodic reaction normally involves the consumption of oxygen. However, under anaerobic (oxygen-free) conditions as may occur in compacted clay soils, corrosion may be stimulated by the activity of microorganisms such as sulphate-reducing bacteria (e.g. Desulphovibrio desulphuricans). The corrosion process is then more complex and the mechanisms involve bacterial utilisation of the hydrogen formed by the cathodic reaction from water and the effects of the sulphide metabolic products of the bacteria. Bacterial corrosion is immediately recognizable on a freshly exposed pipeline surface by a black corrosion product with the strong rotten-egg smell of hydrogen sulphide. The pipe surface is shiny but can be gouged with a knife. On cast iron, graphitisation occurs with the iron being converted to its sulphide, leaving a matrix of low mechanical strength.

3.4 Stray currents

A pipeline can often provide a better conducting path than the soil for earth-return currents from electric railways, electricity installations and cathodic protection systems on nearby pipes. Accelerated corrosion occurs where the stray current leaves the pipe and flows into the soil to return to its source. Stray current corrosion is more likely on lines that are electrically continuous, such as welded lines, than on those that have partly or wholly insulating joints. Figure 2 illustrates a situation in which accelerated deterioration by stray current corrosion can occur. Stray a.c. currents can also be induced in a pipeline if it parallels high-voltage transmission lines, the alternating current apparently being partly rectified by oxide films on the pipe.

The corrosion rate caused by a.c. stray currents is much less than that caused by d.c currents but on high quality coated pipelines with a low number of defects it can be significant and will require investigation and possibly mitigation measures.

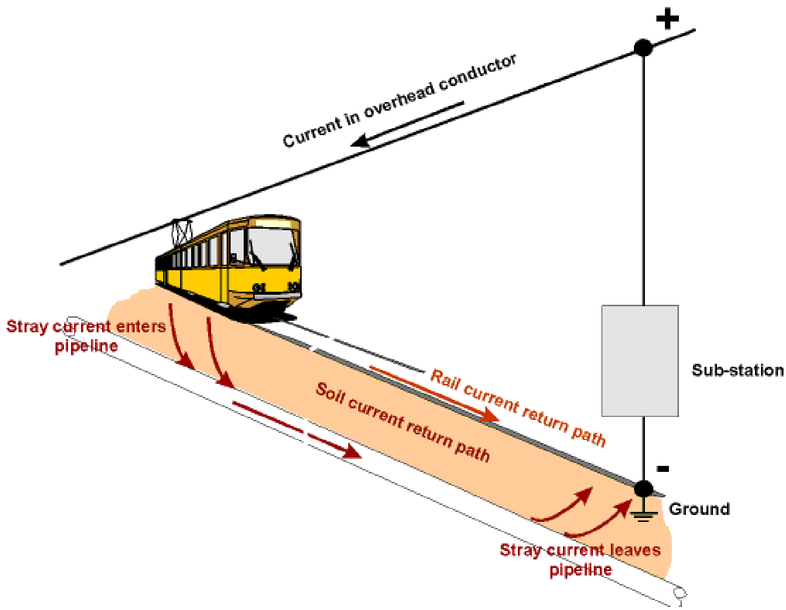

Figure 2. *Stray-current corrosion.*

3.5 Telluric currents

Pipelines may be subjected to telluric current activity due to the modulation of the earth's magnetic field by solar particles. This changing magnetic field produces an electric field that causes charges to flow in the earth and in metallic networks located on the earth such as pipelines, electric power lines and communication cables. This electrical disturbance is observed on pipelines as potential and current fluctuations that can vary with time due to the earth's rotation, tidal cycles, the sun's rotation, eleven-year solar cycles, and solar storms (sunspot activity). The magnitude and location of these disturbances depend on the pipeline's proximity to the earth's magnetic poles, on its length, on its orientation, on changes in direction, on the coating resistance, on electrical continuity along its length, on soil resistivity and the presence of abrupt changes in earth conductivity and proximity to a seacoast.

The effects of telluric currents on pipelines have been considered an inconvenience when conducting cathodic protection surveys for compliance with pipeline codes and regulations. Recently however, as more pipelines have been constructed at higher latitudes and in higher resistivity soils and as higher quality coatings have been used the resulting telluric potential and current variations have become more severe and raised concerns about the following issues:

- Whether or not the pipe is corroding during periods of telluric current discharge
- Will the coating be stressed and possibly disbonded during periods of pick-up?
- How can the effects of telluric current activity be mitigated?
- What techniques are available to measure accurate pipe-to-soil potentials during periods of telluric activity?

These issues need to be addressed by a specialist cathodic protection engineer with suitable knowledge and experience.

3.6 Bimetallic corrosion

Bimetallic corrosion or galvanic corrosion occurs when two different metals are joined electrically and bridged by an electrolyte; the less noble metal becomes anodic and corrodes, while the more noble metal becomes cathodic and is protected. The accelerated bimetallic corrosion of steel or galvanised steel pipes and tanks in domestic water systems caused by coupling to copper components is well known. It is not always appreciated, however, that galvanic corrosion can sometimes occur between two forms of the same metal.

The different forms of iron and steel used for pipelines are, in ascending order of combined resistance to corrosion:

Steel pipe: new	Less noble, becomes anodic and corrodes
Steel pipe: old	
Cast iron pipe: new	
Cast iron pipe: old	
Spun iron pipe: new	
Spun iron pipe: old	More noble, becomes cathodic and is protected

Figure 3 emphasises the significance of this list by illustrating the severe galvanic corrosion that occurred on a new steel tee-piece inserted into an old iron pipe, due to the variation of cathodic and anodic film characteristics on the old and new pipe.

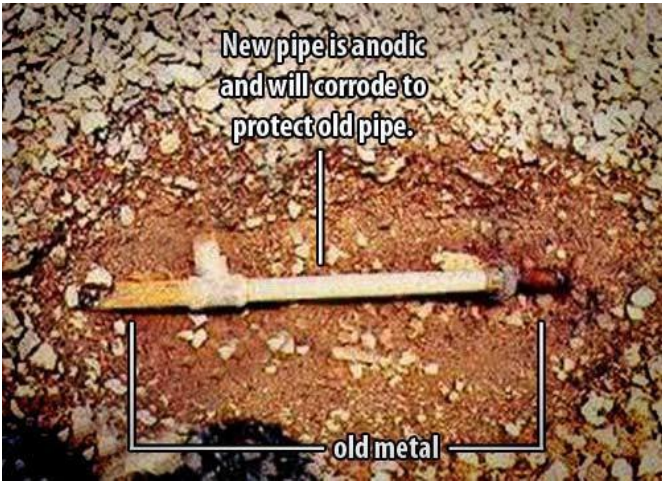

Figure 3. *Galvanic corrosion on a new tee-piece inserted into an old iron pipe.*

4. Corrosion Survey

Before a protective system is chosen for a pipeline, a survey should be made to determine the effect that the environmental soils and waters will have on the long-term life of the structure and the choice of materials for that structure. Such a survey should be completed before the pipeline route is finalised.

The following factors should be considered:

4.1 Resistivity

High resistivity in the electrolyte of a corrosion cell limits the corrosion current between anodic and cathodic areas and so retards corrosion; conversely low resistivity allows the currents to pass readily and so promotes corrosion. Table 1 shows the average resistivity of common pipeline environments.

	Ω m
Seawater	0.25
Brackish river water (depending on the tidal range)	1-10
Town water supply	20-50
Clays	5-20
Alluvial soils	10-50
Mixed soils	40-100
Gravel	100-250
Sand	250-500
Porous rock	> 500
Non-porous rock	> 5000

Table 1. *Average resistivities of common pipeline environments.*

The degree of corrosion likely to be associated with a given resistivity varies for different forms of pipeline materials. Table 2 gives a broad guide for iron and steel pipelines.

Iron	Steel	Assessment
< 7.5 Ω.m	< 10 Ω.m	Severely corrosive
7.5 - 30 Ω.m	10 - 50 Ω.m	Corrosive
30 - 75 Ω.m	50 - 100 Ω.m	Moderately corrosive
> 75 Ω.m	> 100 Ω.m	Slightly corrosive

Table 2. *Degree of corrosion as a function of soil resistivity.*

These are not strict limits because all ferrous metals will gradually corrode in soil or water. The rate of deterioration is also related to the factors discussed below. Even though a soil may be classified as slightly corrosive, in mixed soil conditions the amount of corrosion can still be significant, leading to leaks if no other forms of protective measures are taken.

4.2 Chemical and bacterial tests

Some soils are naturally acidic, so soil analysis should include determination of pH values. Evaluations should also be made of chloride, sulphate, and nitrate content and of organic acids.

Chemical tests are especially important for the detection of local contamination in the soil or in surface drainage water. Common contaminants are chemical waste, refuse, agricultural chemicals, and de-icing salts applied to roads.

Probably the most important soil test for clay soils is to determine whether or not anaerobic bacteria are active.

An examination of Ordnance Survey geological drift maps (1:25,000) will provide a useful guide to sub-surface conditions. The World Soil Survey Archive and Catalogue (WOSSAC) at Cranfield University, UK, contains maps produced by the Soil Survey and Land Research Centre, a limited series of maps detailing surface soil types giving a guide to resistivity. Neither of these authorities takes account of any changes caused by the localised contaminants mentioned above.

4.3 Stray current analysis

Where a pipeline is routed parallel or close to an electric railway or near to factories where welding is extensively used or any similar circumstances where direct current may be picked up on the pipeline then assessment of the effects of these should be made by specialists before the right of way is finalised. Such tests make use of portable recording equipment that enables an assessment to be made of the likely effect of the stray d.c. current on the pipeline so that precautions can be proposed. Generally these are limited to controlling the stray current by earthing or structural bonding.

Where pipelines run parallel to HVAC transmission lines or a.c. electric railways, problems may be caused by induced voltages and currents in the pipeline during steady state conditions and under fault conditions or as line-currents vary as in railway systems. These problems fall into two categories.

1. Safety - induced voltages and currents, if of a sufficient magnitude, may be a danger to personnel operating equipment on the pipeline and can affect welding operations during construction. Earthing the pipeline at relevant locations can remove this danger.
2. Corrosion - if the current is of a sufficient magnitude, it can cause corrosion of the pipe at the point of discharge, similar to d.c. interference. The corrosion rate is dependent upon the current density and the soil resistivity at the discharge point.

4.4 Presentation of results

The results of the tests described above are analysed in conjunction with known topographical and soil-surface data to assess the corrosion propensity over the whole route. Long-term subsoil conditions can be assessed and the pipeline engineer together with the corrosion engineer can then make decisions about the type of pipe material, its thickness, the method of joining, the wrapping or coating material to be applied, whether cathodic protection is required and what type and the extent of inspection proposed. There are several methods of presenting the results of surveys; the corrosion engineer should aim at being as informative as possible to the pipeline designer and relate his results to the working pressure and product of the pipeline, its expected design life and a risk assessment of the consequences of corrosion leaks.

5. Protection by Coatings and Tapes

Coatings and tapes assist in retarding the rate of corrosion by excluding air and moisture from the metal surface and by introducing a high-resistance membrane into the corrosion cell.

5.1 Coatings

A coating should be stable over the range of temperature to be encountered, self-setting, adherent to the pipeline material and relatively impervious to moisture. There are many other desirable properties to suit various conditions of service and the choice must be based on operating requirements and experience. Table 3 summarises the range of materials available and lists the basic advantages and disadvantages of each.

	Advantages	**Disadvantages**
Bare pipe	Corrodes evenly over whole surface unless there are inclusions.	Can corrode rapidly to failure. Difficult to cathodically protect.
Galvanised pipe	Small addition to shipping weight. Provides limited cathodic protection.	Relatively expensive. Scratches easily, allowing increased corrosion at failures.
Bitumen	Can be used in the field (line-travel machine). Readily available Holidays and damage easy to repair. Slightly cheaper than coal tar.	Absorbs moisture and supports root growth.
Coal tar	Long service record (40 years). Resistant to oil products and root penetration. Limited degradation. Slow to age and harden. Can be used in the field (line-travel machine).	Good bond requires proper surface preparation. Limited temperature range (but better than bitumen). Hazardous to health during application.
Epoxy powder	Good bond to pipe. Increased temperature operating range. Pipes can be bent cold. May be subject to disbondment with age	Requires good surface preparation and chromate pre- treatment to produce strong bond and consistent coating free of holidays. More expensive.
Polythene sleeving	Cheap. Lightweight.	Difficult to install properly. Can increase corrosion problems.

(non- adherent)		Precludes the use of cathodic protection.
Extruded polythene	Good quality factory application. Good life expectancy.	Degrades in sunlight. Relatively expensive. Thick heavy coating.
3 layer coating comprising: Epoxy primer Adhesive layer Extruded polyethylene or polypropylene	Very high quality coating. Abrasion resistant. Chemical resistant. Very low cathodic protection current required.	Expensive. Cathodic protection may be very sensitive to minor changes.

Table 3. *Pipe coating materials.*

5.2 Tapes

The chemical requirements of tapes are similar to those of coatings; the difference is that the tape provides a mobile form of pipe protection. Tape systems are used for:

- Protection of bare pipes
- Protection of butt-welded joints
- Protection of joints and fittings
- Repairs to damaged factory-applied coatings
- As an outer wrap for coating sleeve carrier pipe
- As shield material in rocky soils

Tape systems may be applied in several ways:

- By hand
- Hand-operated wrapping machine
- Powered wrapping machine
- In a factory
- On site

Type of tape	Primer	Characteristics and uses
Petrolatum compound/fabric reinforcement	Petrolatum/solvents (optional)	Highly conformable nature, reliable under adverse conditions. Mainly used for the protection of pipe, joints, flanges, valves and repairs, etc. on distribution systems
Petrolatum compound/fabric reinforcement/PVC laminate	As above	Conformability reduced but improved mechanical and electrical properties
Petrolatum compound/glass tissue/woven polypropylene laminate	Bitumen solvents	Machine-applied pipeline tape
Rubber bitumen compound/PVC laminate (discardable interleaving)	Bitumen solvents	Robust, general-purpose cold-applied bitumen tape. Different combinations of coating thickness/PVC backing, allowing suitable choice for individual projects
Self-adhesive mastic laminated to a plastic backing (discardable interleaving)	Rubber, resins/solvents	Range of plastics and coating thicknesses allow suitable choice for individual projects
Butyl rubber compound laminated plastic film (usually polyethylene or PVC)	Butyl rubber compound/solvents	As above
Pressure-sensitive adhesive polyethylene and PVC tape	Resins/solvents (optional)	High electrical resistance
High-melting-point bitumen/fabric reinforcement	Bitumen solvents	Flame-applied bitumen tape
Flexible coal-tar compound/ fabric reinforcements	Synthetic resins/solvents	Flame-applied coal-tar tape
These two tapes are safer to apply than hot-poured flood coat but allow the same material to be used on the joints as for the factory-applied coatings		

Table 4. *Pipeline wrapping tapes.*

The method of formulation of tapes makes them basically more expensive than coatings but they provide a very useful form of pipeline protection. They are usually applied with a 55% overlap, ensuring that a double thickness is always applied. Tapes are not normally used by themselves but as part of a protection system which might comprise:

i. Primer
ii. A mastic to soften the difficult contours on valves, mechanical joints, etc.
iii. The tape itself – possibly consisting of an inner wrap, an outer wrap and a shield wrap, depending on the nature of the backfill and the use of cathodic protection

The precise choice of a tape system will depend upon several factors and it is recommended that a manufacturer's advice be sought if in doubt. Table 4 summarises the properties and uses of the overall tape materials most commonly in use on pipelines.

5.3 Other coatings

Anti-flotation

It is accepted practice to sink underwater pipelines with special concrete coatings that provide negative buoyancy. The concrete may or may not be reinforced, and it is normally applied over the existing anti-corrosion coating. It is not intended to be a protective cover but its method of application may affect any underlying protective system.

Thermal

Thermally insulated coatings are used to retain heat in the pipeline and thereby prevent thickening or solidifying of the material flowing in it. These have an outer coating of highly insulating material to prevent the ingress of water that will also act as a barrier to cathodic protection currents. If possible an anti-corrosion coating should be applied before thermal insulation. Should the coating become damaged and allow water and oxygen to reach the pipe surface, accelerated corrosion, known as corrosion under insulation, may take place due to the elevated temperatures. The application of cathodic protection is unlikely to prevent corrosion under insulated coatings.

Plastic

Plastic coatings give a high degree of protection but are normally considerably more expensive than the coatings previously described. They are usually used over short lengths of pipe where good protection is needed and other systems are difficult to apply. Plastic coatings are applied in one of three ways – by dipping into a liquid plastisol, by immersion in a fluidised bed of powder or by pressure/electrostatic spraying. The range of materials that can be applied to metallic surfaces includes PVC, polyethylene, nylon and various grades of epoxides. Because of the techniques involved application is primarily a factory process. The principal difficulty that remains is that of producing a field joint up to the same standard as the primary coating material. However, thin-film epoxy powders are extensively used on cross-country pipelines and the material itself is claimed to have a high adhesion bond, reducing the risk of delamination during cold bending as well as improved coating characteristics overall compared with coal-tar and bitumen derivatives. Towards the end of the design life increased disbondment may become apparent.

Thin-film sleeves

In this method the environment is excluded by pulling a polythene sleeve over the pipe while it is being laid in the trench; the sleeve is then loosely taped into place. It is essential that the sleeve is continuous; this is difficult to achieve in a trench, especially if the weather is bad. If the sleeve is damaged or if lengths are imperfectly connected, it may provide an easy path for water to drain along the pipeline and corrosion will then be accelerated either by the continuous supply of oxygen or in anaerobic conditions by the proliferation of sulphate-reducing bacteria. Once sleeves have been fitted it is impossible to apply any other form of protection (for example, coatings or cathodic protection) so loose sleeves may only be recommended for mildly corrosive conditions.

6. Cathodic Protection

6.1 Principles

In section 3.1 it was pointed out that corrosion occurs only on anodic areas of a metal surface with the cathode being either other areas of the same metal or a second metal in contact both in an electrolyte. The principle of cathodic protection is to connect an external anode to the metal to be protected and to pass a current so that all areas of the metal surface are forced to a cathodic potential and so do not corrode. The effect is illustrated in Figure 4. In electrochemical terms, the potential of the metal is lowered to a value (on steel, -850 mV or lower, relative to a copper/copper sulphate reference electrode) at which corroding anodic reactions are inhibited allowing only cathodic reactions. Cathodic protection is achieved in either of two ways by galvanic (sacrificial) anodes or by impressed current.

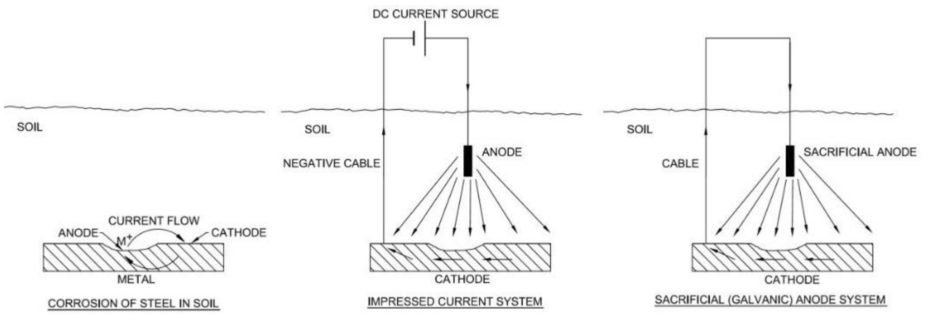

Figure 4. *Cathodic Protection*

6.2 Galvanic anode methods

These systems employ reactive metals buried in the local electrolyte and electrically connected to the steel pipe to be protected. The difference between the natural potentials of the anode alloy and the steel as indicated in the electrochemical series causes a current to flow in the electrolyte (soil) from anode to steel of sufficient magnitude to ensure that the surface of the steel becomes totally cathodic. Table 5 lists the three anode materials most commonly used and their basic properties.

Base alloy	**Grade**	**Voltage (V vs u/CuSO4)**	**Consumption rate (kg/A/y)**	**Capacity (Ah/kg)**	**Uses**
Magnesium	Standard High Potential	-1.50 -1.70	7.5 7.5	1200 1200	Soils below 40 Ω.m. Soils below 50 Ω.m.
Aluminium	Indium	-1.10	3.2	2600	Rarely used for onshore pipelines.
Zinc	High purity	-1.10	11.3	780	Up to 10 Ω.m or special use (earth rods or pre-stressed concrete pipes).

Table 5. *Properties of sacrificial-anode materials*

For most pipeline work the magnesium alloy is used installed in the manner shown in Figure 5. The anode is placed as close as possible to the level of the underside of the pipe (the invert level) and about 2-10 m away from the pipe in order to spread protection over a reasonable surface area. As shown in Table 5, an anode alloy has only a limited voltage to overcome the soil resistance and consequently the working range of galvanic anodes is limited. This method of protection can be described as little and often. An average spacing of 200 m would be needed on a reasonably well-coated 300 mm diameter continuous pipe for an 8-10 year magnesium anode life depending upon the soil resistivity.

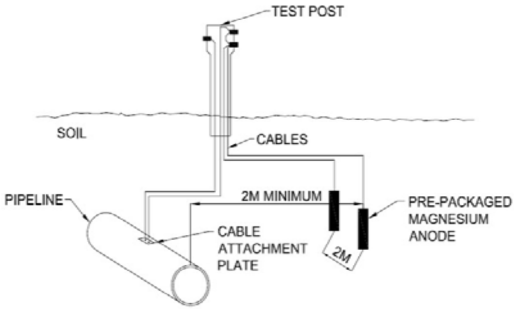

Figure 5. *Installation of sacrificial anode.*

6.3 Impressed-current methods

These systems employ inert (non-galvanic) anodes with an external source of direct current power to impress a current from anode to cathode through the soil. Voltages up to 50 V can be applied to overcome soil resistance so that a substantial impressed current can have a spread of protection from 2 km on a poorly coated pipe and up to 50 km or more for well-coated pipe under cross-country conditions. Anodes can be made of cheap consumable materials such as scrap steel or of inert materials such as silicon iron, graphite or mixed metal oxides (MMO) and they are commonly used in groups buried in low-resistance carbonaceous backfill called a groundbed. Figure 6 outlines a typical installation.

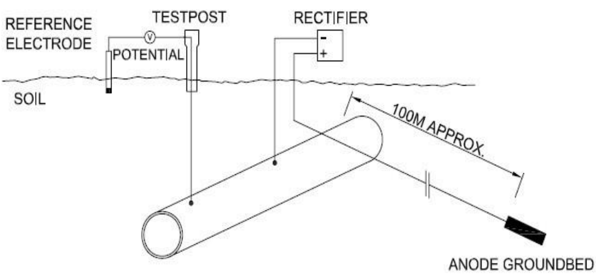

Figure 6. *Impressed-current installation.*

6.4 Design considerations

The cathodic protection engineer needs to consider certain prerequisites for the economic application of cathodic protection.

Electrical continuity

Each pipeline to be protected must be electrically continuous throughout its entire length. This is obviously achieved with welded joints but flexible couplings usually need some form of bonding. Advice should be sought as to the most efficient way of achieving this state for it is important that the cross-sectional area of the bond is compatible with the return current passing along the pipe. The actual method of bonding is a matter of preference but, as a generalisation, the low-temperature brazing technique is preferred provided that a competent operator who adheres strictly to the bonding specification applies it.

Route

Galvanic anode systems are usually used in built-up areas because of the danger of interference from impressed current systems (see below). Impressed current systems are, however, usually the most efficient for long-distance cross-country lines. On occasions, these lines may have a temporary galvanic anode system fitted at the time of laying to give protection until legal, land access, and electricity supply problems have been settled.

Special precautions are also required at sleeved or cased crossings in as much as the carrier pipeline must be isolated from the sleeve with the sleeve ends sealed against water ingress using special casing end seals and the carrier pipe in the sleeve fitted with insulating spacers. Sometimes the annulus is filled with inert gas or grout in order to inhibit the environment within the sleeve but specialist advice should be sought on this matter.

Sacrificial ribbon anodes may also be fitted within the sleeve annulus. Wherever possible sleeves should be avoided by the use of heavy wall pipe.

Electrical Isolation of structure

It is important that cathodic protection is considered at the design stage of the pipeline project. It may not be possible to apply cathodic protection efficiently or to guarantee an effective level unless current flow is controlled on the predetermined lengths. This is achieved by isolating the lengths to be protected using special prefabricated joints or carefully made-up insulating gasket assemblies (Figure 7). Much of the trouble resulting from the failure of cathodic protection installations to perform to design parameters has been a result of current loss through inefficient insulating joints or from un-insulated connections to the pipe. Current loss can also occur where instrumentation/telemetry cables/piping inadvertently short out an insulating joint or through valve chambers when control metering or earthing facilities do not always take into account the requirements of electrical isolation for cathodic-protection purposes. Current losses can also occur on reinforcing bars of concrete structures associated with pipelines such as buildings, reservoirs and chambers.

Again, the importance and siting of isolating facilities must be recognised.

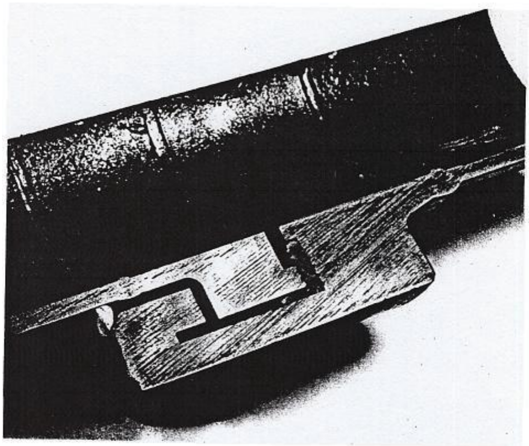

Figure 7. *Typical cross-section of insulating joint.*

Interference testing

The application of cathodic protection to any structure will cause an overall shift in natural ground potential which in turn can cause stray current corrosion in nearby buried structures. The degree of shift is a direct function of the applied current together with its location in the local network and size/number of coating defects and therefore is related to whether impressed-current or sacrificial techniques are used. Care has to be taken in siting anodes and (more particularly) impressed-current groundbeds in relation to the overall existing underground pipeline network. It is the responsibility of the installer of cathodic protection to notify all third parties and to prove that the applied current does not shift the existing foreign service potential more positive (i.e. anodic) than the criteria given in the national standards when the cathodic protection installations are energised at fully operational levels.

Consequently care has to be taken in the choice of cathodic protection system and the location of anodes/groundbeds, in order that the effects of interference are minimised. Fortunately, with the continuing improvements in pipe coatings the necessary current requirements for cathodic protection are being reduced and hence the problems related to interference are also diminishing.

Stainless Steels and Corrosion Resistant Alloys

Cathodic protection is normally applied to carbon steel pipelines with a high quality coating to reduce the amount of cathodic protection current required to meet the protective criteria. However, there are occasions when stainless steels and corrosion resistant alloys are used (because the internal environment is aggressive) and a question arises as to the need for protection. Depending on the environment and whether they are part of a mixed metal structure, stainless steel on its own may be sufficiently corrosion resistant not to require cathodic protection. Where they are part of a mixed metal structure they will normally be protected to the most onerous criteria. However, some corrosion resistant alloys are susceptible to hydrogen embrittlement if potentials become too cathodic. It is therefore essential that advice is sought from a cathodic protection specialist.

7. Backfill

Control and inspection of backfill material around a pipeline, and of the method of filling the trench with it, are important. If aggressive soil, and particularly that containing clinker or acidic chemicals, is excavated to lay the pipeline, it is prudent to consider removal and replacement by less contaminated material, such as washed sand or lime. For highly corrosive soils there are specially formulated backfills that may be worthwhile. Where cathodic protection is to be applied, these considerations become less important.

Where rocky soils are excavated the backfill should exclude the larger rocks which could damage the coating on the pipeline and even the pipe itself. A rough top layer of shielding tape can be used to protect against sharp shale or stones or if cathodic protection is to be applied a plastic mesh that does not interfere with the flow of protective cathodic current is more suitable.

Replacement of soils, particularly clays that have been excavated in a lumpy form possibly by mechanical digger buckets, should be avoided or carefully controlled to eliminate voids in the fill. Not only will natural shrinkage occur with subsequent trench settlement but also the lack of compaction will allow water collection in these voids and so increase the natural corrosion rate.

Special carbonaceous backfills are used around impressed current anodes and gypsum/bentonite/slaked lime around galvanic anodes to ensure good conductivity to enlarge the effective area of the anode and to reduce the self-corrosion of the anode.

8. Pre-stressed Concrete Pipe

Ferrous material forms an integral part of pre-stressed concrete pipe and even though the intimate pH conditions between concrete and metal are considered to be totally alkaline there are circumstances where corrosion has still occurred. Consequently techniques have been developed for the application of cathodic protection to this type of pipeline using primarily zinc anodes. The use of impressed current cathodic protection systems is not normally considered as excessive potentials may be generated that could cause hydrogen embrittlement problems on the pre-stressed steel. Whilst this method may appear to be expensive it should be related to the cost of the pre-stressed concrete pipe itself and the repair of any losses by leakage when it can be shown that the cost of installing a long-life anode (30 years +) is comparatively low and economically desirable.

9. Maintenance

Once a pipeline has been laid it should be inspected regularly to ensure that any protective precautions remain effective. Virtually all coat-and-wrap systems eventually degrade with age or can become damaged by new construction or repair nearby. These coatings can often be tested from the ground surface and without excavation by a number of specialised survey techniques on cross-country routes such as Pearson survey (an a.c voltage gradient survey), a.c. attenuation survey, close interval potential survey and d.c. voltage gradient survey.

With cathodic protection it is advisable that transformer rectifiers are inspected as regularly as convenient to ensure that they are operating correctly. Non-specialist staff can do this easily. Once the system has been correctly set up then comparatively little adjustment is required other than potential checks usually once or twice a year when carrying out a full corrosion-protection survey over the route. Test facilities are normally installed at approximately kilometer intervals at road crossings and at specific locations such as cased crossings, crossings of foreign metallic services, etc. along the pipeline route, or more often where sacrificial anodes are utilised.

Sacrificial anodes themselves are to a large extent self-regulating and consequently do not require much attention unless vandalism is a feature of the area. On average about 5% of marker/test posts become damaged annually and it is necessary for a more frequent check to be made in these locations. Otherwise a twice-yearly check (including sacrificial anodes) should suffice.

10. Checklist

The pipeline engineer and corrosion engineer should consider the following points when contemplating the design of a pipeline related to its lifelong operation with respect to the corrosion problem:

1. Decide pipeline material.
2. If ferrous, consider necessity for corrosion survey. Even if there is no previous leak history, there are new factors likely to arise (such as extra-high-tension power lines).
3. Analyse the corrosion survey. Is a special coating warranted? Life of the pipeline? Type of joint? Bonding? Coating/tape wrapping? Backfill precautions? Possibility of induced a.c. corrosion and electric shocks?
4. Is cathodic protection necessary? Localized (galvanic) or overall (impressed current)? Detailed design? Power supply? Additional way-leaves? Test-post locations?
5. Insulating joints/flanges Location? Type? Access for testing?
6. Inspection during construction. Of coating - holiday detection. Backfill. Damage to coating after backfilling. Coating defect survey. Construction of cathodic protection. Commissioning and interference testing.
7. Maintenance. Consider how easy it will be to repair sections. Is double-wrap worthwhile in sections? Access to sleeve ends? Specialist survey every 5-10 years to check coating integrity and effectiveness of cathodic protection system. If cathodically protected: Access to equipment? Own staff inspection? Specialist inspection? Maintain watching brief for new pipes/cables. Remote monitoring?

A pipeline that does not leak maintains good public relations and remains a constant revenue earner.

11. Standards

11.1 British/European Standards

BS EN 12501 parts 1 and 2, 2003	Protection of metallic materials against corrosion - Corrosion likelihood in soil
BS EN 12474:2001	Cathodic protection for submarine pipelines
BS EN 12495:2000	Cathodic protection for fixed steel offshore structures
BS EN 12499:2003	Internal cathodic protection of metallic structures
BS EN 12696:2000	Cathodic protection of steel in concrete
BS EN 12954:2001	Cathodic protection of buried or immersed metallic structures. General principles and application for pipelines.
BS EN 13173:2001	Cathodic protection for steel offshore floating structures
BS EN 13174:2001	Cathodic protection for harbour installations
BS EN 13509:2003	Cathodic protection measurement techniques
BS EN 13636:2004	Cathodic protection of buried metallic tanks and related piping
BS EN 14505:2005	Cathodic protection of complex structures
BS EN 15112:2006	External cathodic protection of well casing
BS EN 15257:2006	Cathodic protection. Competence levels and certification of cathodic protection personnel
DD CEN/TS 14038-1:2004	Electrochemical realkalization and chloride extraction treatments for reinforced concrete. Realkalisation.
DD CEN/TS 14038-2:2011	Electrochemical re-alkalization and chloride extraction treatments for reinforced concrete. Chloride extraction.
DD CEN/TS 15280:2006	Evaluation of a.c. corrosion likelihood of buried pipelines. Application to cathodically protected pipelines.
BS EN 50162 : 2005	Protection against stray currents from direct current systems.

BS 7430:1998	Code of practice for earthing.
BS 7671:2008	Requirements for electrical installations. IEE Wiring Regulations. Seventeenth edition.
ISO 15589-1:2003	Petroleum and natural gas industries - Cathodic protection of pipeline transportation systems - Part 1: On-land pipelines.
ISO 15589-2:2004	Petroleum and natural gas industries - Cathodic protection of pipeline transportation systems - Part 2: Offshore pipelines.

12. References

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‘Control of Pipeline Corrosion’, A.W. Peabody (2nd edition, Ed. R. Bianchetti), NACE International, Houston, 2000.

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‘Handbook of Cathodic Corrosion Protection', W.V. Baeckmann (3rd edition), Gulf Publishing Company, 1997, ISBN 0 88415-056-9.

‘NACE Corrosion Engineer’s Reference Book’, 2nd edition, ed. R.S. Treseder, R. Baboian, C.G. Munger, NACE, Houston, 1991, ISBN 0 915567 82 2.

‘Corrosion’, 3rd revised edition, ed. L.L. Schreir, revised by R.A. Jarman and G.T. Burstein, 2 vols, Butterworth-Heinemann, 1994, ISBN 0 7506 1077 8.

NPL Guides to Good Practice in Corrosion Control (www.npl.co.uk/ncs)

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