Cathodic & Anodic protection

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Cathodic protection

Definition

Cathodic protection (CP) is a technique used to control the corrosion of metal surfaces by making them the cathode of an electrochemical cell. It is commonly used for protecting pipelines, tanks, and other metal structures exposed to corrosive environments .

Advantages :

1. Effective in Aggressive Environments: Anodic protection is particularly useful in environments where traditional corrosion protection methods (such as coatings) fail, such as in highly acidic solutions (e.g., in chemical processing or desalination plants).

2. Long-term Corrosion Protection: The technique helps to prevent the electrochemical reactions that lead to corrosion, providing long-term protection for metals like stainless steel, titanium, and other alloys.

3. Versatility:Cathodic protection can be used for a wide range of metal structures such as pipelines, storage tanks, ship hulls, and offshore platforms.

4. Cost-Effective Over Time:While the initial installation of CP systems can be costly, the long-term savings from avoiding corrosion-related damage, repair costs, and replacements can be substantial.

5. Low Maintenance:Once the CP system is installed and properly calibrated, it requires relatively little maintenance compared to other corrosion protection methods.

6. Adaptability:CP systems can be adapted to different environments (such as soil, water, or atmospheric conditions), and can be used on both new and existing structures.

Disadvantages

1. High Initial Installation Costs:Setting up a cathodic protection system can be expensive, especially when high-quality materials and sophisticated monitoring systems are required.

2. Requires Regular Monitoring and Maintenance:While CP systems are low-maintenance, they still need periodic inspections, monitoring, and potential adjustments to ensure effectiveness.

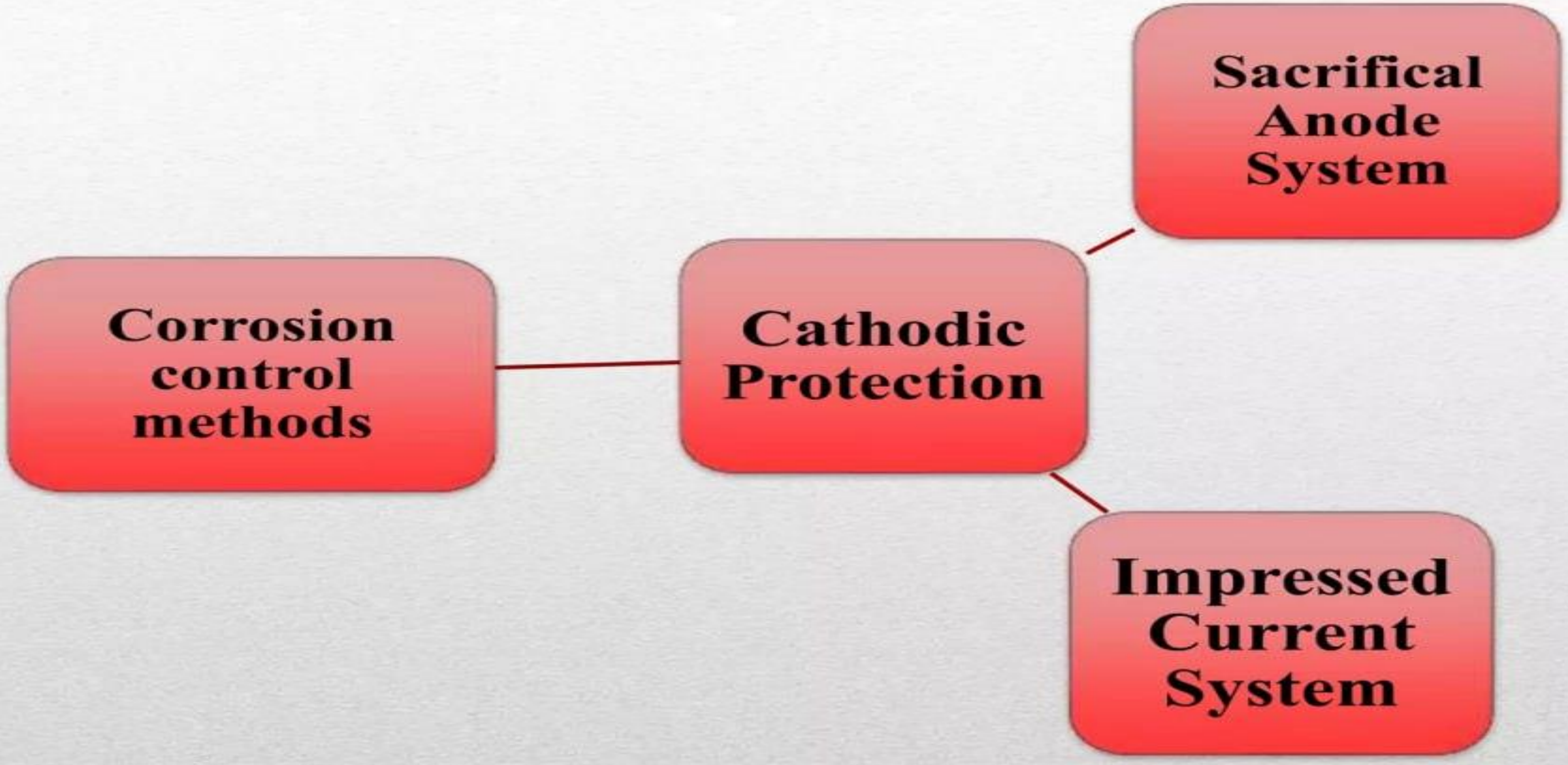
3. Potential for Overprotection:If not properly designed or maintained, CP can cause overprotection, leading to the formation of hydrogen gas on the metal surface, which can result in embrittlement or other issues.

4. Power Source Dependency:In the case of impressed current cathodic protection (ICCP), a reliable power source is necessary, which can be a limitation in certain remote locations or during power failures

5. Limited to Certain Metals:CP is primarily effective on ferrous metals like steel. Non-ferrous materials like aluminum or copper may not benefit from cathodic protection in the same way.

6. Complex Design and Installation:Designing and installing a CP system requires specialized knowledge and expertise, which could make the process complicated and prone to errors if not properly executed.

Overall, cathodic protection is a proven and reliable method for corrosion prevention, but it comes with costs, maintenance requirements, and technical complexities that must be considered
The effectiveness of cathodic protection depends on factors such as the type of metal being protected, the electrolyte composition (e.g., seawater, soil), and the specific design of the protection system


Corrosion control methods
Cathodic Protection
Sacrifical Anode System
Impressed Current System

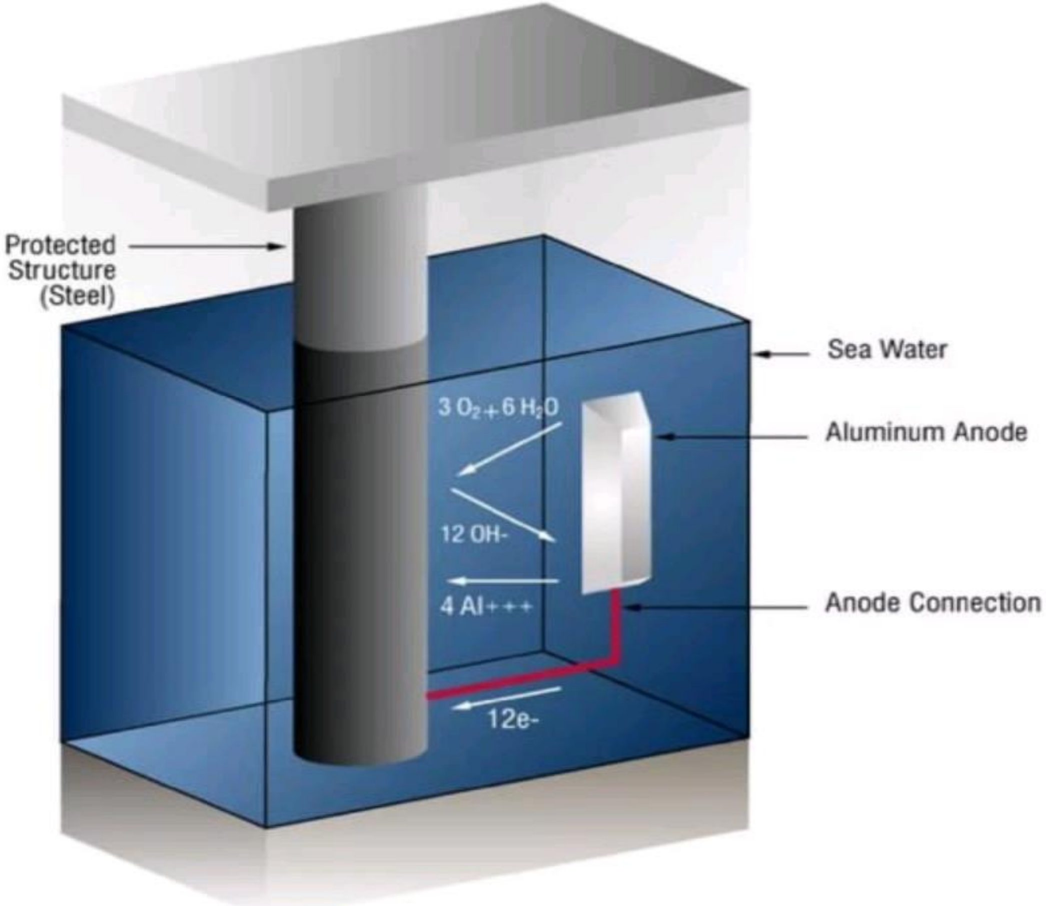
Methods

Mechanism of Cathodic Protection

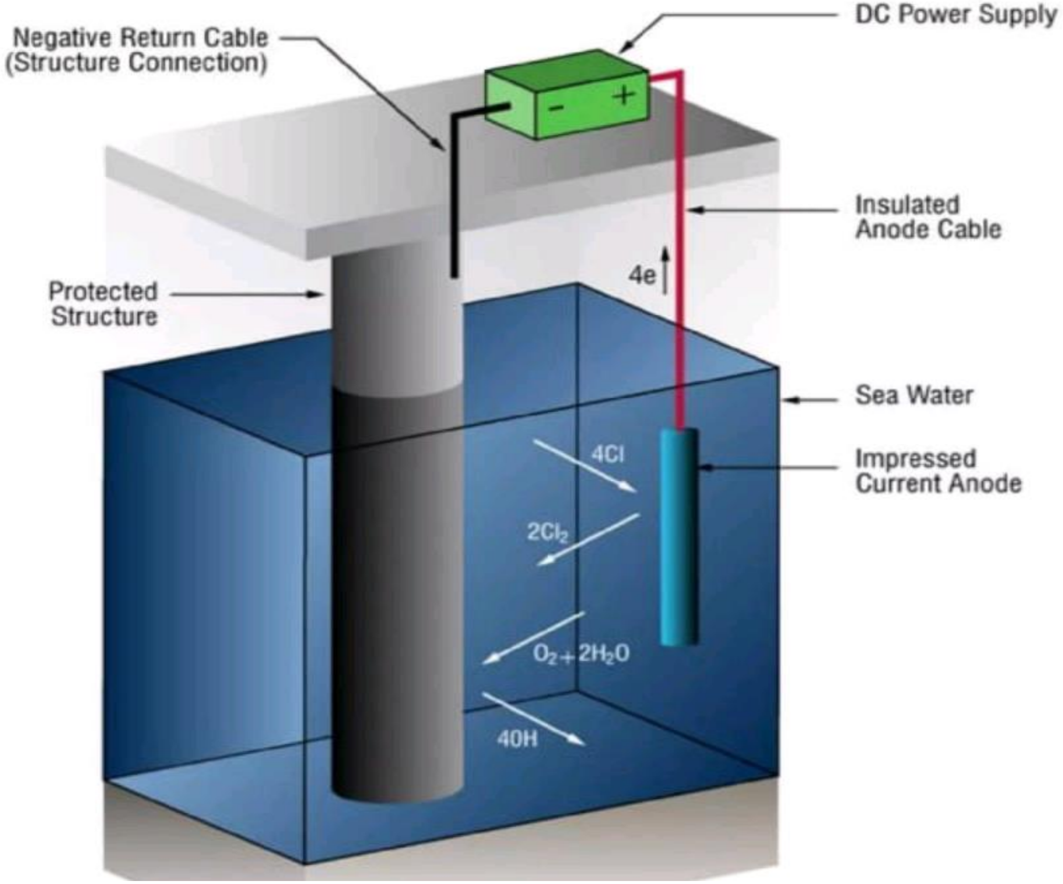
1- **Impressed Current Cathodic Protection (ICCP)**: In this method, an external power source (usually a DC current) is used to provide a flow of electrons to the metal structure (cathode). This current is supplied through an inert anode, which creates a protective environment for the metal.
The metal surface becomes the cathode, preventing the metal from losing electrons and therefore from corroding.

2- **Sacrificial Anode Cathodic Protection:** This method uses a more easily corroded metal (anode), such as zinc or magnesium, which is electrically connected to the metal structure being protected. The sacrificial anode corrodes instead of the protected metal.
The sacrificial anode supplies electrons to the metal structure, preventing it from corroding.

Sacrificial anode system in seawater



Impressed-current cathodic-protection system in seawater



Sacrificial Anode Materials

- **Zinc Alloy** (C-Sentry)
  Sea water, low resistivity soil
- **Aluminium Alloy** (Galvalum I, Galvalam II, Galvalum III, Alanode)
  Sea water
- **Magnesium Alloy** (Galvomag)
  soil

Impressed Current Anode Materials

- Platinum and platinised metals
- High silicon iron
- Lead-platinum
- Lead-silver
- Graphite
- Iron
- Cast iron

Applications of impressed current method

- it is useful for large structures
- Applied to open water box coolers
- Water tanks
- Buried water and oil pipelines
- Condensers
- Transmission line towers.

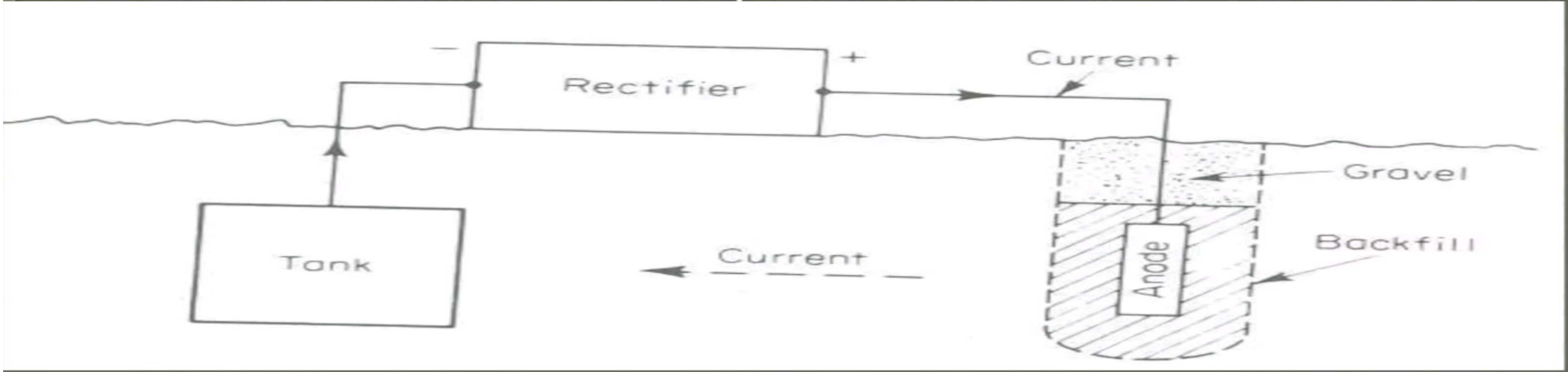
Applications of anodic protection

- Applicable in extremely corrosive environments.
- Low current requirement.
- Acid coolers in dilute sulphuric acid plants.
- Storage tanks for sulphuric tanks
- Chromium in contact with hydrofluoric acid.

For example

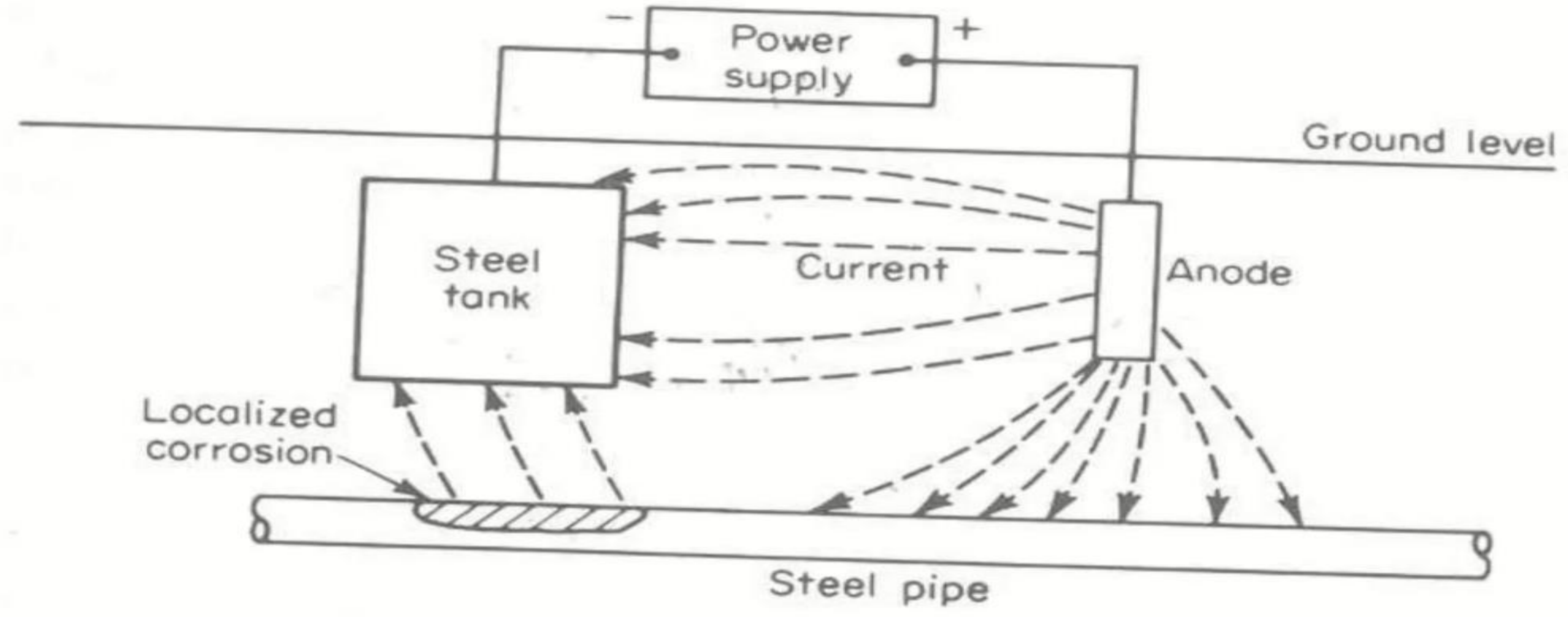
Impressed current cathodic protection method

- The sufficient D.C current is given to underground tank.
- The negative terminal is connected to tank.
- And the positive terminal is connected to inert anode.
- When the power supply is ON, it converts corroding metal from anode to cathode.
- Hence the corrosion can be prevented.



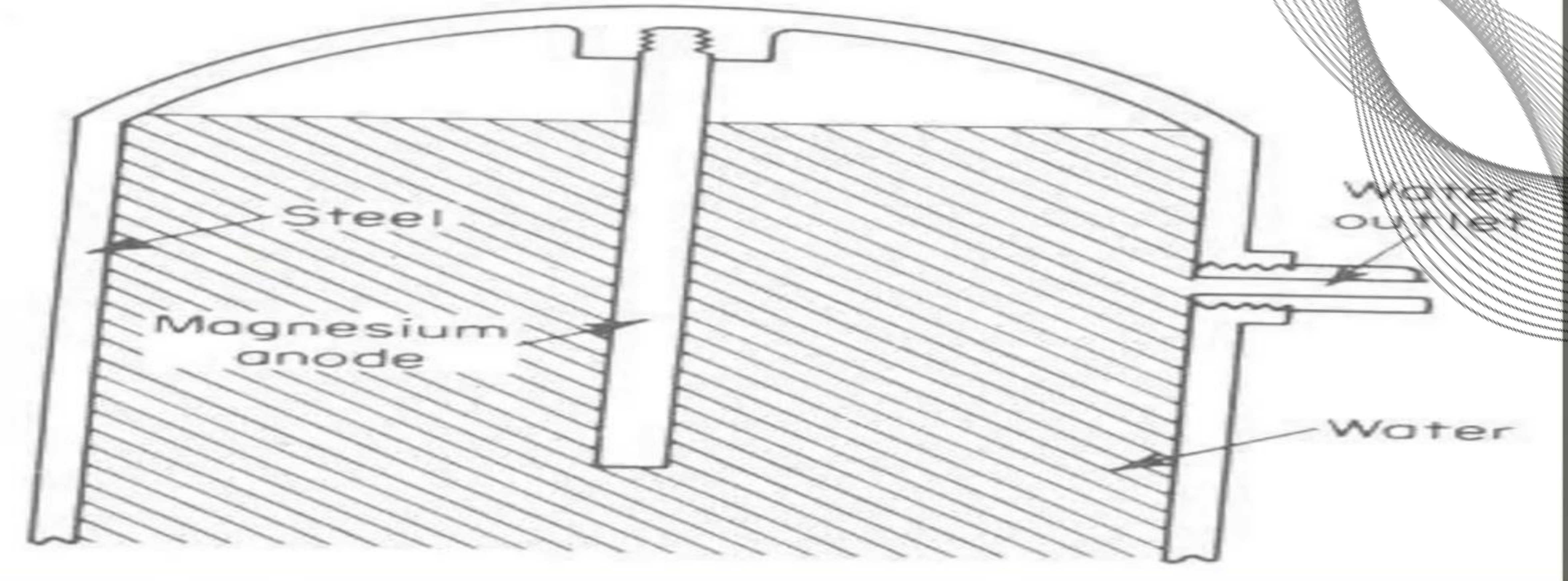
Cathodic protection of an underground tank using impressed currents

Second example



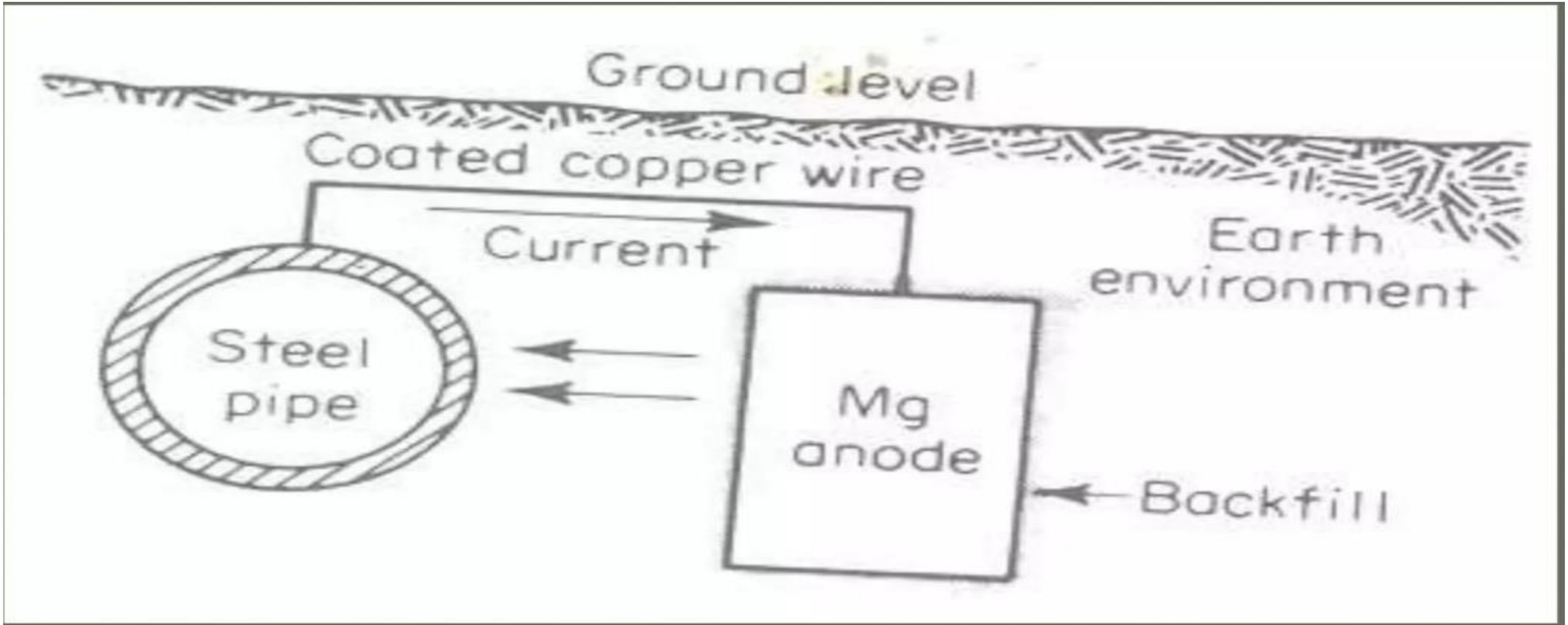
Stray currents resulting from cathodic protection

Example for sacrificial anod



Cathodic protection of a domestic hot water tank using a sacrificial anode.

Second example



Protection of underground pipeline with a magnesium anode

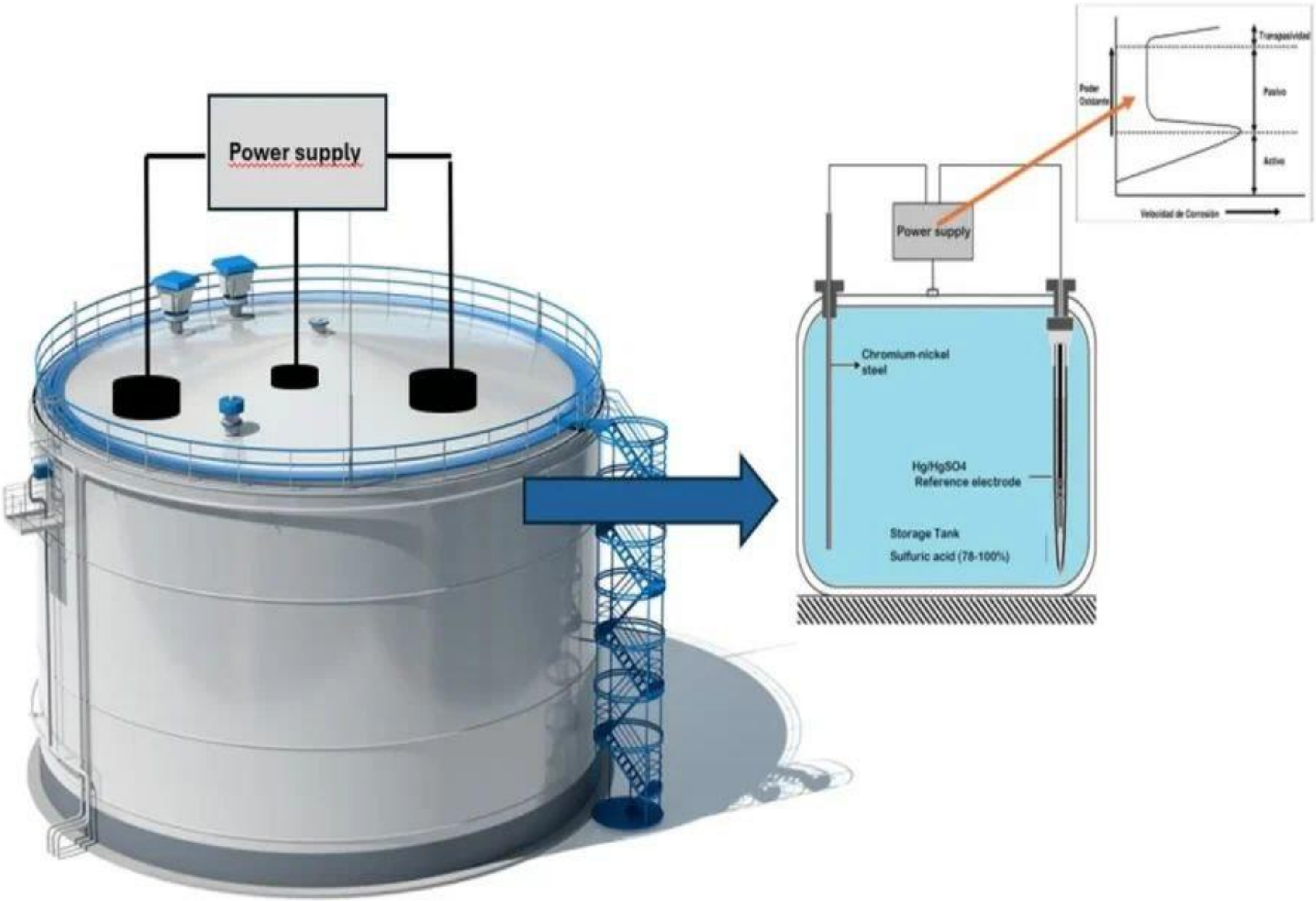
3.4.3 Comparison of sacrificial anode method with impressed current cathodic method

Table 3.1

No.	Sacrificial anode method	Impressed current method
1.	External power supply is not required.	External power supply is required.
2.	Investment is low.	Investment is high.
3.	This requires periodic replacement of sacrificial anode.	Replacement is not required as anodes are stable.
4.	Soil and microbiological corrosion effects are not considered.	Soil and microbiological corrosion effects are taken into account.
5.	This is the most economical method especially when short term protection is required.	This is well suited for large structures and long term operation.
6.	This is a suitable method when the current requirement and the resistivity of the electrolytes are relatively low.	This is a suitable method even when the current requirement and the resistivity of the electrolytes are high.

In summary, cathodic protection prevents corrosion by either supplying electrons to the metal (in ICCP) or by using a sacrificial anode to corrode instead of the protected metal

Aodic Protection



Definition

Anodic protection is another electrochemical method used to prevent corrosion, but unlike cathodic protection, it works by making the metal surface an anode rather than a cathode in the electrochemical cell. This technique is particularly used for metals or alloys that tend to passivate, such as stainless steel, in environments where they are susceptible to localized corrosion.

Advantages

1. Effective in Aggressive Environments: Anodic protection is particularly useful in environments where traditional corrosion protection methods (such as coatings) fail, such as in highly acidic solutions (e.g., in chemical processing or desalination plants).

2. Long-term Corrosion Protection: The technique helps to prevent the electrochemical reactions that lead to corrosion, providing long-term protection for metals like stainless steel, titanium, and other alloys.

3. Lower Maintenance Costs: Once installed, anodic protection systems are relatively low-maintenance compared to alternative solutions such as cathodic protection or coatings that may degrade over time.

4. Minimal Material Use: Anodic protection does not require the application of coatings or sacrificial anodes, which means less material consumption compared to other protection methods.

5. Energy Efficiency: The process typically requires only a small amount of electrical current, making it relatively energy-efficient compared to more aggressive methods like cathodic protection.

6. Protects Large Metal Surfaces: It is effective in protecting large metal structures, such as pipelines, tanks, and heat exchangers, from corrosion.

Disadvantages

1. Requires Power Supply: Anodic protection relies on an external power supply to maintain the protective voltage, which can lead to higher operational costs and dependency on power sources. Power failure can compromise the system.

2. Limited to Certain Materials: It is most effective on materials that can form a stable passive oxide layer, such as stainless steel or titanium. It may not be suitable for all metals, particularly those that do not readily form protective oxide films.

3. Risk of Overpotentiaion: If the applied voltage is too high, it can cause the metal to become overactive, leading to increased corrosion instead of protection.

4. Complex System Setup: The installation and operation of anodic protection systems require specialized equipment, including reference electrodes, power sources, and monitoring systems, making it a more complex solution to implement

5. Initial Installation Costs: The initial setup of anodic protection systems can be expensive due to the need for power supplies, control systems, and ongoing monitoring.

6. Potential for Uneven Protection: In some cases, achieving uniform protection across a large metal surface can be difficult, potentially leaving certain areas vulnerable to corrosion

In summary, anodic protection is an effective technique for controlling corrosion, especially in aggressive chemical environments, but it requires careful management and is not suitable for all metals or all applications

Mechanism of Anodic Protection

Electrochemical Corrosion Process

Normally, metal corrodes through an electrochemical reaction where the metal at the anode loses electrons, which causes it to deteriorate, while the cathode gains electrons.

Anodic protection works by intentionally making the metal the anode in a controlled electrochemical cell, but under conditions that prevent further corrosion.

Anodic Protection Mechanism:

Formation of a Passivation Layer: For materials like stainless steel, the metal forms a protective oxide layer (passive film) when exposed to certain environmental conditions (e.g., presence of oxygen or a specific pH). This oxide layer acts as a barrier that prevents further corrosion of the material.

Applied Potential: In anodic protection, a controlled positive electrical potential is applied to the metal structure (making it the anode) relative to a reference electrode. This causes the metal to remain in a passive state, preventing it from undergoing active corrosion.

The applied potential enhances the formation of the protective oxide layer on the metal surface. This layer typically consists of compounds such as chromium oxide in stainless steel.

Protective Role of Passivation: The key is that, under the applied anodic potential, the metal's oxidation leads to a stable, protective layer (such as chromium oxide for stainless steel) that reduces the further interaction of the metal with the electrolyte, thus preventing localized corrosion (like pitting or crevice corrosion).

Advantages: Anodic protection is especially useful for materials that have a tendency to form stable passive films when exposed to certain environmental conditions (e.g., stainless steel in acid or chloride-rich environments).
It can provide long-term protection for metals in aggressive environments where traditional coatings or inhibitors might fail.

Limitations Anodic protection is generally limited to metals that form a stable passive film at higher potentials, like stainless steel, titanium, or aluminum.

The method requires careful control of the applied potential, as excessive voltage could break down the passive layer, causing the metal to corrode instead of being protected.

Chemical Reactions Involved

At the Anode (the metal surface):The metal undergoes controlled oxidation, forming a protective oxide layer (e.g., or on steel).

At the Cathode (the surrounding electrolyte):Oxygen reduction typically occurs at the cathode, producing hydroxide ions (OH^-) in the surrounding solution.

Summary:

In anodic protection, a controlled positive potential is applied to the metal, which encourages the formation of a protective passive layer on its surfac

Application of anodic protection

Storage Tanks: Anodic protection can be used for storage tanks and pipelines that contain acidic or aggressive chemicals.

Heat Exchangers: Stainless steel heat exchangers used in the chemical or pharmaceutical industry can benefit from anodic protection to avoid scaling and corrosion in acidic process fluids.

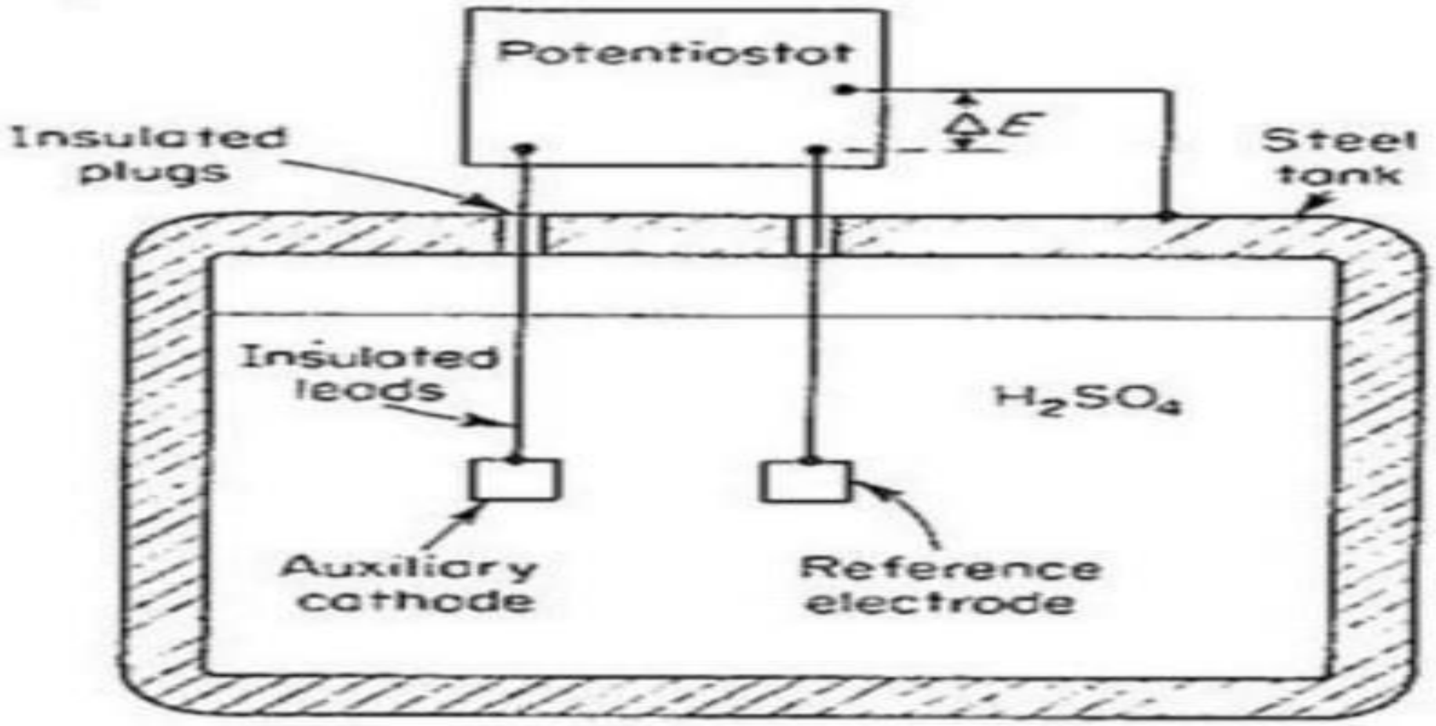


Fig: Anodic Protection of a steel storage tank containing Sulfuric acid.

1. The potentiostat has three terminals one connected to the tank, another to an auxiliary cathode (a platinum clad electrode)and the third to a reference electrode.

2. In operation, the potentiostat maintain a constant potential between the tank and the reference electrode.

3. The optimum potential for protection is determined by electrochemical measurements.

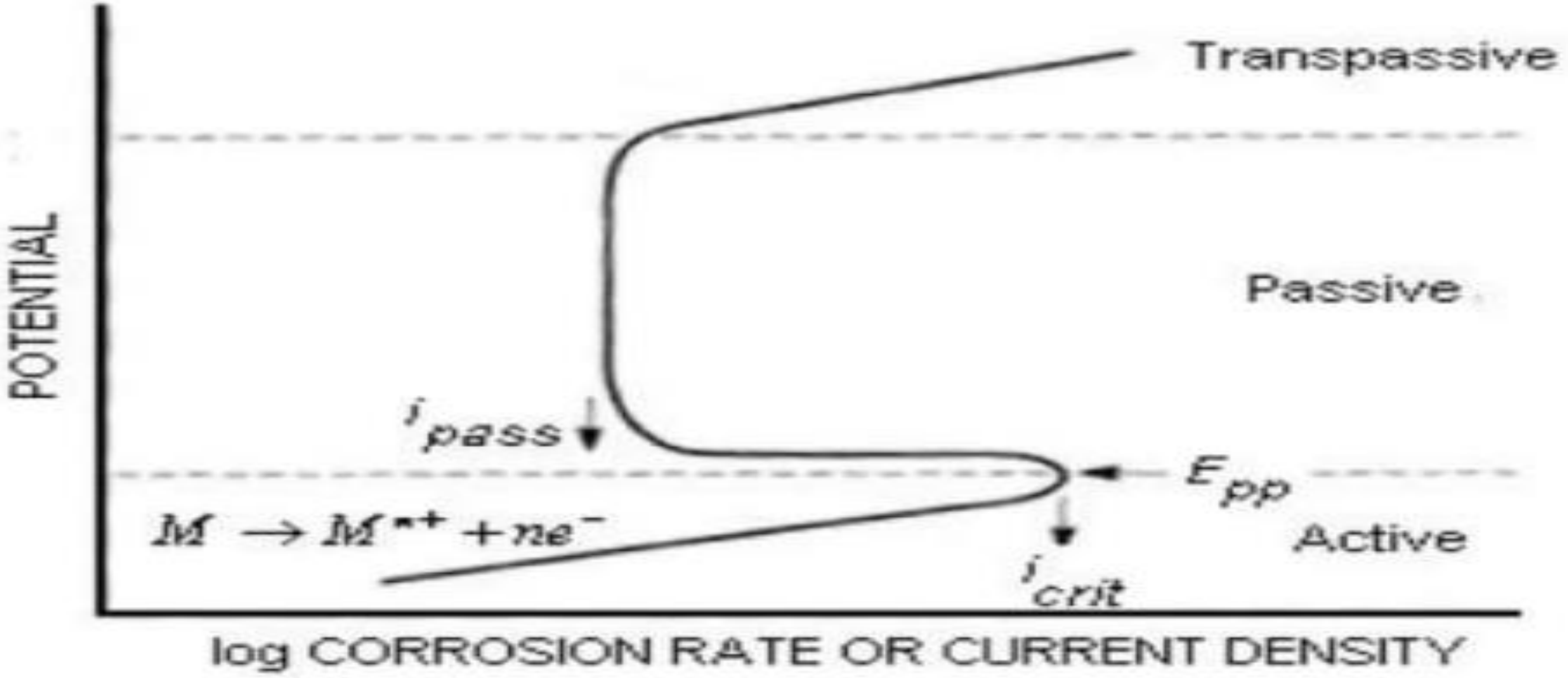


Fig: Polarization curves depicting principles of anodic protection

If an active-passive alloy such as stainless steel is maintained in the passive region through an applied potential (or current) from a potentiostat, its initial corrosion rate (i_{corr}) can be shifted to a low value at i_{pass} as shown in this Figure.

Applied anodic current density = oxidation current density – reduction current density.

3.5.1 Comparison of cathodic protection with anodic protection

Table 3.2

No.	Cathodic Protection	No.	Anodic Protection
1.	Applicable to all metals.	1.	Applicable to only those metals which show active passive behaviour.
2.	Used where there is no source of power by employing sacrificial anodes.	2.	More aggressive corrodents can be handled.
3.	Lower installation costs.	3.	Operating costs are lower although installation costs are higher.
4.	Standard and well established method.	4.	Feasibility can be predicted in laboratory and the design is easier.

THANKS