CATHODIC PROTECTION IN THE OIL INDUSTRY

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ABSTRACT

Corrosion can be separated into four parts, 1) an anodic site, 2) a cathodic site, 3) an electrolyte and, 2) a metallic path. Corrosion can be minimized by eliminating or controlling any one of these four components.

Cathodic protection (CP) works by controlling the anodic and cathodic sites in a corrosion cell. This is accomplished by creating an anode separate from the equipment being protected. The anode can be either a more active metal or a material induced with an outside source of direct current. Cathodic protection has been used successfully to protect buried piping, storage tanks, production separators, well casings, offshore platforms, etc.

This paper is an overview of cathodic protection in the oilfield and presents basic information on the design and maintenance of CP systems.

INTRODUCTION

Sir Humprey Davy, English Navy, is generally given credit for the first application of cathodic protection when, in 1824, he attached zinc plates as sacrificial anodes to the hulls of British naval vessels to protect the copper sheathing. The cathodic protection design worked well enough; however, corrosion products from the copper were no longer present to poison the marine growth which became such a serious problem the zinc anodes had to be removed. For many years we have protected corrugated steel sheathing by galvanizing with a coating of zinc. Cathodic protection in the form of magnesium anodes or impressed current systems for buried pipelines came into full use in the 1950s. Today cathodic protection is considered alongside coatings and metallurgy as a method of corrosion control.

THE CORROSION CELL

A description of the corrosion cell will provide the foundation for understanding cathodic protection. Most corrosion occurs in cells too small to see, that is at or near the grain size of the corroding metal. Figure 1 shows a corrosion cell on the surface of a piece of metal. The electrolyte is the moisture on the metal, the metallic path is the metal itself and the anodes and cathodes can be as small as the grains in the metal. Two chemical reactions are taking place in the cell. At the anode, the metal is reacting with the OH^- ions and becoming rust and leaving electrons in the metal. At the cathode, these electrons are combining with H^+ ions to become hydrogen gas.

The reaction at the anode will proceed faster, for a time, than the reaction at the cathode causing a buildup of electrons in the metal; therefore giving it a negative charge (or potential) relative to the electrolyte. As the negative charge builds up, the reaction at the anode slows to the same rate as the one at the cathode and is maintained at a steady state voltage dependent on the activity of the metal. These negative charges are listed on the galvanic chart as voltages in Figure 2 in the order of their potentials. The reaction at the anode will only take place if the potential of the metal is less than or equal to the potential given in the chart. If the potential is made more negative, the reaction at the anode cannot continue.

Making the metal more negative than its steady state potential (also called its freely corroding potential) is the essence of cathodic protection. The criteria for cathodic protection of steel is maintaining a potential of -0.85 volts relative to the electrolyte as measured by a copper/copper sulfate half cell. Two methods of accomplishing this are sacrificial anodes and impressed current.

Figure 3 is a drawing of a corrosion cell containing a sacrificial anode. For this cell to work, there must be metals with different steady state potentials. The anode and cathode metals are determined by their position on the galvanic chart (Figure 2). The metal producing the more negative voltage will be the anode in that cell. As an example, shiny steel with a voltage of -0.8 will be cathodic to magnesium with a voltage of -1.6. As the anode corrodes, there is a flow of electrons from the anode to the cathode. The circuit is completed with an ionic current flowing through the electrolyte from the anode to the cathode. As the magnesium corrodes and produces a voltage potential of -1.6 volt, and being connected to the steel by the wire, the potential of the steel is also -1.6 volts. Because this is more negative than the -0.8 volts that would be generated by the steel, the steel has become cathodic in its entirety and no reaction (corrosion) can take place on the steel.

Now that the anodic reaction has been stopped on the steel, the cathodic reaction must be addressed. The reaction on the surface of the cathode will deplete the electrons in the steel. This loss of electrons will cause the potential to become less negative and if not replaced will result in the steel no longer being entirely cathodic. The rate at which this reaction takes place is a function of the concentration of the H^+ ion in the electrolyte and the area of exposed metal to the electrolyte. A constant flow of electrons (current) will be required from the anode to replace any electrons used in the reaction at the cathode.

One of the restrictions of sacrificial anodes is the relatively small potential differences between the anode and the cathode (-1.1 volts for magnesium and steel). This limits the distance or "throw" of protection because of the resistance of the electrolyte. A solution to this problem is to employ a system using an outside power source i.e., impressed current. With an impressed current system (Figure 5), a rectifier supplies the power instead of depleting a sacrificial anode. The anode material of choice, for impressed current systems, is one that can supply a surface to drain current into the electrolyte without depleting. Graphite has been able to economically function as anodes for most impressed groundbeds. Other anodes have been constructed of high silicon iron, lead-silver alloys, and mixed metal oxides. The electrolyte (soil or water) resistances can be overcome with rectifier output voltages as high as 20 to 30 volts. Associated currents can also be as high as 100 amps or more.

Typical current requirements for steel structures in more common services are shown in Figure 4. The current required to protect a structure is based on the area of exposed metal. A good coating will decrease the current requirement since only the exposed areas i.e., holidays, need CP. With a good quality coating, less than 5% of the structure is considered uncoated; therefore, the best system to prevent corrosion is to combine CP with a good coating.

APPLICATIONS

Pipelines

More power (impressed and sacrificial) for cathodic protection is used to protect pipelines than any other structure. Usually a pipeline is protected with CP in one of the following three methods; 1) impressed current in its entirety, 2) sacrificially in its entirety, or 3) sacrificially at "hot spots" only. Hot spots are anodic areas along pipelines that are caused by differences in soil conditions. Impressed systems are best for long (several miles) coated pipelines. Sacrificial anodes can be used for short coated or bare lines. Longer bare lines tend to be best suited for hot spot protection, by installing the anodes only at the anodic areas. Examples of these systems are shown in Figure 6.

The design of CP systems for pipelines can be very complex. The basic current density requirement for pipelines is 1 to 3 milliamps per square foot of bare pipe. It is customary to assume that a coated pipeline is 2 to 5% bare. However, because pipelines are installed through changing soil conditions (measured as soil resistivities), this current density requirement will not be uniform along the length of the pipeline. Also, soil resistivities will influence decisions to install a conventional impressed current groundbed, a deep groundbed or to use one of the sacrificial systems. Many times, a contractor familiar with the area can provide the most economical solution.

A monitoring program must be in place to insure that the system is providing the protection that it was designed to do. Impressed current systems should have voltage, current and general condition of the rectifier checked at least bimonthly. Also, certain key locations should be selected for bimonthly pipe-to-soil potentials. These key locations would be at the rectifiers, road crossings, foreign pipeline crossings (especially if an interference bond has been installed), and known spots of low potential voltages. Pipe-to-soil potential surveys of the entire pipeline should be conducted annually. A pipe-to-soil potential measurement is made possible by attaching a wire to the pipe (during construction) and bringing it to the surface at a test station. The potential, in volts, is measured, with a dc voltmeter, between the wire and a copper/copper sulfate reference cell placed on the ground directly over the pipe. More information on pipeline CP can be found in Control of Pipeline Corrosion by A. W. Peabody, a NACE (National Association of Corrosion Engineers) publication.

Tanks

The inside of tanks can be protected by using either sacrificial or impressed current anodes. Sacrificial anodes can be attached either to the inside of the tank or suspended through holes in the top. To provide a convenient ground level monitoring point, bring the connecting wires down the side of the tank to shunts (Figure 7). This can be important for tanks containing H_2S. Impressed current systems are constructed by suspending high silicon iron rod anodes from the roof of the tank with the rectifier installed on the ground next to the tank. Anodes attached to the insides of the tank must be designed to last until an internal inspection is done. It is important that the anodes should be placed in the water (the electrolyte) containing portion of the tank. Figure 9 shows some typical anode shapes.

The bottoms of tanks, that have been installed on dirt or sand without a protective barrier, can be protected with CP using either sacrificial or impressed systems similar to those in Figure 8. The bottoms of tanks installed on gravel generally stay so dry that CP will not function. This same dryness also means little corrosion will take place. The use of a protective barrier, such as plastic or kraft (tar) paper, blocks any protective CP currents.

Pressure Vessels

Pressure vessels are usually protected with anodes that attach to the inside of the vessel or penetrate through the wall. "Through the wall" anodes are similar to the "redheads" or "blueheads" (redheads are designed for ANSI schedule 40 piping while blueheads are for ANSI schedule 80)[2]. These are long rods with Victaulic™ type couplings. These same anodes also come with a flange fitting. Figure 10 shows a typical vessel with anode placements.

Designing CP systems for vessels must take into account what kind of internals are present. Fixtures such as baffles will prevent any CP currents from reaching the surface opposite the anode. Figure 11 illustrates that anodes protect by line of sight, i.e., only what they can "see".

Monitoring a CP system on a vessel is very much like those on tanks. Internally attached anodes must be designed to last until the next internal inspection. Anodes placed through the wall should have shunts in the wire between the anode and vessel to permit monitoring the current output. If there is no shunt the current may be measured with a DC amprobe.

Trouble shooting techniques for anodes in tanks and vessels:

- No amperage readings -
  1. Make sure the anode cables are firmly attached to the anodes and the vessel or tank.
  2. Measure the resistance between the anode lead and the vessel with the anode cable disconnected. If the resistance is zero the anode is shorted to the vessel. This condition, while it prevents taking amperage measurements, does not indicate a nonfunctioning anode. The short is most likely in the isolation material at the flange or union and should be repaired at the next shut down.

- Low amperage measurements -
  1. Can be expected with good internal coatings.
  2. If the amperage measurements are lower than previous measurements, the anode may be near the end of its life. Check records for design life of system.
  3. Check water level. Water should completely cover anodes.

- High amperage measurements -
  1. Can be expected with uncoated tanks and vessels.
  2. Check internal coating at next shut down. A deteriorating coating increases the surface area exposed to the anodes, thus increasing the amperage needed for protection.

- Cycling amperage measurements -
  1. Can be caused by cycling water levels or fluid turbulences. With these conditions, cycling amperages measurements are, in fact, an indication of a properly operating anode.

Well Casings

Determining the need for CP on well casings can be extremely difficult. Often the first indication of a need is an escalation in the rate of externally caused casing failures. A plot of cumulative well failures vs. time on semilog paper may indicate what to expect in the future in the way of failures for a given field of wells. Checking the completion records to determine the extent of cementing can identify where casing corrosion will occur. Cement provides the best protection against casing corrosion. If the wells were not fully cemented, CP is designed to protect that portion not cemented. Casing potential profile logs will reveal where the anodic areas are located on the casing and how much current is needed to remove those anodic areas. Figure 12 shows such a curve and the results of applying CP.These logs can cost from $5,000 to $10,000 and only a few logs per field are necessary to get an indication of general anodic areas of all the wells. For single remote wells it may be more prudent just to install the CP as to pay for a CPP log. Finally, whenever CP is considered for well casings in a field, It must be applied to all the wells in that field to prevent interferences between protected and unprotected well casings.

Monitoring a CP system on well casings is much the same as for pipelines for the rectifiers and groundbeds. The casing-to-soil potential measurements on each well should be taken annually. Because this measurement is taken at the surface to determine the condition of the system many feet underground, a minimum potential of -0.95 volts, as measured with the reference cell placed 50 feet from the wellhead, is used as a "cushion" for any areas on the casing that might be less negative.

CONCLUSION

One thing common to all these applications is that for steel, maintaining a potential of -0.85 to -1.50 volts (pipe-to-soil, water-to-tank, casing-to-soil, etc.) as measured with a copper/copper sulfate reference cell will provide protection from corrosion.

Proper design, installation, and monitoring of cathodic protection systems have proven to be a cost effective method of corrosion control.

REFERENCES

1. Peabody, A. W.: Control of Pipeline Corrosion 1967, page 5
2. Redheads and Blueheads are Cathodic Protection Services' nomenclature.

ACKNOWLEDGEMENTS

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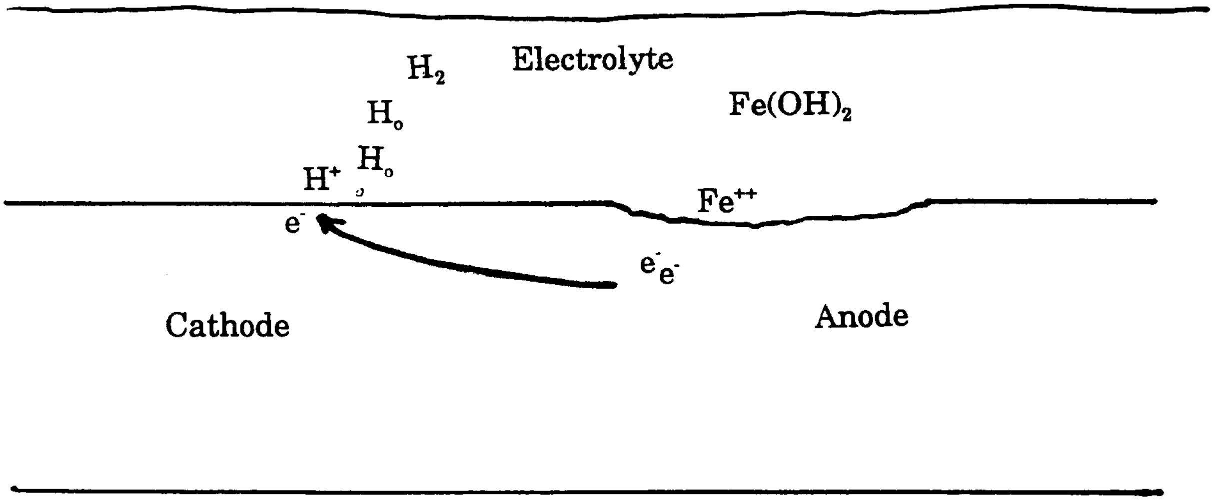


Figure 1 - The corrosion cell

METAL	VOLTS*
Commercially pure magnesium	-1.75
Magnesium alloy (6% Al, 3%Zn, 0.15%Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% zinc)	-1.05
Commercially pure aluminum	-0.8
Mild steel (clean and shiny)	-0.5 to -0.8
Mild steel (rusted)	-0.2 to -0.5
Cast iron (not graphitized)	-0.5
Lead	-0.5
Mild steel in concrete	-0.2
Copper, brass, bronze	-0.2
High silicon cast iron	-0.2
Mill scale on steel	-0.2
Carbon, graphite, coke	+0.3

* Typical potential normally observed in neutral soils and water, measured with respect to copper sulfate reference electrode.

Figure 2(1) - Potential voltages of selected materials

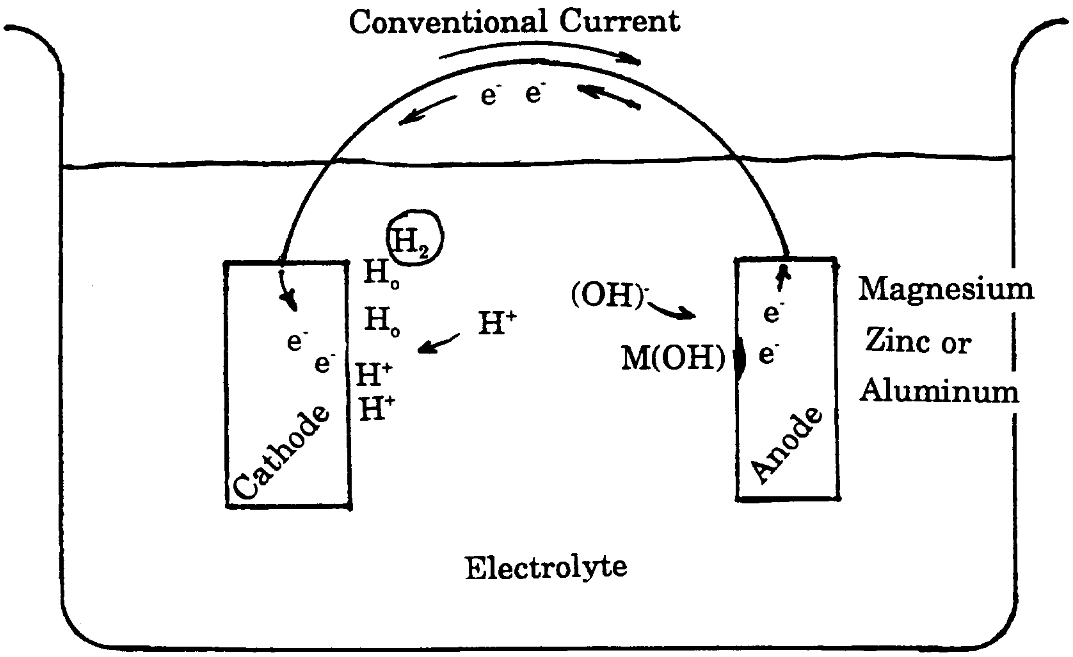


Figure 3 - Corrosion cell with a sacrificial anode

ASSUMED CURRENT DENSITY REQUIREMENTS

APPLICATION	I_D (mA/SQ FT)
• Process Vessels/Tanks	
Produced Water	10
Fresh Water	3
(Assume 10% of coated surfaces to be bare)	
• Onshore Pipelines	1 - 3
(Assume 2% of coated surfaces to be bare)	
• Well Casings	
Cemented	0.25
Non-cemented	0.75

Figure 4

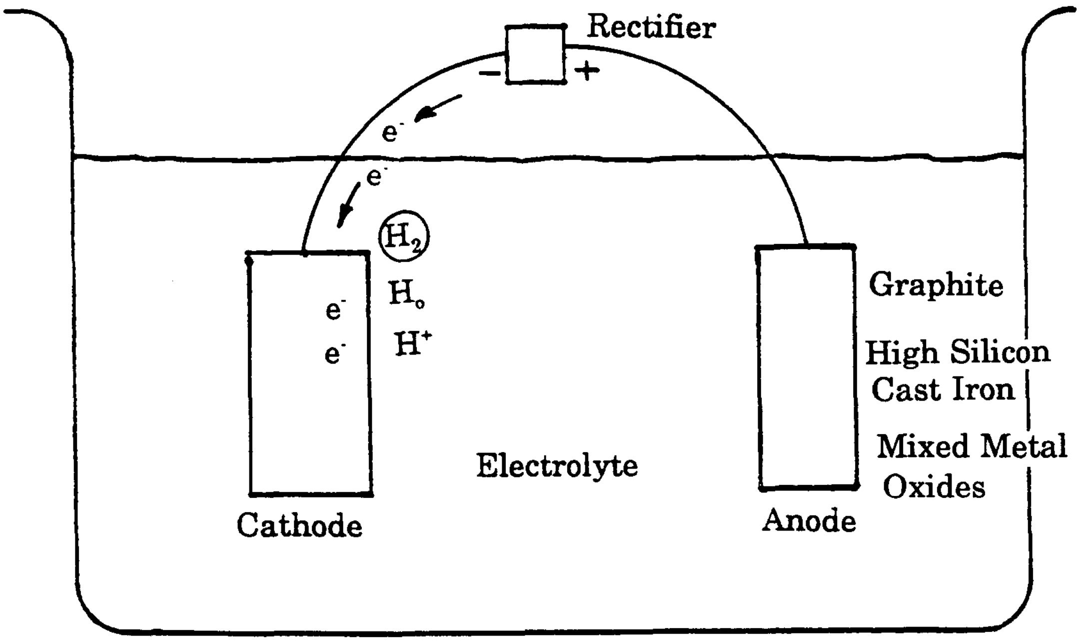


Figure 5 - Corrosion cell with impressed current

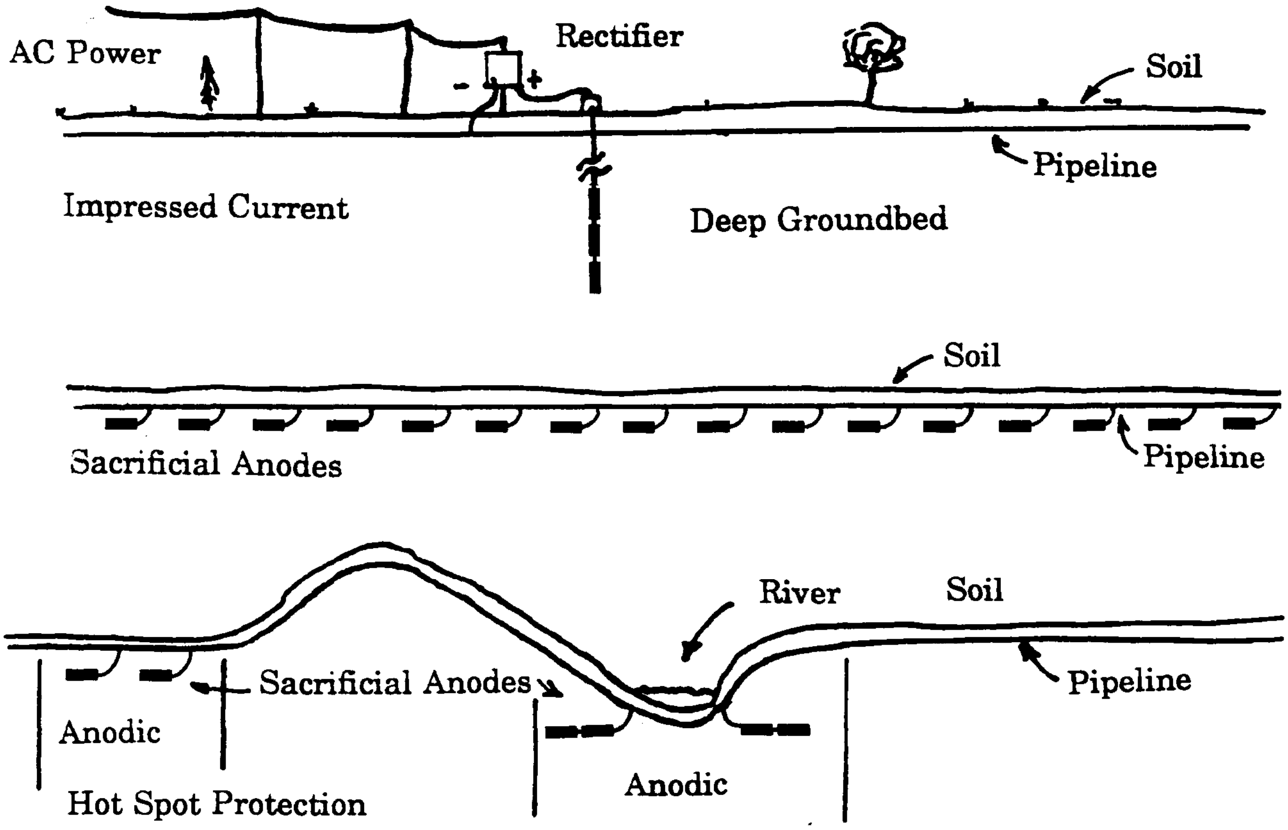


Figure 6 - Typical methods of protecting pipelines

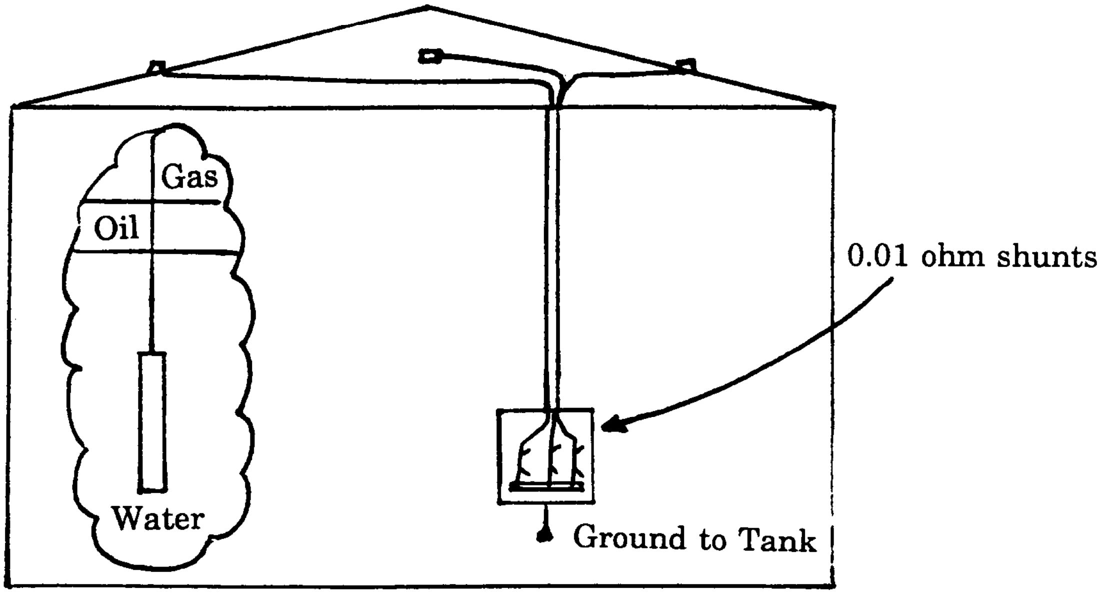


Figure 7 - Anodes suspended inside of tank

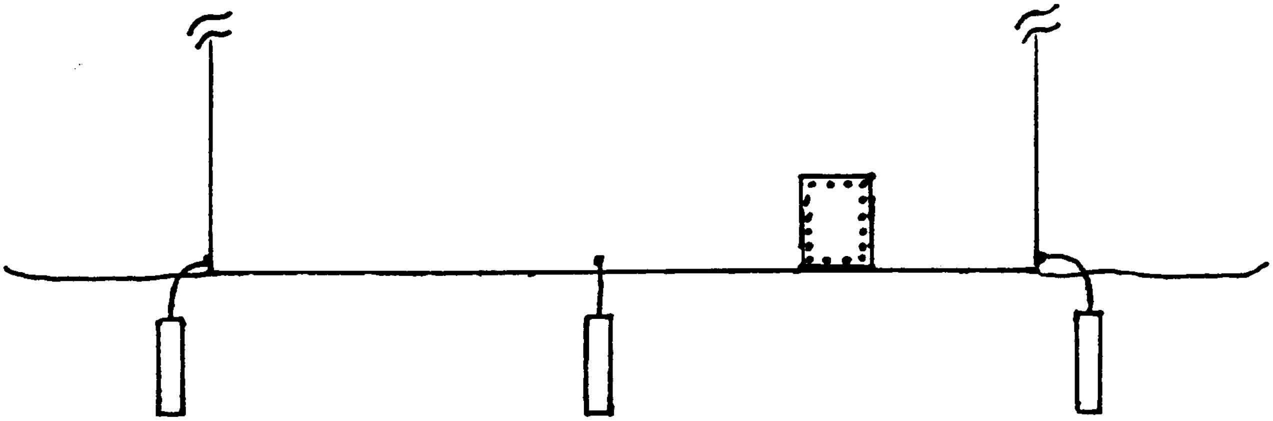


Figure 8 - Sacrificial anodes protecting
the bottom of a tank

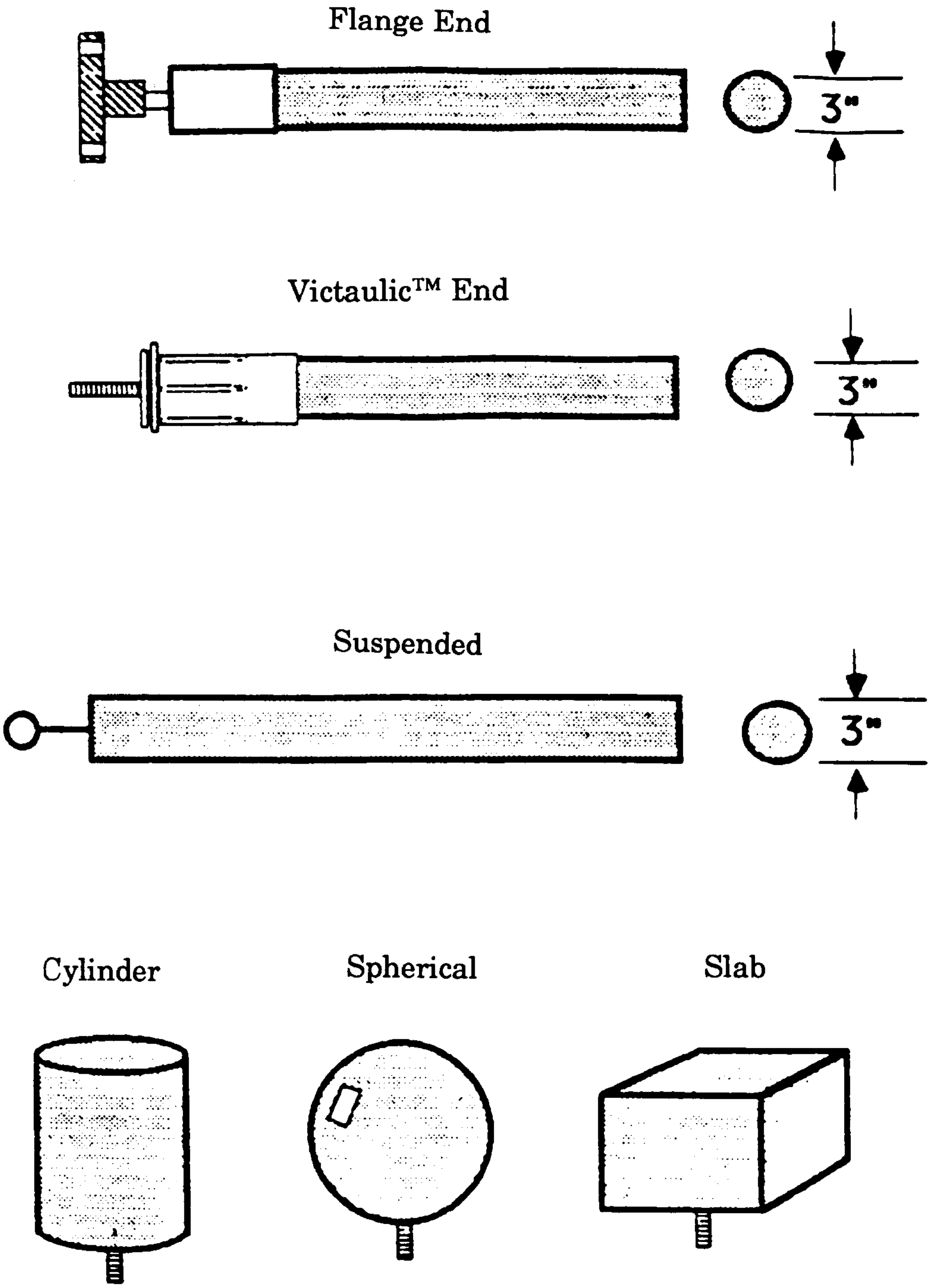
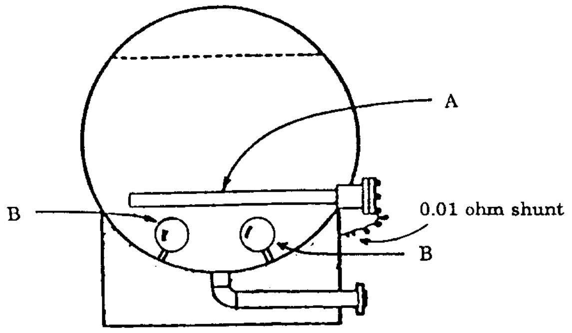


Figure 9 - Typical anodes



A - Flange Mounted

or

B - Anodes Welded to Vessel

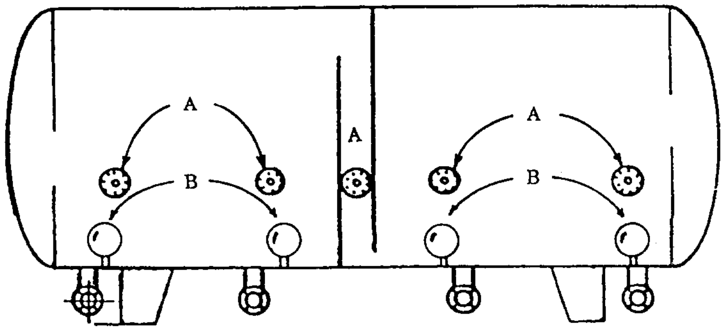


Figure 10 - Internally attached and through-wall anodes

Cathodic Protection is Line of Sight

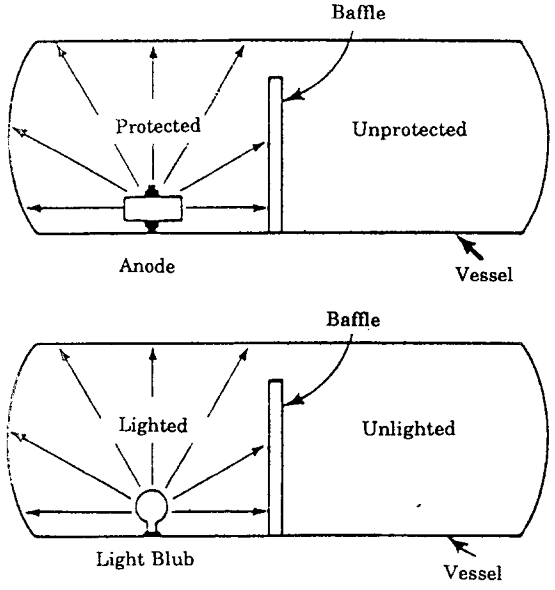
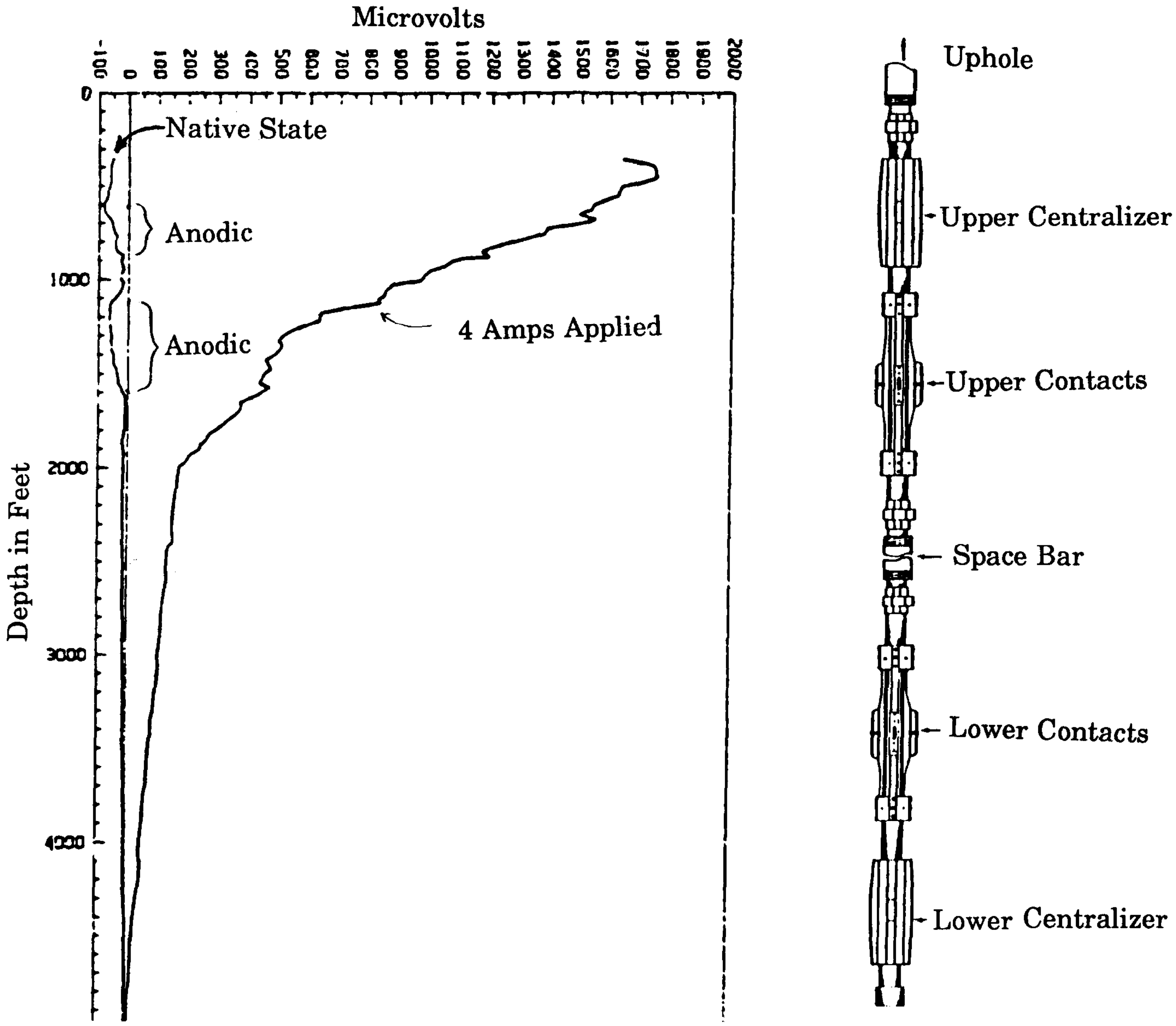


Figure 11 - Area of protection of an anode



CCP tool

Figure 12 - CCP log of well casing