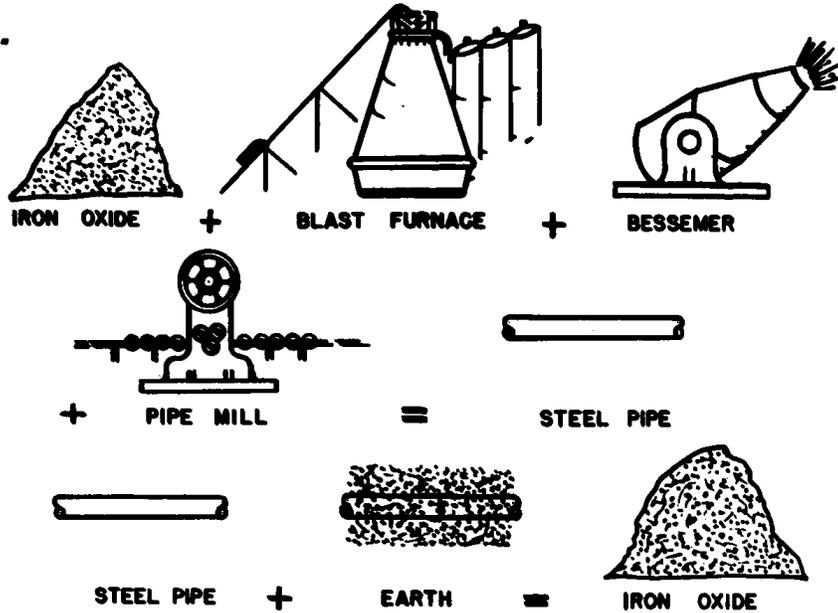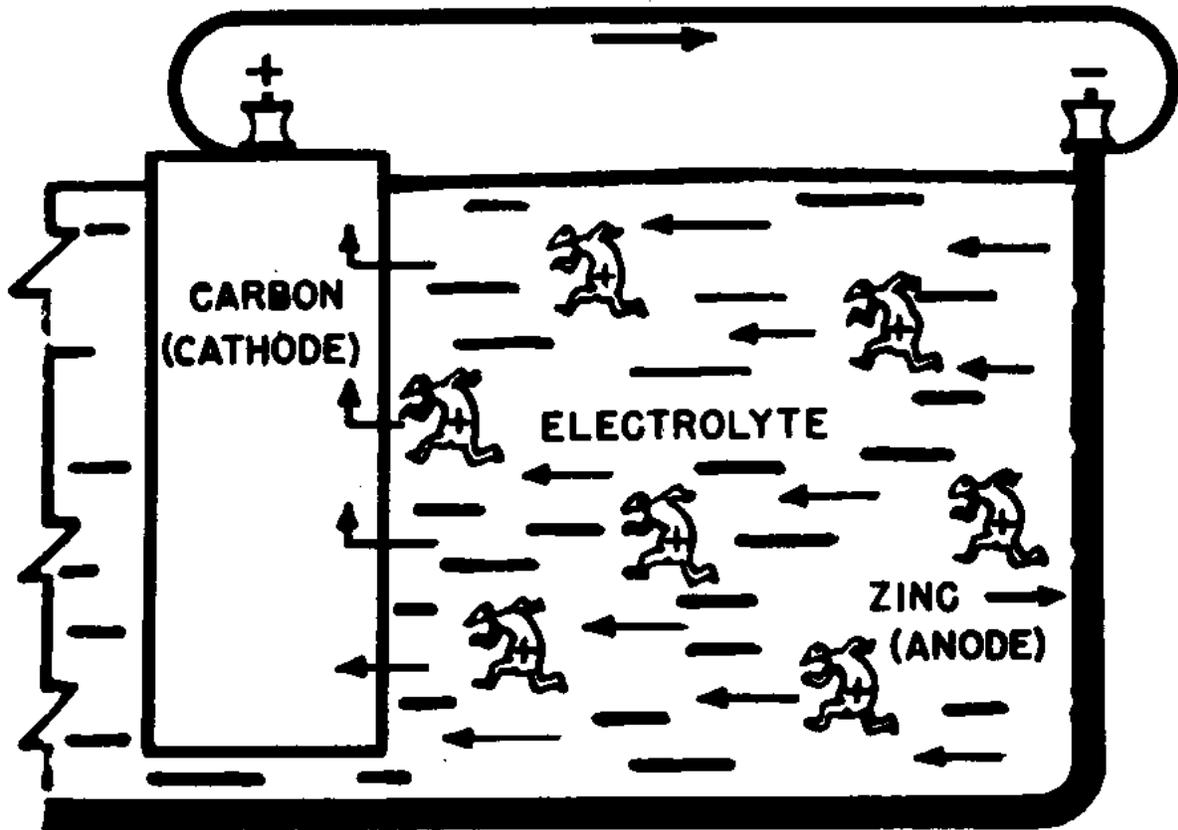# WHY METALS CORRODE
By T.R.B. Watson

This paper will concern itself with the very basic fundamental causes of corrosion. The fact is that metals corrode through sheer cussedness. They want to corrode. This perverse desire stems from the fact that it is much more natural for a metal to exist in the form of a compound, since the compounds such as oxides contain less energy than metals and are therefor more stable.

Dust to dust . . . .

IRON OXIDE **+** BLAST FURNACE **+** BESSEMER

+ PIPE MILL **=** STEEL PIPE

STEEL PIPE **+** EARTH **=** IRON OXIDE

In the making of steel, when iron is divorced from its associated oxygen in the blast furnace, a lot of energy is put into it in the form of heat. As long as it remains metallic, a piece of steel retains this energy, bound up within itself, always urging the metal to corrode back to the ore from which it was unwillingly derived. It is this energy which supplies the power to drive the various corrosion reactions, and which provides the incentive to corrode. When steel rusts the latent energy is released and the metal relieved of it's uneasy hypertension, thankfully reverts to a stable oxide again, and the cycle is complete.

When steel rusts the union with oxygen does not take place directly but by a rather roundabout series of reactions in which the passage of an electric current plays an important part. It is often stated that corrosion is caused by electric currents. It is perhaps more accurate to say that in most cases the electric current is caused by the corrosion, but the two are as interdependent as the chicken and the egg.
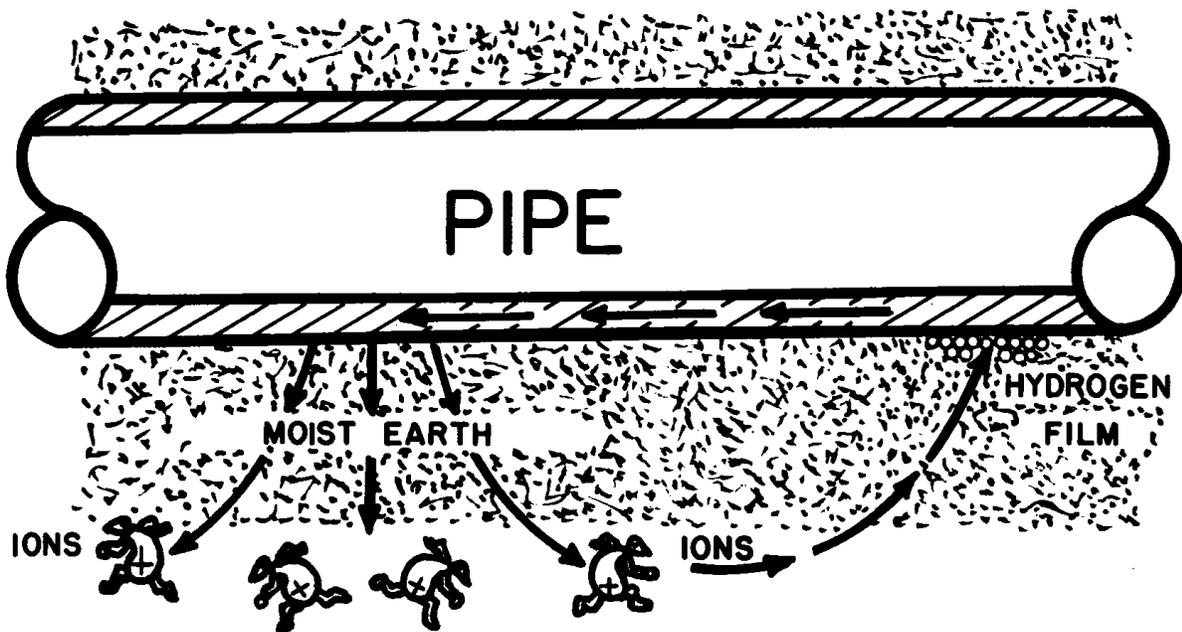
Battery Action
(Galvanic Cell)

A very good example of the way current can be generated by corrosion is that of the galvanic cell. Take the case of the ordinary dry cell battery, which consists of a zinc can holding a moist paste which constitutes the electrolyte, in the center of which is a graphite rod which act as the cathode of the cell. By reason of the fact that the zinc has more stored up energy than has the graphite and is thus more anxious to corrode, a potential of about 1 ½ volts exists between the zinc and the graphite, and if the external terminals are joined with a wire, current will flow in the cell from the surface of the zinc through the electrolyte to the cathode and back again through the wire. If a flashlight bulb is put in the external circuit it will light, and it is interesting to note that the electrical energy which lights it is the energy of corrosion of the zinc, and the same energy which was put into the zinc when it was refined from it's ore. As the zinc corrodes, it releases into the electrolyte small charged particles of itself, called ions, and these travel across the cell to the cathode where they become discharged. The passage of ions constitutes an electric current. The more current flowing in a cell, the more zinc is corroded. After the battery has been used for some time, corrosion will eat a hole in it, and the cell will leak. Most people have had the experience of having a flashlight battery leak inside the case.

If the wire is disconnected from the external terminals the current is interrupted and the ions released at the surface of the zinc have nowhere to go and accumulate in such number that corrosion is virtually stopped. This points out that for corrosion to take place there must be a complete electrical circuit.

Notice that only the anode is attacked in every electrolytic cell. The anode is the place where the current leaves the metal to go into the electrolyte. The cathode is the place where the current flows back out of the electrolyte. For every anode there is always, somewhere, a cathode. Anodes corrode, cathodes don't.
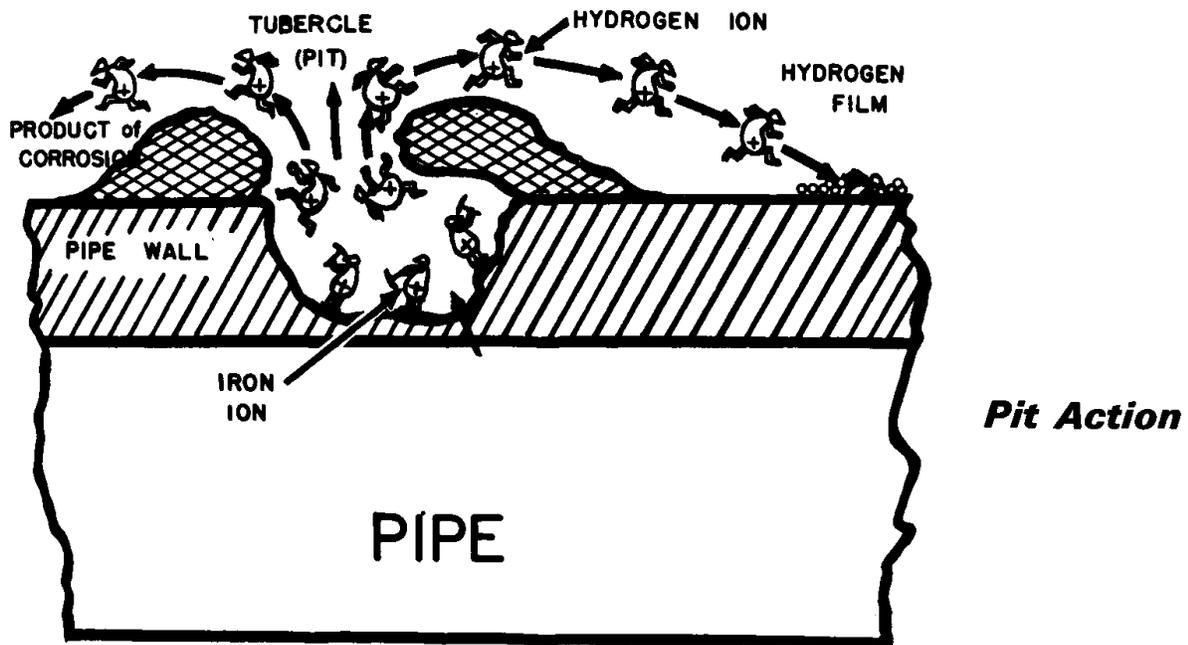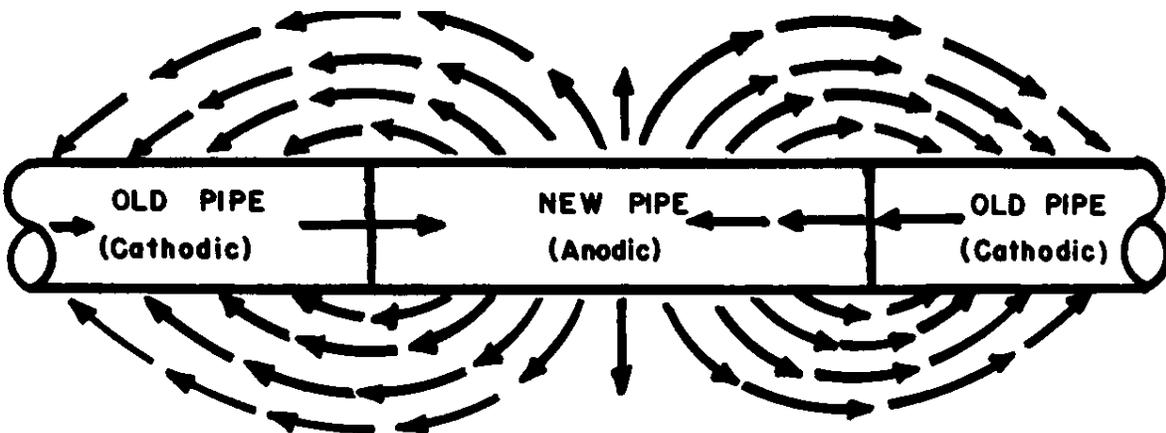
THE HYDROGEN ION

IONS in motion constitute an electric current

Take the case of a bare steel pipe buried in moist earth. Because of slight differences in metal composition of surface condition, and because of slight differences in the nature of the soil touching the pipe, small potentials or voltages tend to be set up between some areas of the pipe surface and other adjacent areas. This is analogous to the battery action just described. From the more negative areas, as before, current will flow into the soil (which acts as the electrolyte) and though it to the more positive or cathodic areas and back again though the metal of the pipe. At the negative, or anodic, area metal will dissolve. At the adjacent cathodes no corrosion will take place. This accounts for the commonly observed action of pitting: the pits are anodes where the metal is corroding, the unaffected areas around the pits have been acting as cathodes and thus having been protected. Nevertheless, because every anode needs a cathode, the uncorroded areas were necessary to the reaction.

Current is conducted in this case through the moist earth by a stream of hydrogen ions. Where these ions arrive at the cathode areas they are discharged and result in a film of hydrogen. This usually reacts with oxygen dissolved in the soil, and is not evolved as gas. This little corrosion cell is representative of millions of similar ones on the surface of any pipe. The length of the current path may be anything from a millimeter or smaller to several miles, but the strength of the current is always proportional to the corrosion rate. One ampere, flowing for one year, will dissolve 20 lbs. of steel.
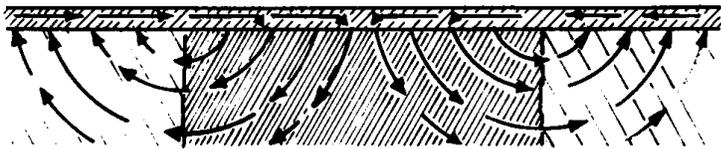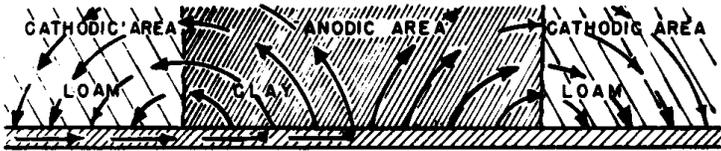

Pit Action

Here we see a well-advanced corrosion cell in which the anode has corroded to form a pit. The corrosion product has built up over the top of the pit to form a tubercle. This rust deposit is soft and quite permeable, and offers no resistance to the passage of current through it and, in fact, aggravates the situation. Once a pit is started, the voltage of the corrosion cell goes up and the action is intensified.

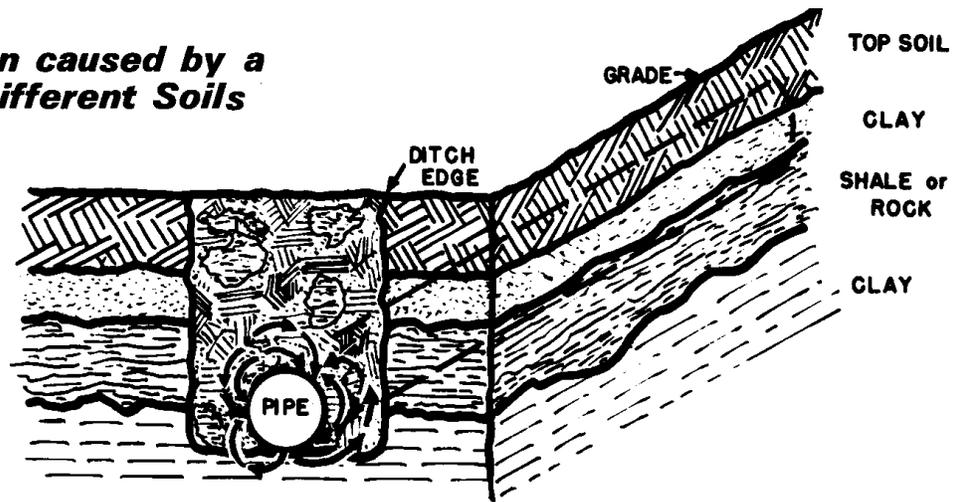

Corrosion due to Dissimilar Metal

In the battery just discussed, the voltage was set up by the fact that the anode and cathode were made of different materials. In fact, it is always some difference of metal or soil which causes current flow and it's associated corrosion. The greater the difference, the more severe will be the attack. Pipeliners are always saying that the pipes these days are not as good as they used to be. The example is often sited of the line that lasted many years until one short section had to be replaced. The new pipe then only lasted a few years before it had to be replaced again. The trouble was not that the new pipe was defective but that in coupling together new and old pipe, a cell of different materials was set up, in which the new clean pipe was strongly anodic to the old rusty pipe, and it corroded as a result of the currents which flowed.
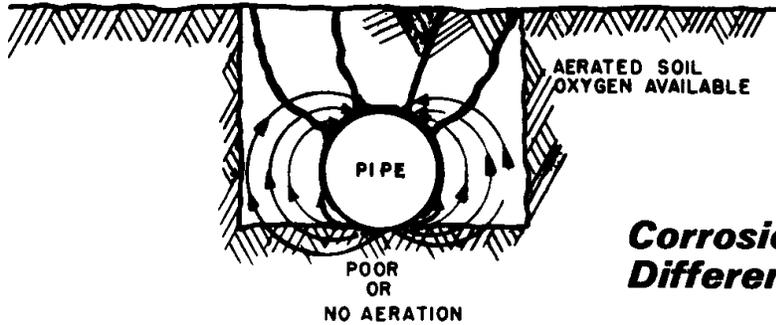

Corrosion caused by Dissimilar Soils

Differences in the nature of the soil in contact with the pipe can form galvanic cells too. The lighter, more porous soils are most likely to become cathodes. The metal in contact with the more impervious clay will suffer.

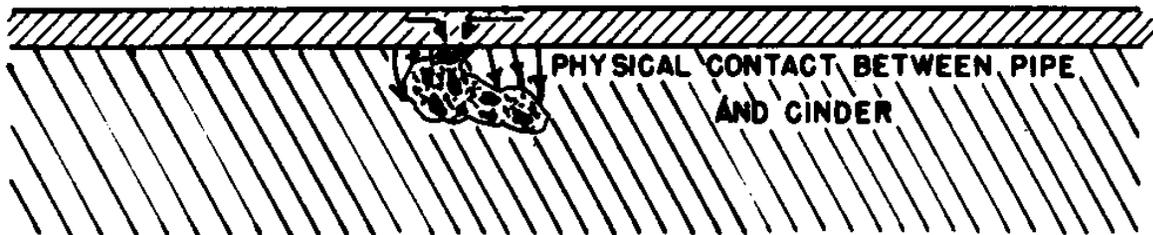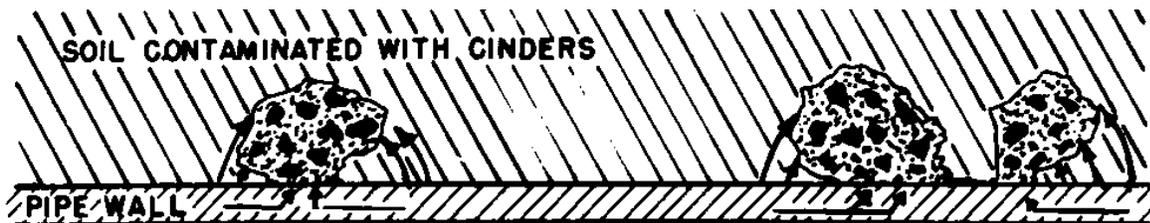**Corrosion caused by a Mixture of Different Soils**

Such a condition often exists when a trench is backfilled with a mixture of lumps of different kind of soils, as shown.

AERATED SOIL
OXYGEN AVAILABLE

PIPE

POOR
OR
NO AERATION

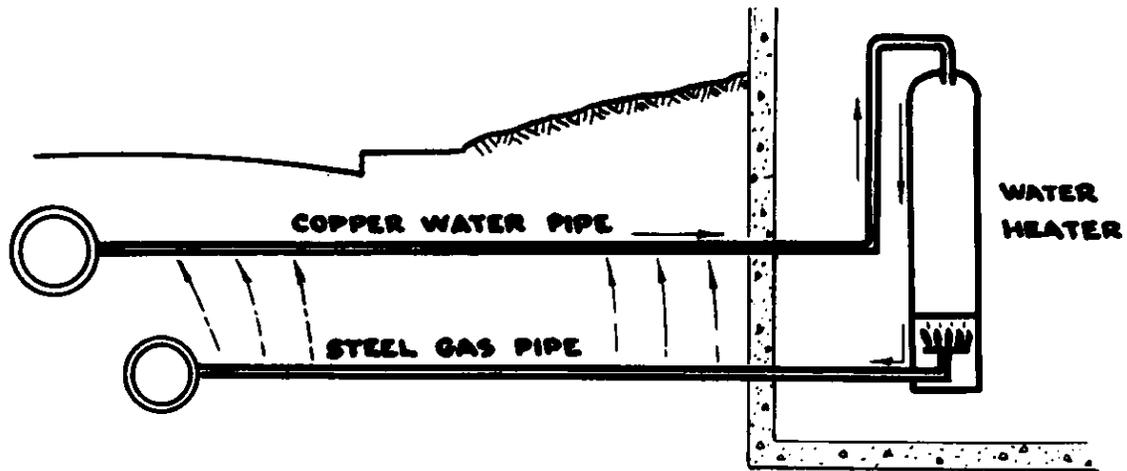## Corrosion caused by Differential Aeration of Soil

If one surface of the pipe has more access to oxygen than has another surface, a similar cell will be set up. This accounts for a familiar condition when the bottom of the pipe, in contact with undisturbed, poorly aerated soil at the bottom of the trench, is subject to more corrosion than is the top of the pipe, which has ample oxygen supply through permeation into the loose backfill.

SOIL CONTAMINATED WITH CINDERS

PIPE WALL

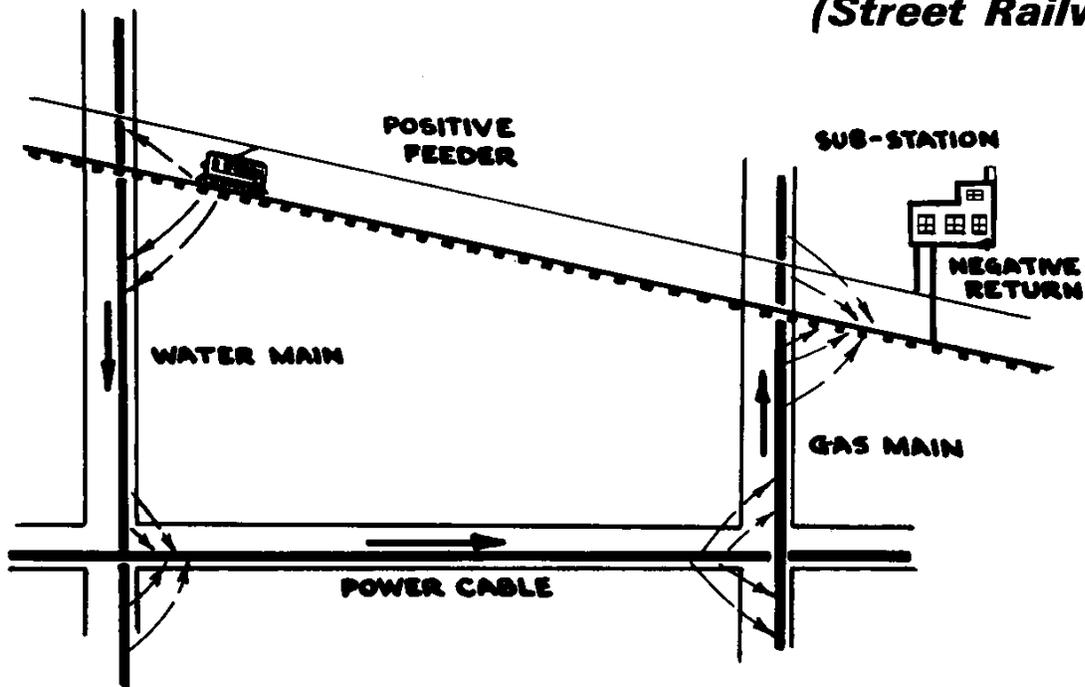PHYSICAL CONTACT BETWEEN PIPE AND CINDER

Corrosion due to Cinders

Another example of corrosion caused by a difference of conditions is that of a pipe in contact with cinders. In this case the carbon particles in the cinder itself act as a cathode as in the case of the battery, and the potential set up between the steel and the carbon is quite high, resulting in severe corrosion of the pipe. When backfilling steel structures, cinders are to be avoided at all cost.

Corrosion due to Dissimilar Metals

A bi-metallic galvanic cell is always established when two different metals in electrical contact with each other are buried adjacent to each other. Take the case of a home supplied by a steel gas service line and a copper water service. The metallic circuit between the two metals is completed through the water heater. The steel in this case will be corroded by the influence of the copper pipe, which acts as a cathode.
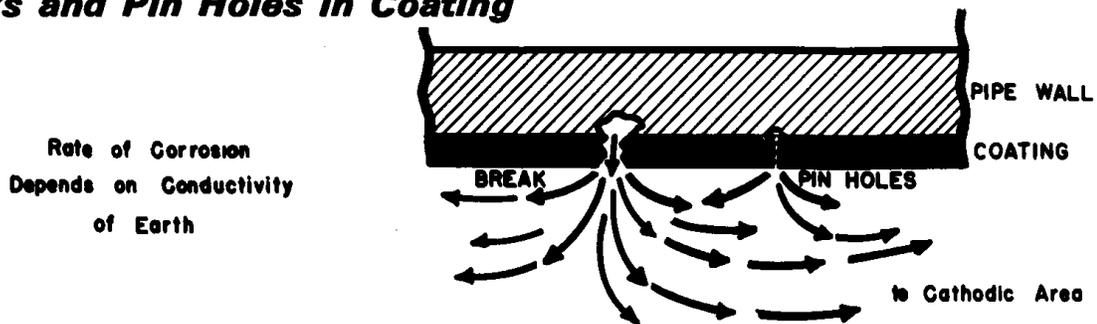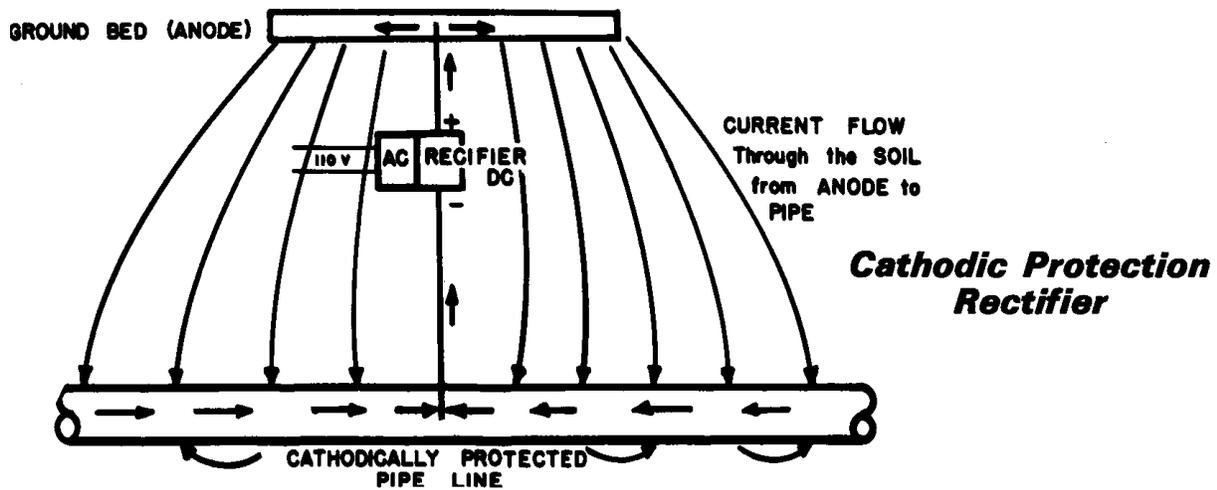
STRAY CURRENT (Street Railways)

Although the current generated in the foregoing examples has been caused by the energy released by the corrosion of metals, any DC electric current from any other source can, conversely, be the cause of corrosion. Whenever current leaves a metal to go into the ground the metal will be attacked: whenever the current comes onto a metal from the ground, the metal will be protected.

Stray currents originating from DC power source can travel for miles over a system of pipelines and cables; and whenever they leave on structure to jump onto another, corrosion will result. In the case of an electric railway, the current goes out from the substation along the third rail or overhead wire until it reaches the locomotive, passing through the motors and theoretically returning along the rails to the substation. Actually, by far the greater part of the current does return along the rails, but if a reasonably low resistance parallel path exists where by the current may follow pipeline and cables to return to the negative ground of the substation, a certain part of the current will take this route. Here some of the current follows a parallel metallic path consisting of a water main, a communications sheath and a gas pipe. Where the current jumps from the rails to the water main, it will protect it from corrosion; where it leaves the water pipe to enter the lead cable it will corrode the water main and protect the cable; where it leaves the cable to enter the gas pipe the cable sheath suffers. Where current goes into the ground from the gas line to return to the substation ground, the pipe is attacked. This is a simple example, but in the complexity of a metropolitan district the course of stray currents can be very difficult to follow. In this case the cable operator has only to connect a bond between his cable sheath and the station ground to secure free cathodic protection. If current is taken away from the sheath by means of a metallic conductor rather than having to pass into the ground, no corrosion will occur.
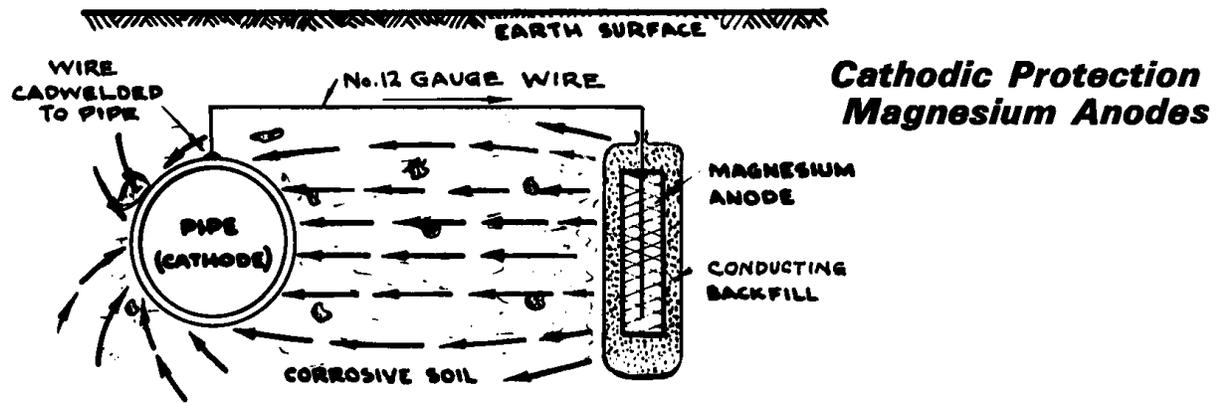
Concentration of Corrosion at Breaks and Pin Holes in Coating

Rate of Corrosion Depends on Conductivity of Earth
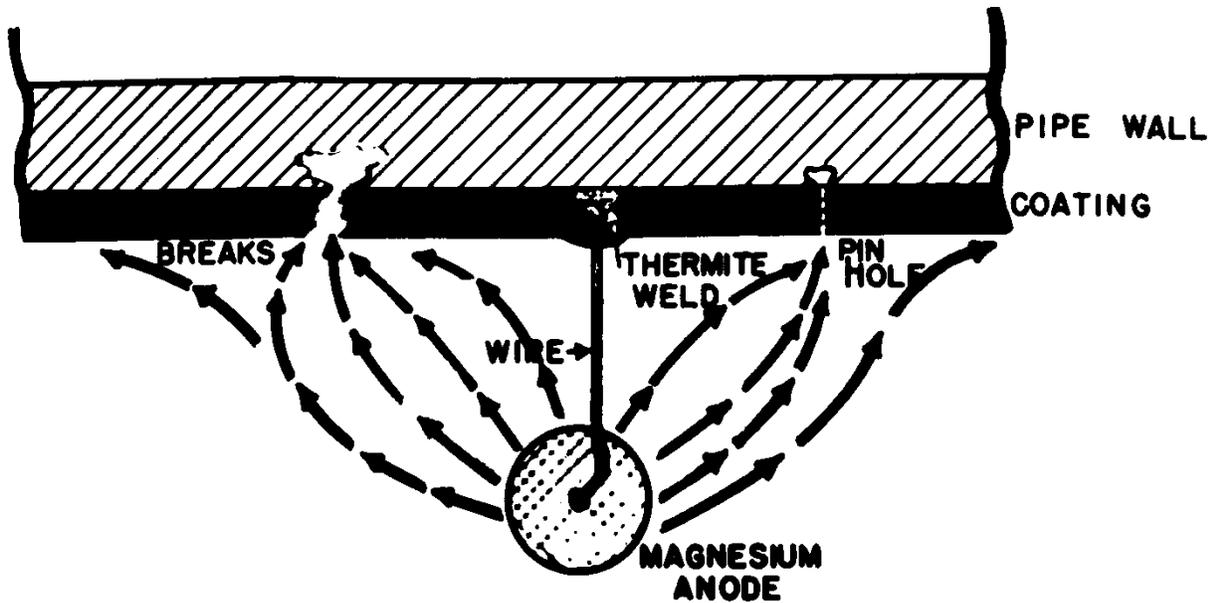
PIPE WALL
COATING
BREAK
PIN HOLES
to Cathodic Area

Since for every ampere-year of current 20 lbs. of metal is dissolved, the rate of penetration is dependent on the area from which this metal is taken. If the pipe is coated and subject to electrolysis from stray currents, the coating can in some cases cause more rapid penetration of the pipe because the areas from which the metal can be taken are confined to pin holes or cracks in the coating.

Cathodic Protection Rectifier

To reiterate an important maxim – Anodes corrode: cathodes don't. It follows from this, that it is only necessary to make a structure sufficiently cathodic to prevent its corrosion. If we pass current form the earth to a pipeline, the incoming currents will nullify any outgoing currents from the anodes of local corrosion cells, and the pipe, receiving current over it's whole area, will be immune form corrosion. The source of the current is immaterial. In this case, a groundbed of graphite or scrap steel is energized by a rectifier, and current flows from the groundbed to the pipeline.

Cathodic Protection Magnesium Anodes

A current may just as easily be produced by galvanic action from the energy of corrosion of a magnesium anode. In this instance a piece of magnesium is connected to the pipe with a wire and buried some 10 ft away from it in the ground. Because the magnesium is much more active than the steel, a considerable voltage is established between the two metals and protective current will flow from the magnesium through the earth to the pipe and back again through the wire. The magnesium being the anode will corrode in proportion to the current that it generates. In fact, the corrosion of the pipeline is transferred to the magnesium.

[9]

PIPE PROTECTION
with COATING and ANODES

It takes far fewer magnesium anodes to protect a coated structure than it does to protect a bare one, since the available current has only to go to the breaks in the coating instead of having to cover a large bare area. The current at the pinholes, although of a very small magnitude, causes a very high protective current density at the minute breaks in the coating.

Today the vast majority of buried pipelines are coated with some kind of organic coating. This is because experience has shown that corrosion can be controlled more cheaply on a coated structure. Corrosion may be stopped in two ways: (1) by maintaining a perfect coating, and (2) by impressing a protective cathodic current density on a bare line. (1) Is impossible, since there is no such thing as a perfect coating, and (2) is unduly expensive because of the high current demand. Somewhere between these extremes of coating perfection and prodigal power demand lies the economic optimal combination of a good coating supplemented by a little cathodic protection to look after the inevitable pin holes. Or you can look at it the other way and say that corrosion is being controlled by the cathodic protection and the coating is applied merely to make the cathodic protection cheaper.

Corrosion control is simply an economic measure and the cheapest way to achieve it is best. The choice is easier if you have some knowledge of why metals corrode.