

# Factors Affecting Corrosion in Water and Waste Water Engineering

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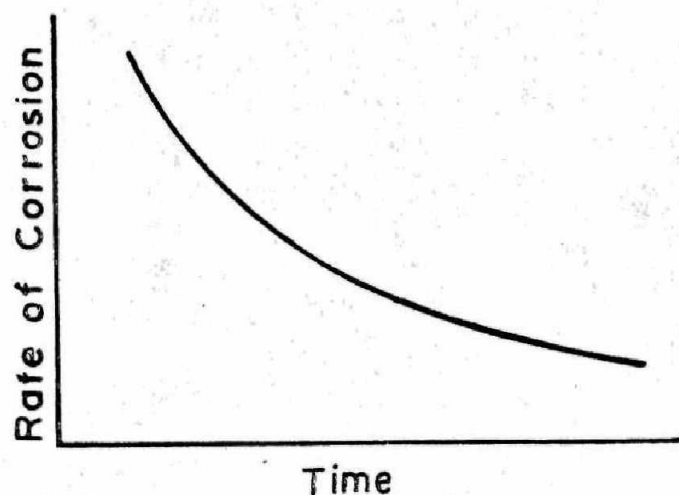
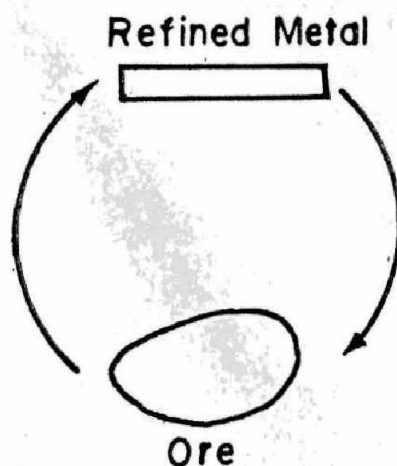
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## CORROSION PROBLEMS IN WATER AND WASTE WATER ENGINEERING

For any water supply scheme the major investment is in its distribution system. A distribution system may cost anything from 60% to 90% of the total cost of a scheme. Corrosion of water mains reduces its useful life, increases leakage of water and even leads to bursts of pipes. Leakage detection surveys in some cities in recent years have shown an astounding loss through leakage of over 50% of the total water supplied to the cities. No estimates of economic losses by way of repairs and replacement costs and cost of water lost by leakage are available for Indian cities. Corrosion in water treatment plants and industrial water usage such as in boilers, cooling towers, condensers, etc. is quite well-known. In sewage and industrial waste treatment plants, corrosion is the operators' enemy No. 1. It is estimated that at any given time in India, half the sewage treatment plants are not functioning owing to corrosion and other causes leading to breakdown. Relatively few operators understand the basic concepts or practical methods of reducing corrosion damage.

## CORROSION PHENOMENON

Corrosion is a process by which the refined metal reverts to its original form of ore or chemical compound. It begins the moment the metal is produced and is a never-ending process. Therefore, there is nothing abnormal about its occurrence because it has to occur.



**CORROSION IS A NATURAL PHENOMENON**

FIG. 1.

Corrosion is an electro-chemical phenomenon because the chemical action is either caused by, or causes the flow of, electric current. It is different from erosion where the loss of metal is due to purely mechanical wear. Every metal has its "normal" rate of corrosion, this rate diminishing with time. Generally speaking corrosion cannot be completely eliminated but it can certainly be controlled and reduced in severity. But, instead of benefiting from this diminishing rate with time, man may by his faulty actions lead to an increasing rate of corrosion. Some knowledge of corrosion theory can help the engineer to prevent unwittingly accelerating the corrosion phenomenon.

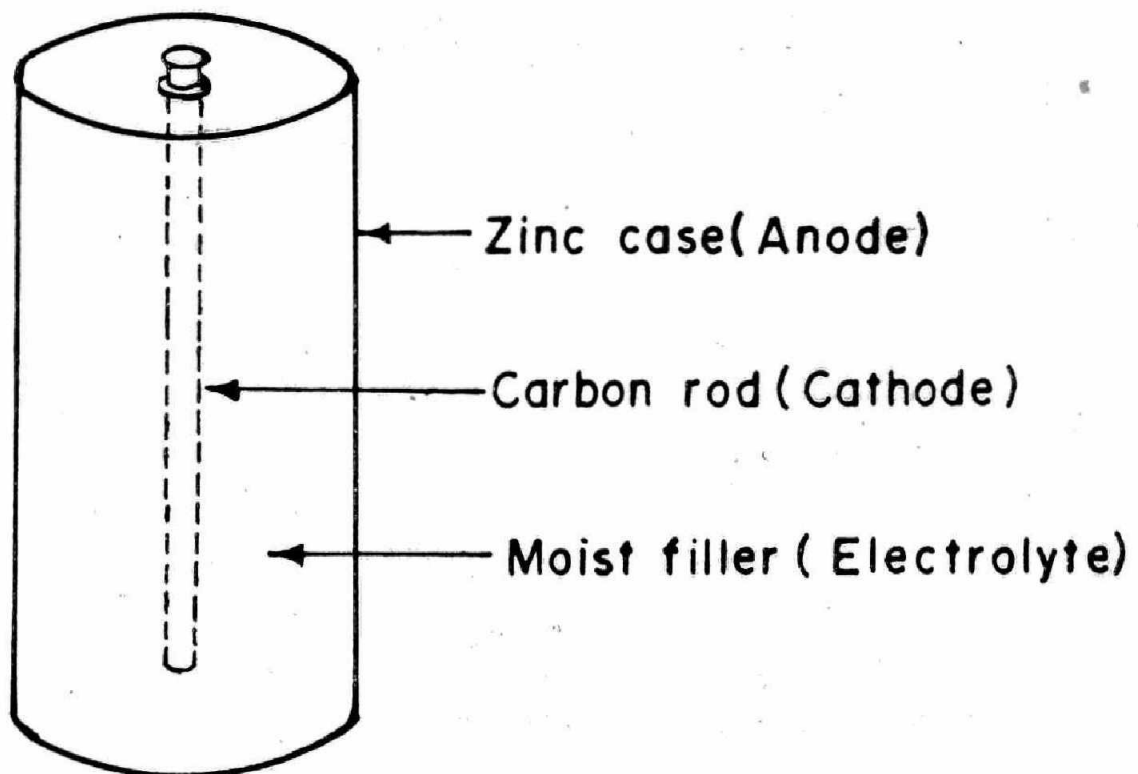
There are four types corrosion in which we are generally interested. These are :

1. Galvanic
2. Electrolytic
3. Stress
4. Bio-chemical

Any of these four types can rapidly accelerate corrosion and we must, therefore, examine them in greater detail.

### **GALVANIC CORROSION**

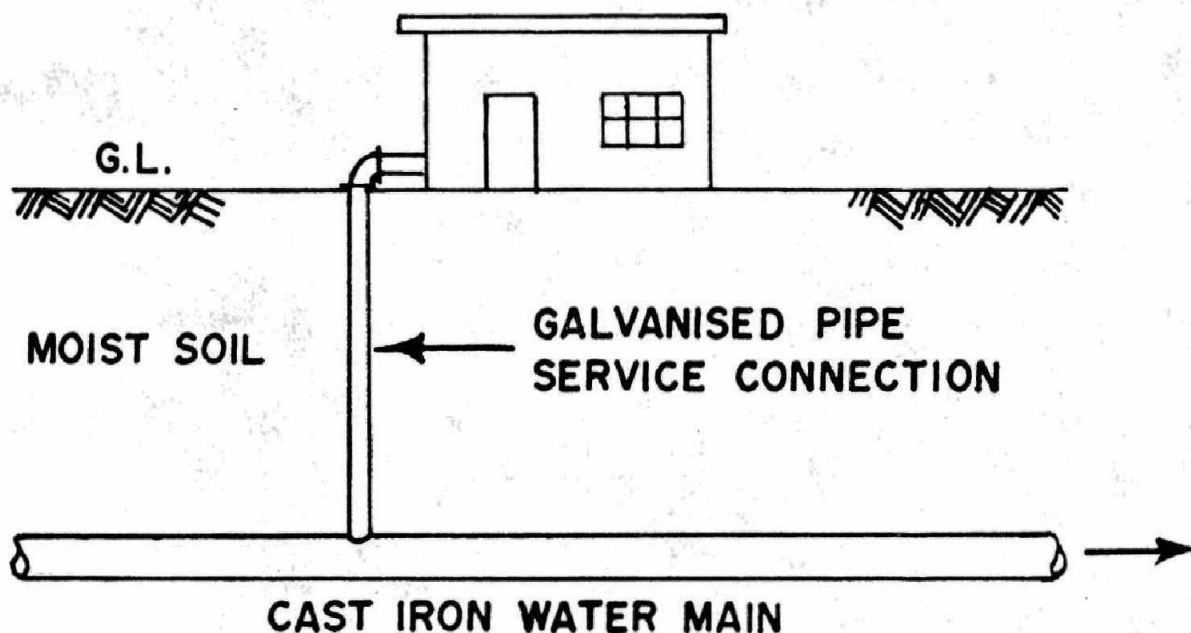
Where rapid corrosion occurs it is usually a result of galvanic action between dissimilar metals. This action is identical with that occurring in an ordinary flashlight cell. Such a dry cell consists of



**A FLASHLIGHT CELL**

the anode (zinc case), the cathode (carbon rod), and electrolyte (moist filler between case and rod). The electrical connection or external circuit between anode and cathode consists of the metallic path from one dry-cell terminal, through the switch and lamp, to the other dry-cell terminal. When the switch is closed the zinc-case anode corrodes, being sacrificed to provide the electric current through a chemical reaction. It is always the anode which is sacrificed, like the proverbial "goat" which has to be given in sacrifice in order to gain something else.

Now, coming to a water distribution system in which, for example, the water main is of cast iron and the surface connection is with a galvanised pipe (see Fig. 3), a similar situation exists as in the example of the flashlight cell given above. The moist soil acts as an electrolyte and the two dissimilar metals (cast iron and galvanised pipe) form a galvanic cell. This is like a flashlight cell on a giant scale.



### CORROSION IN A DISTRIBUTION SYSTEM

FIG. 3.

Which of these two metals will become the anode and which will become the cathode, will depend upon the relative position of these two metals in the galvanic series given in Table No. 1. That metal which stands higher in the galvanic series will always be anodic to any other metal which stands lower in the series. In the case of the water distribution system illustrated in the Fig. 3, the galvanised or zinc coated pipe will be the anode compared to cast iron and will naturally corrode. If the house service connection had been made with a copper pipe (as is generally used in western countries, but not in India owing to copper shortage), then, the cast iron pipe would have become the anode and would have corroded, since cast iron stands higher in the series than copper. The examples given in Figs. 4 to 9 illustrate various forms in which galvanic corrosion is met with commonly in water supply systems.

**Table 1 Galvanic Series of Metals and Alloys\***

**Anodic or Corroded End**

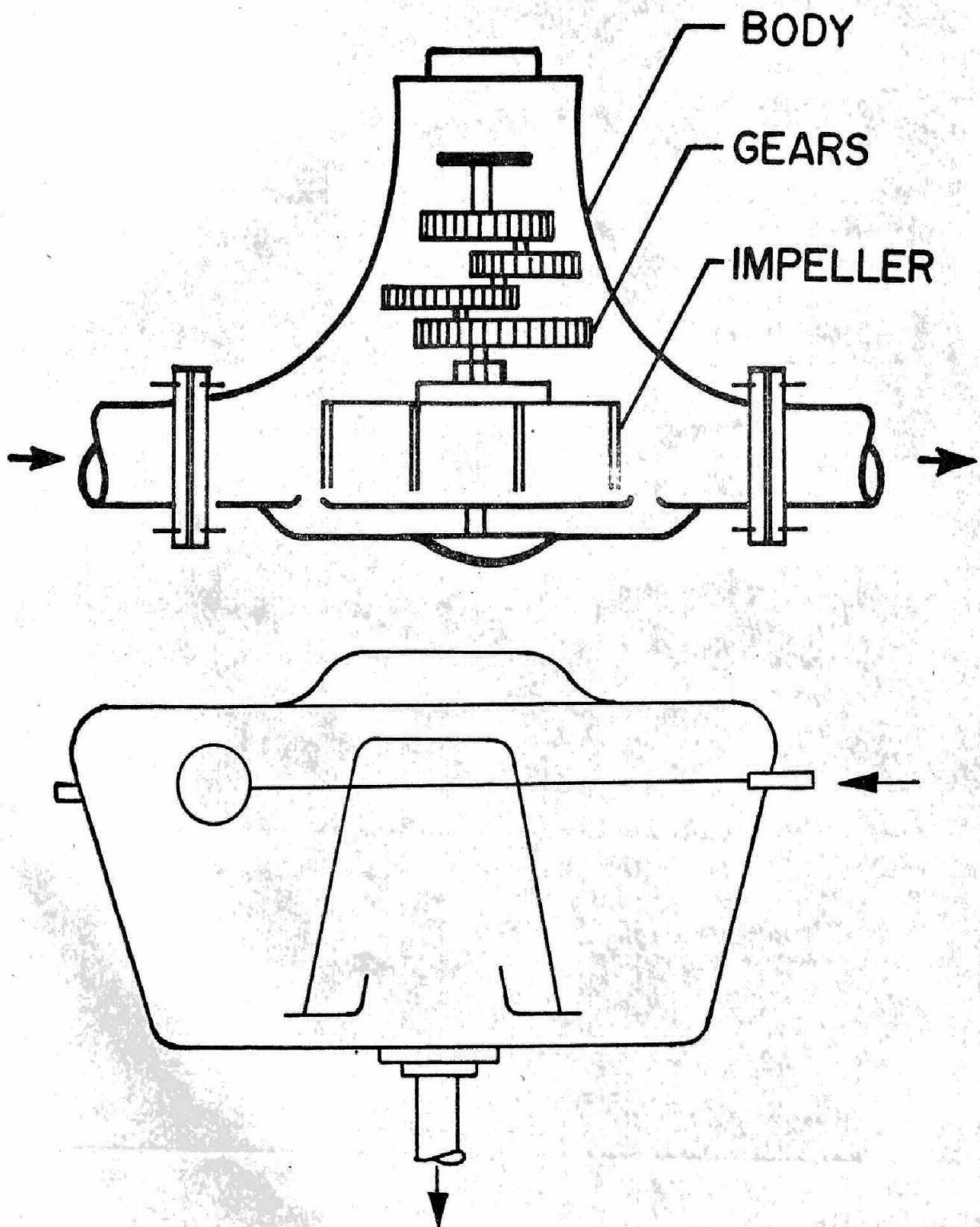
Magnesium and magnesium alloys
Zinc
Aluminum 2S
{ Cadmium
{ Aluminium 17 ST
Steel or iron
Cast iron
Chromium-iron (active)
Ni-Resist
{ 18-8 Stainless steel (active)
{ 18-8-3 Stainless steel (active)
Hastelloy "C"
{ Lead-tin solders
{ Lead
{ Tin
{ Nickel (active)
{ Inconel (active)
{ Hastelloy "A"
{ Hastelloy "B"
{ Brass
{ Copper
{ Bronzes
{ Copper-nickel alloy
{ Monel
Silver solder
{ Nickel (passive)
{ Inconel (passive)
{ Chromium-iron (passive)
{ 18-8 Stainless steel (passive)
{ 18-8-3 Stainless steel (passive)
Silver
{ Graphite
{ Gold
{ Platinum

**Cathodic or Protected End**

\* A "passive" metal has a surface film of absorbed oxygen or hydrogen. A metal may be initially "active" and become "passive" to the other metal when the protective film is formed.

The same metal may in one case be anodic and in another case cathodic, depending on the relative position of the two metals in contact. At times, changes in composition or temperature of electrolyte may also cause metals to shift positions or actually reverse positions. For example, if temperature is greater than 150°F iron will be anodic to zinc.

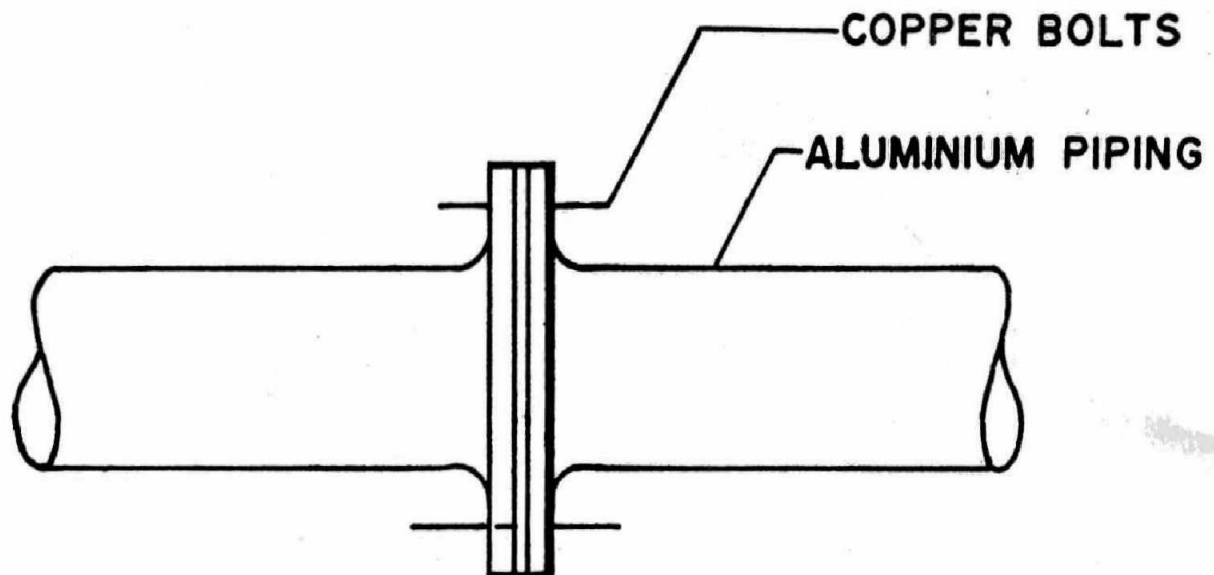
Again, the further apart the two metals in the series, the faster the rate of corrosion. But, the metals grouped together in the series are relatively safe to use in contact with each other, even when installed in an environment where galvanic action could occur. This is the key to good design. If we must have an installation or equipment in which different metals must be used, we should make sure of their compatibility as far as possible.



**SECTION THROUGH A FLUSHING CISTERN**  
**(C.I. Body, G.W.I. Inlet and Overflow Copper Float, Lead Downtake.)**

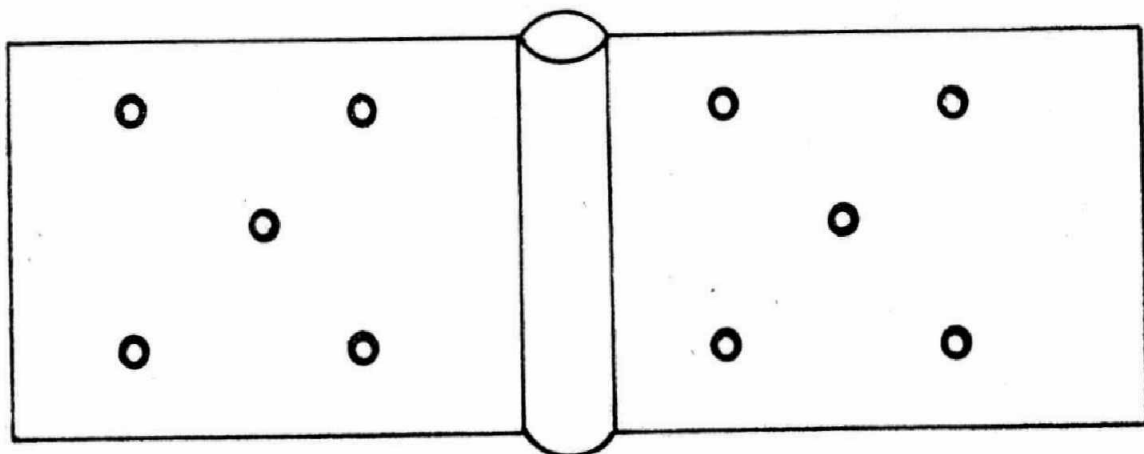
FIG. 5.

Often, dissimilar metals have to be used in an installation and hence galvanic corrosion may be unavoidable. In such cases, to reduce corrosion effects, the cathodic area should be kept as small as possible and the anodic area should be as large as possible, and heavy enough, to withstand the loss of metal by corrosion.



**LET FLANGE BE ANODIC AND BOLTS CATHODIC.**

FIG. 6.



**FIXING CHROMIUM PLATED HINGES WITH IRON SCREWS  
WOULD BE BAD PRACTICE.**

FIG. 7.

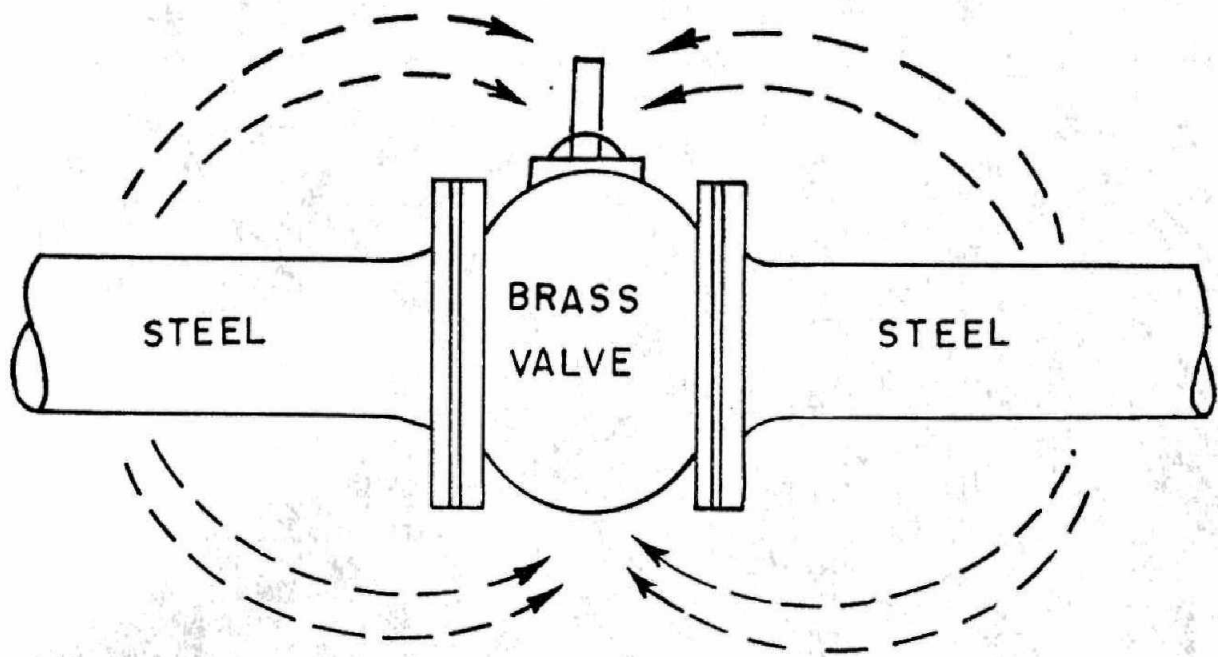
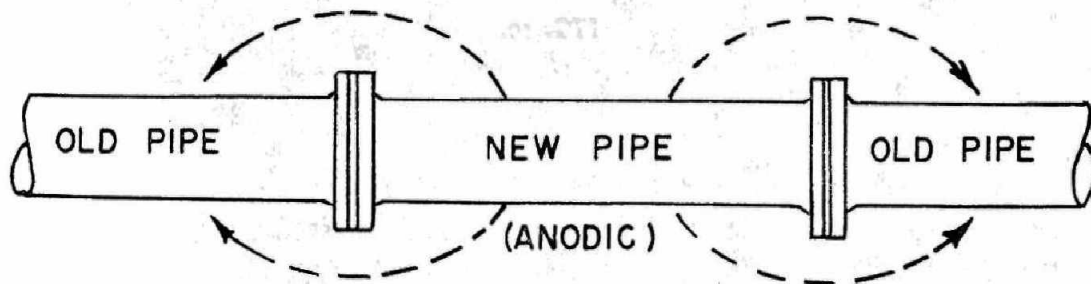


FIG. 8.



**A NEWLY INSERTED PIPE PIECE ALWAYS BECOMES ANODIC WITH RESPECT TO THE OLD PIPE.**

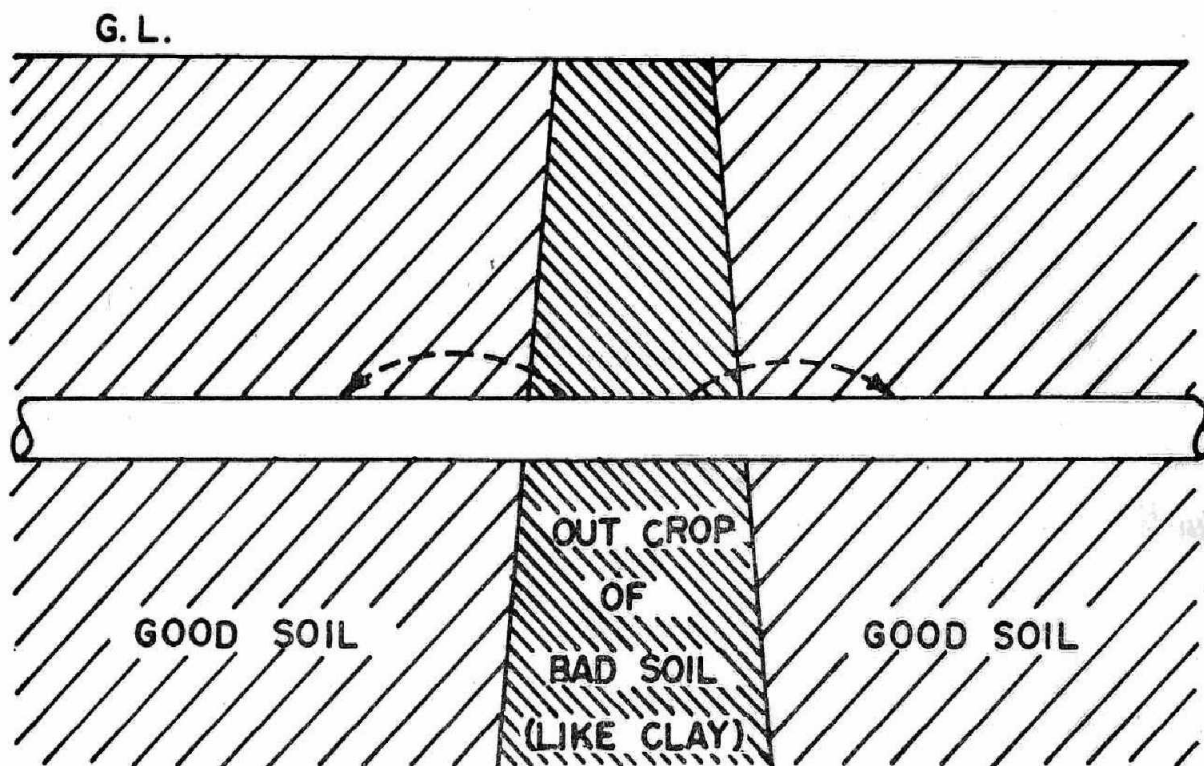
FIG. 9.

### **OTHER EXAMPLES OF GALVANIC CORROSION**

Galvanic action between two dissimilar metals in a common electrolyte is similar to galvanic action occurring between identical metals in two different electrolytes. In submerged or buried water



works structures a pipe or a structural member may pass through different types of soils, (the different types constituting different electrolytes) giving rise to galvanic corrosion (Fig. 10).



**GALVANIC CORROSION CAN ALSO OCCUR WHEN A PIPE PASSES THROUGH DIFFERENT ELECTROLYTES. CORROSION WILL BE IN THE "BAD" SOIL OF LOWER RESISTIVITY.**

FIG. 10.

Differences in electrolytes can result from a difference in ion concentrations or in dissolved oxygen concentrations or soil conductivities or in amounts of dissolved chemicals present in the soil. Soils may be acidic, alkaline or neutral. The resistance offered by a soil to the passage of electric current is measured in ohms per cubic centimeter.

Table 2

Soil Resistivity	Ohms/cm <sup>3</sup>
Good	<2000
Bad	about 1000
Very bad	Less than 1000

Mud, muck, clay, etc. generally fall in the "very bad" category. Even good soils may contain islands or pockets of low resistivity soils. It is at the junction of such soils that corrosion is seen to be maximum. The rate of corrosion depends upon the rate of flow of current which depends inversely upon soil resistance.



Saline waters and sewage also offer very low resistance to the passage of current. This is illustrated below in Table 3.

**Table 3**

Sea Water	20-60 ohms/cm <sup>3</sup>
Primary sewage	250        "
Treated sewage effluent	500        "
Bombay water	19000     "
Calcutta water	2500*     "
* due to greater salinity	

Extensive studies made by the National Bureau of Standards, USA has led to the following classifications of soils :

*Lightly Corrosive* : Sands, sandy loams, light textured silt loams, porous loams or clay loams thoroughly oxidised to great depths. Low water table.

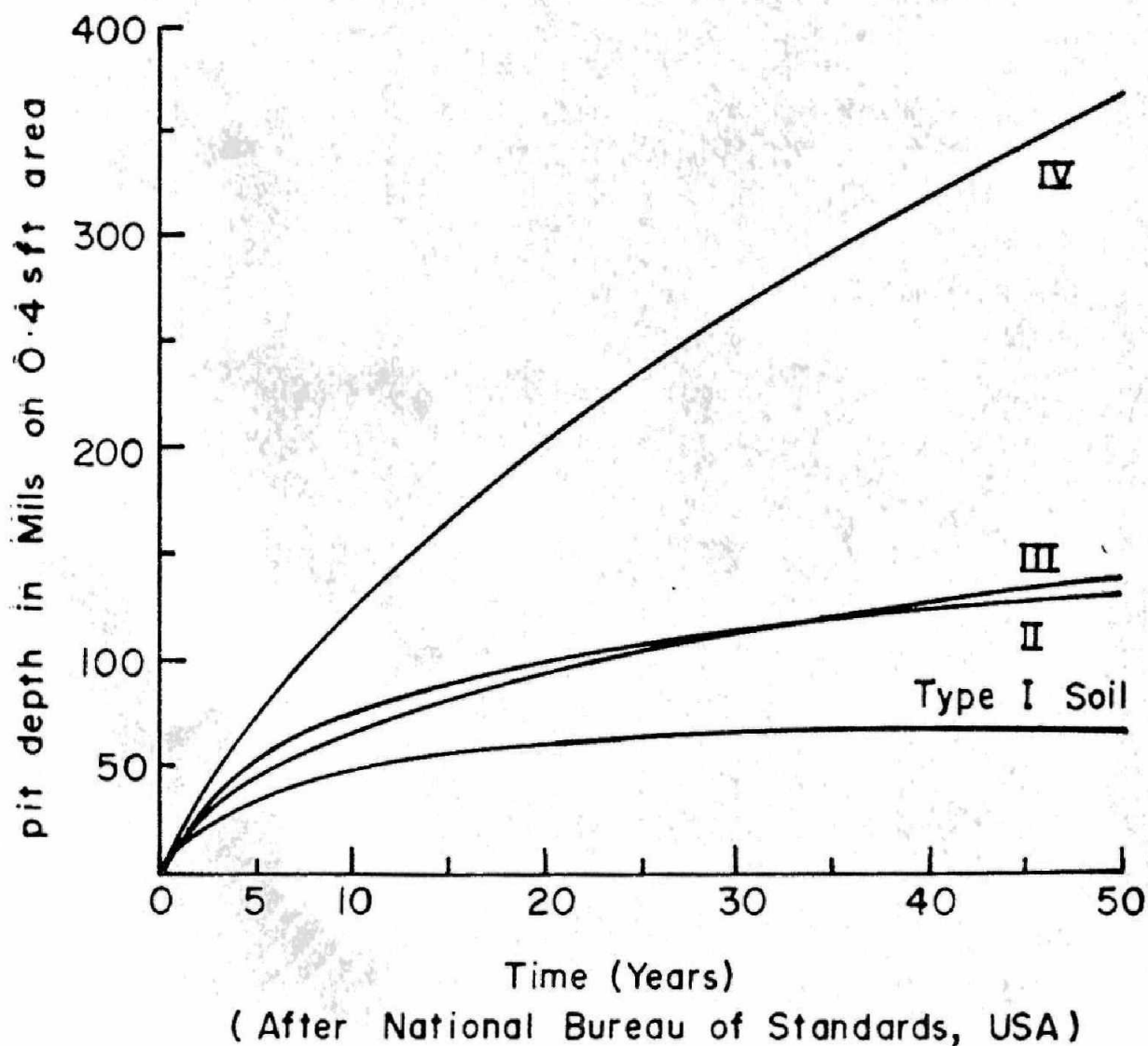


FIG. 11.

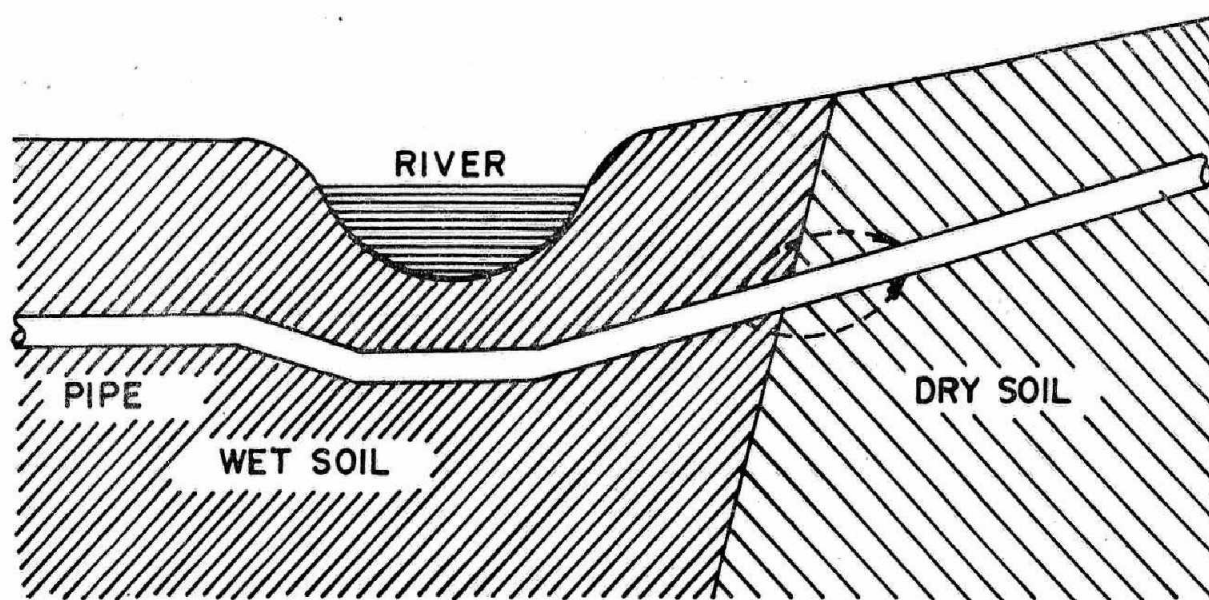
- II. *Moderately Corrosive* : Sandy loams, silt loams and clay loams where aeration and natural soil drainage is fair. Low water table.
- III. *Badly Corrosive* : Clay loams and clays where aeration and drainage is poor. (for example, where water table is only 2-3 ft below ground and would require artificial drainage for crop raising).
- IV. *Unusually Corrosive* : Muck, peat, tidal marsh, clays and organic soils with high water table. Extreme impermeability.

Long term experiments with submerged steel plates have shown (Fig. 11) that except for the very corrosive soils, the rate of corrosion levels off after a few years.

This is not true for galvanic corrosion when a pipe passes through two different electrolytes. In all such cases, the bad soils become corrosive region. For example, pipes running long distances underground will show anodic or corroding portions where the pipe is passing through irrigated lands, rice fields, swamps, clay formations, former tide lands and under pavements. A pipeline passing from a high-resistance (good) soil to a low-resistance (bad) soil will corrode in the low-resistance soil because of the difference in pipe-to-soil potentials of the two soil areas. The current flows from the pipe, through the bad soil to the good soil, then back to the pipe ( Figs. 12 & 13).

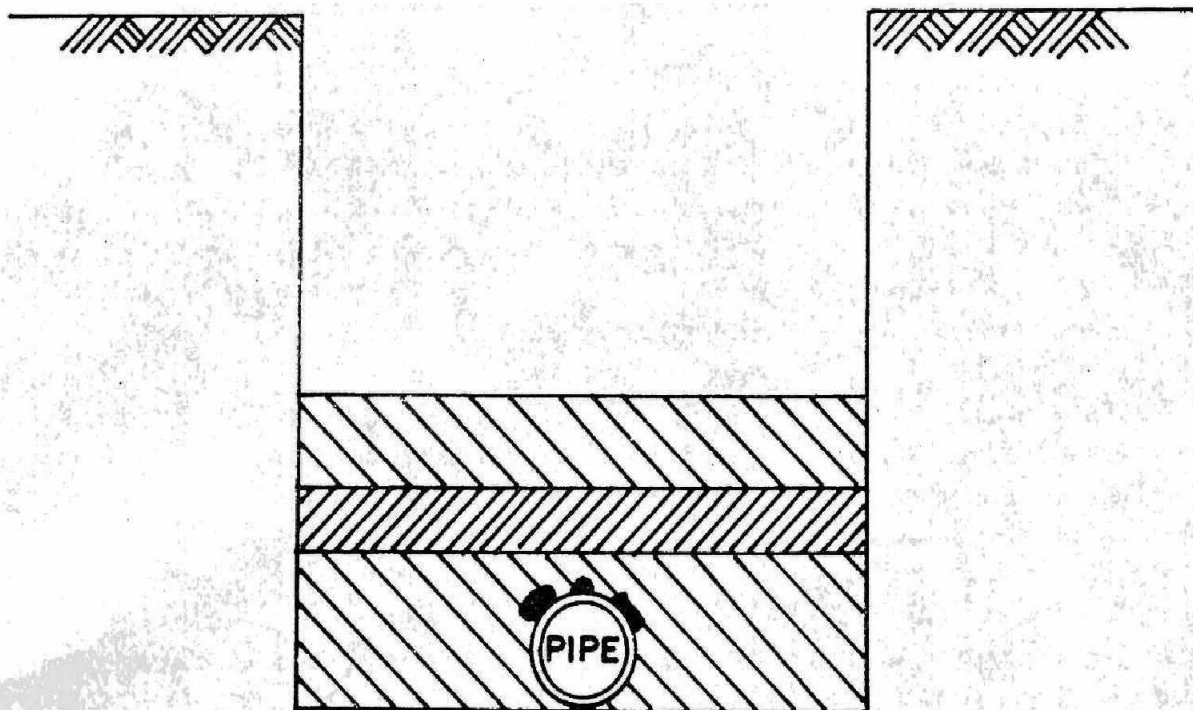
## MECHANISM OF CORROSION

When water is flowing through a metallic pipe (see Fig. 14) minute pitting on the inner surface of the pipe may be noticed at some places. At these places, the iron goes into solution and a series of reactions take place as listed below :



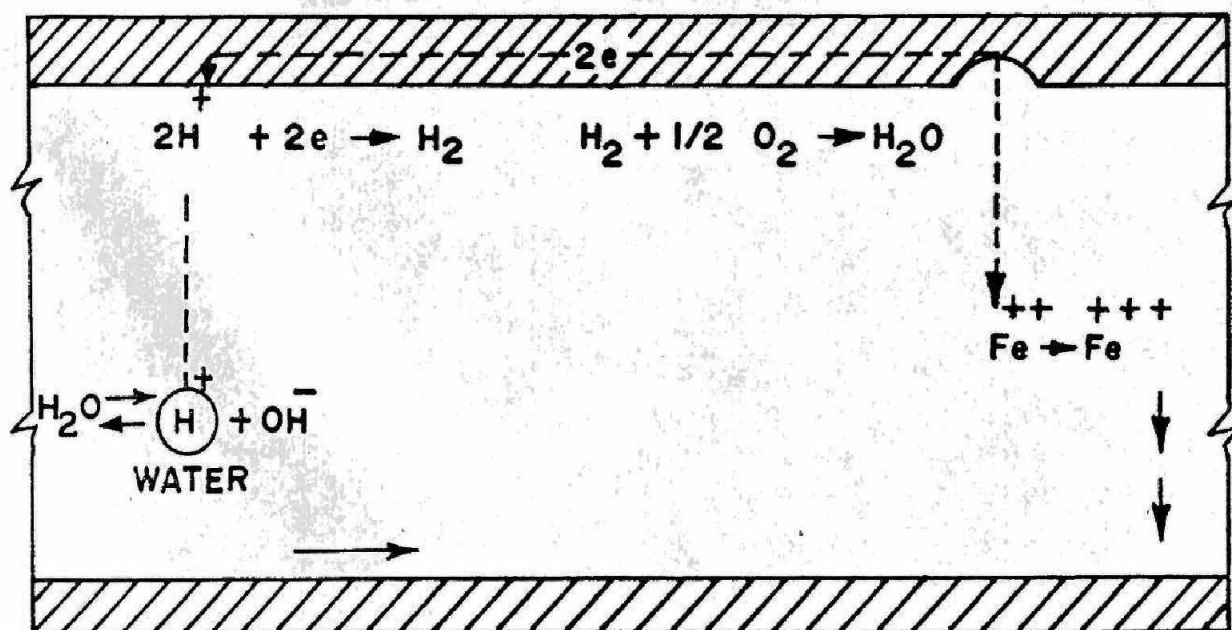
**CORROSION WILL BE NOTICED IN THE WET SOIL AREA**

FIG. 12.



WHEN BACKFILLING, IF LARGE CLOUDS ORIGINALLY FROM DIFFERENT DEPTHS REST DIRECTLY AGAINST PIPE, THE CONTACT AREA TENDS TO BE ANODE & ADJACENT PIPE AREA CATHODE.

FIG. 13.



PITTING ACTION IN A PIPE WITH FLOWING WATER

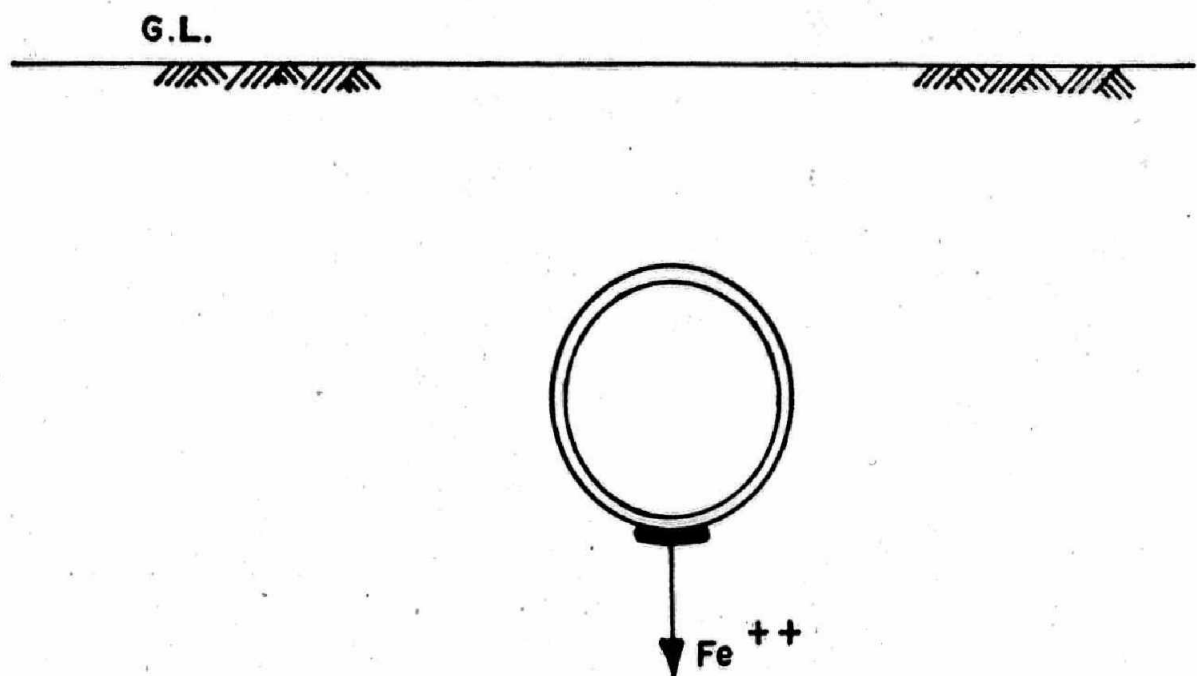
FIG. 14.

- (i) Iron (Fe) goes into solution as  $\text{Fe}^{++}$ , giving off free electrons.
- (ii)  $\text{H}^+$  from water combine with the free electrons from above to give  $\text{H}_2$ .
- (iii)  $\text{H}_2$  gas may bubble off depending on pH or combine with the dissolved oxygen in flowing water. Oxygen is required for reaction with  $\text{H}_2$  or else "polarisation" occurs and further corrosion stops. (For this reason,  $\text{H}_2$  helps to deoxygenate boiler feed waters.)
- (iv)  $\text{Fe}^{++}$  ultimately oxidises to  $\text{Fe}^{+++}$  and precipitates down as rust.

Corrosion takes place where the metal goes into solution and gradually becomes visible in the form of pitting. Since corrosion is a chemical reaction, a rise in temperature increases the speed of reactions and hence gives faster corrosion. For this reason, boiler tubes are more liable to suffer from pitting than cold water pipes.

In a pipeline, pitting action takes place wherever the conditions are more favourable for the metal to go into solution. The lower the ion-concentration the more the chance for the metal at that point to ionise and dissolve. If there are two areas with different ion-concentrations a galvanic voltage will develop between them. These areas are called "concentration cells".

Some examples given in Figs. 15 & 16 illustrate how galvanic corrosion can be expected in certain places such as, for example, the dead ends of a distribution system, or the lower surface of an underground pipe owing to "concentration cell" formation.



**MORE CORROSION OCCURS ON LOWER SURFACE OF PIPE WHERE  
USUALLY OXYGEN IN SOIL IS LESSER THAN ON THE UPPER SIDE.**

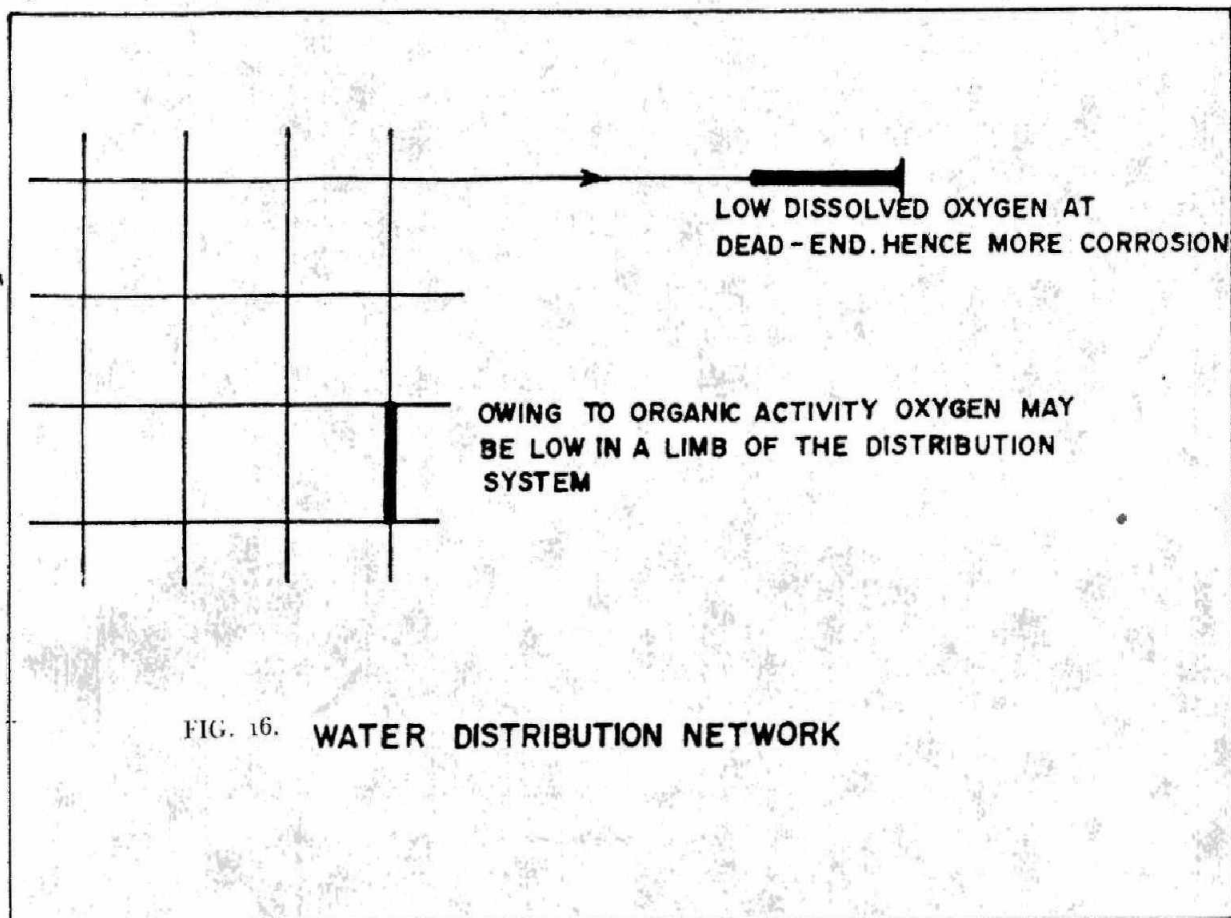


FIG. 16. WATER DISTRIBUTION NETWORK

## ELECTROLYTIC CORROSION

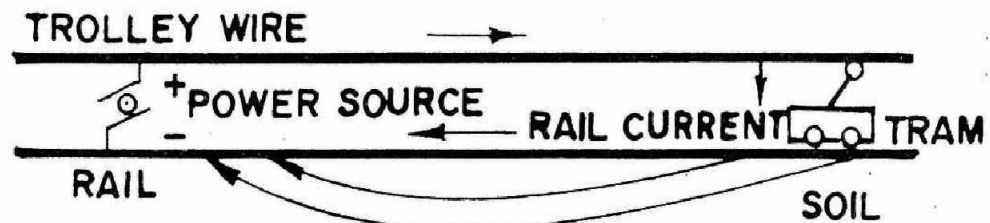
Electrolytic corrosion, or electrolysis, is man-made. Its usual source is stray currents from electric railways, most of which have a d-c generator supplying power to the trains through an overhead trolley wire. The current is supposed to return to the generator through the rails. Actually, because of high resistance in poorly connected rail joints, the current may leave the rails in favour of the lower-resistance paths offered by underground pipelines, cables, or structures running alongside a railway tract. Normally, no harm is done where the current enters the pipes, but corrosion does occur where the current leaves the pipe to return to the d-c generator, because, from this section, the current carries particles of metal with it. (Steel is destroyed at the rate of 20 lbs per ampere year).

Wherever electrolytic corrosion occurs it is the most severe form of corrosion and considerable losses to water mains can occur in the vicinity of surface of underground railways and trams. The danger can be quite high in cities which are gradually discontinuing their tram services. Here the trams may be discontinued in certain areas of the town but the underground rails may be retained for ensuring the return current. Such rails tend to be neglected and may offer considerable resistance to the passage of current.

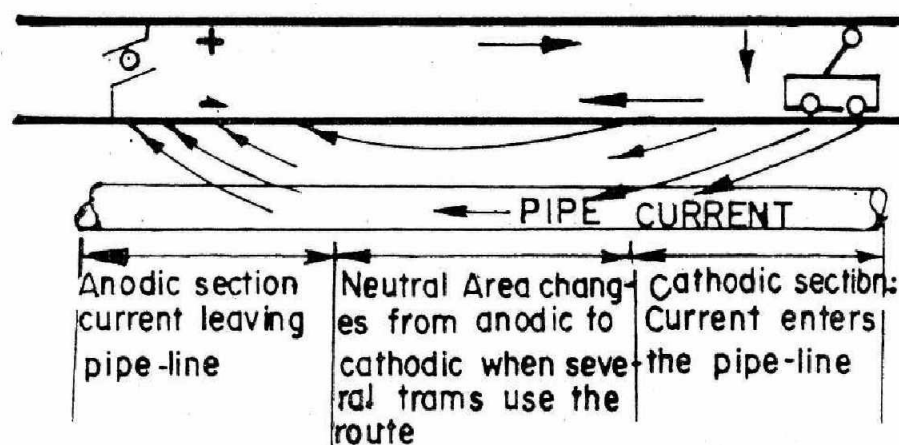
A method of control of electrolytic corrosion is the provision of proper metallic bonding and other protective measures between the d-c generating sub-station and the water mains in the near vicinity. Corrosion occurs where the current leaves the pipe and travels through the soil towards the d-c generating station. If a metallic bond is provided the current would leave the pipe only through this direct bond and hence corrosion would be avoided.



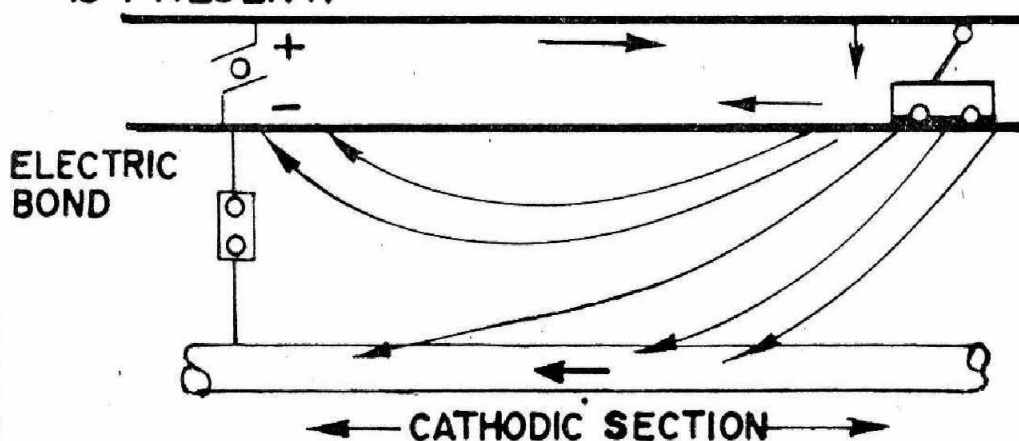
**CURRENT DISTRIBUTION WITH AND WITHOUT ELECTRIC BONDING WHEN STRAY CURRENTS ARE PRESENT.**



**CURRENT DISTRIBUTION IN EARTH WHEN NO PIPELINE IS PRESENT**



**CURRENT DISTRIBUTION IN EARTH WHEN PIPE IS PRESENT.**

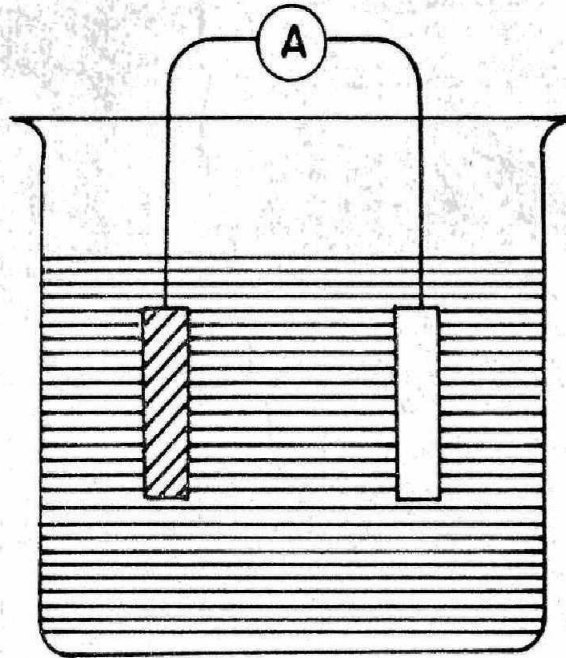


**CURRENT DISTRIBUTION IN SOIL WITH ELECTRIC BOND**



## STRESS CORROSION

Stress corrosion of metals is usually caused by local stresses in the material. For example, if two identical pieces of steel are placed in a common electrolyte (Fig. 18) with the only difference that one piece is hammered, or polished, while the other is not, a current will flow between them when the circuit is closed. Fabricated pipes are bound to have innumerable points of different internal energy levels on their surfaces. Similar differences will also occur at pipeline joints. For this reason, more corrosion will be noticeable near pipeline joints (welded or rivetted) and expansion joints. Stress corrosion can also be caused by differences in temperature between different parts of an installation.



**STRESS CORROSION EVIDENT IF TWO STRIPS OF IDENTICAL METAL INSERTED IN AN ELECTROLYTE, ONE HAMMERED & THE OTHER NOT. HENCE, DIFFERENT INTERNAL ENERGY LEVELS.**

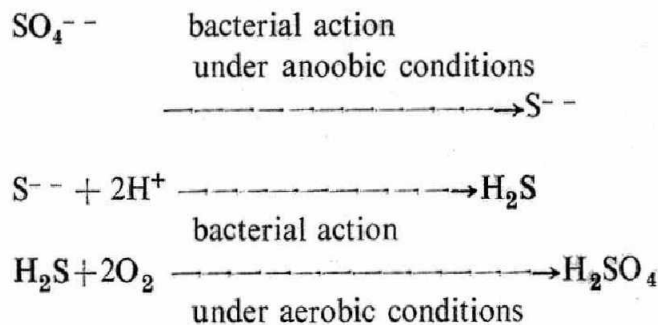
FIG. 18.

Stamped or embossed numbers of metal plates or machines when filed off will reappear when treated with an etching agent, because the stamped portions would corrode faster than the surrounding metal. Metals under stress are not however always more corrosion susceptible. Uniformly distributed stresses normally do not impair corrosion resistance.

## BIOCHEMICAL CORROSION

Biochemical corrosion results from changes in soil resistivity resulting from chemicals produced by bacterial action. At present, sulphate-reducing bacteria appear to be the major cause of extensive corrosion of this type in soil and water. The metabolic products of these bacteria act to combine any available sulphur with water, forming sulphurous and sulphuric acid, an excellent electrolyte which accelerates any possible galvanic action. There seems to be no particular relation between soil

resistivity and this bacteriological action, and, accordingly, jointing material containing sulphur should not be used unless it is actually tested in soil samples taken from the pipeline excavation. Because such tests are very expensive, it would be better to discontinue use of any sulphur-bearing jointing material. Anaerobic environments tend to encourage sulphate-reducing bacteria and problem areas can be encountered in tidal marshes, sewage pumping, sludge handling and sludge digestion.



## CONCLUSION

The various factors which affect corrosion have been discussed with special reference to water and waste water engineering. In conclusion, the severity of corrosion depends upon various factors which may be summed up as follows :

1. Relative position of metals in galvanic series
2. Size of anode area with respect to cathode area
3. Location of anode with respect to cathode
4. Resistance of circuit
5. Type of composition of electrolyte
6. Conductivity or resistivity of electrolyte
7. Uniformity of electrolyte
8. Depolarising conditions

A knowledge of these factors would enable the engineer to avoid those conditions which would be likely to accelerate corrosion. While corrosion is, no doubt, a natural phenomenon, man-made acceleration of the rate of corrosion must be avoided.