Chapter 7

Reduction of Corrosion

7.1 Introduction

Corrosion is a chemical reaction whereby the iron in a pipe (or the iron in steel pipe) combines with oxygen to form various types of oxides. These oxides will then flake an fall off and over time the pipe becomes eroded. This is obviously a serious problem for the water industry.

In this section we explain how Hydropath Technology can reduce the corrosion on the inner surface of a pipe. There are a few different effects that contribute to these.

- The use of hard versus soft water
- Bacterially induced corrosion
- Formation of magnetite
- The Skin Effect

The section on the skin effect is rather technical and is probably unnecessary for most people. Reading the introduction to this section will generally be sufficient.

7.2 Hard versus soft water

There is a very obvious and immediate benefit of Hydropath technology with regards the corrosion rate. This is the fact that use of the technology allows a system to be run using hard water.

Soft water (*i.e.* water with the scale ions removed) is very corrosive; the reason for this can be thought of in a number of related ways. One way to think of this is that soft water has a lower pH, *i.e.* is more acidic, and therefore more able to cause corrosion. Another way to think of it is that soft water has "less stuff in" and therefore wants to take in (dissolve) the metal of the pipe.

Running with Hydropath technology allows a system to be run using hard rather than softened water, with all the consequent benefits for corrosion reduction. Of course, this benefit only occurs for systems that are changing from soft to hard water, but even if systems are already running on hard water (and dealing with the limescale by *e.g.* cleaning) then Hydropath technology has a number of benefits.

Figure 7.1: A tube-in-shell heat exchanger shown before the application of Hydropath (left), and after (right) where not only has the limescale been removed but magnetite has begun to form as a hard black deposit.

7.3 Bacterially induced corrosion

A slightly different form of corrosion is *bacterially induced corrosion* or BIC. This occurs when particular types of bacteria attack the pipe and cause pinholes. The bacteria actually consume veins of carbon inside the steel, and eat their way along these veins to the surface of the pipe.

These bacteria can be particularly hard to treat by chemical means, as they have squirmed their way inside the metal, and the layer of bacteria on the inner surface of the pipe can act as a protective barrier for the rest of the bacteria.

Hydropath technology acts to reduce the corrosion by eliminating bacteria and causing the bacteria on the surface of the pipe to detach.

7.4 The formation of magnetite

An additional way Hydropath technology acts against corrosion is to alter the way the oxides form. One type of iron oxide is known as magnetite. Normally this forms as a flakey substance, which then detaches from the pipe, allowing further corrosion to continue.

When hydropath technology is applied to a pipe, the magnetite forms in a rather different manner. Instead of forming as a flakey substance, the magnetite forms as a hard, black layer on the pipe surface. Because this magnetite has formed as a hard layer rather than as flakes, it acts as a barrier between the iron in the pipe and the water (particularly the oxygen in the water) and stops further corrosion.

In this sense it causes the magnetite to act like the oxides of other metals - for example copper and zinc. Aluminum, when freshly cut, has a shiny appearance that soon fades to a dull grey. This is because a newly-cut surface will expose aluminium, which then turns to aluminium oxide as it is exposed to the oxygen in the air. Similarly, eventually the orange of copper will (if left exposed to the outside elements) turn green. In neither case do we usually think of these cases as 'corrosion', even though they are a metal turning into an oxide. This is because the process is self-limiting. The Statue of Liberty has not corroded away, even though she *has* turned green!

Figure 7.2: After an initial green layer of copper oxide formed on the surface, the copper of the Statue of Liberty has not corroded further.

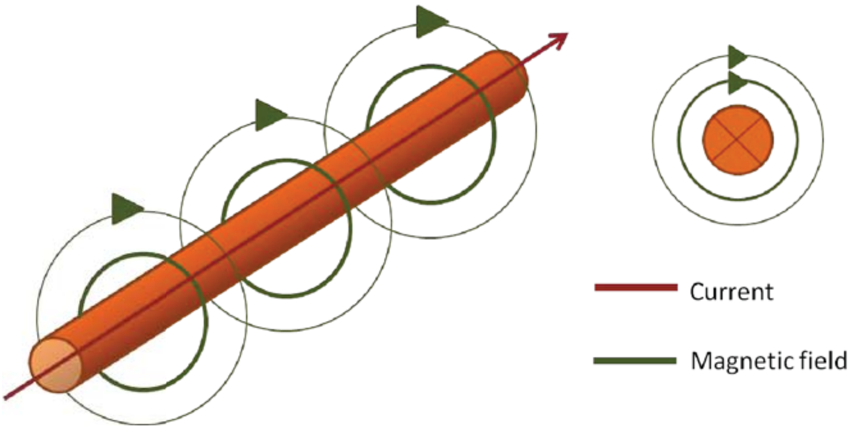

Figure 7.3: The magnetic field of a wire. The circular green lines indicate magnetic field, and the red arrow indicates the direction of the current. The diagram on the right shows the wire end-on. The little cross indicates that the current is flowing "into the page" (the cross represents the feathers of an arrow as seen from behind!).

7.5 The skin effect

To understand the skin effect and how it can reduce corrosion we have to discuss magnetic fields, what the magnetic field of a wire and of a pipe looks like, how this affects the current, and how the current distribution can influence the corrosion rate.

- Magnetic field in wires
- AC magnetic field in pipes
- The Skin Effect
- Reduction of corrosion

Much of the discussion in this section is rather technical, and is only for those who wish a more in-depth picture. Only the last two sections are really essential, and the whole section can be summarised as follows: "AC current only flows on the outside of a conductor (*e.g.* a pipe). Chemical reactions require electron transfer, and any free electrons are removed from the interior surface of the pipe by the skin effect. The skin effect therefore stops the chemical reactions that cause corrosion."

7.5.1 The magnetic field of a wire

We first need to look at the magnetic field around a wire. Initially, let us simply consider a thin wire carrying a constant direct current (DC). The magnetic field is given by Ampere's Law, and it consists of a series of magnetic lines that wrap the wire as shown. The direction of the field lines is given by the "right hand grip rule" - make a fist, point your thumb in the direction of the current, and your fingers will show the direction of the magnetic field. This field is shown in fig. 7.3

When two wires are nearby, the field lines will distort as shown in figure 7.4a, *i.e.* the lines will be a distorted double-loop shape, but the field lines will still run clockwise. Adding extra wires will distort the field further.

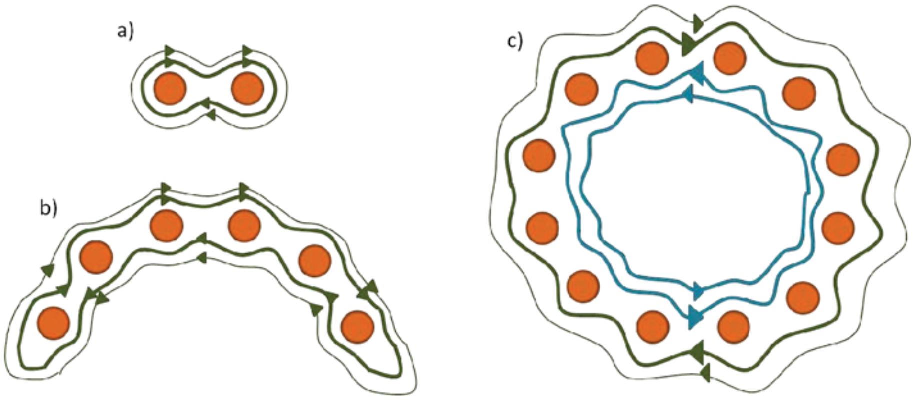

Figure 7.4: a) The magnetic field of two nearby wires. The fields distort as shown, with the direction indicated by the arrows. b) Placing more wires together will distort the signal further. c) If many wires are combined into a cylinder (to make a "pipe made of wires") the field will be as shown, with the field lines running clockwise outside the pipe and anti-clockwise inside the pipe.

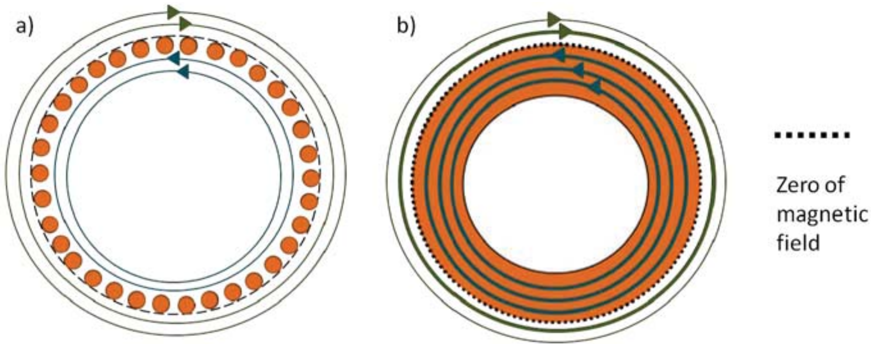

Figure 7.5: Combining many wires into a cylinder (a) makes a good approximation to a pipe (b). The field lines are concentric, going clockwise outside and anti-clockwise inside the pipe. The direction of the field changes so we know that at some point the field strength must pass through zero.

7.5.2 Magnetic field in a pipe

We can now see what the field in a pipe will look like. Imagine taking several wires and making them into a cylinder (so the ends of the wires are arranged in a circle when viewed end-on). The field will distort further as shown in figure 7.4c. We find that the field will run clockwise outside the pipe but anticlockwise inside the circle of wires.

If we have a large number of wires (fig. 7.5a) we have a good approximation for a pipe (fig. 7.5b). Now, the field outside is going clockwise and the field inside is going anti-clockwise. Now, the fact the field goes from clockwise to anticlockwise means that at some point the field must go to zero - this point is at the surface of the pipe.

7.5.3 Back EMF and the skin effect

We have established that at the outer surface of the pipe the magnetic field goes to zero. What happens where the field is not zero? Inside the material of the pipe, we have a magnetic field. The important point is that the field is not static, but changing. Now, a *changing* magnetic field *induces* an electric field (remember that this is how a transformer works - see section 1.3). Which direction does this field operate in? Well, an induced electric field always acts to oppose the *current that causes it*. It is called a "back EMF" because it "acts back" to try to stop the current that caused it in the first place. In this respect it acts as a resistance or a bit like a kind of friction.

The upshot is that away from the surface where the field is strong, the current feels a force opposing it. In fact, the force it feels is such that the current is exactly canceled. Near the surface, the field drops to zero and so there is no opposition to the current. Thus we see that an AC current flowing through a conductor will tend to flow at the surface, with no current flowing in the center.

The width of the region where the current flows is called the skin depth δ (delta). This changes depending on the frequency and the material - the higher the frequency, the smaller the skin depth. Nature does not like change so things that change faster are opposed more! In copper, the skin depth at the frequency of Hydropath units is around 0.2mm. Thus, although the voltage is present all through the pipe (and the water), the *current* is only present in a region within half a millimeter of the pipe surface.

7.5.4 Reduction of corrosion due to skin effect

When AC current flows through a pipe, the current flows just on the outside of the pipe, and there is no current flowing on the inside of the pipe. We now go on to see how this can reduce the corrosion that occurs on the inside of the pipe.

Corrosion is caused by chemical reactions at the inner surface of the pipe between the pipe material and the water. Metal atoms in the pipe material become dissolved in the water. To do this they need to change from neutral atoms to charged ions - i.e. they need to lose an electron. The electron is then transferred to ions within the water.

Figure 7.6 shows one such reaction. Water containing Hydrochloric Acid (HCl) passes through a pipe that is *galvanised* (*i.e.* coated with zinc Zn). Now, when the corrosive reaction occurs, atoms of zinc in the metal become dissolved in the water. In order to dissolve, they have to give up an electron to become charged ions. (An ion is simply an atom that has lost or gained an electron so that it has an electric charge.) Now, this means there are two "spare" electrons in the metal. The metal does not like having too many electrons, and so transfers them back to the water by combining them with hydrogen ions (from the hydrochloric acid) to make hydrogen gas. At the end of this process, both the water and the metal have the same number of electrons as they started with and the process can repeat. With the Hydropath unit in place, any electrons that are released into the pipe by dissolution of the zinc are swept down the pipe by the Hydropath signal. Then by the skin effect they are forced to the outside of the pipe. This means that there are no electrons available for the chemical reactions to continue, blocking the reaction chain. This means the reaction cannot continue and therefore the corrosion stops.

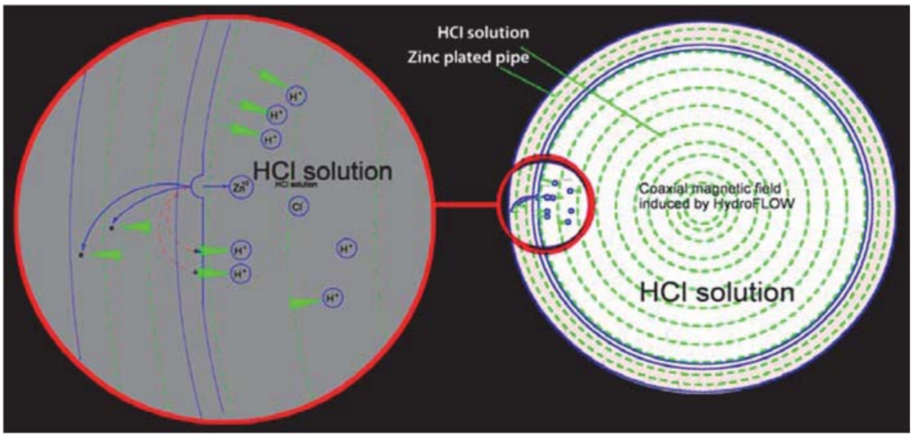

Figure 7.6: A diagram showing how the skin effect reduces corrosion on the inner surface of the pipe. In the zoomed-in plot