CORROSION MONITORING PRIMER

Rohrback Cosasco Systems, Inc.
Corrosion is a natural process which can attack any metal or alloy under the right conditions. Since metals are so widely used in today's modern world, corrosion is all around us and can affect our lives in many ways. Corrosion eats away at steel in outdoor furniture and automobile bodies, causing unattractive appearance and eventual failure if it is not treated. Corrosion also causes tarnishing of silver, rusting of iron cookware, etc. Of far greater importance, corrosion of steel rebar in reinforced concrete can proceed out of sight and suddenly (or seemingly so) result in failure of a section of highway, collapse of electrical towers, damage to buildings, etc., resulting in significant repair costs and endangering public safety. Perhaps most dangerous of all is corrosion in the process industries. Corrosion-related failures in the process industries all too often result in catastrophic failures of piping and equipment which can cause explosions, fires, and the release of toxic materials into the environment. Corrosion is not only dangerous, but costly, with annual damages in the billions of dollars! If this is difficult to believe, consider some of the direct and indirect effects of corrosion which contribute to these costs:

1. Replacement of corroded equipment
2. Unscheduled plant shutdowns for replacement
3. Process upsets resulting from corrosion
4. Product contamination
5. Product loss from a vessel that has corroded
6. Otherwise unnecessary preventive maintenance
7. Overdesign to allow for corrosion
8. Inability to use otherwise desirable materials

While the economic costs are frightening, we must consider them to be of secondary importance to the potential loss of life and damage to the environment — problems which can have widespread effects upon modern industrial businesses.

It is essential, therefore, for operators of industrial process plants to have a program for controlling corrosion. For such a program to be effective, it should facilitate safe operation of the process unit over its intended life and maximize the economic return to the owner. To accomplish these objectives, a corrosion control program should be considered: characteristics (toxicity, flammability, etc.) of the process; selection of construction materials; control of operating conditions; addition of neutralizing or inhibition chemicals; and monitoring to ensure that anticipated results are obtained.

Selection of construction materials almost always involves a compromise between expensive and often hard-to-obtain alloys which are highly resistant to corrosion caused by the process and less expensive, more available materials which are more susceptible to corrosion. Often, a material can have acceptable resistance to a process at design conditions but corrode at very high rates during process upsets. In these cases, on-line monitoring and control of process operating parameters and direct on-line monitoring of corrosion rates are essential to an effective program. Several types of materials are often used in the construction of process facilities. For instance, corrosion-resistant alloys are used in particularly susceptible equipment (heat exchanger tubes, for example) with less expensive materials used elsewhere in the process. It is, of course, essential that the behavior of various metals in the anticipated operating environment be known in advance of selection. While there is a vast array of available literature on the subject, laboratory and field trials are often performed to verify theoretical predictions or try out new materials before a commitment is made to use them in the process unit.

Sometimes a less expensive material, which would otherwise be unacceptable due to low corrosion resistance, can still be the best choice when used in conjunction with a chemical corrosion inhibitor injection system or anodic or cathodic protection systems.

As explained in Chapter 2, there are many operating and environmental parameters which can affect the corrosion of a metal - and changes in any of the parameters can greatly accelerate the corrosion rate. Without early detection and accurate measurement of the impact of these changes, costly and potentially hazardous damage can occur before
corrections are made. Accurate and timely corrosion measurement is therefore an essential part of almost all corrosion control programs. The technology of corrosion detection and measurement has advanced rapidly in the recent past so that today's corrosion engineer has many proven techniques available for both laboratory analysis and on-line monitoring to devise and manage an effective corrosion control program for his or her particular plant, process, and environmental conditions.
Chapter 2
Corrosion Mechanisms

Corrosion is an electrochemical process in which metal atoms are oxidized to form positive ions (cations) while other chemical species (e.g. O₂, H₂O, H⁺ and other cations) are reduced. This results in a flow of electrons from one site on the metal surface to another. Consider the corrosion of iron in hydrochloric acid as depicted in Fig. 2-1.

![Fig. 2-1 Diagram of Oxidation and Reduction Processes in a Hydrochloric Acid/Iron Corrosion Cell](image)

The overall reaction of Fig. 2-1 is described by equation No. (1)

\[
Fe + 2 \text{HCl} \rightarrow Fe\text{Cl}_2 + \text{H}_2 \uparrow \quad (1)
\]

This reaction can be considered as the sum of two different reactions occurring at different sites on the metal surface:

\[
Fe \rightarrow Fe^{++} + 2e^- \quad (Oxidation) \quad (2)
\]

\[
2H^+ + 2e^- \rightarrow H_2 \quad (Reduction) \quad (3)
\]

A site where oxidation occurs is defined as an Anode and one where reduction takes place as a Cathode. The anodic and cathodic areas together form a Corrosion Cell and the reactions at each site are a Half-Cell. The hydrochloric acid in this reaction is the Electrolyte, a fluid containing ions which migrate in an electric field. There must be an electrolyte for corrosion to occur. The current which flows in the corrosion cell per unit area is referred to as the Corrosion Current Density (i_corr). Referring to Fig. 2-1, please note that one iron cation is released into the HCl (corroding the metal) for each 2 electrons which flow in the corrosion cell. Since \( i_{corr} \) is a measure of current (electron) flow per unit area per unit time, it is directly related to units of Metal Loss per unit time, which is how corrosion rate is expressed (mils per year of metal thickness reduction, for example) so \( i_{corr} \) is a good measure of corrosion rate in the cell.

Each half-cell reaction has a characteristic potential when compared to a standard reference electrode. While there are several measurement techniques available, we will use Redox Potential which is the potential of the half-cell reaction when it is at equilibrium in a solution of its own ions compared to the potential of a standard hydrogen reference electrode (which has an arbitrarily established potential of 0 volts).

To be in equilibrium means that an equal number of ions are being reduced as are being produced by oxidization at any given time. Considering the iron half-cell of Fig. 2-1, this means that reactions (2) and (4), as shown below, are proceeding at the same rate:

\[
Fe \rightarrow Fe^{++} + 2e^- \quad (Oxidation) \quad (2)
\]

\[
Fe^{++} + 2e^- \rightarrow Fe \quad (Reduction) \quad (4)
\]
It can be demonstrated that each of these reactions has a potential-current relationship which can be drawn as a straight line on a semi-log graph, as shown in Fig. 2-2:

![Fig. 2-2 Potential-Current Curves of Iron Oxidation and Reduction Reactions](image)

As shown in Fig. 2-2, the point where these reactions cross is the point of equilibrium and is, by definition, the redox potential of the half-cell. The redox potential of commonly encountered metals is shown in Table 2-1.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Redox Potential</th>
<th>Active End</th>
<th>Passive End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>K ↔ K⁺ + e⁻</td>
<td>-2.92</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg ↔ Mg⁺² + 2e⁻</td>
<td>-2.38</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al ↔ Al⁺³ + 3e⁻</td>
<td>-1.66</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn ↔ Zn⁺² + 2e⁻</td>
<td>-0.76</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr ↔ Cr⁺³ + 3e⁻</td>
<td>-0.71</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>Fe ↔ Fe⁺² + 2e⁻</td>
<td>-0.44</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni ↔ Ni⁺² + 2e⁻</td>
<td>-0.23</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2H⁺ + 2e⁻ ↔ H₂</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Cu ↔ Cu⁺² + 2e⁻</td>
<td>+0.34</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>Ag ↔ Ag⁺ + e⁻</td>
<td>+0.80</td>
<td></td>
</tr>
<tr>
<td>Platinum</td>
<td>Pt ↔ Pt⁺² + 2e⁻</td>
<td>+1.20</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Au ↔ Au⁺³ + 3e⁻</td>
<td>+1.42</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1 Redox Potentials of Metals
The more negative the redox potential is the more reactive is the metal. As shown in Fig. 2-2, the redox potential of the iron half-cell is -0.44 volts.

*In order for corrosion to occur there must also be a cathodic reaction.* Referring once again to Fig. 2-1, the cathodic reaction involves the reduction of hydrogen cations [Equation (3)] to form hydrogen gas.

Note that iron is not involved in the cathodic reaction. This is a standard hydrogen half-cell and has a redox potential of zero volt. A list of the more common cathodic reactions and their redox potentials is presented in Table 2-2.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Redox Potential Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5) Hydrogen Ion Reduction</td>
<td>(2H⁺ + 2e⁻ ↔ H₂)</td>
</tr>
<tr>
<td>(6) Oxygen Reduction in Acid Solutions</td>
<td>(O₂ + 4H⁺ + 4e⁻ ↔ 2H₂O)</td>
</tr>
<tr>
<td>(7) Oxygen Reduction in Base or Neutral Solutions</td>
<td>(O₂ + 2H₂O + 4e⁻ ↔ 4OH⁻)</td>
</tr>
<tr>
<td>(8) Metal Ion Reduction</td>
<td>(Fe³⁺ + e⁻ ↔ Fe²⁺)</td>
</tr>
<tr>
<td>(9) Metal Deposition</td>
<td>(Cu²⁺ + 2e⁻ ↔ Cu)</td>
</tr>
</tbody>
</table>

*Table 2-2 Redox Potentials of Cathodic Reactions*

A graph similar to Fig. 2-2 can be drawn for each cathodic reaction, and at equilibrium the oxidation and reduction reactions are proceeding at the same rate.

Superimposing the graph of Fig. 2-2 and the potential curves for the hydrogen half-cell gives us a polarization diagram for the complete corrosion cell of Fig. 2-1, as shown in Fig. 2-3 below:

![Fig. 2-3 Polarization Curves for Iron-HCl Corrosion](image)

Polarization is defined as the change in the potential of an electrode from the open circuit potential (i.e. at zero current flow) to the potential resulting from a current flow. The redox potential of any half-cell is the same as its open circuit potential, since there is no net current flow in the half-cell.
However, we know that once the iron and hydrogen half-cells are connected electrically, corrosion current flows in the cell. Since the two half-cells are now connected through metal with negligible electrical resistance, the two half-cells must now be at the same potential for all practical purposes. Fig. 2-3 illustrates that this occurs where the iron oxidation and hydrogen reduction curves cross.

The point where the curves cross is defined as the Corrosion Potential, or $E_{\text{corr}}$, of the cell. Each half-cell has been polarized due to the flow of current in the cell, $i_{\text{corr}}$. It may also be seen from Fig. 2-3 that the reverse reactions in each half-cell (iron reduction and hydrogen oxidation) proceed at much lower than equilibrium rates and are usually negligible (note the logarithmic scale on current) but they do not disappear! The Tafel Slope, used in electrochemical measurement techniques, is the slope of the straight line for the anodic or cathodic reaction.

Note that the redox potential of the anodic iron reaction is more negative than that of the cathodic hydrogen reaction. In all cases, if the metal has a more negative redox potential than the cathodic reaction, it tends to be corroded. We would not, therefore, expect copper with a redox potential of +0.34 volts to be corroded in a de-aerated HCl solution since the redox potential of the metal half-cell is more positive than the only possible cathodic reaction, hydrogen reduction. If the HCl solution is free of dissolved oxygen, our prediction holds true - no corrosion occurs. But in the presence of oxygen, together with the hydrogen cations from the acid solution, the cathodic reaction shown in Equation (6) in Table 2-2 can occur. Now the redox potential of the copper half-cell is more negative by 0.89 volts and the copper corrodes.

**NOTE:** Although redox potentials are generally useful in predicting the corrosion tendency of a metal in a specific environment, they cannot be used to predict corrosion rates since other factors may inhibit or enhance the corrosion rate.

Returning once again to the iron-HCl corrosion cell in Fig. 2-1, we might expect for corrosion to eat a hole through the metal at the anode, leaving the cathodic areas untouched. This does not happen, however. In an oxygen-free HCl solution Uniform Corrosion (sometimes referred to as General Corrosion) actually occurs with the iron being corroded away in a more or less uniform manner over the entire surface. To understand why this happens we must look at the effect of the cathodic reaction on the concentration of hydrogen cations. As the reaction proceeds, hydrogen cations are consumed to form hydrogen gas. This causes a reduction in hydrogen cation concentration at the cathode compared with the anode, where no depletion of hydrogen cation occurs. But it can be shown that an area with a greater concentration of hydrogen cations tends to be cathodic to a site with a lesser concentration. Thus, the anode and cathode are constantly reversing as a direct result of the effect the reaction has on hydrogen cation concentration. These changes occur continually on a microscopic level so the whole surface appears to be corroding at once.

Now that we have a basic understanding of the electrochemical nature of corrosion and the behavior of metals in corrosive fluids, let’s examine a Galvanic Corrosion Cell. We are all familiar with the corrosion of ferrous metals (e.g. steel) when in contact with copper-based materials (e.g. brass).

Why does the iron corrode leaving the copper alone? From Table 2-1 we see that the redox potential of copper is +0.34 and of iron -0.44, a difference of 0.78 volts with iron by far the most negative. Since the more negative area is anodic, the steel corrodes, and the brass is protected.

**Caution:** The potential of a metal compared to a reference electrode depends upon its environment. A Galvanic Series lists metals in order from the most active to the most noble in a specific environment (e.g. seawater). While the relative position of two metals in a galvanic series will usually be as predicted by their redox potentials, there are some cases where this does not hold true, i.e. where two metals will switch positions in a given environment. For example, zinc is usually anodic to steel at ambient temperatures but can become cathodic to steel at elevated temperatures!

Cathodic Protection (CP) operates according to the same principle. Consider Fig. 2-4 where a magnesium Sacrificial Anode is connected to a buried steel pipeline. The open circuit potential of the magnesium anode is more negative than that of the steel pipe. This voltage difference causes conventional (positive) current to flow from the anode, through the soil (electrolyte), to the pipe (cathode). The electrical circuit is completed by the anode lead wire attachment to the pipe.
The flow of cathodic protection current causes the magnesium anode to corrode (oxidation), while the steel pipe is protected from corrosion (reduction).

Cathodic protection is also commonly employed by Impressed Current Systems. The electrical circuit is similar to that of a sacrificial anode system except for the fact that a DC power supply and impressed current anodes are used. The DC power supply is most often a transformer-rectifier that converts AC power to DC power much like a battery charger. The positive terminal of the transformer-rectifier is connected to the impressed current anode and the negative to the pipeline. In this case, the impressed current anode is made of material, such as high silicon iron or mixed metal oxide coated titanium that has a very low rate of consumption and therefore a long service life. Cathodic protection is achieved when sufficient current flows from the anode, through the soil, onto the surface of the pipe.

Although a complete discussion of CP is beyond this Primer, the following points are worthy of note:

1. CP is a simple, proven, economical corrosion control technology.

2. When the CP anode is placed in the soil (electrolyte) outside the pipe, such as in Fig. 2-4, the flow of CP current only protects the outside of the pipe.

3. CP is used for corrosion protection of metal structures buried in soil, submerged in water and embedded in concrete.

4. The effectiveness of a CP system in controlling corrosion can be easily monitored by measuring the structure-to-electrolyte potential in accordance with established industry standards.

More information on Cathodic Protection can be obtained by contacting Rohrback Cosasco.

Oxygen in a solution dramatically increases the rate of corrosion due to its effect on cathodic reactions and can also be an important contributing factor in some of the more dangerous forms of corrosion, Pitting and Crevice Corrosion, especially in more active metals. Crevice corrosion occurs in crevices found at gaskets, lap joints, bolts, rivets or under deposits of scaling materials, corrosion products or dirt. Pitting is similar to crevice corrosion except the initial pit usually results from failure of a passivating film at one point or from some other similar surface imperfection. Unlike crevice corrosion, therefore, its location cannot be predicted. The oxygen concentration in a crevice or pit is lower than on the rest of the surface because the fluid in the crevice or pit is stagnant while the majority of the surface is exposed to fluid flow which tends to replenish the dissolved oxygen supply.

Unlike uniform corrosion, however, the cathodic and anodic sites do not change location in such Oxygen Concentration Cells, so the pit or crevice remains anodic and corrosion proceeds much more quickly at that site. In many processes, therefore, particularly high-pressure water systems (e.g. oil field waterflood and boiler feedwater
systems), equipment and/or chemicals are added to remove dissolved oxygen. Other types of Concentration Cells (e.g. metal ion) can have similar effects.

Another important concept is **Passivation**. In some metals, initial corrosion produces a thin coating on the surface which protects the underlying metal from further corrosion. This is why aluminum is suitable for use outdoors; an aluminum oxide film makes the metal passive to further corrosion. Stainless steels derive their resistance to corrosion from an oxide of chromium, the primary alloying component in stainless steels. **Anodic Protection** works by making the potential of the metal even more positive (more anodic) than normal. Although we feel that intuitively this should increase rather than decrease corrosion, certain materials in certain environments (e.g. stainless steel in sulfuric acid) form very strong protective films when the anodic potential is maintained within a range of pre-determined values.

**Erosion Corrosion** occurs when high velocity fluid flow and/or flow of abrasive materials prevent formation of protective films, allowing fresh material to be continually exposed to the corrosive environment. Fretting and cavitation are each special forms of erosion corrosion.

**Area Effects** are also important, especially in galvanic and localized corrosion. Consider the difference between a cell with a very large anode area compared to the cathode and one in which the cathode is significantly larger than the anode. Since metal is corroded at the anode only, the rate of corrosion will be proportional to the rate at which the anodic reaction proceeds. For the anodic reaction to proceed, however, there must be corresponding cathodic reactions. The cathodic reaction therefore controls the rate of the overall reaction.

With a large cathode and a small anode, there is more surface area on which cathodic reactions may proceed so the anodic reaction proceeds at a much faster rate than if the reverse (i.e. large anode, small cathode) is true. Where use of dissimilar metals is unavoidable, therefore, it is desirable to use the more noble (cathodic) metal in the smallest possible exposed area relative to the anode.

Fig. 2-5 illustrates the most common types of corrosion. Many have already been discussed in detail. The others are described briefly below:

**Exfoliation** is characterized by the flaky, blistered appearance of the surface and is common in aluminum alloys.

**Selective Leaching** involves the removal of one element in an alloy; dezincification (the removal of zinc from brass alloys) is the most common example.

**Intergranular Corrosion** is a localized attack at the grain boundaries which proceeds much as pitting corrosion but along grain lines primarily due to small differences in metallurgical properties.

![Common Types of Corrosion](image)

**Fig. 2-5 Common Types of Corrosion**

**Heat Affected Zones (HAZ)** are locations in the base metal that have sustained sufficient heat during welding to have caused residual stresses or changes in the metals metallurgical structure.
**Stress Corrosion Cracking (SCC)** can occur when a metal is both stressed and exposed to relatively mild corrosive conditions, causing the metal to fail at applied stresses well below predicted mechanical failure levels. The most notable example is the cracking of austenitic stainless steels (e.g. type 316) when exposed to environments containing the chloride ion. SCC is an anodic process which can be reduced or eliminated through CP.

**Hydrogen-Induced Cracking (HIC)** is similar to SCC, and occurs under stresses which would not ordinarily lead to failure but which are made worse by corrosion processes. HIC is, however, a cathodic process in which the presence of atomic hydrogen (H+) is important. HIC occurs most often in environments containing poisons which inhibit the formation of hydrogen gas from atomic hydrogen at the cathode. Hydrogen sulfide (H₂S) is the most noteworthy of these poisons. Being a cathodic process, HIC is actually made worse by cathodic protection systems.

**Microbiologically-Influenced Corrosion (MIC)** is the result of the growth of bacteria and other biological organisms in a system, causing or worsening corrosive conditions. Generally, the types of corrosion encountered are similar to other forms of localized corrosion as discussed previously.
Chapter 3
Inspection and On-Line Monitoring of Corrosion

In this text, measurement of corrosion refers to any technique which can be used to determine the effects of corrosion:

1. while the facilities are in operation,
2. during shutdowns, and
3. while laboratory analyses are performed outside the process equipment.

On-line monitoring refers to a special group of measurement techniques which are suitable for use while the facility is in operation.

A comprehensive corrosion control program should include several techniques since no single technique is capable of providing all the information necessary in a timely manner. An overview of measurement techniques is presented below, with an emphasis on those techniques which are useful in practical online monitoring.

Radiography (X-ray) permits two-dimensional views of the piping or equipment walls and is suitable for detecting major flaws or a severe corrosive attack, when results are compared to an earlier (or baseline) study. Radiography is not suitable for detecting small changes in residual wall thickness due to accuracy limitations. Radiography is an inspection technique which requires specialized equipment and trained operators (usually provided by contractor personnel), and is not currently used in continuous on-line monitoring.

Ultrasonic Measurement techniques are similar to radiography in that specialized equipment is required and the techniques are almost exclusively used for inspection rather than on-line monitoring. There are several types of ultrasonic equipment: A-Scan provides a simple depth measurement from the exterior surface of a pipe or vessel to the next interface which reflects sound waves. Generally, this measures wall thickness, but A-Scan can be fooled occasionally by mid-wall pipe flaws. B-Scan instruments are much more powerful since they produce cross-sectional images similar to X-rays. C-Scan systems produce a 3-dimensional view of a surface using complex and expensive equipment. C-Scan systems can be very useful for large and critical surfaces such as aircraft skins, but are much less commonly used in process plants at this time because of cost, speed of coverage, and the very large quantity of data produced. Rohrback Cosasco’s ULTRACORR® utilizes high sensitivity ultrasonic technology to provide noninvasive monitoring of corrosion and erosion. Please consult Chapter 8 for a complete review of ULTRACORR® transducer and instrument.

Visual Inspection is rarely practical in a working process plant. However, whenever an opportunity presents itself, full advantage should be taken of it. Only through direct visual inspection can we be absolutely certain as to the condition of a process unit. Consequently, during any turnaround activities, internal visual inspection should be carried out to verify the results of on-line monitoring programs, choose new locations for monitoring, etc.

Destructive Analysis is less practical than visual inspection, but can be important and should therefore be performed as often as possible. The most common opportunity arises when piping is replaced for one reason or another. Sections of the replaced piping can then be examined for evidence of SCC, HIC, pitting, and any other unusual or unexpected corrosive activity.

Chemical Analysis is the monitoring of the chemical composition or other chemical characteristics of the process fluids. Since corrosion is an electrochemical phenomenon, chemical analysis can be a useful indicator of corrosivity of the process. In water systems, for instance, pH and conductivity are two parameters frequently monitored to give an indication of corrosivity. Increases in concentrations of corrodes such as H2S or CO2 can also be useful in determining corrosivity, but such measurements require more complex equipment and are usually made only infrequently.

Another technique which can be useful involves analyzing process streams for the presence of corrosion products, for example the quantity of metal and metallic compounds. This type of analysis can yield a good estimate of the
current metal loss from corrosion. When compared with previous data, it can be used to establish trends and approximate corrosion rates. Such data must be used with caution, however. For instance, "iron counts" in fluid produced by oil wells can be a good indicator of the amount of corrosion taking place on the casing, tubing, and completion equipment. If iron is present naturally in the producing formation, however, information gained from such chemical analysis will most likely be meaningless.

**Coupons** are the oldest and simplest device used in the monitoring of corrosion. Coupons are small pieces of metal, usually of a rectangular or circular shape (as shown in Fig. 3-1), which are inserted in the process stream and removed after a period of time for study.

![Fig. 3-1 Typical COSASCO® Weight-Loss Coupons](image)

The most common and basic use of coupons is to determine average corrosion rate over the period of exposure. This is accomplished by weighing the coupon before and after exposure (coupons must first be cleaned following exposure to remove corrosion products and any other deposits) and determining the weight loss. The average corrosion rate can easily be calculated from the weight loss, the initial surface area of the coupon and the time exposed. It is advisable to leave a coupon exposed for at least 30 days to obtain valid corrosion rate information. There are two reasons for this recommended practice. First, a clean coupon generally corrodes much faster than one which has reached equilibrium with its environment. This will cause a higher corrosion rate to be reported in a short test than is actually being experienced on the pipe or vessel. Second, there is an unavoidable potential for error as a result of the cleaning operation. Coupon cleaning procedures are designed to remove all of the deposits without disturbing the remaining uncorroded metal of the coupon. A small amount of the underlying metal is often removed with the deposits, however, and if the actual metal loss from corrosion is small (as would be the case in a short test) the effect of metal removed during cleaning would create a significant error. Care must be taken to correct for this effect. It should be recognized that a coupon can only provide corrosion rate data based on the total weight loss divided by the total time of exposure. A major shortcoming of coupon monitoring is that high corrosion rates for short periods of time may be undetectable and cannot be correlated to process upset conditions. If more frequent information on weight loss is desired, Rohrback Cosasco recommends use of **Electrical Resistance** monitoring systems. In many cases, it is recommended that coupons and electrical resistance probes be used in conjunction with each other.

One of the most important roles of coupons is to provide information about the type of corrosion present. Unlike electrical resistance probes, which only detect the amount of metal removed, coupons can be examined for evidence of pitting and other localized forms of attack. It is also important to remember that coupons or monitoring probes indicate the attack of the environment only at the point of exposure. It is important, therefore, that the coupon or probe be installed at **representative locations** as close as possible to critical points where corrosion measurements are desired (e.g. such as vessel or pipe walls, tube sheets, trays, lateral lines upstream to major tie-ins, etc.). Conditions of flow, temperature, concentration, etc., may change considerably only a few inches away from any given location, with resulting differences in corrosion rates. Coupons suspended in the center of a pipeline or vessel may corrode at different rates than coupons suspended near the wall of the vessel or pipe, for example. Since corrosive conditions can change significantly from one location to another, coupon data is best used for relative
comparisons (changes in the rate or characteristics of corrosion over time at a single point) and to obtain an approximate corrosion rate at a particular point in the system rather than to precisely calculate the corrosion rate.

There are several other types of coupons available for specialized analysis. These include disc coupons which can be mounted flush to the pipe wall; ladder coupon holders for mounting coupons at several depths at the same point in the piping; prestressed coupons which are for the investigation of possible stress-cracking mechanisms; and welded coupons which are used to detect preferential corrosive action on weldments.

**Hydrogen Probes** are used to detect the penetration of atomic hydrogen into metal, pipe, and vessel walls. As discussed in Chapter 2, this can occur in cathodic reactions in acid solutions, particularly in the presence of hydrogen sulfide. There are three basic types of hydrogen probes. The simplest and most common consists of a thin-walled carbon steel tube inserted into the flow stream with a solid rod inside the tube forming a small annular space. Hydrogen atoms small enough to permeate the carbon steel collect in the annular space and combine to form molecular hydrogen gas which is too large to pass back into the process. As hydrogen gas collects, pressure builds in the annular space and registers on a pressure gauge located outside the piping. "Patch Probes" operate identically except that the "patch" is sealed to the outside of the pipe or vessel and collects hydrogen atoms which penetrate the pipe wall. Rohrback Cosasco manufacturers COSASCO® hydrogen probes of both pressure-sensitive varieties. The third type of hydrogen probe is the palladium foil type electrochemical cell which produces an electrical output proportional to hydrogen evolution rate.

All three types of hydrogen probes provide useful information about changes in the corrosive environment in processes where hydrogen induced corrosion (HIC) is present or could occur. If pressure is accumulating at a certain rate per day and then increases by a factor of 10, this indicates a significant change which should be addressed. Rohrback Cosasco has not, however, found hydrogen probe readings to be suitable for direct determination of corrosion rate, only of changes in the process, and we recommend that they be applied carefully as part of a complete corrosion control program in applications where HIC is a concern.

**Electrical Resistance** probes and instruments are basically "automatic coupons" and share many characteristics with coupons, as discussed above, when it comes to advantages and limitations. Electrical resistance systems work by measuring the electrical resistance of a thin metal probe. As corrosion causing metal to be removed from the probe, its resistance increases. The major advantage of the electrical resistance method compared to coupons is that measurements can be obtained on a far more frequent basis and require much less effort to make. With automated systems, continuous readings are in fact made and sophisticated data analysis techniques are now available which permit the detection of significant changes in corrosion rate in just a few hours.

Rohrback Cosasco's CORROSOMETER® product line pioneered the electrical resistance technique over 30 years ago and remains the leader today with the widest range of probe types and alloys of construction and the most powerful instrumentation systems. Rohrback Cosasco’s MICROCOR® product line applies to any environment just as CORROSOMETER® but due to the high resolution and the rapid response it affords, its greatest benefit is for online monitoring where prompt corrective actions (chemical inhibition or modification of process parameter) can be made. Please consult Chapter 4 for a complete review of MICROCOR® systems, Chapter 5 for a complete review of CORROSOMETER® probes and instruments, and Chapter 9 for a discussion of Integrated Corrosion Monitoring System (ICMS™) product line capabilities.

**Linear Polarization Resistance (LPR)** is an electrochemical technique which measures the DC current ($i_{meas}$) through the metal/fluid interface which results from polarization of one or two electrodes of the material under study by application of a small electrical potential. Since $i_{meas}$ is related to $i_{corr}$ by a relationship based on the anodic and cathodic Tafel Slopes, which are relatively constant for a given metal/fluid system, and since $i_{corr}$ is directly proportional to corrosion rate (as discussed in Chapter 2) LPR techniques result in instantaneous corrosion rate readings. This is a significant advantage over electrical resistance or coupon monitoring in which a series of readings over a period of time is required to determine corrosion rate. LPR measurements cannot, however, be made in non-conductive fluids or fluids which contain compounds which coat the electrodes (e.g. crude oil). LPR techniques are, therefore, used most commonly in industrial water systems. Rohrback Cosasco's CORRATER® product line is an industry leader in LPR monitoring instruments and includes several unique and patented features, such as pitting tendency readings and Solution Resistance Compensation. CORRATER® systems and the theory of LPR measurements are discussed in more detail in Chapter 6.
**Polarization Studies** are electrochemical methods that have primarily been used in the laboratory to study corrosion phenomena (especially pitting). With this method, the natural corrosion potential of a system is disturbed, frequently by substantial voltage (a few volts compared with a few millivolts in linear polarization measurements) and external current flow is measured. In the laboratory, the metal/fluid environment can be carefully controlled. Such control is more difficult in the field, and the technique must be used more judiciously there. A variety of methods and equipment is used for such studies which are generally classified under the following types:

- **Potentiostatic** - Potential held constant
- **Galvanostatic** - Current held constant
- **Potentiodynamic**
  1. Potential changed continuously at a specified rate
  2. Potential changed in steps and held constant at each step
- **Galvanodynamic**
  1. Current changed continuously at a specified rate
  2. Current changed in steps and held constant at each step (galvano-staircase)

The potentials or currents applied with these techniques may make irreversible changes to the metal/fluid interface since they may polarize the metal substantially away from its natural state in the fluid environment, generally preventing re-use of the test electrodes after one scan. As with other electrochemical methods, these potentials can only be made in sufficiently conductive media where the wetted electrode area is known. Although corrosion rates can be estimated with these techniques through Tafel Slope extrapolation, it tends to be less precise than linear polarization resistance because of the high polarization potentials required, and the effects of solution resistance on the measurement.

**Electrochemical Impedance Spectroscopy (AC Impedance)** is now a well-established laboratory technique used to determine the electrical impedance of the metal/electrolyte interface at various AC excitation frequencies. Impedance measurements combine the effects of DC resistance with capacitance and inductance. In order to make impedance measurements, it is necessary to have a corrosion cell of known geometry, a reference electrode and instrumentation capable of measuring and recording the electrical response of the test corrosion cell over a wide range of AC excitation frequencies. AC Impedance is capable of characterizing the corrosion interface more comprehensively. With high quality equipment, accurate measurements of the corrosion interface can be made in lower conductivity solutions or under high resistivity coatings. AC Impedance measurements are particularly useful in the laboratory to predict corrosion rates and characterize systems under study and are commonly used for performance studies of chemical inhibitors and protective coatings to evaluate the resistance of alloys to specific environments, etc.

**Electrochemical Noise** is a monitoring technique which directly measures naturally-occurring electrochemical potential and current disturbances due to ongoing corrosion activity. It has the same media conductivity limitations, and requirement for a known electrode area, as the other electrochemical techniques. It is generally less quantitative than linear polarization resistance for corrosion rate calculations. It is more useful in detection of transient effects in marginally conductive situations. Laboratory and field interpretation is still rather developmental. Its proponents claim this technique can provide a large quantity of information which can be useful in determining what's actually happening in real-time with corrosion activity in the piping or equipment being monitored. Detractors contend that there is in fact too much information, and analysis is confusing, especially when there is a constant but acceptable level of corrosion activity in the system or another source of potential electrical disturbance in the system. Rohrback Cosasco feels the technique may develop into a useful transient corrosion detection and quantitative pitting analysis. It may have merit as part of an on-site corrosion survey conducted by specialists trained to interpret the data, but by no means do we recommend it as a permanent monitor or a substitute for other techniques. Rohrback Cosasco's CORRATER® instruments operating in the "Pitting Index" or "Imbalance" mode provide a simple electrochemical current noise sample. This measurement has been incorporated into CORRATER® systems for many years, and has proved to be useful as an indicator of pitting tendency or surface instability. This is essentially the current state-of-the-art of electrochemical noise.
Chapter 4
MICROCOR® Measurement Technologies

Theory of Operation

Corrosion is an expensive, potentially disastrous phenomenon, and the leading cause of process equipment and piping failures. Companies pay billions of dollars annually in damages, clean-up, and down time. Rohrback Cosasco Systems developed MICROCOR® in response to the need to rapidly, safely, and accurately determine corrosion changes.

The MICROCOR® corrosion monitoring technology has been developed to substantially increase the speed of response over conventional monitoring, such as coupons, electrical resistance (ER) probes, and linear polarization resistance (LPR), and is functional in all environments.

MICROCOR® is the result of patented technology which combines the rapid response of LPR and the universal applicability of ER. Fig. 4-1 below compares the real world response of various corrosion monitoring methods to the MICROCOR® system. Corrosion rate on a logarithmic scale is plotted against time, also on a logarithmic scale. At 10 mpy, the common W40 electrical resistance probe takes nearly 3 days to show a clear response. A MICROCOR® probe with the same useful probe life will show a clear response in 1 hour, and the trend is visible in 15 minutes. Even an LPR probe in water will take 5 to 10 minutes to produce a steady corrosion rate reading. This means that the MICROCOR® system is 50 to 100 times more sensitive and faster in response than ER systems. The absolute resolution of the MICROCOR® electronics in 256 times more sensitive than ER system electronics.

The MICROCOR® technology measures the metal loss that is occurring on the probe element with very high resolution. Consequently, it is useable in virtually any environment, as distinct from electrochemical methods which may only be used in essentially aqueous environments. From the collection of these metal loss readings over time, the corrosion rate can be computed. The very high resolution of the metal loss measurements enable the corrosion rate to be determined in minutes or hours, and provide rapid feedback on changes of corrosion rates, 50 to 100 times faster than other metal loss methods.

Therefore, MICROCOR® offers, for the first time, the ability to make rapid, accurate corrosion rate measurements in any environment. Measurements can be made in conductive or non-conductive liquids, brines, gases, under multiphase conditions, underground, or in concrete. Short-term changes in corrosion rate, which would be undetectable with conventional techniques, are clearly visible using MICROCOR®. This makes the technique ideal for process monitoring, process control, inhibitor evaluation, and cathodic protection studies.
MICROCOR® Probes

MICROCOR® Probes are an integral component of the new high-resolution MICROCOR® system. Special design of the probes provides advanced thermal performance, and reliable operation in all environments including sour service. The active element of a MICROCOR® probe is measured to an 18 bit resolution, or 262,144 probe life units (PLU’s). 1 PLU is the resolution of the MICROCOR® transmitter.

\[
\text{Probe Life (years)} = \frac{\text{Probe Span (mils)}}{\text{Average Corrosion Rate (mpy)}}
\]

This compares to the 10 bit resolution (1000 divisions) of an ER system. As a result of the proprietary design of the probe and the electronics, the MICROCOR® measurement system is much less sensitive to fluctuations in temperature. Table 4-1 shows the technical comparison of MICROCOR® and standard ER.

<table>
<thead>
<tr>
<th></th>
<th>ER</th>
<th>MICROCOR®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>10 bit</td>
<td>18 bit</td>
</tr>
<tr>
<td>Probe Life Units</td>
<td>1,000</td>
<td>262,144</td>
</tr>
<tr>
<td>Approximate Speed of</td>
<td>3 days</td>
<td>Less than 1 hour</td>
</tr>
<tr>
<td>Response @ 10 mpy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>corrosion rate and 10 mil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>span probe element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Type</td>
<td>Analog – Dedicated cable required for each transmitter</td>
<td>Digital – Up to 32 transmitters can be connected with a single cable</td>
</tr>
</tbody>
</table>

Table 4-1  Technical Comparison of MICROCOR® and Standard Electrical Resistance (ER)

The MICROCOR® probes are available in two element forms – flush and cylindrical:

**Flush Probes** are used for best thermal performance where flush mounting with the pipe wall is desirable or essential. A typical example is the bottom-of-line locations in oil and gas production pipelines. In these applications, water films commonly collect in the bottom of the line and are the primary cause of corrosion. The flush probe ensures the whole of the probe element is exposed to the water film, whereas a cylindrical probe would only be partially exposed. In other pipeline applications flush probes are essential if the line is pigged, thereby avoiding possibility of probe damage.

**Cylindrical Probes** are suited to more aggressive environments. Since there is no sealing material other than the parent metal, they are suitable for virtually any aggressive environment. The measurement area of the element is much greater in this design and is suitable for use in a single phase flow. In multiphase or stratified flows care must be taken to position the whole probe element in the corrosive phase to be monitored.

Both forms of the MICROCOR® probes are shown in Fig. 4-2. Several mounting configurations are available, the most common of which allow the probes to be inserted and removed under full process operating conditions without shutdown.

![Fig. 4-2 M4700 Flush and M4500 Cylindrical Probes](image-url)
**MICROCOR® Data-Logging System**

MICROCOR® data-logging system is shown in Fig. 4-3 and it features the following:

- Stand Alone Data Collection
- Internal Battery Powered
- Hazardous Area Certified
- Download with Checkmate™ DL or MATE II

![Fig. 4-3 MICROCOR® Data-Logging System](image)

The Data-Logging System comprises the following:

1. **MICROCOR® Probe** – A wide range of fixed, retractable, and retrievable probes are available, with standard types to suit most applications. For special applications, custom design is available.

2. **Probe Connecting Adapter** – The probe connecting adapter allows the MICROCOR® transmitter to be close-coupled to the probe and provides a mounting for the transmitter. The two types of adapters are shown in Fig. 4-4. The probe adapter is the preferred and simplest method of mounting the MICROCOR® transmitter.

![Fig. 4-4 4000 Series Adapter & 2000/3000 Series Adapter](image)

3. **MICROCOR® Transmitter** – The MICROCOR® transmitter Model MT-9485A is the latest model of a new generation of high resolution digital instruments and is rated explosion-proof to the latest ATEX, UL, and CSA standards.
4. **Transmitter to Data-Logger Cable** – This cable enables the data-logger to be mounted up to 500 ft from the MICROCOR® transmitter at a convenient location for data collection and battery change-out. Fig. 4-5 shows both UL/ULc certified and ATEX certified cables.

![Fig. 4-5 Transmitter to Data-Logger Cables](image)

5. **MICROCOR® Data-Logger** – The MICROCOR® data-logger Model ML-9500B uses the same enclosure as the MICROCOR® transmitter and its rating is explosion-proof plus intrinsic safety.

For non-hazardous areas, a portable PC can configure and retrieve data from the data-logger with the data-logger to PC serial cable. For electrically hazardous areas, an intrinsically safe Checkmate™ DL or MATE II hand-held terminal is required for configuration and data transfer. Either instrument collects data from all of the data-loggers in the field, and is then carried to the safe area for data transfer to the PC running MICROCOR® Tools Software, which allows for easy data storage and graphical analysis of the results, showing metal loss and corrosion rate.

The MICROCOR® Model ML-9500B data-logger and the Model MT-9485A transmitter are a part of a new generation of high-resolution digital instruments, which operate with special high-resolution MICROCOR® probes. The resolution of the system is 18 Bit, or 256 higher than previous electrical resistance measurement instruments. This increased resolution greatly improves response to corrosion upsets, and at the same time allows measurements to be made in virtually any environment. The patented technology combines speed of response, similar to linear polarization resistance, with the universal applicability of electrical resistance measurements.

Another software option is ICMS3™ Integrated Corrosion and Erosion Management System software that provides complete corrosion management, where corrosion rate data can be plotted in real time in parallel with related process variable such as temperature, pressure, pH, dissolved oxygen, and inhibitor concentrations. Please consult Chapter 9 for more details on ICMS3™.

**MICROCOR® Online System**

MICROCOR® Online Corrosion Monitoring System allows you to make rapid, accurate corrosion rate measurements in any process environment. Its primary benefit is its increased speed of response over conventional monitoring techniques (coupons, electrical resistance measurements). It also treats corrosion monitoring as a process parameter enabling more efficient management of costly inhibitors, allowing better asset management and extending plant life. The features of the MICROCOR® online system are:

- High Resolution Corrosion Measurement
- Rapid Response
- Online or Data-Logging Configurations
- Rated for Hostile Environments
- Approved for Hazardous Locations
The MICROCOR® transmitter may be used for continuous on-line monitoring systems, or in conjunction with a separate battery operated data-logger for autonomous operation. A single cable may be used to connect up to 32 transmitters with a single cable run. This single cable contains the 24 VDC power supply and the RS 485 communications bus, which allow multi-drop connections between the central corrosion monitoring computer and all of the transmitters. This design avoids the need to run a cable to each transmitter and minimizes cabling costs.

**MICROCOR® Wireless Transmitter**

In keeping with its history of developing innovative corrosion management solutions, Rohrback Cosasco Systems introduced the MICROCOR® Wireless Transmitter (MWT) shown in Fig. 4-6. The MWT offers unprecedented benefits:

- High Resolution Wireless Corrosion Monitoring and Metal Loss Measurement
- Simple Set Up and Low Installation Costs
- Independent Operation of Seamless Integration with Emerson’s Smart Wireless Range of Solutions
- Operations in Hazardous Locations
- Ideal Solution for Hard to Access Areas

The MWT uses the same MICROCOR® patented technology, with the additional benefits of wireless communication. Each MWT works as a node in a self-organizing network (mesh) to ensure consistent delivery of data. Unlike many approaches to in-plant wireless systems which require direct line-of-sight between the instrument and the communications gateway, the RCS approach ensures network integrity by allowing MWT’s to communicate with each other. Because every device serves as a network connector there can be no single point of failure. In the event a temporary obstruction blocks a direct connection, the network automatically reroutes the signal to an adjacent device, ensuring network reliability and data integrity. Fig. 4-7 shows the MICROCOR® wireless network, gateway and interface.
The MWT uses high resolution metal loss measurement providing 18 bit resolution, and will be rated for operation in hazardous locations. Like its rugged predecessor MICROCOR® which has performed well in both arctic and desert conditions, the MWT has an allowable operating range of from -40°C to 70°C.

The MWT is based on RCS’s MICROCOR® technology and provides corrosion rates in any process media at speeds approaching real time. MICROCOR® online systems are in use throughout the world and have proven that accuracy and reliability can co-exist. Correlating real time corrosion rates with other process parameters enables facility operators to realize unprecedented process control related to variables such as chemical inhibitor feed. Chemical inhibitor costs can be reduced without compromising plant safety, thereby ensuring a speedy recovery of the investment in the corrosion monitoring system. Continued use provides alerts to system upsets, lengthens the time between plant shutdowns, extends overall asset life, and gives peace of mind with respect to potential environmental mishaps caused by corrosion.
Chapter 5
CORROSOMETER® and CORROTEMP®
Measurement Technologies

CORROSOMETER® Theory of Operation

CORROSOMETER® technology is based on the electrical resistance method of corrosion monitoring pioneered by Rohrback Cosasco in the 1950's and 1960's. CORROSOMETER® Probes are basically "automatic coupons." They determine the loss of metal from the probe by measuring the change in its resistance. Because of the very low resistances involved, very sensitive monitoring circuits are used in CORROSOMETER® instruments to measure the change in probe resistance compared to the resistance of a protected reference element connected in series to the corroding measurement element. A "check" element is also included and is protected from the process along with the reference element. The ratio of check-to-reference resistance should remain constant. If it doesn't, this indicates that degradation of the reference element may be occurring and that metal loss readings obtained from the probe are questionable. A simplified diagram of a typical electrical resistance monitoring circuit is shown in Fig. 5-1.

![Fig. 5-1 Simplified Electrical Resistance Monitoring Circuit](image)

As with coupons, CORROSOMETER® probes must be allowed to corrode for a period of time before accurate corrosion rate measurements can be made. The actual length of time required depends upon the corrosion rate—the higher the rate, the shorter the time required, and vice-versa. CORROSOMETER® probes are available in a variety of styles and with useful probe life ("span") ranging from 2-25 mils in styles commonly used in process piping systems.

Probe Sensitivity Selection

Instrumentation to measure electrical resistance probes divides the probe span into 1000 "divisions." A probe with a 2 mil span is therefore theoretically capable of measuring thickness changes of 0.002 mils. In practice, for detection of corrosion upsets, Rohrback Cosasco generally recommends that a change in indicated metal loss of 10 divisions or 1% of probe span be required before the data is used to indicate a corrosion upset rate from background noise. Indications of an upward or downward trend can be obtained with as little as a 4 division change, but care must be exercised in interpreting such small changes because other factors (e.g. temperature changes) can also be responsible. The actual time required to produce meaningful corrosion rate upset information with common probe spans at different corrosion rates is shown in Fig. 5-2 and summarized in Table 5-1.
From Table 5-1 it would appear desirable to always choose probes with the lowest span available in order to get the greatest sensitivity. However, the more sensitive the probe, the faster the entire probe span will corrode away and require a new probe to be installed. Table 5-2 illustrates this relationship.

<table>
<thead>
<tr>
<th>Corrosion Rate (mpy)</th>
<th>Probe Span (mils)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>0.1</td>
<td>73 days</td>
</tr>
<tr>
<td>0.5</td>
<td>15 days</td>
</tr>
<tr>
<td>1.0</td>
<td>7 days</td>
</tr>
<tr>
<td>5.0</td>
<td>35 hours</td>
</tr>
<tr>
<td>10</td>
<td>18 hours</td>
</tr>
<tr>
<td>25</td>
<td>7 hours</td>
</tr>
<tr>
<td>50</td>
<td>4 hours</td>
</tr>
<tr>
<td>75</td>
<td>140 min.</td>
</tr>
<tr>
<td>100</td>
<td>105 min.</td>
</tr>
</tbody>
</table>

Table 5-1 Response Times for Various CORROSOMETER® Probe Spans
It is our experience that the objectives of most monitoring programs can be achieved cost-efficiently by selecting CORROSOMETER® probes which will reach the end of their useful life in 6-12 months at the expected corrosion rate. Unlike a monthly coupon replacement program, an electrical resistance probe will continuously produce data that verifies the average corrosion rate over the previous 2-3 days is still at the originally expected (design) rate. If the corrosion rate increases to twice the design rate, meaningful data to permit the new rate to be accurately calculated will be available in a day and a half, although a steady increase in the calculated corrosion rate would be apparent throughout this period. Conversely, if the actual corrosion rate is below design, a longer period is required before the new rate can be calculated.

### CORROTEMP® Theory of Operation

CORROTEMP® technology is a patented incorporation of temperature measurement into CORROSOMETER® probes in a totally integrated way. Corrosion, like all chemical reactions, proceeds more quickly with increased temperature, simply because of the greater energy created by the higher temperature. Consequently, simultaneous tracking of corrosion and temperature is commonly an important aspect of corrosion management. Careful integration of temperature measurement into CORROTEMP® CORROSOMETER® (COT) probes and CORROTEMP® CORROSOMETER® (COT) electronics has enabled the simultaneous measurement of temperature and metal loss without the need for additional connections on the probes. The design also allows CORROTEMP® CORROSOMETER® electronics to be compatible with both CORROSOMETER® and CORROTEMP® CORROSOMETER® probes.

Temperature is measured in the CORROTEMP® CORROSOMETER® probe by a platinum resistance detector (RTD) located at the tip of the probe in the configuration shown in Fig. 5-3. A three wire measurement system compensates for lead resistance when all three leads have the same resistance. For longer cable lengths, a four wire system compensates fully for lead resistance irrespective of the value of the resistance in each line. The four wire system is employed in CORROTEMP® systems.

<table>
<thead>
<tr>
<th>Early Trend Indication (4 Div.)</th>
<th>Meaningful Rate Data (10 Div.)</th>
<th>End of Useful Probe Life (1000 Div.)</th>
<th>Corrosion Rate w/ 10 mil Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6 hours</td>
<td>4 hours</td>
<td>17 days</td>
<td>220 mpy (5.6 mm/yr)</td>
</tr>
<tr>
<td>4 hours</td>
<td>10 hours</td>
<td>1.4 months</td>
<td>88 mpy (2.2 mm/yr)</td>
</tr>
<tr>
<td>9.6 hours</td>
<td>1 day</td>
<td>3.3 months</td>
<td>37 mpy (0.94 mm/yr)</td>
</tr>
<tr>
<td>18 hours</td>
<td>1.8 days</td>
<td>6 months</td>
<td>20 mpy (0.51 mm/yr)</td>
</tr>
<tr>
<td>1.1 days</td>
<td>2.7 days</td>
<td>9 months</td>
<td>13 mpy (0.33 mm/yr)</td>
</tr>
<tr>
<td>1.5 days</td>
<td>3.7 days</td>
<td>12 months</td>
<td>10 mpy (0.25 mm/yr)</td>
</tr>
<tr>
<td>1.8 days</td>
<td>4.6 days</td>
<td>15 months</td>
<td>8 mpy (0.20 mm/yr)</td>
</tr>
<tr>
<td>2.2 days</td>
<td>5.5 days</td>
<td>18 months</td>
<td>6.7 mpy (0.27 mm/yr)</td>
</tr>
<tr>
<td>2.9 days</td>
<td>7.3 days</td>
<td>24 months</td>
<td>5 mpy (0.13 mm/yr)</td>
</tr>
</tbody>
</table>

Table 5-2 Comparison of Response Time vs. Useful Probe Life
CORROSOMETER® and CORROTEMP® CORROSOMETER® Probes

CORROSOMETER® and CORROTEMP® CORROSOMETER® probe elements are available in a variety of styles. A selection of the available styles is shown in Figures 5-4 and 5-5. Wire loop, tube loop, and strip-loop styles all have a loop of metal exposed to the process. The loop protrudes from the end of the probe body through either a hermetic glass seal or a Teflon/ceramic, Teflon/epoxy or epoxy seal/packing system.

Choice of materials is dependent upon stream composition, process conditions and performance requirements. Cylindrical elements utilize specially-made, thin-wall tubing as the measurement element. Cylindrical probes are generally “all-metal;” i.e., there is no other material exposed to the process. There are, however, some cylindrical probes available which join the probe body at a hermetic glass seal. A variety of flush-mounted probes are also available; so-called because the measuring element is mounted parallel to the flow stream, flush with the inside pipe wall.
CORROSOMETER® and CORROTEMP® CORROSOMETER® Monitoring Systems can be applied to all processes. However, some types of probes are better suited to the requirements of particular applications than others.

Different styles of CORROSOMETER® and CORROTEMP® CORROSOMETER® probe elements are affected to different degrees by pitting attack. Pitting initially has little effect on the metal loss measurement until any pits have nearly penetrated the element completely. In such pitting environments the probe element functions essentially as a "fuse" link to pitting, corresponding to the thickness of the element.

Cylindrical elements on the other hand are affected to a much lesser degree by pitting because of the much larger circumference of the measuring element.

Wire loop and tube loop elements do have a tendency to be electrically shorted by a bridge of iron sulfide corrosion product. This is especially prevalent in low-velocity streams over an extended period. The effect of such bridging is to reduce the measured metal loss of the probe, creating a misleadingly low corrosion rate. Cylindrical probes demonstrate more resistance to iron-sulfide bridging due to their construction and lower inherent resistance per unit length, thus minimizing the effect of the shunt resistance. Where substantial FeS₂ depositions are expected to be problems, cylindrical probes should be chosen over loopstyle probes, if possible.

Most cylindrical probes are of all-welded construction in order to eliminate the need for sealing metal elements to non-metallic glass, epoxy or ceramic. This all-welded construction gives the probe superior resistance to leaking. Probes with higher temperature ratings can also be constructed in the all-welded style. A drawback to the all-welded style is that the element is electrically connected to the pipe wall which can, in certain conditions, interfere with the corrosion reaction on the probe unless insulating mountings are used. Also, because cylindrical probes are welded, in some conditions preferential corrosion can occur in the heat-affected zones near the weld or end grain attack can occur.

Flush probe elements are thin, flat metal sections embedded in epoxy or a hermetic glass seal inside a metal probe body. Flush probes also experience certain characteristic problems, most notably: lack of adhesion of the metal element to the epoxy; cracking of glass seals due to differential expansion in changing temperature environments; and erosion of the epoxy or glass due to high velocities, abrasive materials in the flow stream or both. Flush CORROSOMETER® or CORROTEMP® CORROSOMETER® probes mounted on the bottom of the line have been shown to provide good results in a sour gas gathering system.

Because the measurement element is part of the primary pressure seal, and because it is designed to corrode, CORROSOMETER® or CORROTEMP® CORROSOMETER® probes have a reduced resistance to leaking after prolonged exposure. Once the measurement element has corroded through, the internals of the probe body are exposed to the process fluid. Although materials are chosen in part for their strength and lack of permeability, it is our experience that process fluids will permeate throughout the probe fill material. For this reason, quality probes are constructed of corrosion-resistant body materials and include an outboard pressure seal, often consisting of a hermetic glass-sealed connector. Other sealing materials are utilized in special cases, especially where process fluids will attack glass (e.g. hydrofluoric acid service) and secondary seals are also used in some probes, particularly when highly-dangerous or toxic fluids are to be contained.

The reference/check elements are protected from the process to which the measurement element is directly exposed and are used to provide temperature compensation. However, temperature changes in the process will affect the measure element before the reference and check element readings. CORROSOMETER™ probes incorporate special design features to minimize the thermal resistance of the materials insulating the reference and check elements from the process. It should also be noted that cylindrical probes are inherently better able to react to temperature changes due to location of the reference and check elements concentrically inside the measure element.

**DCMS™ Downhole Corrosion Monitoring System**

The DCMS™ tool is another RCS innovation, and the only tool available which provides real time corrosion and temperature data for the hostile conditions of downhole operation. The sensitivity of the system enables the film
persistence of inhibitors to be evaluated in actual operating conditions, something that was not possible prior to the development of the DCMS™. The DCMS™ tool may be attached to a variety of wire-line approved running tools for insertion into the production well at the start of testing and retrieval from the well at the end of the testing period. Selection of the appropriate wire-line tools allow the DCMS™ tool to be set at any required depth — wherever the most critical corrosion regions are located. Several DCMS™ tools may be run simultaneously in a well, in order to obtain corrosion data for the different depths, while under the same operating conditions.

The DCMS™ tool is comprised of a CORROSOMETER® probe, an electronic memory module, and a battery pack. Fig. 5-6 shows the data-logging probe used for downhole corrosion monitoring at pressures up to 10,000 psi (69 MPa) and up to 325°F (163°C). The probe is attached to a suitable packer or locking mandrel and set in the hole for up to 60 days to record continuous corrosion history. The whole assembly is normally set and retrieved by wire-line, E-line, or slick-line.

**CORROSOMETER® and CORROTEMP® CORROSOMETER® Instruments**

The industry standard for ER (Electrical Resistance) corrosion probes in retrievable, retractable, fixed and flanged mounting that are rated for up to 6,000 psi (41 Mpa) and 850°F (454°C). RCS provides a range of internal corrosion monitoring measuring instruments that span from simple portables to continuous on-line or data-logging instruments to large scale systems that integrate process parameters and corrosion information to optimize control strategies.

Remote Data Collectors (RDC’s), shown in Fig. 5-7 are used at every probe location where maximum visibility and sensitivity to corrosion rate changes are required. Readings of corrosion and temperature data may be set as frequently as every five minutes for RDC-COT or every thirty minutes for RDC-CAT.

Programming of all the RDC’s, and data retrieval from the RDC’s is accomplished by a single Checkmate™ DL, Checkmate™ Plus, or MATE II for direct transfer to a portable or desktop PC running CORRDATA® Plus Corrosion Management Software. For non-intrinsically safe applications the RDC may be configured directly from the PC.

For probe locations where less frequent monitoring is required, the CORRDATA® Mate II is capable of monitoring probes directly without an RDC, as well as transferring accumulated probe data from RDC’s.

The Checkmate™ and Checkmate™ Plus CORROSOMETER® Portable Instruments use “state of the art” surface mount integrated circuits. The sophisticated electronics provides higher resolution and measurement accuracy of
CORROSOMETER® (Electrical Resistance) corrosion probes. The measurement cycle time for direct probe readings has been reduced to 30 seconds while still maintaining high accuracy. Stored readings are easily downloaded to a PC where graphing and analysis can be performed with CORRDATA® Plus Corrosion Management Software. Both instruments are well suited for use in harsh field environments and certified for use in Class I, Zone 1 (Hazardous Locations).

The combination of corrosion and temperature measurement is particularly useful in process plants, chemical plants, and refineries – where changes in operating temperature can have a major impact on corrosion rates. High temperatures that push or exceed the design conditions may improve output, but may result in unacceptably high corrosion rates which are costly and shorten plant life. RCS offers CK-4 and MATE II Portable Instruments which utilize the advanced RCS technology in CORROSOMETER® probe measurement with the ability to measure temperature from the CORROTEMP® probes. Now operators and corrosion engineers can obtain a direct correlation between temperature and corrosion rate from one instrument.

**Ultra-high Sensitivity CORROSOMETER® Sensors**

The CORROSOMETER® probe technology has been applied to ultra-thin films enabling metal loss down to half of one Angstrom (1 Angstrom is the wave length of light = 0.000,000,04 inch) to be measured. This allows the corrosivity of air in filtered environments to be continuously monitored on-line to the ISA (Instrument Society of America) categories of G1 (<300 Å/month), G2 (<1000 Å/month), G3 (<2000 Å/month) or GX (>2000 Å/month). Please consult Chapter 10 for ECM™ Environmental Condition Monitoring Systems.
Chapter 6
CORRATER® Measurement Technologies

Theory of Operation

Rohrback Cosasco's CORRATER® systems measure the instantaneous corrosion rate of a metal in a conductive fluid using the DC linear polarization resistance (LPR) measurement technique. This technology only applies to conductive liquids (water) and is usually used to monitor corrosion rates in cooling water systems of all kinds. It provides the feedback for the chemical treatments being employed. Some instruments also include an AC measurement for correction of solution resistance. As described in Chapter 2, corrosion is an electrochemical process in which electrons are transferred between anodic and cathodic areas on the corroding metal resulting in oxidation (corrosion) of the metal at the anode and reduction of cations in the fluid at the cathode.

Stern and Geary originally demonstrated that the application of a small polarizing potential difference (\(\Delta E\)) from the corrosion potential (\(E_{corr}\)) of a corroding electrode resulted in a measured current density (\(i_{meas}\)) which is related to the corrosion current density (\(i_{corr}\)) by equation (5):

\[
\frac{\Delta E}{i_{meas}} = \frac{b_a \cdot b_c}{2.303 \cdot \frac{E_{corr}}{(b_a + b_c)}}
\]  

where:  
- \(b_a\) = Anodic Tafel Slope  
- \(b_c\) = Cathodic Tafel Slope

Since the Tafel coefficients are more or less constant for a given metal/fluid combination, \(i_{meas}\) is proportional to \(i_{corr}\) which, as described in Chapter 2, is proportional to the corrosion rate. Equation (5) and the entire LPR technique are only valid when the polarizing potential difference is very low (typically up to 20 mV). In this region, the curves approach linearity, hence the term LPR. Inspection of equation (5) shows that the result \(\Delta E/i_{meas}\) is a resistance term called, the Polarization Resistance, \(R_p\). The resistance to current flow between electrodes of a two-electrode LPR probe is the sum of polarization resistance values at each electrode and the resistance of the solution between the electrodes (\(R_s\)) as shown in equation (6):

\[
\Delta E = i_{meas} \cdot (2R_p + R_s)
\]

From equations (5) and (6), obtaining results from the LPR technique would seem to require only instantaneous readings of resistance. In practice, however, the determination of polarization resistance is complicated by a capacitance effect at the metal/fluid interface (double-layer capacitance).

Fig. 6-1 is an equivalent electrical circuit of the corrosion cell formed by the measuring electrodes and the fluid, showing the importance of \(R_s\) and double-layer capacitance effects.

![Fig. 6-1 Equivalent Circuit of LPR Probe](image)

The effect of the double-layer capacitance is to require the direct current flow to initially charge-up the capacitors to the polarization potential, resulting in a decaying exponential current flow curve vs. time, after application of the polarizing potential difference. A typical LPR DC polarization current vs. time curve is shown in Fig. 6-2.
The double layer capacitance of each metal/fluid interface can vary, which in turn determines the amount of time required to obtain valid measurements of \( i_{corr} \) and corrosion rate. The actual time required can vary from approximately 20 seconds up to 6 minutes, depending upon the metal/process combination being measured. Choosing too short a polarization time can result in current readings much higher than \( i_{meas} \) and hence the true \( i_{corr} \), thus causing measured corrosion rate to be higher than actual, sometimes by a significant amount.

Solution resistance can also have a significant effect on accuracy if it is relatively high compared to the polarization resistance. In most industrial water applications, conductivity of the solution is high so that solution resistance is low compared to the polarization resistance. In these cases, \( i_{meas} \) is an accurate measure of polarization resistance, and therefore, corrosion rate.

A serious problem develops, however, when the solution resistance increases or the polarization resistance decreases enough to make the solution resistance a significant portion of the total resistance to current flow between the electrodes. In these cases, the accuracy of the LPR measurement is affected.

This situation tends to occur at high corrosion rates (low polarization resistance) and in solutions with low conductivity (high solution resistance) and is manifested by the indicated (measured) corrosion rate being lower than the actual corrosion rate. The graph in Fig. 6-3 shows the effect of this limitation on the recommended operating range of LPR instruments. In the typical range of cooling waters and maximum corrosion rates of 10 mpy, compensation for solution resistance is not significant. The portable 9000 Plus and SCA-1 instrument operates on this basis. For lower conductivities or higher corrosion rates, knowledge of solution conductivity (inverse of solution resistivity) enables corrections to be made extending the range of operation. The 9030 Plus, AquaMate®, and MATE II instruments use a patented technique which makes a high frequency measurement to determine the resistance \( R_s \) which is automatically applied to further extend the range of operations. Table 6-1 shows the comparison of features of CORRATER® instruments.
In laboratory corrosion studies, it has become the standard over the years to reduce the effect of solution resistance by the use of a three electrode measurement configuration.
Here the polarization current is measured between the test and auxiliary electrode, while the polarization potential is measured between the test and a close-spaced reference electrode (see Fig. 6-4). The concept is that since essentially no current flowed between the reference and test electrode, by ohms law, there is no voltage drop.

\[ V = iR \text{ by ohms law, if } i = 0, v = 0 \]

In reality it is more complex, because the reference electrode potential depends on its position in the electrical field created by the current flow from the test to auxiliary electrodes.

In the laboratory, it is easier to make a very close spaced reference electrode (normally a salt bridge capillary) almost touching the test electrode, but even this is not perfect. In the field, such electrodes are not practical and are easily subject to bridging by deposits that short circuit the electrodes which would completely negate the measurement. Rohrback Cosasco maximized the use of this correction method in the field with its close spaced reference electrode shown in Fig. 6-5.

The introduction of Electrochemical Impedance Spectroscopy (EIS) or AC impedance, brought the application of a complete range of AC polarization signals to the measurement electrodes, of similar magnitude to the DC method. This yields a plot of real impedance versus imaginary impedance (due to capacitance) for the equivalent circuit shown in Fig. 6-6.
Rohrback Cosasco implemented a patented variation of this technology called Solution Resistance Compensation (SRC) into CORRATER® systems. Instead of applying multiple frequencies, essentially only two are used. The first is a normal DC LPR measurement, which is equivalent to a half cycle of a low frequency. This corresponds to point A in Fig. 6-6 (i.e. measures 2Rp+Rs on a two electrode system). The second is a single high frequency corresponding to point B (i.e. measures Rs). In essence the double layer capacitance acts as a low impedance or "short circuit" to the high Frequency AC polarization so that Rs is directly measured. By subtraction, the result is 2Rp, and independent of Rs. (For more detailed analysis see ASTM G96 Appendix A). This is a simplified way of determining the diameter of the semi-circle used in EIS calculation of Rp.

The state-of-the-art, patented SRC technology also eliminates the need for a third electrode, even in low conductivity solutions. Consequently, Rohrback Cosasco's two-electrode probes have become the standard RCS offering, with the three-electrode probe available on special order only. The above points are clearly indicated in ASTM Standard Guide G96 which quotes:

```
3.2.8 Two-electrode probes and three-electrode probes with the reference electrode equidistant from the test and auxiliary electrode do not correct for effects of solution resistance without special electronic solution resistance compensation. With high to moderate conductivity environments, this effect of solution resistance is not normally significant.

3.2.9 Three-electrode probes compensate for the solution resistance Rs by varying degrees depending on the position and proximity of the reference electrode to the test electrode. With a close-spaced reference electrode, the effects of Rs can be reduced up to approximately ten fold. This extends the operating range over which adequate determination of the polarization resistance can be made.

3.2.10 A two-electrode probe with electrochemical impedance measurement technique at high frequency short circuits the double-layer capacitance, Cdl, so that a measurement of solution resistance Rs can be made for application as a correction. This also extends the operating range over which adequate determination of polarization resistance can be made.
```

**Pitting Index**

In addition to general or uniform corrosion, localized corrosion (pitting) may occur in a system. This can result in much more rapid failure of a structure than a simple measure of corrosion rate would indicate. A pit on the metal surface is the result of a localized, high anodic current density. Positive ions flow away from the pit into the solution and electrons flow away from the pit into the surrounding metal.

If it were possible to place a zero-impedance ammeter between the pit and the nearby metal surface, the current in the anode-cathode system of the pit could be measured. Individual measurements are not practical because the areas are small. Instead, current flow between the two relatively small metallurgically identical electrodes of a CORRATER® probe under short-circuit conditions can be used to indicate pitting tendency. This type of measurement has more recently been named electrochemical (current) noise.
All Rohrback Cosasco CORRATER® instruments include a Pitting Index or Imbalance reading. The user should note that this electrochemical current noise sample is a qualitative measurement (or index) and utilize it accordingly.

The Pitting Index or Imbalance measurement has proven very useful in many applications (e.g. cooling water treatment) and offers information not generally available about a system except by coupons which lag behind actual events and offer no way of detecting upsets.

If the pitting reading is low compared to the corrosion reading, the pitting problem will probably be minimal. On the other hand, a pitting reading which is high compared to the corrosion reading can indicate that pitting or crevice corrosion will be the main form of corrosive attack. When the readings are about equal, some pitting is indicated but the pits will probably be broad and shallow.

**CORRATER® Probes**

CORRATER® probes have the economy of replaceable electrodes that double as corrosion coupons, which can be made of most alloys and can be easily changed when one desires to test a different alloy, providing a significant advantage over other electrochemical and electrochemical noise probe designs with fixed electrodes. The average corrosion rate of the electrode, determined as coupon, is correlated with that from the electrochemical measurements, allowing verification of all of the important empirical and electrochemical scaling factors, which cannot be achieved by electrochemical measurements alone. As with CORROSOMETER® probes, a variety of models are shown in Fig. 6-7 that will operate in pressures as high as 6,000 psi (41 Mpa) and temperature as high as 500°F (260°C).

![Fig. 6-7 Selection of CORRATER® Probes](image)

Both two-electrode and three-electrode probes are available. However, because most applications are in the middle of the CORRATER® operating range and because the SRC technique has virtually made the three-electrode probe obsolete, the vast majority of probes are now of the two-electrode variety.

**Soil LPR Corrosion Rate Monitoring**

Soil Corrosivity influences where corrosion is most likely to occur and is often estimated, or inferred from soil resistivity measurements, but this is not quantitative. The CORRATER® Soil Corrosion Rate Monitor changes all of that, and allows a quantitative measurement to be made quickly and easily at the time of the pipe excavation and inspection. Multiple readings can be taken, at different locations around the pipe to check on the consistency of the soil corrosivity. The AquaMate™ instrument is an electrochemical corrosion rate measurement with an added patented Solution Resistance Compensation (SRC) to extend the range of soils in which measurements can be made, and the instrument gives a direct corrosion rate measurement. Typically the soils have a level of hydration that gives sufficient conductivity to allow corrosion rate readings to be taken directly. On the rare occasion that the soil is too dry (too high a resistivity) this is detected by the instrument. Such dry conditions correspond to very low corrosion rates. In these conditions, distilled water may be added to soil to check the corrosion rate if and when the soil becomes hydrated. The Soil Corrosion Rate Probe (shown in Fig. 6-8) has been developed specifically for this application. The heavy duty construction makes it suitable for field use and the probe head is replaceable. Typically
the probe element is carbon steel but may be supplied in other alloys if required. Exact matching to the pipe grade is not typically required as this usually has little effect on the corrosion rates.

**Fig. 6-8 Soil Corrosion Rate Probe**

**On-line Instruments**

On-line instruments are essential in plants where continuous supervision of corrosion is required to maintain system control, prevention of corrosion upsets, regulation of corrosion inhibition, and the protection of valuable assets.

For line-powered, indicating analog transmitters RCS offers:

- The SCA-1 for simple basic applications
- The more powerful 9030 Plus for more comprehensive capabilities

Both units are housed in NEMA 4X weatherproof enclosures for the toughest conditions, provide 4-20 mA outputs and essential electrical isolation between the input and output circuits. The SCA-1 displays and transmits corrosion rates up to 20 mpy in common conductivity waters. The 9030 Plus is available in a one or two probe configuration, and provides both analog 4-20 mA output and data-logging capabilities. Its SRC provides a wider range of operation, and it incorporates the ever useful pitting tendency. The unit is particularly attractive for applications where the analog output feeds into the plant process control system and the data-logging function is available for independent use by the chemical vendor.

For blind field-mounting transmitters RCS offers:

- The analog 9020 and 9020 OEM
- The digital explosion proof E-9020

All units share the same increased performance front end even with long probe to transmitter cables. The analog units are 4-20 mA loop-powered, with one loop for corrosion rate and one for pitting tendency. The 9020 OEM is supplied without the NEMA 4X enclosure of the 9020 for installation in other instrumentation enclosures, such as chemical vendor instrumentation systems. The digital explosion proof E-9020 transmitter is ideal for plant application in electrically hazardous areas. It operates on an economical 24 VDC/RS 485 multi-drop cable for up to 32 transmitters, which can be a mix of E-9020 and MICROCOR® transmitters for applications with mixed aqueous and non-aqueous monitoring points. The E-9020 integrates easily into our advanced ICMS3™ Integrated Corrosion and Erosion Management System for complete corrosion management solutions. Please consult Chapter 9 for more details on ICMS3™.

The IIU Intelligent Interface Unit allows flexible input configurations for up to 100 transmitters in any combination of MICROCOR® and CORRATER® E-9020. These include direct-wired configurations, or connection via TCP/IP converters over LAN/WAN connections. Please consult Chapter 9 for more typical system layouts.
Chapter 7
Comparison of MICROCOR®, CORROSOMETER®, and CORRATER® Measurement Techniques

Principle Properties

The MICROCOR®, CORROSOMETER®, and CORRATER® techniques are extremely effective corrosion monitoring methods. The choice of which is “better” is dependent upon the application. The principal attributes and limitations of each are briefly summarized below:

1. CORRATER® systems require a sufficiently conductive liquid; MICROCOR® and CORROSOMETER® systems are suitable for all environments.
2. MICROCOR® and CORROSOMETER® systems measure metal lost directly. Their accuracy is comparable to the coupon method. CORRATER® systems determine corrosion rate directly based on electrochemical theory and average calibration constants.
3. CORRATER® systems measure corrosion rate virtually instantaneously. MICROCOR® systems measure metal loss on the probe element with very high resolution enable the corrosion rate to be determined in minutes or hours. CORROSOMETER® systems measure metal lost so that corrosion rate must be determined over a period of time, usually a few hours to a few days.
4. CORRATER® systems supply pitting tendency information while MICROCOR® systems do not; some CORROSOMETER® probes indicate pitting, but by element failure only.

Applications

Because of these intrinsic properties, CORRATER® and CORROSOMETER®/MICROCOR® systems are generally used in different applications. Occasionally, all are used to obtain complimentary information particularly in water-based systems, but usually application requirement will dictate the choice of one or the other.

The following are the principal uses of and applications for some CORRATER® products:

1. Control of Inhibitor addition in water systems
   a. For control of injection to minimize corrosion increases
   b. Evaluate different inhibitors and optimize their effectiveness over time
2. Evaluation and pre-screening of inhibitors in the laboratory before field trials
3. Cooling towers – to optimize inhibition control, detect process leakage or oxygen activity, and micro-biologically-induced corrosion effects on the alloys of construction
4. Potable water systems – to test effectiveness of inhibitors and corrosiveness of biocides
5. Oil field waterfloods – to protect the injection equipment, particularly from oxygen ingress
6. Oil field drilling mud – to control inhibitor additions
7. Geothermal systems – to monitor the condition of produced brine and changes occurring before reinjection
8. Desalination systems – to monitor water quality
9. Process waters, scrubbers – to detect particularly corrosive contaminants
10. Evaluation of various alloys to solve material selection options, particularly in pilot or full scale plant environments

The CORROSOMETER® and MICROCOR® techniques have much broader application and can be used in any medium, specifically:

1. In oil and gas production
2. In gas sweetening, storage and transportation systems
3. In refineries and petrochemical plants
4. In inhibitor evaluation/optimization programs
5. In power plants – for cooling water, feedwater and scrubber systems. In bag houses and stacks for special functions such as dew point alarming in flue gas systems
6. In chemical processes
7. In cathodically-protected systems to quantitatively confirm the effectiveness of the system
8. In air cleaning systems for control rooms
9. In paper mills or other plants with a volatile, inherently-corrosive process stream
Chapter 8
ULTRACORR® Ultrasonic Corrosion Monitoring System

Theory of Operation

Ultrasonic is the most common non-intrusive device for internal corrosion monitoring and detection. The use of high frequency sound waves for the measurement of ferrous and non-ferrous materials has been employed since the Second World War. Technological advancements through the years have improved the resolution of the measurements, and the speed of operation, in addition to the reduction in the size and weight of the instrumentation.

Wavelength is dependent on the speed of sound propagation through the material under test but remains constant in a given material. Since different materials propagate sound waves at different speeds, the wavelength in the different materials will vary. It is important to choose a transducer frequency that is best suited for the material under test. Wavelength (as depicted in Fig. 8-1), can be determined by the formula:

$$\lambda = \frac{v}{f}$$  \hspace{1cm} (7)

Where

- $\lambda$ = wavelength
- $v$ = ultrasonic velocity in inches per microsecond
- $f$ = the center frequency of the transducer in megahertz

The relative flaw detection threshold ($F_t$) can then be determined by:

$$F_t = \frac{\lambda}{10}$$  \hspace{1cm} (8)

It can be seen from equation (8) that, in general, the higher the frequency the greater the sensitivity (or the smaller the detectable flaw) and conversely, the lower the frequency the lower the sensitivity.

Ultrasonic instrumentation is available for monitoring of pipe or vessel wall thicknesses. Permanently mounted transducers provide high resolution thickness measurement which, when combined with surface temperature compensation, permits corrosion rates to be determined non-invasively. To conduct a survey, the pipeline is dug up and then a portable device is held against the metal. Inside the device, voltage is applied across a piezoelectric crystal to generate an ultrasonic sound wave that propagates through the metal. The time it takes to travel through the metal and back to the transducer is directly proportional to its thickness. The devices are quick, easy to use and
inexpensive, and operators do not have to shut off flow or risk breaching the pipeline in order to take a reading. On the other hand, they still have to expend thousands of dollars digging up the pipeline each time they run a test. Also, traditional ultrasonic monitors have a sensitivity range in the order of 5-10 mils accuracy, so if the corrosion is only 3 mils/y, it takes three years to start to see it in a statistically-significant manner.

ULTRACORR® Applications

Rohrback Cosasco’s ULTRACORR® utilizes high sensitivity ultrasonic technology to provide non-intrusive monitoring of corrosion and erosion. The instrument can be used to log multiple transducers from a common connection point, to provide periodic time and date stamped measurements of wall thickness, or for more critical applications. It can automatically collect and store continuous measurements from a single transducer. Unlike normal ultrasonic devices, ULTRACORR® is capable of monitoring low rates of corrosion at a resolution of one tenth of a mil and once installed, ULTRACORR® provides years of continuous service without the need for replacement.

ULTRACORR® is ideally suited to form the backbone of an ICDA (Internal Corrosion Direct Assessment) asset integrity system for pipeline operators. Sensors are permanently attached to the exposed surface in areas such as low lying spots, drips on other locations where corrosion should be monitored. After backfilling, the sensors are read from the surface by way of attached cables. The high resolution of ULTRACORR® enables pipeline operators to detect changes in corrosion rates and readjust accordingly scheduled reassessment intervals to suit. Repeat excavations are unnecessary, and the guesswork about re-inspection intervals is removed.

Typical measurement time per transducer is a few seconds. The user can program the ULTRACORR® instrument to collect data from as many as 50 transducers, or alternatively, it can be programmed to collect up to 1,024 data points from one transducer at programmed intervals. Operation is made very simple by a series of user prompts shown on the LCD display. The ULTRACORR® ultrasonic corrosion instrument with ultrasonic transducer/sensor are shown in Fig. 8-2.

Fig. 8-2 ULTRACORR® Ultrasonic Corrosion Instrument with Ultrasonic Transducer

Fig. 8-3 shows the ULTRACORR® system diagram and it features:
• Ideal for ICDA Compliance
• Highest Resolution Transducer Available
• Portable Instrument
• Automatic Corrosion Data Collection
• Automatic Download to PC
• Battery Operated for Maximum Versatility
• Smart Sensor Enables Electronic Tagging
• Resolution of 0.1 mil (0.0001 inches) Provides True Corrosion Monitoring

**Fig. 8-3 ULTRACORR® System Overview**

A) ULTRACORR® Transducer  
B) Signal Cabling  
C) Reading Point  
D) ULTRACORR® Instrument  
E) PC Running CORRDATA® Plus Corrosion Management Software

**ULTRACORR® System Major Components**

**ULTRACORR® Transducer**
The transducer (probe) is a small (1 inch diameter by 1 inch high) sensor which is permanently mounted to the monitoring point. This is accomplished using a special adhesive which also acts as an ultrasonic couplant. The transducer has a magnetic base to aid in holding it in position while the adhesive cures. The temperature sensor on the transducer allows for automatic correction of acoustic velocity as a result of the metal temperature. This provides a significantly more accurate reading of thickness. These newest generation transducers also have the capability of storing and transmitting location and configuration information to the ULTRACORR® instrument, for ease of operation and to eliminate operator errors.

**Signal Cabling**
Two types of cables are available to bring the reading point to a convenient location. For example, if a monitoring point is on a vessel 20 feet above the ground, then access to the monitoring point location is only required for the initial installation of the transducer. A cable may then be run from the transducer to a junction box located at ground level. Each installation must be evaluated for the proper type of cable installation. Standard cables have a weather resistant polyurethane jacket and a stainless steel armored cable is available for severe applications.

**Reading Point**
There are various options available for a remote reading site. For a location with a single monitoring point, the transducer cable is fitted with a weather resistant connector. An optional NEMA 4X junction box with provision for
up to seven connectors is available. Larger junction boxes are also available. For underground applications, standard above ground or flush-with-grade monitoring locations are available.

**ULTRACORR® Instrument**
The ULTRACORR® instrument is the heart of the ULTRACORR® Corrosion Monitoring System. A single ULTRACORR® instrument may be used to periodically take individual time and date stamped wall thickness and temperature readings of up to 50 sensors. It will store up to 256 readings for each of these sensors.

**Personal Computer**
The last readings from the ULTRACORR® instrument may be displayed on its LCD. For optimal data analysis, the ULTRACORR® instrument can download all of its data to a personal computer. Use the CORRDATA® Plus Corrosion Management Software package for trend analysis, data analysis and storage.

**CORRDATA® Plus Corrosion Management Software**
The CORRDATA® Plus Corrosion Management Software controls the transfer of data from the ULTRACORR® instrument into a personal computer. It can display and print the data in tabular format. It can also convert the data to a CSV (comma separated value) format for export into any spreadsheet program. The CORRDATA® Plus software is a powerful application that can perform the above functions and much more.

**Installation Toolkit**
Toolkits containing all the tools for uncoated and coated pipeline installations are available, or tools may be ordered on an individual basis. The toolkits contain such items as a cordless drill with a spare battery and charger, tools for paint removal and surface preparation, and the required epoxy to attach the transducer to the pipeline.
ICMS™ Integrated Corrosion and Erosion Management System and Intelligent Interface Unit (IIU)

The ICMS™ Integrated Corrosion and Erosion Management System is the most comprehensive and powerful online system available. It is ideally suited for medium to large scale systems, or for small systems with the need for future growth. The ICMS™ allows integration of all the RCS range of corrosion, erosion, and cathodic protection monitoring inputs including the latest in metal loss MICROCOR® technology, CORRATER® corrosion rate, pitting tendency and galvanic probe transmitters. With the varying range of applications, communication and network infrastructure, no two ICMS™ systems are alike. The simple flexibility of the ICMS™ allows different configurations to be easily designed and implemented to meet the specific requirements. The ICMS™ features:

- Total Corrosion Data Management
- Data Exchange with DCS/PCS/SCADA Systems
- Correlate Corrosion & Process Data
- Enables Highly Cost-Effective Asset Management
- Designed Specifically for Corrosion Management Personnel
- Full Client-Server Operation

The ICMS™ corrosion management server is the heart of the corrosion or erosion monitoring system, integrating several forms of corrosion monitoring and process data into one complete online system. Corrosion and erosion monitoring is managed as a process parameter with constant streaming data directly into the preferred system interface. ICMS™ software provides complete corrosion management, where corrosion rate data can be plotted in real time and correlated with related process variables such as temperature, pressure, pH, dissolved oxygen, and inhibitor concentration.

The complete ICMS™ system architecture is shown in Fig. 9-1 and it comprises the following:

1. On-line Monitoring Hardware
   a. MICROCOR® Digital High Resolution
   b. CORRATER® Digital LPR
   c. Quicksand™ Digital Erosion
   d. CORROSOMETER® Analog
   e. CORRATER® Analog
   f. Cord-Com™ Cathodic Protection
   g. Any other Related Analog Inputs
2. Data-Logging Hardware
3. Metal Loss Coupons
4. Ultrasonic Measurement Data
5. Manual Inputs and Imported Data
6. ICMS™-Amulet Software
7. Client Server Operation over Network
8. Customer VPN Client Operation
9. RCS VPN or Modem Remote Support
On-line Digital Systems

MICROCOR® advanced Digital Metal Loss technology is perfectly complemented by the ICMS3™ on-line system. Useable in any process environment, it provides 50 times greater sensitivity than existing ER methods, allowing a 10 mpy upset to be detected in about 1 hour instead of 2 days. MICROCOR® digital or CORROSOMETER® analog technology is essential in process fluids, such as hydrocarbon service, where a continuous corrosive water phase is not consistently present at the probe. Corrosion rate is computed from the change of metal loss over time.

CORRATER® electrochemical technology is generally preferred for clean water systems (hydrocarbon content less than 5%) as it produces an instantaneous corrosion rate with a single reading. In addition it also has a pitting tendency measurement based on electrochemical current noise. The ICMS3™, as shown in Fig. 9-2 enables the MICROCOR® and CORRATER® E-9020 transmitters to be “mixed and matched” as required in the systems using the same communications protocol and wiring system.

The Quicksand™ System utilizes the same high resolution technology as MICROCOR® with a probe specifically designed for sand erosion detection. Often times sand production can cause rapid erosion and wear on the outer diameter of bends and areas downstream of changes in pipeline diameter. The Quicksand™ ST-9485A transmitters
operate on the same power and communication bus as the MICROCOR® and CORRATER® digital transmitters. Fig. 9-3 shows the ICMS3™ with MICROCOR® and Quicksand™ transmitters.

Fig. 9-3 ICMS3™ with MICROCOR® and Quicksand™ Transmitters

On-line Analog Systems

Legacy systems with 4-20 mA CORROSOMETER® and CORRATER® transmitters, or systems that bring in any other 4-20 mA signals to be monitored are easily integrated into the ICMS3™ system through analog to digital interface modules. If existing corrosion transmitters or other transmitters are connected to the DCS or SCADA system, these parameters can be transferred to the ICMS3™ server through a variety of interface drivers, such as Modbus, PI system drivers, or OPC.

CORRDATA® Data-Logging Systems

ICMS3™ systems are assisting an increasing number of corrosion monitoring systems to go fully on-line, often replacing earlier data-logging systems. However, additional remote or investigative probe locations may also need monitoring on an on-going or occasional basis. Battery operated Remote Data Collectors (RDC’s) are well suited for these locations, and with Checkmate™ DL or Checkmate™ Plus instrument this data can be collected and transferred to the ICMS3™ System, providing a single location for all of the corrosion data as shown in Fig. 9-4.

Fig. 9-4 ICMS3™ with CORRDATA® Data-Loggers
Metal Loss Coupons

Coupon data is one of the simplest forms of corrosion monitoring. Coupon data is used in on-line systems as a calibration standard for other means of corrosion monitoring (ER and LPR). In addition coupons can be examined for evidence of pitting and other localized forms of attack that are not recognized by other on-line monitoring techniques. Coupon monitoring points are strategically located throughout the system. Coupons are then retrieved, weighed, and analyzed at set intervals, usually three months, and entered into the ICMS3™ server for correlation with other corrosion data and process parameters.

Ultrasonic Measurement Data

ICMS3™-Amulet Software supports ultrasonic inspection data from Krautkramer and Panametrics Units. RCS’s on-line ULTRACORR® System provides an unparalleled accuracy in continuous on-line monitoring offering a resolution of 0.1 mil, approximately 40 times better than normal inspection ultrasonic. It is ideal for buried pipelines where intrusive monitoring is difficult. ULTRACORR® uses high resolution technology to detect both erosion and corrosion. Multiple transducers are connected to a junction box where the ULTRACORR® instrument can easily be connected to download periodic time and date stamped measurements of wall thickness. Data can then be transferred directly in from the ULTRACORR® instrument to the ICMS3™ server for analysis and computation of corrosion rates.

ICMS3™-Amulet Software

The Corrosion Monitoring server is commonly mounted on a 19” rack in an equipment room adjacent to the plant central control room along with the DCS and SCADA servers. The server uses Microsoft SQL Server as its database providing client/server operation to users over the network.

Designed by corrosion engineers for corrosion engineers, the program has extensive capabilities. Some of its many features are as follows:

- Extensive Powerful Graphical Data Displays
- Correlation Graphical Displays
- Extensive Hardware Input Options
- Built-In Corrosion Coupon Calculator
- Excel Import and Export Functions
- Easy Interfacing with DCS and SCADA Systems
- Multiple Database Exchange Options
- Multi-Level Alarms
- Built-In Standard Reports
- Custom Report Generator
- Built-In Powerful Calculator for Easy Set Up of KPI’s
- Log Book for Related Data Storage and Linkage
- Log Book Links to Graphical Displays
- Log Book Search Function
- Properties Function for Point Related Information
- Powerful Properties Search Tool
- RCS Remote Support

The Intelligent Interface Unit (IIU)

The Intelligent Interface Unit shown in Fig. 9-5 is designed for use on small to medium size MICROCOR® and CORRATER® E-9020 on-line systems for easy integration into existing SCADA and DCS systems.
The IIU allows flexible input configurations for up to 100 transmitters in any combination of MICROCOR® and CORRATER® E-9020. These include direct-wired configurations, or connection via TCP/IP converters over LAN/WAN connections. Some typical system layouts are shown in Fig. 9-6 and 9-7.
The primary purpose of the IIU is to provide the computation of corrosion rate from the metal loss made by the MICROCOR® transmitters, since these calculations are too complex for most SCADA and DCS systems to achieve without custom programming. Output from the IIU to the SCADA or DCS system is available in engineering units over Modbus serial port or via OPC over the Network. For MICROCOR® transmitters the available outputs are metal loss, standard computed corrosion rate, diurnal filtered corrosion rate in metric or imperial units, and transmitter status. For CORRATER® E-9020 the available outputs are instantaneous corrosion rate, pitting tendency (or imbalance) in metric or imperial units, and transmitter status.

The IIU is most commonly supplied in 19” rack mounted form as shown above, but is also available in a wall mount NEMA 4 and NEMA 4X enclosures. Configuration of the IIU is achieved through local connection of a laptop (not supplied) or over the LAN/WAN connection through PC Anywhere or Windows Remote Desktop. The IIU provides data storage and archiving, with direct graphical displays of the data through the installed MICROCOR® Tools Software. This permits operation as either a blind interface to a SCADA or DCS system, or as a stand-alone corrosion data storage and analysis system.
Chapter 10
ECM™ Environmental Condition Monitoring System

System Overview

The ECM™ (Environmental Condition Monitoring) System is a multi-parameter monitoring system providing constant surveillance of the environment and rapid detection of any deterioration that could result in damage to expensive equipment and valuable assets. Early detection of humid, high temperature, or corrosive conditions will permit corrective action to be taken before substantial damage occurs to sensitive computer and instrumentation systems or electrical equipment. Fig. 10-1 shows the Environmental Condition Monitor.

![Fig. 10-1 Environmental Condition Monitor](image)

The system measures humidity, temperature, and the corrosive attack on two replaceable thin-film sensors. The corrosion severity rate is shown by indicator lights that correspond to the Instrument Society of America’s Standard ISA-S71.04-1985 classification of environments (G1 through GX) for copper and silver. The metal loss on thin films of copper and silver is measured every minute and stored in short term memory. Concurrently, the average corrosion rate is computed for the previous 8 to 99 hour period as specified by the user. This rate is then normalized to yield a theoretical corrosion rate in Angstroms per month in accordance with the characteristics specified in the ISA Standard. The severity level for this corrosion rate is then alternately displayed for each sensor until the next reading.

<table>
<thead>
<tr>
<th>Severity</th>
<th>LED</th>
<th>Rate Å / Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Green</td>
<td>0-299</td>
</tr>
<tr>
<td>G2</td>
<td>Yellow</td>
<td>300-999</td>
</tr>
<tr>
<td>G3</td>
<td>Orange</td>
<td>1000-2000</td>
</tr>
<tr>
<td>G4</td>
<td>Red #1</td>
<td>Reserved For Proposed Amendments to ISA Standard</td>
</tr>
<tr>
<td>GX</td>
<td>Red #2</td>
<td>=&gt;2000</td>
</tr>
</tbody>
</table>

Table 10-1 ECM™ Severity Level

Analog and/or digital outputs of corrosion, humidity and temperature information provide remote alarming, display and recording. The information may also be stored in the on-board data-logger, and accessed via PC software. The system can also be used as a high-sensitivity corrosion monitor for special applications. The ECM™ is particularly useful for environmental monitoring in refineries, chemical plants, pulp and paper plants, control rooms, computer rooms, museums, and clean rooms.

Atmospheric Sensors
**Corrosion**
The ECM™ comes with one copper and one silver atmospheric sensor (Fig. 10-2), which have 2,500 nominal life (span). The sensitive measurement surface of the sensor is protected from the environment by a sealed polycarbonate vial containing a desiccant capsule. The sensors should be kept in the sealed container until installation and they are installed on the right side of the instrument. A stainless steel shield with many holes is used to protect the sensors from physical damage, while allowing airflow. Please consult ECM™ Environmental Condition Monitoring System Reference Manual for installation instructions.

![Fig. 10-2 Silver and Copper Corrosion Sensors](image)

**Relative Humidity**
The ECM™ comes with a relative humidity sensor already installed and is located inside a secondary stainless steel shield. The relative humidity is displayed as a percentage (%) on the front panel.

**Temperature**
The ECM™ comes with a temperature sensor already installed and is located inside a secondary stainless steel shield and heat sink. The heat sink is required to ensure accurate measurement of temperature. The temperature display can be configured to show the reading in either degrees Fahrenheit or Celsius through the front panel interface.

**Differential Pressure**
When ordered as an option, a 4-20mA pressure differential transmitter is installed in the ECM™ enclosure and is wired for operation. Tubing should be connected to at least one, if not both of the airports, and run to the areas to be monitored for pressure differential. The display can be set for inches, centimeters or millimeters water gauge through the front panel interface.

**Data-Logger**
The data-logger is accessed through a 9-pin D-Sub connector on the bottom of the ECM via a RS-232 communication. To use the data-logger, connect a standard serial cable from a personal computer serial port to the ECM™ and make note of the communications port number. While the data-logger is integrated, it operates independently from the ECM™ itself and cannot be accessed through the front panel. This feature is not available when RS-485 communications is used.

The ECM™ has a finite memory capacity when storing logged data. If the memory capacity is exceeded (due to lack of downloading the stored data) then the ECM™ will begin to overwrite the data beginning from the oldest stored data forward. The number of data parameters selected and the frequency at which they are logged will determine the maximum length of time that data can be stored in the system memory. The ECM™ Data Collector Software will display the maximum possible time length and number of readings during the data-logger configuration process on the bottom of the ECM™ Configuration screen. Please consult ECM™ Environmental Condition Monitoring System Reference Manual for operation instructions.
Chapter 11
Electronic Corrosion Measurement Technology

It is important to understand the differences among MICORCOR®, CORROSMETER® and CORRATER® measurement technologies in order to know how they are best applied. The fundamental differences in the technologies require different monitoring electronics. In addition, the differences in the technologies generally cause them to be used in different applications with relatively little overlap, (see Chapter 7). As a result, the simplest hand-held/portable instruments have generally been dedicated to one technology or the other.

MICORCOR® Hand-Held/Portable Units

The MICORCOR® instrument range includes the portable CORRDATA® MATE II and Checkmate™ DL instruments (shown in Fig. 11-1 and 11-2 respectively). Either instrument is a convenient and hassle-free way of collecting data from MICROCOR® data-loggers in the field, and is then carried to the safe area for data transfer to the PC running MICROCOR® Tools Software, which allows for easy data storage and graphical analysis of the results, showing metal loss and corrosion rate. Both instruments are suited for use in harsh field environments and certified for use in hazardous locations.

Fig. 11-1 MATE II Instrument

Fig. 11-2 Checkmate™ DL Instrument
CORROSOMETER® Hand-Held/Portable Units

The CORROSOMETER® instrument range includes the portable MATE II, Checkmate™ Plus, Checkmate™, and CK-4 instruments (shown in Fig. 11-1, 11-3, 11-4, and 11-5 respectively), which read all CORROSOMETER® probes. MATE II and Checkmate™ Plus have the capability to download stored corrosion data from CORRDATA® Remote Data Collectors (RCD’s) and stored readings are easily downloaded to a PC with CORRDATA® Plus Corrosion Management Software, where graphing and analysis can be performed. MATE II and CK-4 are multi-parameter corrosion monitors, designed to read corrosion metal loss in CORROSOMETER® probe measurement with the ability to measure temperature from the CORROTEMP® CORROSOMETER® probes. Checkmate™ Plus and Checkmate™ both feature a rapid measurement cycle time for direct probe readings of 30 seconds while still maintaining high accuracy. All of these instruments are suited for use in harsh field environments and certified for use in hazardous locations.
CORRATER® Hand-Held/Portable and Mountable Units

The CORRATER® instrument range includes the portable MATE II, AquaMate™, and 9000 Plus instruments (shown in Fig. 11-1, 11-6, and 11-7 respectively), which read all CORRATER® probes and provide quick and easy corrosion rate measurements in water systems. All of these instruments also measure the imbalance current between the electrodes, which is related to pitting activity. However, AquaMate™ is the only hand-held instrument that reads the CORROTEMP® CORRATER® probes for water temperature and the Soil Corrosion Rate Probe for soil corrosivity.
The mountable Model 9020, 9030 Plus, and SCA-1/1L instruments (as shown in Fig. 11-8) are ideal for accurately monitoring corrosion rate in water systems ranging from high conductivity cooling water and seawater to low conductivity condensates. Models 9020 and 9020 OEM are two-wired loop powered analog transmitters with one loop for corrosion and one for pitting tendency. The 9020 transmitter is mounted in a NEMA 4X (IP66) weatherproof enclosure suitable for field mounting while the 9020 OEM is supplied without the NEMA 4X for installing in existing systems or tower controllers. The E-9020 is a digital transmitter designed for on-line corrosion monitoring rate and pitting tendency in water systems in electrically hazardous areas. The 9030 Plus instrument is available with one or two channels of corrosion rate, imbalance, and temperature data for rapid response to process upset conditions. It also provides both analog 4-20 mA output and data-logging capabilities. The SCA-1/1L is a single range field mountable instrument for continuous corrosion monitoring and is suited to on-line monitoring applications where chemical treatment is being employed and compliance with regulatory standards is highly important. The 4-20 mA analog output of the SCA-1 allows the corrosion rate to be recorded or sent to a plant monitoring system and the SCA-1L has an internal data-logger that will retain up to 82 days of data which can be directly downloaded to a PC with the SCA-1L Software. Both 9030 Plus and SCA-1/1L instruments are housed in rugged NEMA 4X weatherproof enclosures suitable for field mounting.
Typically, probes, coupon holders, and injection fittings are installed in pressurized piping systems in one of the three configurations:

1. **Fixed Mount**

   This technique is the simplest and least costly per point. However, the piping must be depressurized and made safe before the device can be removed for replacement or servicing. Fixed mounting is often used with hazardous fluids or where extreme pressure and temperature conditions make maintenance while the system is operational impractical. The most secure style uses a flanged connection. A fixed, flanged CORROSOMETER® probe is shown in Fig. 12-1.

![Fig. 12-1 Fixed, Flanged CORROSOMETER® Probe](image)

2. **Retractable Mounting**

   In this technique, probes, coupons, or injection tubes are inserted in the process through a stuffing box and a one-inch full opening ball valve or any other type of valve with at least a one-inch diameter opening. A retractable CORROSOMETER® probe is shown in Fig. 12-2.

![Fig. 12-2 Retractable CORROSOMETER® Probe](image)

3. **COSASCO® 2-Inch Access System**

   The COSASCO® 2-inch Access System permits insertion and removal of probes, coupons, and injection fitting into piping while it is in service and pressurized up to 6000 psi with operation at temperatures up to 450°F.
The COSASCO® system consists of: an access fitting, welded or flanged to the piping; hollow or solid plugs which screw into internal threads in the access fitting; and a service valve/retriever combination which is screwed onto external threads on the access fitting and used to remove the plug and the attached coupon, probe, or injection tube (see Fig. 12-3).

![COSASCO® Retriever and Service Valve in Operation](image)

The service valve and retriever are removed in normal service and a protective cap is usually installed. Caps range from simple plastic thread protectors to steel covers with bleed valves and pressure gauges rated for full system operating pressure.

Probe, coupons, or injection tubes are screwed onto the bottom of the plug. Hollow plugs are used for probes; solid plugs for injection tubes and coupons. The entire plug/probe assembly is inserted and removed by the retriever. A cutaway view of a typical probe installation in a COSASCO® fitting is shown in Fig. 12-4.
Fig. 12-4 Typical Probe Installation in COSASCO® Access Fitting

Fig. 12-5 shows the RBS retriever, valve, hot tap kit, and fittings, which are especially designed for internal corrosion monitoring and for use with COSASCO® Access Fittings. Fig. 12-6 shows the RSL retriever as a shorter, non-telescoping retriever for those tight bottom-of-the-line installations. The design reduces the clearance required for access by over 10 inches. The RSL retriever is completely self-contained without the need of hydraulics or additional equipment.
The system is a result of careful design and precise manufacturing which has been perfected over decades of in-the-field operations. COSASCO® access systems meet all manufacturing and safety standards, including the NACE MR0175/ISO 15156 and fire-safety to AP16FA and AP1607. As the industry standard, COSASCO® access systems are the safest, most reliable and most widely used access, insertion, and retrieval systems in the world.

**Chemical Injection**

One of the most practical preventive maintenance methods for minimizing or controlling corrosion in product pipelines, vessels, etc., is to treat the corrosive environment with chemical inhibitors. While corrosion inhibition is a complex technology and is under constant study and development, it is an effective means of corrosion control. Using the COSASCO® Injection System for easy, reliable access, inhibitors can be injected with safety and simplicity while under full operating pressure. In addition, a variety of injection devices and systems can be used to provide the most efficient delivery and dispersion for a given application. Most of the parts involved in the COSASCO® Injection System are interchangeable with the COSASCO® Sampling System. The COSASCO® Sampling System offers a means of extracting samples from pipelines or vessels while under full system operating pressure. A typical COSASCO® Injection System with various injection dispersion ends and components is shown in Fig. 12-7.
1. Access Fitting Assembly with Solid Plug Assembly
   Tee Access Fitting Assemblies offered as standard by COSASCO® are for hydraulic injection only and therefore utilize a single Tee for injection product inlet.

2. Injection/Sampling Nut
   This is, depending upon application, a multiple-use nut that replaces the nut of the Solid Plug Assembly in the Access Fitting Assembly. Its function is to direct the injection product to the Injection Tube or directly to the atomization device. The injection/Sampling Nut has bleed ports in the side wall above an access fitting body bore o-ring seal; and is drilled and tapped with ¼" NPT threads to enable attachment of different size Injection/Sampling Tubes or Nozzle Assemblies.

3. Injection/Sampling Tubes
   The Injection Tube is the pathway for the injected product flowing from the Injection Nut to the process. Standard COSASCO® Injection Tubes are offered in ¼" NPT sizes to mate with like size NPT Injection Nuts.

4. ¼" NPT Flush Nozzle (Male)
   This nozzle threads directly into the Injection Nut Assembly to provide spray injection flush with the pipe wall when the correct injection nut is used.

5. Nipples and Shutoff Valves
   Short nipples and shutoff valves are available to interface the Tee Access Fitting Assembly with the Injection/Sampling System.
Hydrogen Monitoring

Atomic hydrogen (H\(^+\)), generated by the cathodic corrosion reaction can lead to two types of failures in steels; Hydrogen Blistering and Hydrogen Induced Cracking (HIC). Part of the hydrogen produced by the cathodic corrosion reaction may permeate the steel by diffusion, and the balance is dissolved in the process electrolyte or released as bubbles of gas. Poisoning agents in the process, electrolyte or released as bubbles of gas. Poisoning agents in the process, such as hydrogen sulfide, cyanide, and arsenic, inhibit the formation of molecular hydrogen on the metal surface and therefore increase the proportion of atomic hydrogen which diffuses into steel.

Hydrogen monitoring instruments indicate the susceptibility of steel to HIC and hydrogen blistering by measuring the rate of atomic hydrogen permeation. Generally, the utility of this application is in qualitatively detecting process upsets which tend to markedly increase the flux of nascent hydrogen. Because the hardness and stressing of the steel affects the susceptibility to hydrogen damage, quantitative assessment is often difficult. However, relative hydrogen flow rates and the estimated associated damage they create are available. Hydrogen monitoring is also used on occasions to monitor the rate of corrosion, but the relationship between corrosion rate and hydrogen permeation varies with fluid dynamics, the method of hydrogen monitoring, and relative content of poisoning agents in the process. RCS hydrogen probes detect hydrogen gas by the simple hydrogen pressure increase produced in an artificial cavity in the steel, i.e. the same mechanism as hydrogen blistering. The pressure build-up is directly proportional to the flux of atomic hydrogen, which can be determined by implementation of the ideal gas law. If the volume of the hydrogen probe cavity and the cross-sectional area across which diffusion is occurring is known, determination of the flux is a simple calculation. COSASCO\textsuperscript{®} Series 6400 Hydrogen Probes are shown in Fig. 12-8 and they feature:

- Simple Reliable Method
- Meets NACE MR0175 and MR0103
- Intrusive and Non-Intrusive Models
- No Chemicals or Shelf Life Problems

![Fig. 12-8 COSASCO\textsuperscript{®} Series 6400 Hydrogen Probes](image-url)
Rouge Monitoring

Rouging is a thin film of iron oxide or hydroxide, usually reddish-brown or golden in color, typically found on stainless steels. Rouge can also consist of iron, chromium, nickel and other elements. Rouge is prevalent in the Biotech and Pharmaceutical industry because most of their systems are made up of stainless steel, typically 316/316L grade and the operating temperature is high. Rouge normally builds up on the interior surfaces of high purity water distillation units, storage tanks, distribution systems (piping, valves, pump housings, fittings, etc.) and process vessels. Many drug manufacturers are concerned about the particulate matter from build-up contaminating their products and sterile systems. An effective way to deal with this problem is monitor the rouging rate on-line in case of process upsets to prevent contamination.

The Rouge Alert™ was developed specifically for stainless steel ultrapure water systems. The patented Solution Resistance Compensation (SRC) incorporated in our electrochemical measurement technology enables very low corrosion (rouging) rates to be measured accurately in the high resistivity of ultrapure water.

The Rouge Alert™ has a high sensitivity front end probe/transmitter and a remote display, data-logger, and analog retransmission unit. The remote display unit provides analog 4-20 mA outputs of rouging rate in microns/month and accumulated rouging in microns for connection to a DCS or SCADA system. In addition, the on-board data-logger enables independent data accumulation for direct transfer to a laptop, which is convenient for your water treatment service provider. The display unit provides power and RS 485 digital communication to the sensing probe and transmitter, enabling the display unit to be mounted up to 4000 feet from the probe/transmitter.

The resistivity of ultrapure water is 18.2 Megohms at 25°C. Normal rouging rates are in the range of 0 to 0.010 microns per month. The Rouge Alert™ accurately measures the rouging rate in the range of 0 to 0.100 microns per month, and will display rouging rate excursions up to 2.000 microns/month. Fig. 12-9 shows the Rouge Alert™ Passivation Monitor and it features:

- Downtime costs reduced by planned re-passivation schedules
- Alarm abnormal water quality and process changes
- Instantaneous Rouge Rate in microns/month
- Accumulated Rouge in microns

![Fig. 12-9 COSASCO Rouge Alert™ Passivation Monitor](image-url)
Chapter 13
Ancillary Equipment

In order to properly complete a corrosion monitoring system, equal care must be given to selection and installation of cables, safety devices and other ancillary devices.

Safety Clamps

Fig. 13-1 shows a safety clamp installed on a retractable probe. Rohrback Cosasco recommends that safety clamps be installed on any retractable probe in service at 100 psi or above. With the threaded rods installed in the safety clamp, as shown in Fig. 13-1, the probe is provided with back-up protection against being forced back out of the piping by the internal pressure. In ordinary service, the probe is held in place by the packing gland, but when the packing gland is not tightened properly or in the event of a failure, the probe can come free. A safety stop is also built into almost all probes at the element end, but this of course can also fail or be dislodged by corrosion or damage inside the pipe.

When the threaded rods are removed for probe replacement or servicing, a safety cable integral to the clamp assembly limits the probe travel to ensure that the stuffing box pressure seal remains intact until the isolation valve can be closed. Safety cables are not designed to resist maximum possible impact forces, so threaded rods should always be installed except when servicing probes.

Probe Retractor

Rohrback Cosasco also recommends use of a probe retractor shown in Fig. 13-2 to insert and remove retractable probes when process piping pressures exceed 100 psi. This is a safety precaution only, but a sensible one, since safety clamps are removed when a probe is replaced.
Safety Barriers

In electrically-hazardous areas, intrinsically safe equipment is generally required to limit the amount of energy and thereby prevent possible ignition of explosive gases. This is achieved by means of intrinsically safe approved equipment such as the CORRDATA® range. In cases of line powered equipment, this may require safety barriers for the connections to the hazardous areas such as in PIM enclosures in an ICMS™ installation.

Shields

Most CORROSOMETER® probes can be supplied with protective shields to prevent damage to the exposed measuring element. High velocity shields are recommended for probes with loop elements when they are exposed to flow rates above ten feet per second or when there is significant particulate matter or high viscosity in the product stream. In addition, coupon-holding shields are available which permit simultaneous coupon and CORROSOMETER® data acquisition at a single location. Either rod or blade type coupons can be accommodated and are electrically isolated from the shield and the probe body.

Cables

Several special types of cable are required for the MICROCOR®, CORROSOMETER®, and CORRATER® range of equipment. The most critical are those between the probes and their monitoring electronics. These cables are critical because of the low levels of signals inherent in these systems.

It is critical to use the correct cable. Use of other substitute cables may severely impede performance or completely prevent operation of the system. Rohrback Cosasco provides a complete range of cables for these systems including fire-retardant cable where required. If the customer is providing cables as part of a major cabling contract, please consult Rohrback Cosasco for the correct cable specifications.

When cathodic protection is used, grounding cables can be used to connect the probe sensing element electrically to the vessel or pipe whose corrosion is being measured. The cable ensures that no difference in electrical potential exists between the element and the metallic systems, so that the effect of the CP system is monitored.