

## CONTROLLING FLOW EFFECTS ON CORROSION

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### A. INTRODUCTION

The effect of flow on corrosion is complex and varied and dependent on both the chemistry and physics of a system. The key variable defining the effect of flow on corrosion is turbulence. High turbulence can result in flow-induced corrosion, erosion–corrosion, or cavitation. Low turbulence can result in corrosion in a separated water phase and allows the occurrence of corrosion under deposits and/or in separated liquid water. *Flow-induced corrosion* is the term used to describe the increase in corrosion resulting from high fluid turbulence due to the flow of a fluid over a surface in a flowing single or multiphase system. *Underdeposit corrosion* is the term used to describe the increased corrosion occurring in a separated water phase beneath deposits of nonmetallic solids on a metal surface resulting from low-flow turbulence.

The key element in controlling flow-induced corrosion is an understanding of the flow characteristics that can produce conditions that favor specific corrosion mechanisms for specific materials and mitigating those conditions by modifying the flow conditions, the material of construction, or the

corrosive environment. The concentration of this chapter is on modification of the flow conditions.

### B. OCCURRENCE OF FLOW-INDUCED CORROSION

Knowing when and where flow-induced corrosion could occur in an operating system is a major help in controlling flow-induced corrosion. A logic tree that can be employed to determine the type of flow-induced corrosion expected in an operating system is given in Figure 64.1 [1]. This procedure provides a method to determine whether equilibrium or steady-state corrosion conditions are present.

The first step is to determine if liquid water is present. If it is not, no corrosion can occur. Similarly, if liquid water cannot contact the pipe wall, no corrosion can occur. The determination of the level of turbulence in the water phase from both the flow regimes and the existence of flow disruption then determines whether or not the corrosion reactions are based on equilibrium or steady-state conditions. Steady-state conditions can occur due to either flow disruptions or a nonequilibrium flow regime such as slug flow. Once either steady-state or equilibrium corrosion is confirmed, the expected corrosion rate can be determined. The term *equilibrium* is used to denote a fully developed flow condition for either mass transfer or wall shear stress.

### C. METHODS FOR CONTROLLING FLOW CORROSION

A number of methods are available to control flow-induced corrosion. They can involve design modifications, process

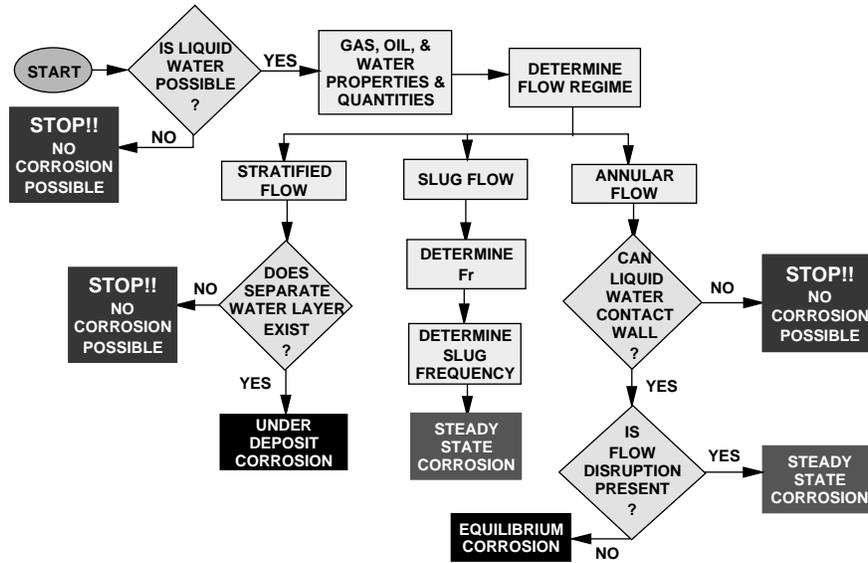


FIGURE 64.1. Logic tree to determine type of flow-induced corrosion in an operating system [1].

changes, and modifications to the corrosive environment. The methods include any one or a combination of the following:

- Minimizing fluid turbulence
- Modification of flowing fluid
- Minimizing flow disruptions
- Modification of flow regimes
- Using a more corrosion resistant alloy

These methods can also be used to control low-turbulence flow corrosion. They also involve design modifications, process changes, and modifications to the corrosive environment.

**C1. Minimize Fluid Turbulence**

Applied to single-phase systems, lowering the fluid velocity lowers the turbulence intensity (mass transfer and wall shear stress) and hence lowers the corrosion rate. This effect is demonstrated in Figure 64.2 for corrosion of carbon steel in single-phase fluid flow at varying chloride concentrations [2]. Though intuitively obvious, this method of control is not always available due to process and equipment limitations.

Many industries have established “rule-of-thumb” velocity limits for various processes. These are generally based on operational experience regarding flow velocities where corrosion rates increase dramatically. In reality, these “rules” serve to limit the turbulence intensity (mass transfer and wall shear stress), thereby effectively limiting the corrosion rate.

**C2. Modify Flowing Fluid**

There are two ways to control flow-induced corrosion by modification of the flowing fluid. These are removal of a corrosive species and chemical additives, for example, the addition of corrosion inhibitors. These methods are also used to control corrosion where flow is not a problem, but they can be particularly effective for flow-induced corrosion.

Removal of a corrosive species limits the diffusion of the corrosive species to the metal surface, thereby reducing the corrosion rate. Chemical additives such as corrosion

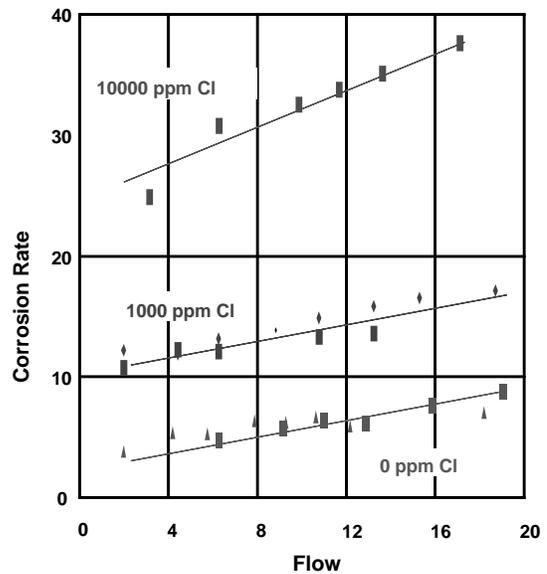


FIGURE 64.2. Effect of single-phase flow on corrosion rate at different chloride concentrations [2].

inhibitors can be employed to modify the surface corrosion products, making them more protective and lowering the corrosion rate. Corrosion inhibitor formulations can also be designed to modify turbulence in the fluid through alterations in viscosity and interfacial surface tension.

Examples of controlling flow-induced corrosion by removal of corrosive species are the removal of oxygen from seawater and raising the pH of a brine solution. The removal of oxygen through either mechanical or chemical means reduces the oxygen concentration in the solution. Consequently, the mass transfer of oxygen to the corroding metal surface is reduced, reducing the corrosion rate. Raising the pH results in a decrease in the concentration of hydrogen ions in a solution. As with oxygen, this reduction results in a decreased mass transfer of hydrogen ion to the corroding metal surface, reducing the corrosion rate.

### C3. Minimize Flow Disruptions

Flow disruptions are a major contributor to flow-induced corrosion and resulting failures. As a result, minimizing flow disruptions in equipment design and construction is important. Ways to minimize flow disruptions include the following:

- Minimize the mismatch when welding pipe joints and fittings.
- Grind internal welds smooth, when possible.
- Use long-radius elbows.
- Avoid step changes in pipe diameter.
- Ream and deburr tubing ends before installation.
- Protect stored pipe to prevent internal corrosion before it goes into service.
- Don't use corroded pipe that contains internal pits, even if it still meets the required strength criteria.

### C4. Modify Flow Regimes

Flow regime modification is used primarily for pipelines. Flow regimes are modified by changing the gas and/or

liquid flow rates in a pipeline. The effects of these changes on flow regime are reflected in the flow regime maps. Resolution of the flow regime existing in various sections of a pipeline can be used to determine where to expect corrosion in the pipeline and consequently where to monitor corrosion.

In the design stage, pipeline sizes can be adjusted to prevent slug flow at the anticipated liquid and gas flow rates. If the anticipated problem is corrosion under deposits in the bottom of the pipeline, the pipe size can be adjusted to eliminate stratified flow and keep the deposits suspended in the fluid.

### C5. Corrosion-Resistant Alloys

In some cases, the only alternative available to prevent flow-induced corrosion is the use of a more corrosion-resistant alloy. This is usually the most expensive option and is generally only a last resort. An example is the use of a stainless steel in a situation where high flow rates result in excessively high corrosion rates for carbon or alloy steel.

Corrosion-resistant alloys may also experience turbulence limits in different environments, and the use of a corrosion-resistant alloy should not, a priori, be assumed as the final answer to a flow-induced corrosion problem. In some cases, low flow can be a problem, such as the use of some stainless steels in chloride environments where pitting can occur under deposits.

## REFERENCES

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