STRESS ENGINEERING SERVICES INC.

TECH BRIEF

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Corrosion Technology

Flow Corrosion Effects Using Jet Impingement Corrosion Testing

Jet impingement testing is effectively employed to study the effects of flow on the corrosion of materials, and the effects of flow on corrosion inhibitor performance. Stress Engineering Services has improved and refined this technique to allow both in-depth scientific investigations and routine testing.

The wall shear stress on the test sample is the correlation factor used to relate the corrosion results to field operating systems. Wall shear stress measures the interaction of a flowing fluid with a solid surface. It can be related to any flow geometry, because it is a basic fluid/wall interaction phenomena and not a function of the specific flow geometry.

Jet impingement experiments using technology developed by have well defined wall shear stress acting on the test specimen, which is effectively correlated to any flow geometry. The wall shear stress in an operating system is identical in its effect on corrosion to the wall shear stress in the jet impingement experiment. Therefore, the corrosion rate measured in the jet impingement experiment is directly related to the expected corrosion rate in the operation.

Features of this jet impingement testing system used by Stress Engineering Services include:

- **Correlation of test results to actual process flow conditions and flow regime.**
- **Accurate slug flow simulation and correlation.**
- **Instantaneous corrosion measurements in multiphase environments; water with entrained oil and gas, gas with entrained water and low water cut oil.**
- **Recirculating and once-through flow tests.**
- **Corrosion inhibitor evaluation at varying shear stress, and for shear stress transients.**
- **Accurate determination of critical corrosion inhibitor concentration.**
- **Accurate of corrosion inhibitor persistency (once-through).**
- **Determination of acidizing and spent acid flow-back flow effects.**
- **Accurate evaluation of batch and batch/continuous corrosion inhibition.**

Test Apparatus Design

The jet impingement test apparatus design is simpler and easier to operate than previous designs, and provides vastly superior temperature control, without the temperature fluctuations that occur with immersion heaters. The wall shear stress range obtainable with the present system is from 20 to 1000 Pa.

Modification of the basic recirculating liquid apparatus allows flow through operation and/or operation with liquid containing entrained gas, simulating of multiphase production and gas lift systems. The jet impingement test system is combined with corrosion probe technology allowing linear polarization corrosion measurements in high resistivity systems.[4,5] This permits the application of jet impingement techniques to gas flow with entrained liquid (simulating annular flow conditions in gas production systems), and to oil flow with entrained water phase (simulating of low water cut multiphase production).

A schematic diagram of the jet impingement test cell, showing the relative position of the jet, test probe, and thermocouple monitoring the fluid temperature inside the cell, is shown in Figure 1. A schematic diagram of the test probe, containing the concentric ring electrodes that allows electrochemical corrosion measurements during the test, is shown in Figure 2. This figure shows the relative position of the reference, working and counter electrodes

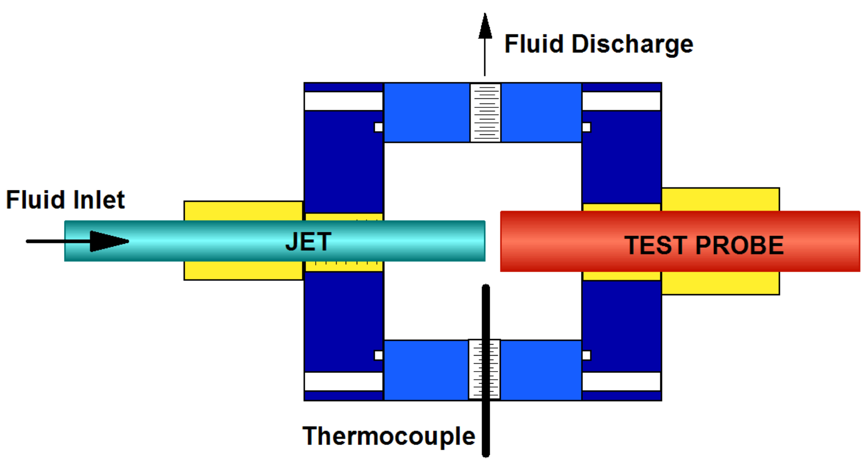

Figure 1. Schematic diagram of the jet impingement apparatus test cell.

Why Jet Impingement Testing Works

Jet impingement is useable for flow corrosion testing due to the hydrodynamic characteristics of a jet impinging on a flat plate, diagrammed in Figure 3. The fluid flow across the flat surface contains characteristic flow regions that are mathematically definable. Placing the working electrode of the test probe at a specific radial location in the jet allows measurement of the corrosion rate under those specific conditions.

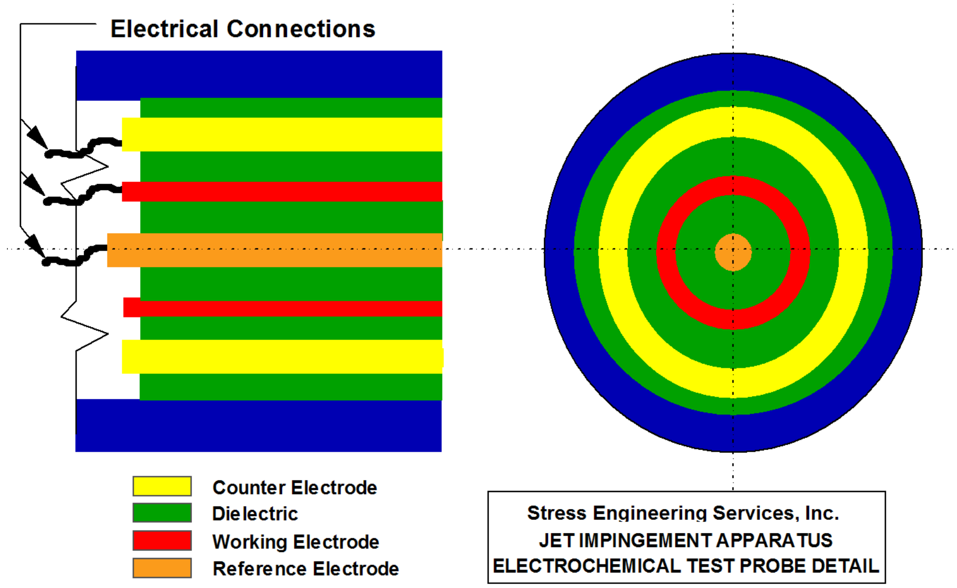

Figure 2. Cross-section and electrode arrangement of the test probe.

The result, when the test ring is properly placed, is the ability to accurately and reproducibly measure corrosion rates under defined wall shear stress conditions.[1] This wall shear stress can be experimentally measured through mass transfer correlation, or the wall shear stress can be mathematically calculated.

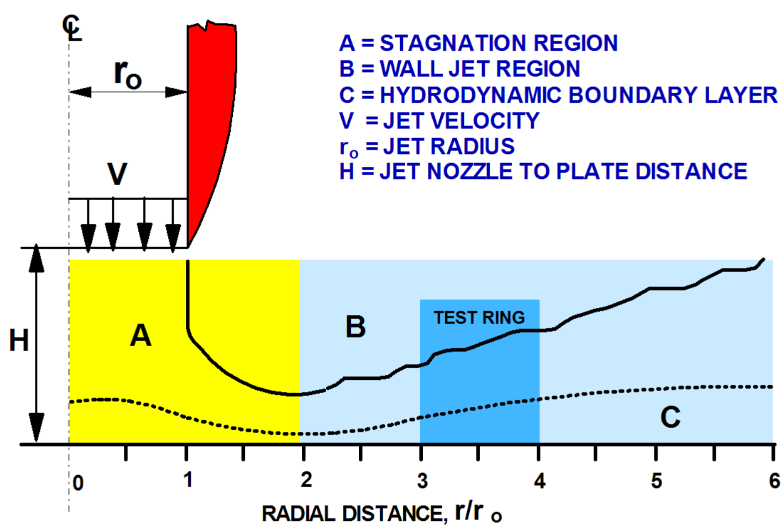

Figure 3. Hydrodynamic characteristics of a jet impinging on a flat plate showing the four characteristic flow regions

Correlation with Operating Systems

The wall shear stress on the test sample is the correlation factor used to relate the corrosion results to field operating systems. Wall shear stress measures the interaction of a flowing fluid with a solid surface. It can be related to any flow geometry, because it is a basic fluid/wall interaction phenomena and not a function of the specific flow geometry.

Data from any experiment that determines the wall shear stress acting on the test specimen can be effectively used for direct correlation to any flow geometry. Therefore, the wall shear stress calculated for an operating system is identical in its effect on corrosion to the wall shear stress in the experiment. The corrosion rate measured in the experiment is then directly related to the expected corrosion rate in the operation. This procedure is diagrammed in Figure 4.

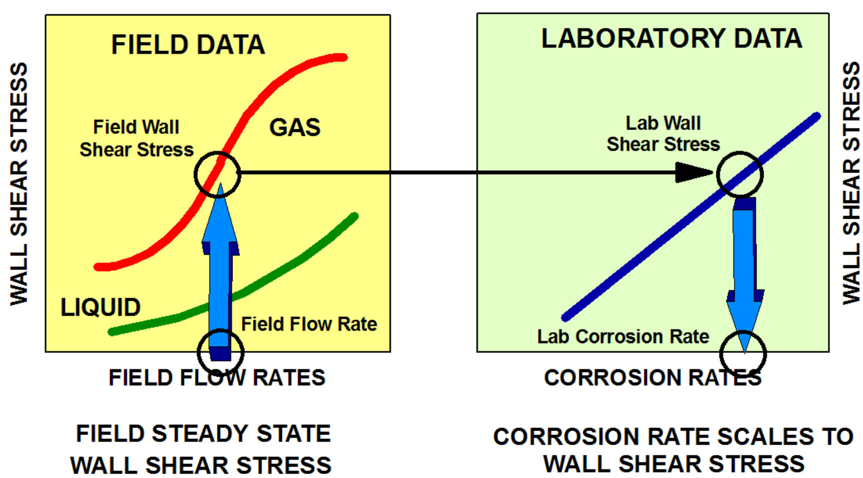

Figure 4. Procedure for correlating experimental laboratory corrosion data with field operating systems.

Techniques for Slug Flow and Disturbed Flow Correlation

Slug flow and disturbed flow (flow over weld beads and pits, or through chokes, valves and bends, etc.) destroys the equilibrium diffusion boundary layer. The solution composition at the metal surface is equivalent to that of the bulk solution, in that fresh corrosives are brought into contact with the surface and corrosion products are swept away, destroying the equilibrium process. The effect is the production of a steady state corrosion situation, where the normal equilibrium corrosion reaction cannot be attained, but instead generates a kinetic steady state. The result is increased corrosion rate at the location of the flow disturbance, although the corrosion rate in the bulk of the system may be low.

Slug Flow Correlation

Slug flow is a transient flow disruption, in that each time a slug passes a point the flow is violently disturbed, but then re-establishes after the slug passes. This process is simulated in the jet

impingement test by initiating a step change in the jet flow rate, hence wall shear stress during a test, while continuously monitoring the corrosion rate. This is a very effective means of testing the efficacy of corrosion inhibitors to slug flow corrosion, as shown in Figure 5.

Distured Flow Correlation

The existing, applicable equations for both wall shear stress and mass transfer coefficient assume equilibrium conditions. The reality of operating systems, however, is that both equilibrium and disturbed steady state flow conditions exist. While the existing equations and test methods are effectively used for equilibrium flow conditions in operating systems, they cannot be directly applied to disturbed flow conditions. Steady state mass transfer and wall shear stress relationships to steel corrosion and corrosion testing are required for application to corrosion of steel under disturbed flow conditions.[6]

The diffusion layer for a disturbed flow condition is simulated in the jet impingement apparatus through use of a thin (1.0 mm) sample that maintains an equilibrium hydrodynamic boundary layer, while simultaneously resulting in a non-equilibrium diffusion layer. This simulation allows the measured diffusion to occur in a known hydrodynamic environment, allowing correlation of the measured steady state diffusion with a known wall shear stress.

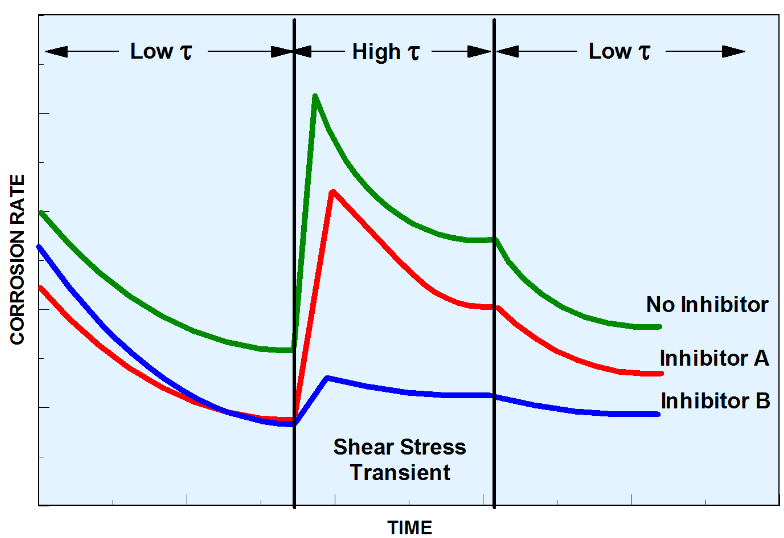

Figure 5. Effect of a large step increase in wall shear stress on corrosion rate for carbon steel freely corroding and with corrosion inhibitor additions.

Critical Corrosion Inhibitor Concentration

The effect of sequential increases in the concentration of corrosion inhibitor at constant wall shear stress on the corrosion rate of steel is given in Figure 6. The corrosion inhibitor reduces the corrosion rate differently for the two corrosion inhibitors shown as the corrosion inhibitor concentration increases. The minimum corrosion inhibitor concentration with a reasonable efficiency, or giving the maximum allowable corrosion rate, is the critical corrosion inhibitor concentration required for the system under test.

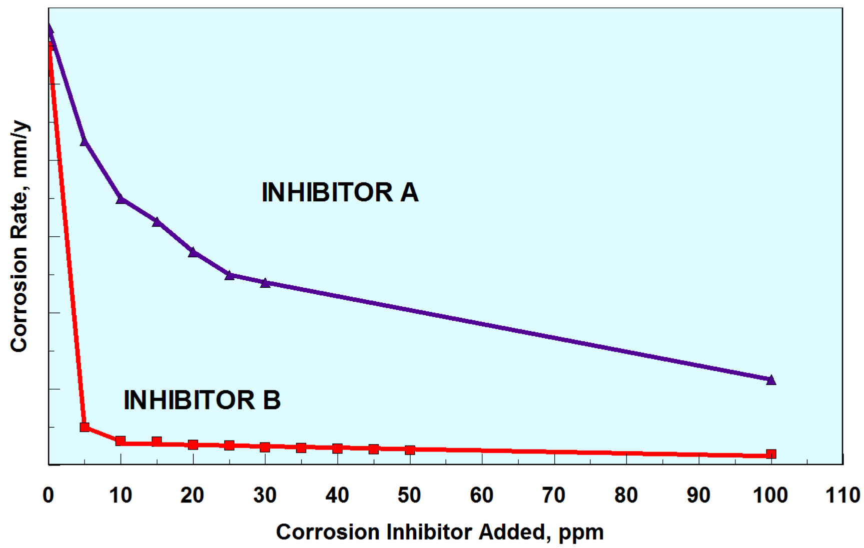

Figure 6. Effect of sequential increases in corrosion inhibitor concentration at a fixed wall shear stress on corrosion rate for carbon steel to determine the critical corrosion inhibitor concentration.

Corrosion Inhibitor Persistency

The remaining effectiveness of a corrosion inhibitor after discontinuing inhibitor injection, or corrosion inhibitor persistency, is determined using the flow through jet impingement apparatus. This is accomplished by first allowing the corrosion rate to stabilize without corrosion inhibitor, adding corrosion inhibitor at a fixed rate until the inhibited corrosion rate stabilized, followed by discontinuing the corrosion inhibitor injection. The effect of this protocol on the corrosion rate of steel at constant wall shear stress is given in Figure 7.

The corrosion inhibitor reduces the corrosion rate when it is introduced into the stream. When the corrosion inhibitor has formed a stable corrosion product film, the corrosion rate stabilizes at a value that reflects the efficiency of the corrosion inhibitor at the test wall shear stress. When injection of the corrosion inhibitor is discontinued, corrosion begins to increase at a rate that reflects the rate of desorption and resulting destabilizing of the corrosion product film.. This is also a measure of the effectiveness of the corrosion inhibitor.

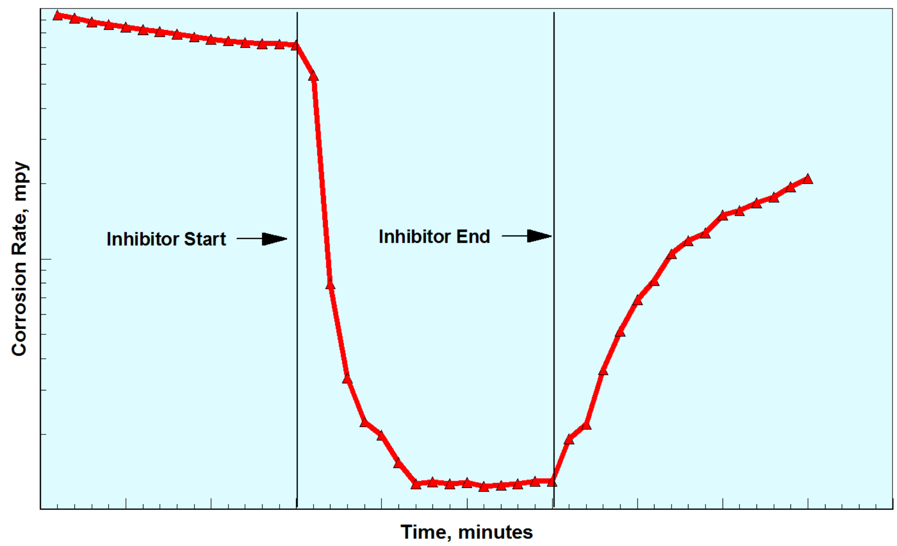

Figure 7. Effect of corrosion inhibitor at a fixed wall shear stress on corrosion rate for carbon steel to determine the persistency of the corrosion inhibitor after injection is terminated.

The Bottom Line

All flow corrosion test methods are not created equal. The correct use of jet impingement methods to study the effect of flow on materials and corrosion inhibitors provide significant advantages over other test methods:

- **The improved test apparatus design provides effective flow testing employing recirculating or once-through liquid flow, liquid with entrained gas, gas with entrained liquid, and oil at low water cuts.**
- **Improved methods for jet calibration give added confidence in the resulting corrosion data.**
- **Improved test techniques allow accurate correlation of the results to disturbed flow and slug flow conditions.**
- **Corrosion inhibitor evaluation for low and high shear conditions, and for shear stress transients is possible.**
- **Accurate determination of the critical corrosion inhibitor concentration is possible.**
- **Accurate determination of the corrosion inhibitor persistency is possible using once-through flow tests.**

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