



Best Management Practice

Internal Microbiologically
Influenced Corrosion of
Pipelines

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2800, 421 – 7 Avenue SW
Calgary, AB
Canada T2P 4K9
Tel 403-267-1100

1820, 275 Slater Street
Ottawa, ON
Canada K1P 5H9
Tel 613-288-2126

1004, 235 Water Street
St. John's, NL
Canada A1C 1B6
Tel 709-724-4200

201, 1114 Langley St.
Victoria, BC
Canada V8W 1W1
Tel 778-265-3819

www.capp.ca • communication@capp.ca

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1 Overview

Internal corrosion is a dominant contributing factor to pipeline failures and leaks. To deal with this issue, the CAPP Pipeline Technical Committee has developed industry recommended practices to improve and maintain the mechanical integrity of upstream pipelines. They are intended to assist upstream oil and gas producers in recognizing the conditions that contribute to pipeline corrosion incidents, and identify effective measures that can reduce the likelihood of corrosion incidents.

This document addresses design, maintenance and operating considerations for the mitigation of internal corrosion in pipelines and associated systems and equipment. This document does not address the deterioration of aluminum and non-metallic pipelines.

This document complements CSA Z662 and supports the development of corrosion control practices within pipeline integrity management programs, as required by CSA Z662 and the applicable regulatory agency. In the case of any inconsistencies between the guidance provided in this document and either CSA Z662 or regulatory requirements, the latter shall apply.

This document is intended for use by corrosion professionals involved with the development and execution of corrosion mitigation programs, engineering teams involved in the design of gathering systems, and operations personnel involved with the implementation of corrosion mitigation programs and operation of wells and pipelines in a safe and efficient manner. It contains a consolidation of key industry experience and knowledge used to reduce internal corrosion. However, it is not intended to be a comprehensive overview of all practices.

Additional corrosion mitigation best management practices:

- Mitigation of Internal Corrosion in Carbon Steel Gas Pipeline Systems
- Mitigation of Internal Corrosion in Carbon Steel Oil Effluent Pipeline Systems
- Mitigation of External Corrosion on Buried Carbon Steel Pipeline Systems
- Mitigation of Internal Corrosion in Water Pipeline Systems

Leak detection is addressed in a separate best management practice called Pipeline Leak Detection Programs. The use of HDPE lined pipelines and reinforced composite pipe (non-metallic pipelines) are also addressed in separate best management practices.

These documents are available free of charge on the CAPP website at www.capp.ca.

2 Introduction

Microbiologically Influenced Corrosion (MIC) is a corrosion mechanism that takes the form of under deposit corrosion. If the bacteria are alive, they can create an aggressive environment beneath the deposit by creating acids and further accelerate corrosion. Bacteria deposits can also create a corrosion cell due to potential and/or concentration differences between the bulk electrolyte and the electrolyte.

Within a pipeline system, bacteria can be categorized as either planktonic or sessile. Planktonic remain suspended within the fluids, while sessile adhere to the pipe surface and create colonies. Planktonic bacteria are not a corrosion threat, only sessile bacteria pose a corrosion threat. Higher fluid velocities do not necessarily prevent accumulation of sessile bacteria.

Depending on the type, bacteria can survive in aerobic (with oxygen) and anaerobic (no oxygen) conditions.

3 Common Types of Bacteria

There are numerous different species of bacteria. The most common species that can create an internal corrosion issue in oilfield pipelines are sulfate reducing bacteria (SRBs) and acid producing bacteria (APBs). Iron reducing bacteria (IRBs) have been detected as well in fresh water systems, but have generally not been as prevalent in Western Canada.

4 Corrosion Mechanisms and Recognition

MIC is categorized as a form of under-deposit corrosion. Sessile bacteria, whether active, dormant or deceased create a corrosion cell under the bacteria. Otherwise relatively benign corrosion threats, e.g., CO₂ corrosion, can be significantly accelerated beneath the bacteria.

Active SRBs consume sulfates and create hydrogen sulfide gas, which quickly dissolves into the electrolyte to form sulfurous acids. Active APBs produce organic acids which also dissolve into the electrolyte. In both cases, this lowers the pH, which in itself accelerates corrosion.

MIC is typically found at or near the 6:00 o'clock position, i.e., the location where deposits are most likely to occur. Two further characteristics that may signal possible MIC are:

- Iron sulfide corrosion products within the pit in a sweet corrosion environment, as the only source of H₂S required to create this product would be from SRB activity.
- If the pitting has a terraced appearance, it is highly likely due to MIC that has stopped and started several times. This is usually either due to availability of

food sources for the bacteria to metabolize or between biocide treatments that initially slow/halt MIC, but has limited longer term effectiveness.

5 Bacteria Sources

There are various sources of bacteria, as described below.

- Directly from the reservoir or surface fresh water sources
- Contamination of the reservoir due to contaminated injection water used for increased oil production from surface fresh water sources, e.g., lakes, rivers, sloughs.
- General contamination from external sources such as contaminated pigs, inline inspection tools, or hydrotest water.
- Trucked in oilfield fluids or fluids from closed and open drain systems, can be a source if they are introduced into a clean system

NOTE: In thermal production situations, initial produced gases are sweet, however, with time, they begin to sour with H₂S. Initially, this was thought to be due to bacteria being liberated with the bitumen. In reality, 80% quality steam is injected into the reservoir to produce bitumen. The small amounts of sulfates in the steam react directly with bitumen to produce H₂S and bacteria is not involved.

6 Detection and Enumeration

The usual first step to determine a possible MIC threat is to sample the water at the location that it originates. The origin of bacteria is typically downhole from the reservoir. It is usually not possible to take samples at oil well sites. Sampling at the outlet is usually the easiest. If the source is tankage site(s), then drawing water from the bottom of the tank may be possible. If very low levels are detected, it is unlikely that MIC is a threat. High levels of bacteria in a water sample does not necessarily indicate a corrosion threat, as these are planktonic bacteria. If the line is piggable, capturing solids immediately after a pig run and analyzing for bacteria is a common practice to more accurately evaluate the threat. Alternately samples of bacteria can be removed by physically swabbing pipe surfaces.

Historically, the most common method used to enumerate bacteria was serial dilution. Specialized solutions were provided in sealed bottles. Different solutions were used for different species, e.g., SRB enumeration required different bottles than APBs. The usual practice was to enumerate both SRBs and APBs. After sampling, it required 28 days to before the results could be properly evaluated. It only enumerated active bacteria. It was also much more sensitive to errors due sample collection and handling techniques. That method is still commonly used.

Advantages:

- Provides quantitative results for specific bacteria

- It comparatively inexpensive to other techniques
- It is an established technique that is widely accepted and standardized within the industry

Disadvantages:

- Time consuming as it requires 28 days before results are known
- Every specific type of bacteria requires its own unique set of test bottles
- Enumerates only live/active bacteria
- Labour intensive and requires proper training to avoid errors
- Sample collection, preservation and transportation can lead to errors
- Sample chemistry may affect detection

Luminultra (Adenosine Triphosphate/ATP Fluorescence) is the preferred method. This technique enumerates all types, whether active or dormant, but does not differentiate between different species. This method provides results within 5 minutes. Quantitative results for different species can be done use polymerase chain reaction (PCR).

Pros:

- Rapid Results: Provides results within minutes, enabling quick responses
- Broad Detection: Detects all living cells, giving a total bacterial load
- Ease of Use: Simple procedure that can be performed on-site
- High Sensitivity: Can detect low levels of bacterial contamination
- Real-Time Monitoring: Allows for continuous monitoring of bacterial activity

Cons:

- Non-Specific: Does not differentiate between types of bacteria
- Sample Handling: Requires careful handling to ensure accuracy, as ATP degrades quickly
- Cost: ATP testing kits and luminometers can be expensive
- Interference: Presence of other organic matter can affect results
- Limited Information: Provides total bacterial load but not specific bacterial identification

6.1 Biological Activity Reaction Test (BART) Bottle Testing

BART uses a specialized vial containing specific media and a ball to create a gradient of oxygen levels, promoting the growth of different bacteria types. The test visually indicates the presence and activity of various bacteria

Pros:

- Ease of Use: Simple and cost-effective, can be performed on-site without specialized equipment
- Visual Indicators: Provides observable reactions (e.g., color changes, gas formation) indicating bacterial activity
- Specific Detection: Can target specific bacterial groups like SRBs

- Low Cost: Affordable compared to other testing methods
- No Specialized Training: Can be performed by personnel with minimal training

Cons:

- Qualitative Results: Provides qualitative rather than quantitative data
- Time Lag: Reaction times can vary, sometimes taking several days
- Limited Scope: May not detect all types of bacteria
- Potential for Misinterpretation: Visual indicators can be subjective
- Environmental Sensitivity: Results can be influenced by environmental conditions

7 Mitigation

Several approaches to mitigating MIC have been used. Each approach is discussed below.

Pigging – Regular pigging, using a proper pig for removing solids, is the simplest. The advantage is that it is relatively inexpensive.

The disadvantages include:

- Establishing the appropriate frequency can be difficult. Quantifying and analyzing pig returns can assist with this approach.
- Existing pits may not be properly cleaned and corrosion continues.
- Ensuring that the proper pigs (e.g., properly sized scrapers, brushes) are used and at the prescribed frequency can be an issue.
- Having available manpower to adhere to the required pigging schedule must be considered. Manpower cutbacks in field operations have created issues with executing integrity programs. Before prescribing a program from behind a desk, it has to be practical to execute.
- Access issues in remote/winter only situations can affect ability to meet prescribed pigging frequency requirements

Continuous biocide application – This effectively kills virtually all living bacteria. The prime advantage is that accelerated corrosion due to bacterial metabolism is eliminated.

The disadvantages include:

- This is an ongoing cost and ensuring no live bacteria exist on the pipeline surface is difficult.
- Pigging may still be required as accumulation of dead bacteria can still cause under deposit corrosion.
- Biocides can be harmful to the environment if not handled and contained properly.
- Compatibility with other chemicals and/or pipeline system materials in the pipeline could be an issue.

7.1 Batch or shock biocide application

This is the application of a biocide for a fixed amount of time, e.g., 4 hours once per week, using slug batches or chemical pill applications. Treatment can be done in the pipeline or shock treatment at the source (e.g. tanks, closed drain systems).

7.2 Continuous Corrosion Inhibitor Application

Continuous inhibitor films are several molecules thick and are easily compromised when sessile bacteria are present. Continuous inhibitor will adhere to the outer surface of sessile bacteria and are ineffective in reducing corrosion rates beneath the bacteria.

7.3 Batch Corrosion Inhibitor Application

Applying a batch corrosion inhibitor film on the pipeline can prevent biofilms from contacting the steel surface as the film is thicker and much more viscous than continuous inhibitor films. Predicting the frequency of such applications can be difficult and is best determined by knowing the historical volumes of deposits are removed after pig runs.

7.4 Material Selection

Alternative corrosion immune materials that can be used to prevent MIC include:

- Corrosion resistant alloys, e.g., stainless steels
- Non-metallic materials, e.g., fibreglass, composites, HDPE
- Internally coated pipelines, e.g., epoxies, phenolics, nylons, etc.,
- Internal expanded (tight fit) liners, e.g., polyethylene

8 Corrosion Monitoring Techniques

Table 5 describes the most common techniques for monitoring corrosion and operating conditions associated with internal corrosion in oil effluent pipelines.

Table 1: Corrosion monitoring techniques

Technique	Description	Comments
Water Analysis	<ul style="list-style-type: none"> Ongoing monitoring of water for bacteria. 	<ul style="list-style-type: none"> Monitor changes in planktonic bacteria levels
Mitigation Program Compliance	<ul style="list-style-type: none"> Ongoing monitoring of mitigation program implementation and execution 	<ul style="list-style-type: none"> Chemical pump reliability, injection rate targets and inhibitor inventory control are critical where mitigation program includes continuous chemical injection The corrosion mitigation program must be properly implemented to be effective The impact of any non-compliance to the mitigation program must be evaluated to assess the effect on corrosion
Bio-spools	<ul style="list-style-type: none"> Used to monitor for bacteria presence and mitigation program effectiveness 	<ul style="list-style-type: none"> Bio-spool placement and data interpretation are critical to successful application of these methods Bio-spools should be used in conjunction with other monitoring and inspection techniques Solids pigged out of pipelines (pig yields) can be tested for bacteria levels Consider following NACE TM0212 Bacteria presence on pipeline internal surfaces, determined by analyzing solids produced after pigging, is considered a better way to quantify type and numbers present in the system
Pigging Returns	<ul style="list-style-type: none"> Used to monitor levels of sessile bacteria 	<ul style="list-style-type: none"> Monitor bacteria levels for biocide effectiveness

9 Corrosion Inspection Techniques

Table 6 describes common techniques to be considered for the detection of internal corrosion in oil effluent pipelines.

Table 2: Corrosion inspection techniques

Options	Technique	Comments
Inline Inspection	<ul style="list-style-type: none"> Magnetic flux leakage is the most common technique 	<ul style="list-style-type: none"> Inline inspection data should be verified using other methods Effective method to determine location and severity of corrosion along the steel pipelines Inline inspection can detect both internal and external corrosion wall loss as well as other types of imperfections The pipeline must be designed or modified to accommodate inline inspection The tools are available as free swimming or tethered To run a tethered tool inspection, it is often necessary to dig bell holes and cut the pipeline
Non-Destructive Examination (NDE)	<ul style="list-style-type: none"> Ultrasonic inspection, radiography or other NDE methods can be used to measure metal loss in a localized area 	<ul style="list-style-type: none"> Evaluation must be done to determine potential corrosion sites prior to conducting NDE is commonly used to verify inline inspection results and corrosion at excavation sites. NDE methods may be used to measure corrosion pit growth at excavation sites, however the practical limitations of NDE methods and the factors affecting accuracy must be understood. The use of radiography is an effective screening tool prior to using ultrasonic testing Corrosion rates can be determined by performing periodic NDE measurements at the same locations
Destructive Examination	<ul style="list-style-type: none"> Physical cut out and examination of sections from the pipeline 	<ul style="list-style-type: none"> Consideration should be given to locations where specific failure modes are most likely to occur.

10 Repair And Rehabilitation Techniques

Table 7 describes common techniques for repair and rehabilitation of pipelines damaged by internal corrosion.

Prior to the repair or rehabilitation of a pipeline, the appropriate codes and guidelines should be consulted, including:

- CSA Z662, Clause 10 Including Temporary and Permanent Repair Methods
- CSA Z662 Clause 13 Reinforced composite, thermoplastic-lined, and polyethylene pipelines

Table 3: Repair And Rehabilitation Techniques

Technique	Description	Comments
Pipe Section Replacements	<ul style="list-style-type: none"> • Remove damaged section(s) and replace 	<ul style="list-style-type: none"> • When determining the quantity of pipe to replace, consider the extent of the corrosion and as well as the extent and severity of damage or degradation of any internal coatings or linings along with the condition of the remaining pipeline • Impact on pigging capabilities must be considered (use same pipe diameter and similar wall thickness) • The replaced pipe section should be coated with corrosion inhibitor prior to commissioning or coated with an internal coating compatible with the existing pipeline
Repair Sleeves	<ul style="list-style-type: none"> • Reinforcement and pressure-containing sleeves may be acceptable for temporary or permanent repairs of internal corrosion as per the limitations stated in CSA Z662 	<ul style="list-style-type: none"> • For internal corrosion it may be possible in some circumstances for the damaged section to remain in the pipeline as per the requirements in CSA Z662 Clause 10 along with proper corrosion control practices to prevent further deterioration • Different repair sleeves are available including composite, weld-on and bolt-on types. The sleeves must meet the requirements of CSA Z662 Clause 10

Technique	Description	Comments
<p>Polymer Liners/Coatings</p>	<ul style="list-style-type: none"> • A polymer liner is inserted in the steel pipeline • The steel pipe must provide the pressure containment capability • Internal coatings can be utilized but application or making them holiday-free can be challenging, particularly at connection ends 	<ul style="list-style-type: none"> • A variety of materials are available with different temperature and chemical resistance capabilities • Impact on pigging capabilities must be considered • Polymer liners may eliminate the need for internal corrosion mitigation, corrosion monitoring and inspection • Reduction of inhibition programs may impact the integrity of connecting headers and facilities constructed from internally bare carbon steel • Coatings can degrade over time (limited life expectancy)
<p>Composite or Plastic Pipeline</p>	<ul style="list-style-type: none"> • Freestanding composite or plastic pipe can be either plowed-in for new lines, or pulled through old pipelines • This pipe must be designed to provide full pressure containment 	<ul style="list-style-type: none"> • A variety of materials are available with different temperature and chemical resistance capabilities • Freestanding plastic pipelines are typically limited to low-pressure service • Impact on pigging capabilities and pig selection must be considered • Composite or plastic pipelines may eliminate the need for internal corrosion mitigation, corrosion monitoring and inspection • Reduction of inhibition programs may impact the integrity of connecting headers and facilities constructed from internally bare carbon steel
<p>Entire Pipeline Replacement</p>	<ul style="list-style-type: none"> • Using internally coated steel pipeline systems with an engineered joining system should also be considered • The alteration or replacement of the pipeline allows for proper mitigation and operating practices to be implemented 	<ul style="list-style-type: none"> • Should be pig and inspection tool compatible (required for sour systems per CSA Z662 Clause 16) • Refer to Section 4 “Recommended Practices” in this document for details • Ensure that when replacements in kind occur, the replacement of the pipeline allows for proper mitigation and operating practices to be implemented

11 Additional Resources

For more information on pipeline corrosion, the reader should refer to the following organizations:

- Association for Materials Protection and Performance: <http://ampp.org>
- European Federation of Corrosion (EFC): <http://www.efcweb.org>