Different Types of Corrosion

- Recognition, Mechanisms & Prevention

Microbiologically Influenced Corrosion (MIC)

Recognition of Microbiologically Influenced Corrosion (MIC)

What is Microbiologically Influenced Corrosion (MIC)? Microbiologically Influenced Corrosion refers to corrosion affected by the presence or activity, or both, of microorganisms. In the corrosion literature, other non-standard terms used by some authors include microbial corrosion, bacterial corrosion, and biological corrosion.

There are about a dozen of bacteria known to cause microbiologically influenced corrosion of carbon steels, stainless steels, aluminum alloys and copper alloys in waters and soils with pH 4~9 and temperature 10^{o}C~50^{o}C.

These bacteria can be broadly classified as aerobic (requires oxygen to become active) or anaerobic (oxygen is toxic to the bacteria). Sulphate reducing bacteria (SRB) is anaerobic and is responsible for most instances of accelerated corrosion damages to ships and offshore steel structures. Iron and manganese oxidizing bacteria are aerobic and are frequently associated with accelerated pitting attacks on stainless steels at welds.

Many industries are affected by Microbiologically influenced corrosion (MIC):

- Chemical processing industries: stainless steel tanks, pipelines and flanged joints, particularly in welded areas after hydrotesting with natural river or well waters.
- Nuclear power generation: carbon and stainless steel piping and tanks; copper-nickel, stainless, brass and aluminum bronze cooling water pipes and tubes, especially during construction, hydrotest, and outage periods.
- Onshore and offshore oil and gas industries: mothballed and waterflood systems; oil and gas handling systems, particularly in those environments soured by sulfate reducing bacteria (SRB)-produced sulfides
- Underground pipeline industry: water-saturated clay-type soils of near-neutral pH with decaying organic matter and a source of SRB.
- Water treatment industry: heat exchangers and piping
- Sewage handling and treatment industry: concrete and reinforced concrete structures
- Highway maintenance industry: culvert piping
- Aviation industry: aluminum integral wing tanks and fuel storage tanks
- Metal working industry: increased wear from breakdown of machining oils and emulsions
- Marine and shipping industry: accelerated damage to ships and barges

Positive identification of microbiologically influenced corrosion requires chemical, biological and metallurgical analysis of the waters, soils and the metal samples.

Mechanisms of Microbiologically Influenced Corrosion (MIC)

What causes Microbiologically Influenced Corrosion (MIC)? Microbiologically influenced corrosion is caused by specific genera of bacteria which feed on nutrients and other elements found in waters and soils. Sea water is a primary source of sulphate reducing bacteria (SRB). The biological activities modify the local chemistry (acid-producing) and render it more corrosive to the metals. For example, iron-oxidizing bacteria can perforate a 5mm thick 316 stainless steel tank in just over a month!

Prevention of Microbiologically Influenced Corrosion (MIC)

How to prevent Microbiologically Influenced Corrosion (MIC)? Microbiologically influenced corrosion, or microbial corrosion or biological corrosion can be prevented through a number of methods:

- Regular mechanical cleaning if possible
- Chemical treatment with biocides to control the population of bacteria
- Complete drainage and dry-storage

Modeling and Prediction of Microbiologically Influenced Corrosion

MIC-Compass®: Modeling and Prediction of Microbiologically Influenced Corrosion in Oil and Gas Pipelines

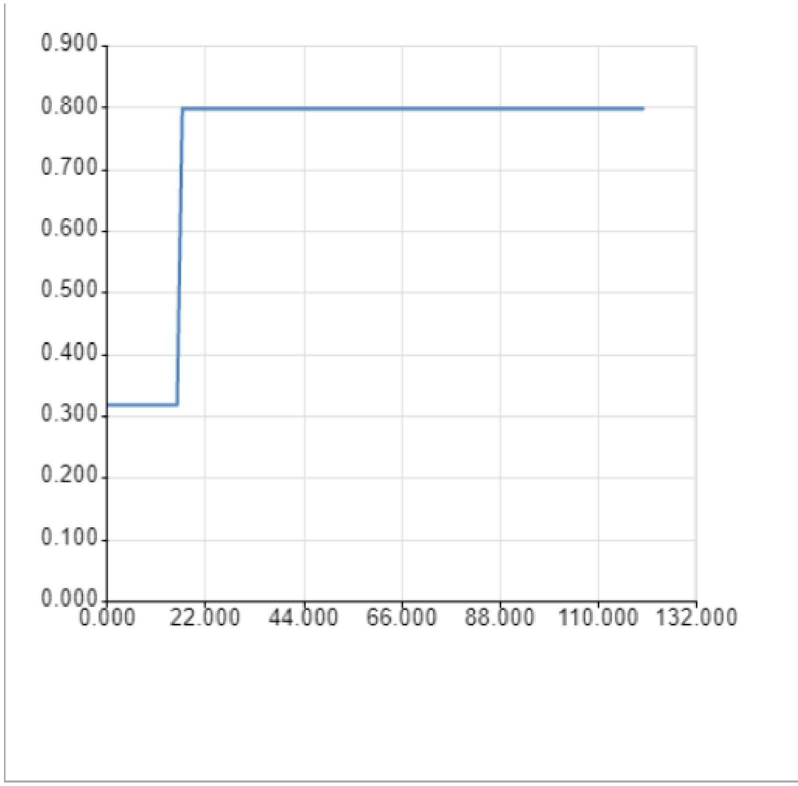
MIC-Compass is the only device and OS independent software tool on the market for the prediction and modeling of microbiologically influenced corrosion (MIC) in oil and gas pipelines. Pipeline engineers, consultants, operation personnel, maintenance and inspection engineers can quickly assess the MIC risk, identify the dominating corrosion process in the pipeline (be it MIC or other types of corrosion such as CO_2 corrosion, H_2S corrosion, CO_2-H_2S mixed corrosion, and oxygen corrosion), and determine the corrosion rates under the prevailing operating conditions. MIC-Compass works on any device running any OS without the need to install or download anything.

The presence of bacteria in the water/deposit samples collected from a pipeline does not necessarily mean that MIC will occur in the pipeline and the absence of bacteria in the water/deposit samples doe not necessarily mean that MIC will not occur in the pipeline. There is no single factor that can trigger the initiation of MIC. The initiation and the growth rate of MIC are determined by a number of factors working in synergy:

- operating temperature
- in-situ pH
- liquid velocity
- oxygen content
- sulphate content
- total dissolved solids (TDS)
- total carbon from fatty acids
- nitrogen content
- biocide
- debris/deposit
- pigging frequency
- operation and maintenance

Figures below demonstrate the operation of MIC-Compass. MIC-Compass has a built-in *in-siu* pH calculator that determines the *in-situ* pH under the prevailing operating temperature and pressure. The pH reported from water analysis conducted by testing labs at room temperature and pressure is not the "*in-situ*" pH. It is the "*in-situ*" pH that matters in MIC and other types of corrosion such as CO2 corrosion in oil and gas pipelines.

MIC-Compass®: Modeling and Prediction of Microbiologically Influenced Corrosion in Oil and Gas Pipelines					
Pipeline Name/ID	ABC Pipeline XL 123		Date		
Design Data					
Pipe Length	km	120.000	Operating Pressure at Inlet	bar	50.00
Pipe ID	m	0.386	Operating Pressure at Outlet	bar	40.00
Remaining Pipe Wall Thickness	mm	10.000	Operating Temperature at Inlet	°C	48.00
Pipe Age	years	15.00	Operating Temperature at Outlet	°C	25.00
Flow Data					
Gas Flow Rate	$MMSm^3/d$	4.0000	CO_2 in Gas	%mole	0.600
Oil/Condensate	m^3/d	400.0000	H_2S in Gas	%mole	0.000
Oil/Condensate Density	kg/m^3	780.000	Glycol Injection Rate	kg/d	0.000
Total Water at Inlet	m^3/d	20.0000	Gas Gravity vs Air	0.5 ~ 1.0	0.700
Water Density	kg/m^3	1024.000	Compressibility of Gas	0 ~ 1.0	0.900
Water Analysis					
Iron, Fe^{2+}	ppm	0	Dissolved O_2	ppm	0.500
Calcium, Ca^{2+}	ppm	4,800	Sulphate, SO_4^{2-}	ppm	50
Magnesium, Mg^{2+}	ppm	0	Strontium, Sr^{2+}	ppm	0
Sodium, Na^+	ppm	0	Bicarbonate, HCO_3^-	ppm	49
Chloride, Cl^-	ppm	10,000	All Organic Acids ($HAc+Ac^-$)	ppm	100
Potassium, K^+	ppm	0	Total Carbon from Fatty Acids	ppm	40
Barium, Ba^{2+}	ppm	0	Nitrogen (as utilizable N)	ppm	10
Other Data					
Biocide in Chemical Injection		Not used	Presence of Debris on Pipe Bottom	Yes/No	Yes
Pigging Frequency		5 years or more	Total Downtime Todate	days	15
Prediction Results					
MIC Rate (mm/y) vs. Pipeline Length (km)			*in-situ* pH	pH	5.27



Liquid Velocity	m/s	3.547
Max. MIC Rate	mm/y	0.799
Corrosion Dominating Process		MIC
Max. MIC Rate	mm/y	0.799
MIC Risk in the Pipeline	**High**	
Spot Analysis		
Spot Location (KP)	km	60.000
Temperature	°C	36.50
Liquid Velocity	m/s	3.55
pH	pH	5.23
TDS	ppm	15,000
Sulphate, SO_4^{2-}	ppm	50
Predicted MIC Rate	mm/y	0.799

Figure 1 MIC-Compass Predicts the MIC risk and the corrosion rate in oil and gas pipelines

Based on the users' inputs of the prevailing operating conditions, MIC-Compass assesses the critical conditions for microbiologically influenced corrosion and other different types of corrosion, and determines the dominating corrosion process in the pipeline. The prediction results include the following:

- in-situ pH
- liquid velocity
- the maximum growth rate for microbiologically influenced corrosion

- the dominating corrosion process (MIC, CO_2 corrosion, H_2S corrosion, CO_2-H_2S mixed corrosion, O_2 corrosion)
- the maximum corrosion rate for the identified dominating corrosion process
- the MIC risk ranking (very high, high, moderate, low, no risk)
- a chart showing MIC growth profile along the pipeline length

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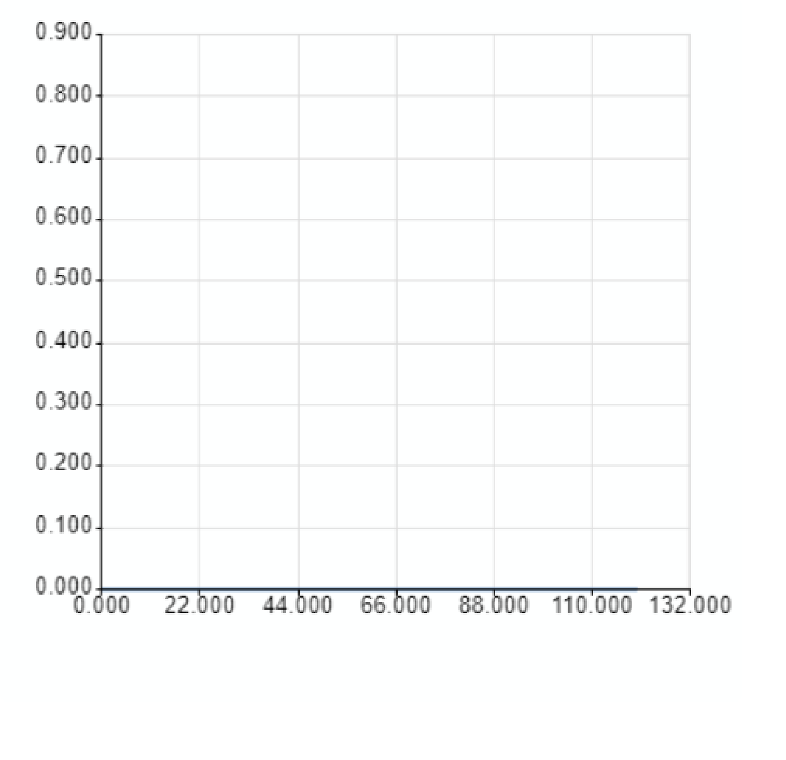
Flow Data					
Gas Flow Rate	$MMSm^3/d$	4.0000	CO_2 in Gas	%mole	2.000
Oil/Condensate	m^3/d	100.0000	H_2S in Gas	%mole	0.000
Oil/Condensate Density	kg/m^3	780.000	Glycol Injection Rate	kg/d	0.000
Total Water at Inlet	m^3/d	0.1000	Gas Gravity vs Air	0.5 ~ 1.0	0.700
Water Density	kg/m^3	1024.000	Compressibility of Gas	0 ~ 1.0	0.900
Water Analysis					
Iron, Fe^{2+}	ppm	0	Dissolved O_2	ppm	0.500
Calcium, Ca^{2+}	ppm	4,800	Sulphate, SO_4^{2-}	ppm	50
Magnesium, Mg^{2+}	ppm	0	Strontium, Sr^{2+}	ppm	0
Sodium, Na^{+}	ppm	0	Bicarbonate, HCO_3^{-}	ppm	49
Chloride, Cl^{-}	ppm	10,000	All Organic Acids ($HAc+Ac^{-}$)	ppm	100
Potassium, K^{+}	ppm	0	Total Carbon from Fatty Acids	ppm	40
Barium, Ba^{2+}	ppm	0	Nitrogen (as utilizable N)	ppm	10
Other Data					
Biocide in Chemical Injection		Not used	Presence of Debris on Pipe Bottom	Yes/No	Yes
Pigging Frequency		5 years or more	Total Downtime Todate	days	15
Prediction Results					
MIC Rate (mm/y) vs. Pipeline Length (km)			*in-situ* pH	pH	4.75



Liquid Velocity	m/s	1.300
Max. MIC Rate	mm/y	0.000
Corrosion Dominating Process		No Corrosion!
MIC Risk in the Pipeline	No Risk	

No liquid water to support MIC activity. Use Spot Analysis to assess the MIC rate at low points where water drop out may occur.

Spot Analysis		
Spot Location (KP)	km	60.000
Temperature	°C	36.50
Liquid Velocity	m/s	3.55
pH	pH	5.23
TDS	ppm	15,000
Sulphate, SO_4^{2-}	ppm	50
Predicted MIC Rate	mm/y	0.799

Figure 2 MIC-Compass assesses the critical conditions for microbiologically influenced corrosion. No water, no corrosion!

Using the "Spot Analysis" function, users can quickly assess the MIC rate at low points along a pipeline where water drop out may occur. Under the prevailing operating conditions in Figure 2 above, liquid water is generally not expected in the pipeline as the gas phase is under-saturated with water. However, at river crossings or some low points along the pipeline length, water drop out may occur. MIC-Compass gives users the power to assess the what-if scenarios.

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Flow Data					
Gas Flow Rate	$MMSm^3/d$	0.1000	CO_2 in Gas	%mole	2.000
Oil/Condensate	m^3/d	100.0000	H_2S in Gas	%mole	0.000
Oil/Condensate Density	kg/m^3	780.000	Glycol Injection Rate	kg/d	0.000
Total Water at Inlet	m^3/d	0.1000	Gas Gravity vs Air	0.5 ~ 1.0	0.700
Water Density	kg/m^3	1024.000	Compressibility of Gas	0 ~ 1.0	0.900
Water Analysis					
Iron, Fe^{2+}	ppm	0	Dissolved O_2	ppm	0.500
Calcium, Ca^{2+}	ppm	4,800	Sulphate, SO_4^{2-}	ppm	50
Magnesium, Mg^{2+}	ppm	0	Strontium, Sr^{2+}	ppm	0
Sodium, Na^+	ppm	0	Bicarbonate, HCO_3^-	ppm	49
Chloride, Cl^-	ppm	10,000	All Organic Acids ($HAc+Ac^-$)	ppm	100
Potassium, K^+	ppm	0	Total Carbon from Fatty Acids	ppm	40
Barium, Ba^{2+}	ppm	0	Nitrogen (as utilizable N)	ppm	10
Other Data					
Biocide in Chemical Injection		Not used	Presence of Debris on Pipe Bottom	Yes/No	Yes
Pigging Frequency		3 years	Total Downtime Todate	days	15
Prediction Results					
MIC Rate (mm/y) vs. Pipeline Length (km)			*in-situ* pH	pH	4.75

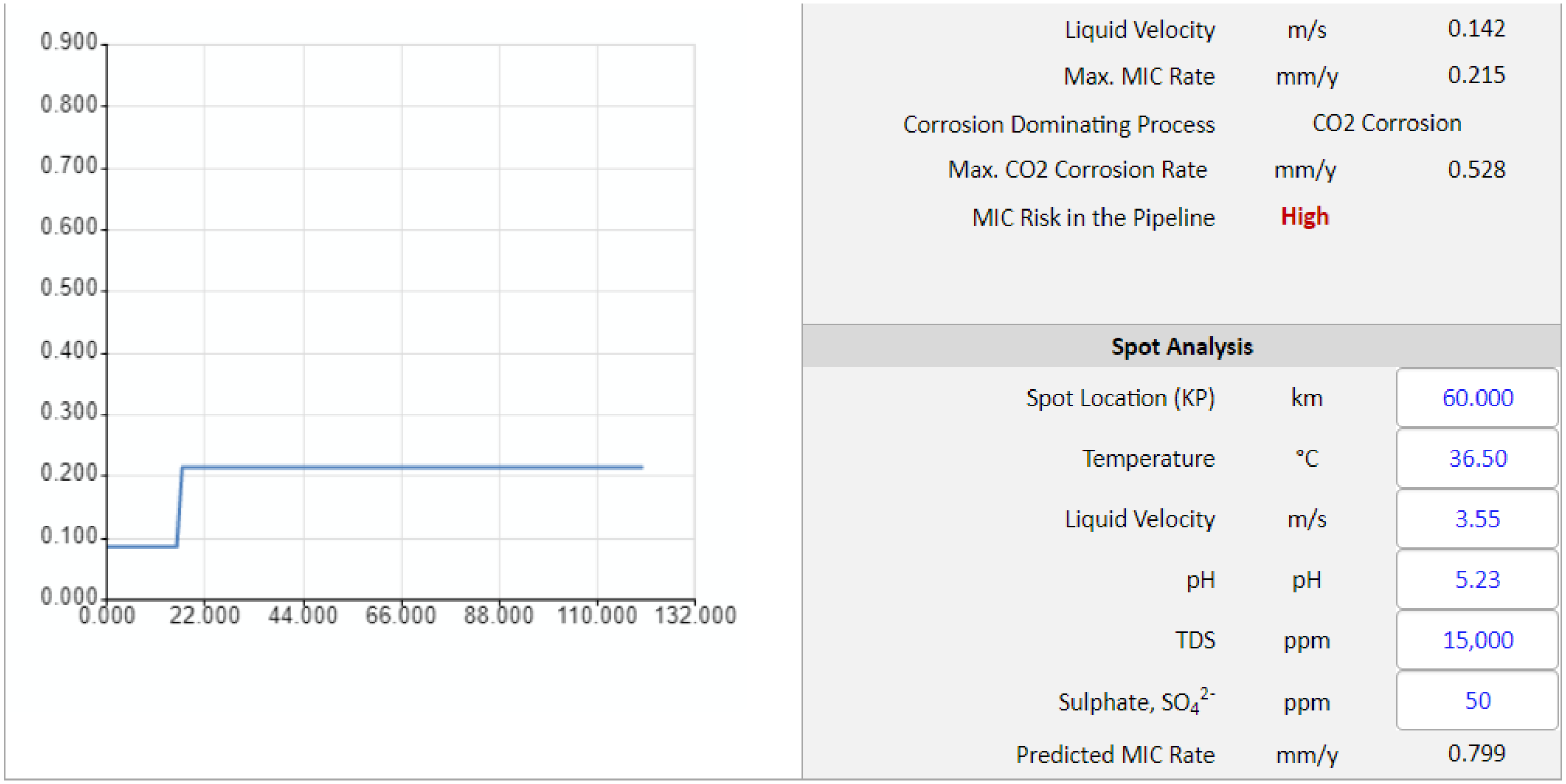

Figure 3 MIC-Compass predicts that carbon dioxide corrosion is the corrosion dominating process under the prevailing operating conditions.

Under the prevailing operating conditions in Figure 3, MIC-Compass identifies CO2 corrosion as the dominating corrosion process and the maximum CO2 corrosion rate in the pipeline is 0.528 mm/y while the MIC growth rate is predicted to be 0.215 mm/y. The spot analysis at the user selected pipeline location gives a MIC growth rate of 0.799 mm/y.

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Flow Data					
Gas Flow Rate	$MMSm^3/d$	4.0000	CO_2 in Gas	%mole	0.200
Oil/Condensate	m^3/d	400.0000	H_2S in Gas	%mole	0.000
Oil/Condensate Density	kg/m^3	780.000	Glycol Injection Rate	kg/d	0.000
Total Water at Inlet	m^3/d	100.0000	Gas Gravity vs Air	0.5 ~ 1.0	0.700
Water Density	kg/m^3	1024.000	Compressibility of Gas	0 ~ 1.0	0.900
Water Analysis					
Iron, Fe^{2+}	ppm	0	Dissolved O_2	ppm	6.000
Calcium, Ca^{2+}	ppm	4,800	Sulphate, SO_4^{2-}	ppm	50
Magnesium, Mg^{2+}	ppm	0	Strontium, Sr^{2+}	ppm	0
Sodium, Na^+	ppm	0	Bicarbonate, HCO_3^-	ppm	49
Chloride, Cl^-	ppm	10,000	All Organic Acids ($HAc+Ac^-$)	ppm	100
Potassium, K^+	ppm	0	Total Carbon from Fatty Acids	ppm	40
Barium, Ba^{2+}	ppm	0	Nitrogen (as utilizable N)	ppm	10
Other Data					
Biocide in Chemical Injection		Not used	Presence of Debris on Pipe Bottom	Yes/No	No
Pigging Frequency		3 years	Total Downtime Todate	days	7
Prediction Results					
MIC Rate (mm/y) vs. Pipeline Length (km)			*in-situ* pH	pH	5.75

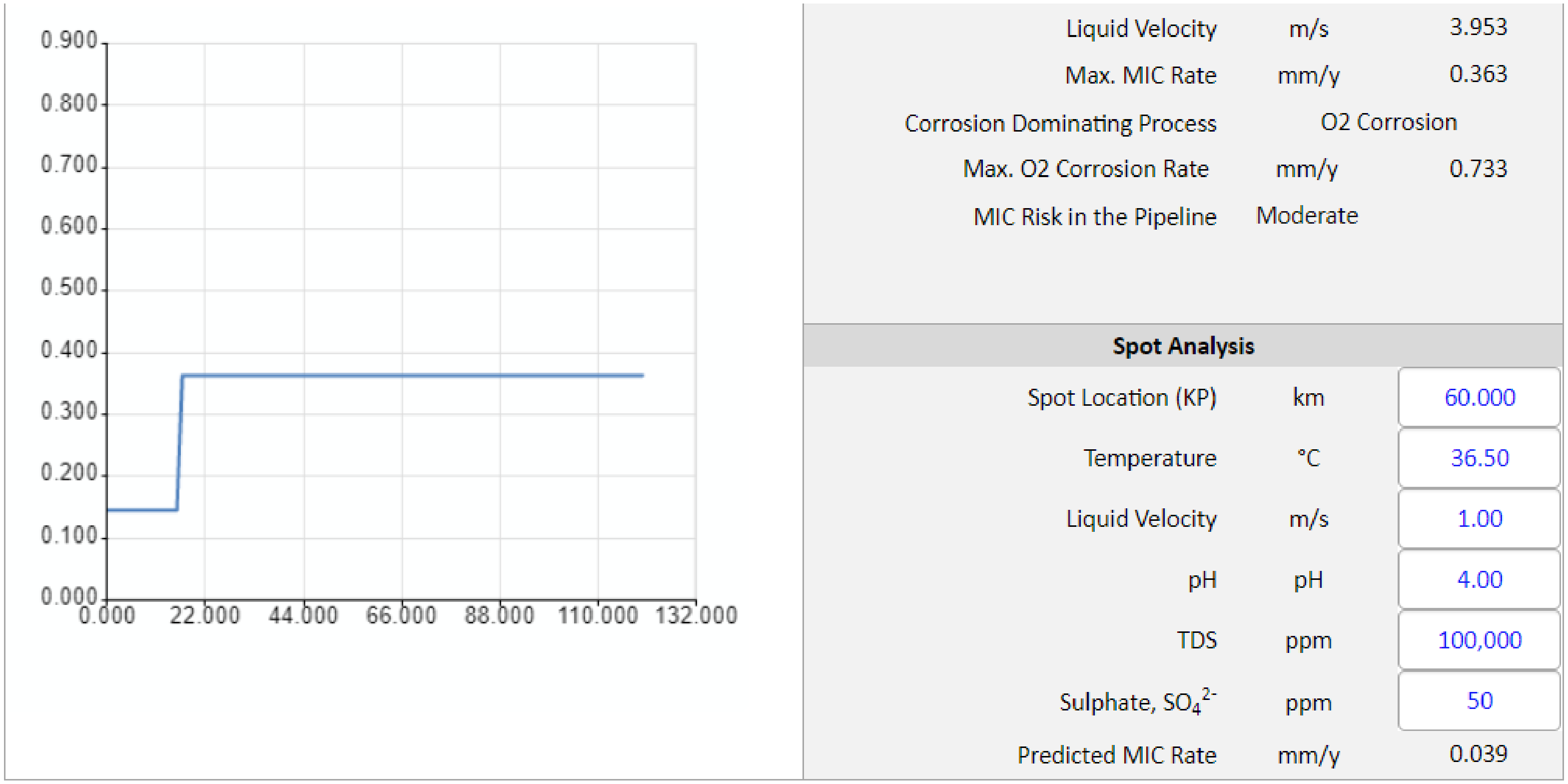

Figure 4 MIC-Compass predicts oxygen corrosion is the corrosion dominating process under the prevailing operating conditions.

Under the prevailing operating conditions in Figure 4 above, MIC-Compass identifies oxygen corrosion as the dominating corrosion process and the maximum O2 corrosion rate is 0.733 mm/y while the maximum MIC growth rate is 0.363 mm/y.

MIC-Compass is a powerful software tool for internal corrosion direct assessment and pipeline integrity management. Both prevailing and historical pipeline operating data can be used to model and predict the growth rates of microbiologically influenced corrosion and other different type of corrosion mechanisms (CO_2 corrosion, H_2S corrosion, CO_2-H_2S mixed corrosion, O_2 corrosion) in oil and gas pipelines.

Click here to contact us for licensing details and experience the power of MIC-Compass.

For more details on Microbiologically Influenced Corrosion (MIC)

Where can I learn more about Microbiologically Influenced Corrosion (MIC)? More details on microbiologically influenced corrosion or biological corrosion are included in the following corrosion short courses which you can take as in-house training courses, course-on-demand, online courses or distance learning courses:

- Microbiologically Influenced Corrosion (MIC): -Recognition, Mitigation and Prevention (5 days)
- Corrosion and Its Prevention (5-day module)
- Corrosion, Metallurgy, Failure Analysis and Prevention (5 days)
- Marine Corrosion, Causes and Prevention (2 days)
- Accelerated low water corrosion (ALWC) - Mechanisms, Mitigation and Prevention (1 day)
- Materials Selection and Corrosion (5 days)
- Stainless Steels and Alloys: Why They Resist Corrosion and How They Fail (2 days)
- Corrosion in Fire Protection Systems (FPS): - Detection, Mitigation and Prevention (1 day)

If you require corrosion expert witness or corrosion consulting service on microbiologically influenced corrosion, our NACE certified Corrosion Specialist is able to help. Contact us for a quote.

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