

Failure of 24" Common Crude Piping and Formation of Iron Sulfides Due to the Influence of Sulfate & Iron Reducing Bacteria and Methanogens

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ABSTRACT

A leak suddenly occurred at the 24-inch common crude piping from the separators heading to the degassing boot inlets and the wet crude tanks at an oil gathering center in Kuwait Oil Company. The initial observations showed the leak was due to a deep isolated pit and localized corrosion. Consequently, the piping spool was opened, deposits were collected for analysis and an action report was issued recommending replacing the leaky spool. Additional inspection by manual and long range ultrasonic thickness measurements for the 24" common crude line showed similar deep isolated pits (up to 70% thickness reduction) scattered across the length of the 1100 meter piping. This was extremely concerning since the facility has just been commissioned and been in service for 1.5 - 2 years only. Subsequently, an investigation was carried to determine the root causes for the failure concluded that an active Microbiologically Influenced Corrosion (MIC) possibly was taking place due to the influence of sulfate & iron reducing bacteria and methanogens. These different bacteria types formed biofilms at different pockets leading to deep isolated pitting, and the formation of iron sulfide layer found adhered at the 6 o'clock position along the length of the piping. The iron sulfide layer observed was confirmed to be present due to the activities of sulfate reducing bacteria and influenced by iron reducing bacteria and methanogens, since H_2S was found in the crude stream at extremely low content in gas (1 ppm). Additionally, other factors such as flow velocity have contributed to the MIC and pitting / localized corrosion as it was found to be below 1 m/s, which promoted stagnation and stagnant conditions in the process stream. Further, calcium carbonates ($CaCO_3$) played a major part in the observed damages, since it was formed non-uniformly across the length of the piping, promoting exposed pockets for biofilm formation, tubercles and under deposit corrosion. The results of this interesting investigation is presented in this paper.

Key words: 24" Common Crude Piping, Failure, Pitting Corrosion, SRB, IRB, Methanogens, MIC

INTRODUCTION

A leak suddenly occurred at the 24-inch common crude piping from the separators heading to the degassing boot inlets and the wet crude tanks in an oil gathering center. The initial observations showed the leak was due to a deep isolated pit and localized corrosion.

Additional inspections by manual ultrasonic thickness (UT) and long range ultrasonic thickness (LRUT) measurements for the 24" common crude line showed similar deep isolated pits (up to 70% thickness reduction) scattered across the length of the 1100 meter piping (See Figure 1 below). This was extremely concerning since the facility has just been commissioned and in service for 1.5 - 2 years only. Interestingly, no severe general corrosion was observed in all inspected piping. On that basis, the inspection team issued action reports recommending immediate replacement of the spools with most severe localized thickness reduction and pose immediate integrity risk to the facility. The spools with minor and moderate damages were planned for replacement in the upcoming shutdown for the facility, scheduled for December 2020 (88 meters in total for all inspected piping scattered at different spools). Subsequently, an investigation was carried out to determine the root causes and probable reasons for the damages that have occurred.

In this paper, we will highlight a step-by-step investigation for the failures and damages at the 24" common crude piping, findings, root causes, recommendations that were set to ensure both internal corrosion risks are minimized and continuous production is achieved with no stoppages.

SKETCH DIAGRAM

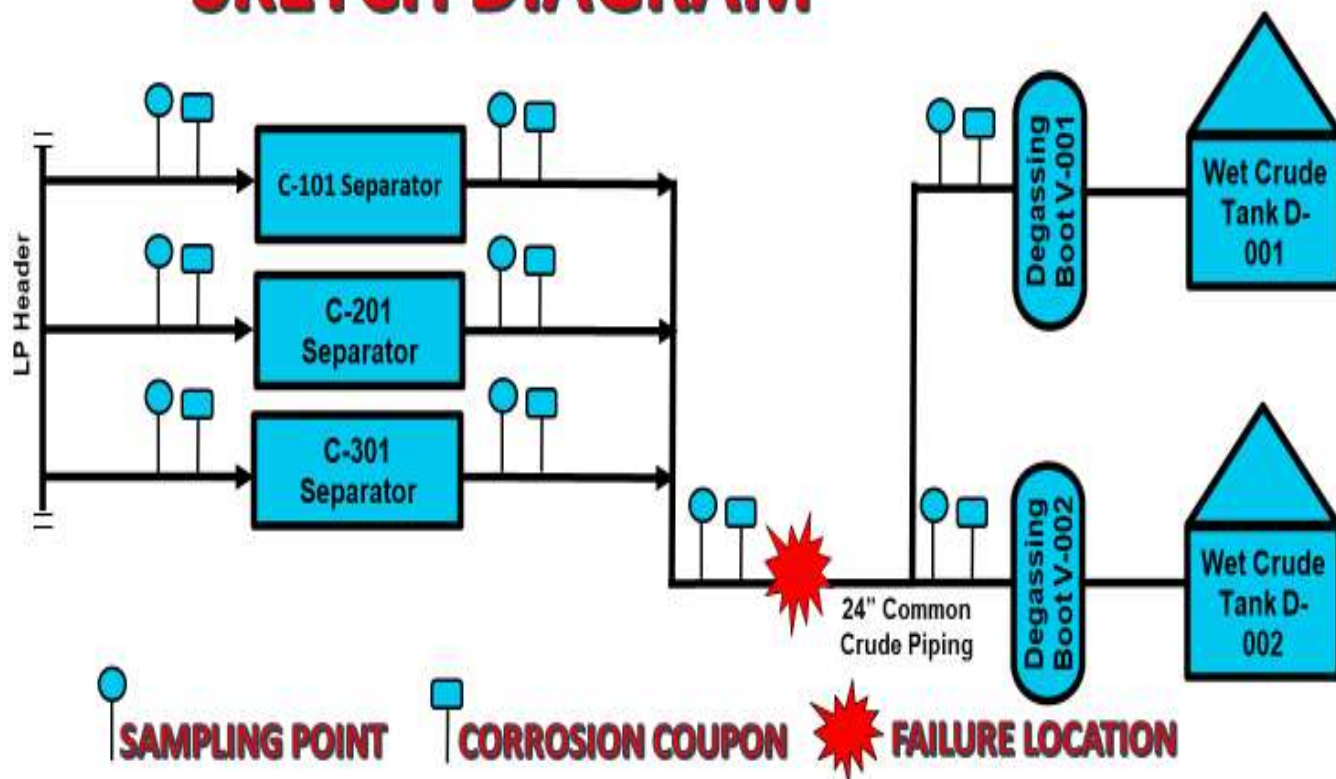


Figure 1: Sketch Diagram for the 24" Crude Stream and Location of Piping Failures

INVESTIGATION

To determine the root causes for the failures, the following was investigated:

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Damaged and Replaced Spools

It was agreed to cut three (3) failed pieces and observe the damage morphology and collect deposits from the pits and surfaces for the initially replaced spools in September 2020 (most severe thickness reduction sections). Additionally, the same will be carried out for the spools with minor and moderate damages that are planned for replacement in December 2020 during the shutdown; to immediately observe the morphology of the damages and collect fresh deposit samples from pits and surfaces of the spools for analysis.

All spools material is carbon steel (CS) 5L Grade B, STD SCH., 9.5 mm, with 3 mm corrosion allowance.

Fluid Sampling Trends & Gas Analysis for the Crude Stream

Fluid analysis trends for the LP separators crude outlets heading to the 24" common piping (typically with temperatures between 50°C-60°C) is essential to determine the corrosivity of the environment and identify the parameters that may have increased internal corrosion mechanisms in the process stream.¹ Additionally, gas analysis for the gas phase in the separator will inform on the influence of acid gases (CO₂ & H₂S) on the corrosion damages observed. The fluid analysis trends and gas analysis are from periodical sampling carried out by the inspection & corrosion team.

Deposit Analysis for the Crude Stream

Deposit analysis for the crude stream (separators and failed pieces) by X-Ray Diffraction (XRD) will inform on the constituents of the deposit. The deposit analysis will provide insights on the type of corrosion or what are the influences that led to the damages that occurred in the crude stream (analysis carried out by XRD specialists).

Bacterial Proliferation

Bacterial levels and types must be determined, as they can influence the environment in the crude stream and lead to microbial influenced corrosion. The analysis was initially as per the Most Probable Number serial dilution technique (MPN) from NACE standard TM0194-2014² and TM0106-2016-SG³ which is typically and periodically carried out by the inspection & corrosion team, to identify sulfate reducing bacteria (SRB), general aerobic bacteria (GAB) and general anaerobic bacteria (GAnB). Subsequently, it was decided to utilize Molecular Microbiological Method (MMM) and Quantitative Polymerase Chain Reaction (qPCR) for this investigation. This is the first time MMM method is carried out in a failure investigation or bacterial analysis for identification of all different bacteria types in damaged spools in our facilities. Furthermore, the effectiveness of utilizing MPN bacterial proliferation method and trending can be determined, in comparison to the MMM technique.

Review of Chemical Treatment

It is well known that effective chemical treatment management will control process streams environments, leading to minimized internal corrosion risks for the assets. Therefore, review of the chemical injection history for the facility since commissioning was carried out to determine if it was a factor for the failure and damages that occurred in the crude stream.

Flow Velocity Effects on Corrosion in the Crude Stream

The flow velocity is one of the major parameters that can and will increase corrosion mechanisms in process streams. It is well documented that lower flow velocities will increase the likelihood of pitting and localized corrosion. As per the API 571⁴ standard for damage mechanisms, flow velocity below 1 meter per second will promote MIC in process streams that are infested with bacteria. Furthermore, at flow velocity below 1 m/s, deposits and microbes will have higher chances for settlement at different pockets

across the length of the piping and establishing biofilms and tubercles, leading to microbiologically influenced corrosion (MIC). It should be noted that if the flow velocity is even higher than 1 meter per second but is on the lower end (i.e., 1 to 1.3 m/s); internal corrosion in the form of pitting/localized and microbial influenced corrosion is still possible. Hence, it is always advisable to increase the flow velocity in process streams if found at borderline acceptable limits. Therefore, flow velocity will be investigated to confirm if it contributed to the pitting and localized corrosion that occurred.

FINDINGS

The Damaged and Replaced Spools

The initial cut spool showed pitting / localized corrosion scattered across the length of the piping with various severities. However, one particular pit that leaked was considerably large in size, approximately 55 mm. This suggests extremely aggressive corrosion taking place at that location. Most of the pits (small or large) had smooth rounded edges with terraced sidewalls and other pockets showed a cluster of mini pits (Figure 2 & 3). Additional damaged spools cut during the shutdown in December 2020 showed similar damage morphologies in all replaced spools as can be seen in Figure 4, 5 & 6 (total length of replaced spools 88 meters).

There was no significant general corrosion found in all spools (initial or replaced during the shutdown), which confirmed that all the corrosion damages are localized. All the replaced spools had deposit layer adhered at the 6 o'clock position and running across the length of the spools. The layer removal was easily done at many spots; however, was challenging at others. The adhered deposit layer suggests that pitting / localized corrosion was aggravated and accelerated under these deposits, which caused concentration corrosion cells beneath these uniform films, as seen in Figure 7, 8 and illustrated in Figure 9.

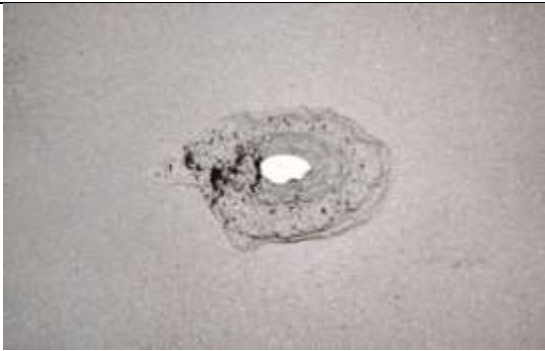
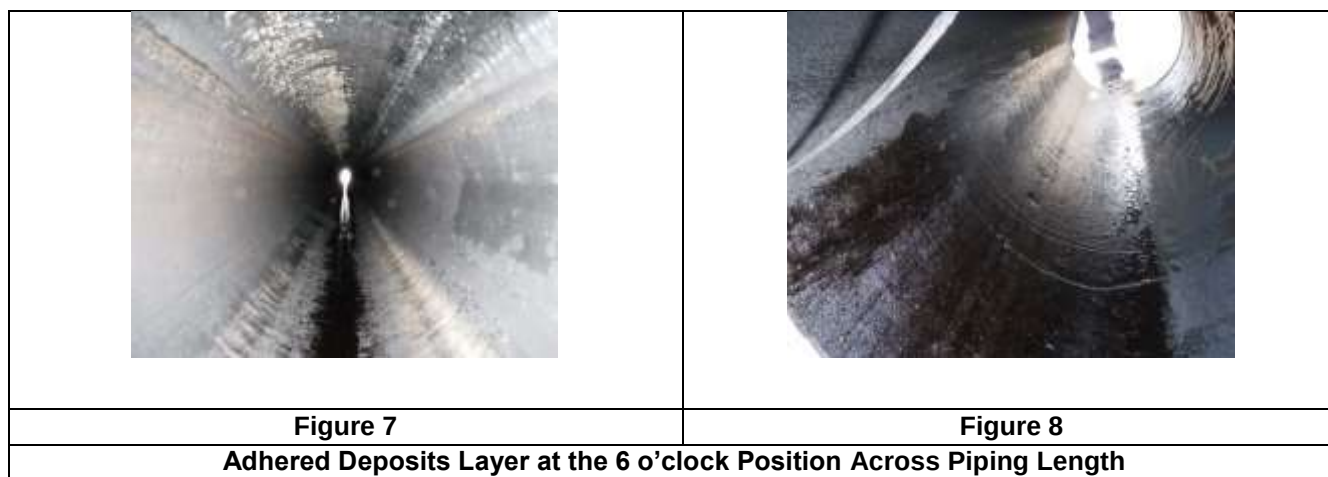
	
Figure 2: Extremely Severe Pitting & Localized Corrosion @ Initially Leaked / Inspected Spools	Figure 3: Smooth Rounded Pits Observed in the Initially Cut Spools

		
Figure 4	Figure 5	Figure 6
Smooth Rounded & Cluster Pits Observed in December 2020 Cut Spools		



Fluid Sampling Trends & Gas Analysis for the Crude Stream

Fluid samples analysis for the crude (pH, chloride, TDS, sulfide, sulfate, Fe and Mn) showed pH of 5 to 5.5 in separators C-101, C-201 and C-301 for most of the services (Table 1). Significant Iron content between 33 ppm to 109 ppm (Table 1). Iron content indicates active corrosion in the crude stream, also confirmed by the manganese content of 1.3 ppm to 4.5 ppm (Table 1).

Sulfate content was mostly significant between 300 ppm to 450 ppm (Table 1). In environments with high sulfate content, SRB bacteria is known to flourish as they require sulfates to produce H_2S . It should be noted that SRB can flourish even in low sulfate contents.⁵

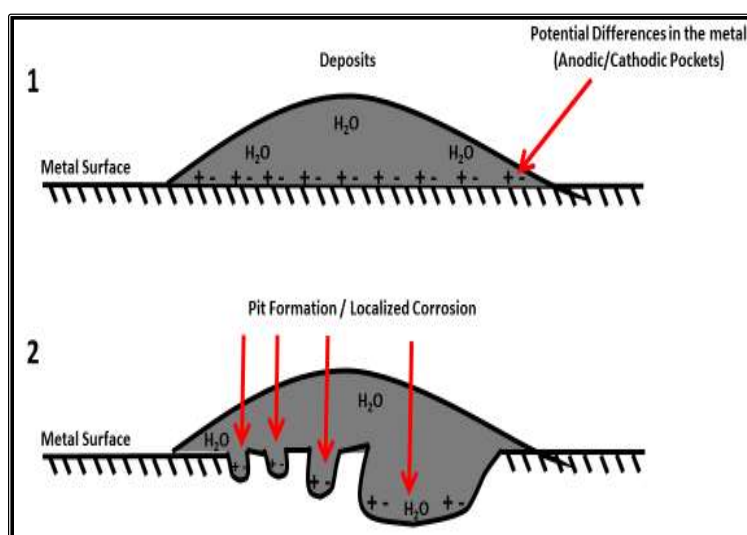


Figure 9: Under Deposit Pit Formation / Localized Corrosion

Water cut % is extremely high and continuously between 40% to 66% (Table 1). Increased water content will increase water wetting of piping surface and increase corrosion mechanisms in the crude stream. Calcium carbonates ($CaCO_3$) levels were also extremely high in all services (between 44,000 ppm – 52,000 ppm), which promote scaling and prevent corrosion in crude streams if it forms a uniform film in piping (Table 1). H_2S content was extremely low continuously, at 1-3 ppm in the gas phase (testing carried out at the separators gas outlet). Subsequently, calculation for the H_2S levels in crude stream showed 0.2-0.3 ppm content, which is extremely low. Contrarily, CO_2 levels were found to be extremely high at 10,000 ppm in the gas phase (testing carried out at the separators gas outlet), and subsequently, the CO_2 content will be significant in the crude stream (calculation found it to be approximately 180 ppm). Therefore, it is both possible and probable that the CO_2 have contributed to the acidic condition (pH mostly 5 to 5.5) in the crude stream by forming carbonic acids (weak acids) as seen in Equation 1, and likely expedited the internal corrosion mechanisms influenced by MIC across the length of the piping.

