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Implementing Pipelines Integrity Management Using KPIs

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Abstract

Pipeline Integrity Management (PIM) involves a series of activities, using a systematic and comprehensive approach, to manage the safety and integrity of pipeline systems. Key Performance Indicators (KPIs) are commonly used to monitor and assess these activities. Corrosion control is an integral part of integrity management. Fifty (50) KPIs have previously been identified to economically and efficiently control corrosion[1]. The paper explains how to apply and implement the KPIs to control corrosion. Publically available failure analysis report of an oil production pipeline has been used for this purpose.

Keywords: Pipeline Integrity Management, Key Performance Indicators, Implement.

1. Introduction

Pipelines are described as "energy highways" and are essential part of Canada's oil and gas delivery network. They are the most efficient and cost-effective mode to transport crude oil, natural gas and diluted bitumen (dilbit)[2,3]. Pipeline failures may cause serious personnel injuries, significant environment damage, and substantial financial loss. Due to improvements in government regulations, in standards for pipeline design, construction, and operation, and in industry collaboration, the incident frequency of pipelines has significantly declined over the years. According to Alberta Energy Regulator (AER)[4], incident frequency of oil and gas production pipelines in Alberta, Canada declined from ~ 5.0 per 1000 km in 1990 to ~ 1.5 per 1000 km in 2010. The AER analysis has however indicated that still corrosion caused 70% of failures/incidents; internal corrosion caused ~ 55 % and external corrosion caused ~ 15% of total pipeline failures. Analysis by National Energy Board (NEB) of Canada[5] has indicated that cracking and corrosion are the predominant causes of oil and gas transmission pipeline ruptures but the number of pipeline rupture incidences has been steadily decreasing over the last twenty years.

Pipelines Integrity Management (PIM) is a system that helps to maintain pipelines operations profitable and productive, conform to good industry practices, and comply with health, safety & environmental regulations. Corrosion control strategies are integral part of PIM. The corrosion control strategies ensure that all possible corrosion-related threats are identified and mitigated so that overall integrity of the pipeline is maintained. In order to ensure that the corrosion control strategies are relevant, efficient, and up-to-date at all times, their performances should be monitored and assessed on a regular basis. For this purpose, 50 key performance indicators (KPIs)[6] have been previously developed.

This paper illustrates how the 50 KPIs can be effectively implemented using information obtained from failure investigation carried out by the regulator and from company's PIM document[7].

2. Pipeline Specification, History, the Failure Mechanism, and Root Causes

The 323.9 mm (12 inches) diameter, 305 km (189 mile) long pipeline was manufactured from American Petroleum Institute (API) 5L, X46 grade carbon steel. The nominal wall thickness was 4.78 mm (188 mil) and for the section of pipeline crossing the river the wall thickness was increased to 7.92 mm (312 mil). The external surface of the pipe was protected either with coal tar or with polyethylene tape coating. The section of the pipeline crossing the river was coated with polyethylene tape and was further protected with concrete weight coating.

This pipeline carried light, high-sulphur-content (>0.5 weight %) crude oil from Sundre terminal through the town of Cochrane to Pincher Creek, Alberta. Maximum allowable operating pressure (MAOP) of the pipeline was 9,930 kilopascals (kPa) (1,440 psi). The pipeline operation was controlled from company control centre and was monitored using supervisory control and data acquisition (SCADA) system.

The pipeline was constructed in 1966 following ASME B31.4-1966 standard. It was laid across the watercourse using "open cut" trenching method. However, minimum depth of cover was not prescribed in the 1966 version of the standard. Therefore, original depth of cover of the pipeline at the time of construction was not recorded.

The ownership of the pipeline has changed several times and the current owner acquired it in November 2006. A depth-of-cover measurement was conducted in 2004. Due to the flood in June 2005, the west bank of the river at the subject crossing eroded and exposed the pipeline. Therefore, rock groynes were installed to aid in mitigating scour and bank erosion during flood. In September 29, 2008, AER requested the current owner to conduct a river crossing survey, including depth-of-cover measurements, and a hydraulic review. The survey results were submitted to AER on November 24, 2008. In September and November 2011, the current owner commissioned a water crossing inspection (that included the crossing where the pipe failure later occurred); however, swift water conditions prevented a complete inspection.

A failure occurred in June 2012, in the section of the pipeline crossing the Red Deer River. The failure analysis indicated that:

- The pipeline experienced a full guillotine failure at a circumferential (girth) weld located along the west bank of the river;
- The pipeline failed due to high-cycle fatigue, likely caused by vibrations induced by river flow;
- It was inferred that the section of the pipeline that failed was exposed during the incident and was likely uncovered by scour;
- Corrosion, weld, and other material property are not considered to have contributed to the failure.

The AER report has further identified the following deficiencies in the company operating practices:

- infrequent inspections of the river crossing, i.e., frequencies were not in line with the company's own Integrity Management Program;
- failed to inspect the pipeline annually as required by section 43 of the *Pipeline Rules*;

- failed to take necessary action with respect to scour hazards identified by previous inspections at the release site;
- failed to apply appropriate mitigation measures in accordance with its own hazard assessments; and
- failed to ensure that the pipeline remained in a safe condition during a period of increased water flow and scouring potential.

3. Application of 50 KPIs for Corrosion Activities

The applicability of 50 KPIs to corrosion management activities was evaluated using the data from 2012 Red Deer river pipeline failure report. Although corrosion was not a contributing factor for this failure, available information can be used to evaluate if corrosion could have caused failure in that pipeline. Detailed descriptions of 50 KPIs are presented elsewhere[6] and are beyond the scope of this paper. The process scores each KPI as follows:

- 0-1 for accounted for adequately
- 2-3 for accounted for inadequately
- 4-5 for not adequately accounted for.

The scoring of the 50 KPIs and the rational for the score are described in the following paragraphs.

3.1. General

- ✓ Activity 1 - Segmentation of the infrastructure: The pipeline was built with two different wall thicknesses and two types of external coatings. Other than that no documented evidence was available on the segmentation of the pipeline. Therefore the score is 4.
- ✓ Activity 2 - Corrosion risks: external corrosion, external damage and internal corrosion were identified as three potential risks for the pipeline. Pipeline was almost half century old. External corrosion risk was the primary concern due to ageing of external protective coatings and the pipeline itself. The risk of pipeline to internal corrosion was high because it carried high-sulphur-content (>0.5 weight %) light crude oil. Sulphur is well known to be corrosive to carbon steel. Therefore the score is 4.
- ✓ Activity 3 - Location of the infrastructure: The pipeline was passing through a highly populated rural areas and portions of the pipeline crossed river water. Therefore, consequence of failure was high. Therefore the score is 5.
- ✓ Activity 4 - Overall corrosion risk (risk times consequence): Both corrosion risk and consequence were high for the pipeline. Consequently, overall corrosion risk of the pipeline was high. Therefore the score is 4.
- ✓ Activity 5 - Life of the infrastructure: The design life of the pipeline was not available. But the pipeline had been in service for about 50 years. It was assumed that the pipeline life exceeded design life. Therefore the score is 5.

3.2 Internal corrosion control

3.2.1 Model

- ✓ Activity 6 - Materials of construction: The pipeline was built as per pipeline standard. Therefore the score is 1.
- ✓ Activity 7 - Corrosion allowance (wall thickness): high corrosion risk at the subject river crossing was taken into consideration during the pipeline design and construction. The section in the river crossing the pipeline had higher wall thickness of 7.92 mm (312 mil). Therefore the score is 1.
- ✓ Activity 9 - Upset conditions or operation excursions in the upstream segment: No information was available. It was assumed that operation excursions in the upstream segment did not affect this section. Therefore the score is 1.

- ✓ Activity 10 - Potential upset conditions in this sector affecting downstream sector: No information was available. It was assumed that operation excursions in the segment did not affect downstream section. Therefore the score is 1.
- ✓ Activity 11 - Mechanisms of corrosion: Company's Asset Integrity Management Plan (AIMP) had appropriately identified potential corrosion mechanisms including internal corrosion and environmentally assisted cracking (in particular stress corrosion cracking)[8]. Therefore the score is 1.
- ✓ Activity 12 - Maximum corrosion rate (Internal surface): Available information within the company identified the severity of internal corrosion and stress corrosion cracking as moderate. Therefore the score is 1.
- ✓ Activity 14 - Installation of proper accessories during construction: Although no information was available, it was assumed that the required accessories were installed in order to implement the company's mitigation plan. Therefore the score is 1.
- ✓ Activity 39 - Internal corrosion rate, after maintenance activities: No data on maintenance activities were available. However since the internal corrosion rate itself was moderate, it was assumed that maintenance activities did not increase the corrosion rate. Therefore the score is 1.
- ✓ Activity 40 - Percentage difference between targeted mitigated internal corrosion: It was assumed that the corrosion rates before and after the maintenance activities were within 10%. Therefore the score is 1.

3.2.2 Mitigation

- ✓ Activity 16 - Mitigation to control internal corrosion – is it necessary? The company's AIMP document indicated that mitigation strategy was necessary. Therefore the score is 2.
- ✓ Activity 17 - Mitigation strategies to control internal corrosion: The primary mitigation strategy used in the company was to clean the line with utility pigs. Frequency of pigging was either between twice per week or once per month. Therefore the score is 1.
- ✓ Activity 18 - Mitigated internal corrosion rate, target: It was assumed that the mitigated internal corrosion rate target was achieved. Therefore the score is 1.
- ✓ Activity 19 - Percentage time efficiency of internal corrosion mitigation strategy: No data were available. Considering no concern was raised by AER during audit, it was assumed that mitigation practices were completely implemented. Therefore the score is 1.

3.2.3 Monitoring

- ✓ Activity 24 - Internal corrosion monitoring techniques: Company's AIMP indicated that corrosion coupons had been placed at strategic locations on certain pipelines to monitor internal corrosion rate[8]. Further, laboratory chemical analysis of samples from pigging operation, corrosion coupon field monitoring and ILI were performed. Therefore the score is 2.
- ✓ Activity 25 - Number of probes per square area to monitor internal corrosion. No data were available. However it was assumed that adequate numbers of corrosion coupons were placed at critical locations. Therefore the score is 1.
- ✓ Activity 26 - Internal corrosion rate, from monitoring technique: Though actual corrosion rates were not reported, available information indicated that the coupon corrosion rates were generally low. Therefore the score is 1.
- ✓ Activity 27 - Percentage difference between targeted mitigated internal corrosion rate and corrosion rate from monitoring technique: No information was available, but it is assumed that the percentage difference was less than 10%. Therefore the score is 1.
- ✓ Activity 32 - Frequency of inspection: According to company's Pipeline Integrity Management Manual (PIMM), the ILI inspection interval was:
    - within one year following the acquisition of an operating pipeline

- within six months following the repair of a failure (caused by a mechanism that ILI technology is capable of detecting); and
- maximum of 10 years for re-inspection[9].

ILI inspection result in 2009 indicated that a cluster of corrosion anomalies with wall loss up to 58%[10]. Based on this deep corrosion pit, the ILI run frequency in PIMM was appropriate. Therefore the score is 2.

- ✓ Activity 33 - Percentage difference between targeted mitigated internal corrosion rate or corrosion rate from monitoring techniques and corrosion rate from inspection technique: No information was available, but it was assumed that the percentage difference was less than 10%. Therefore the score is 1.

3.3 KPIs for External corrosion control

3.3.1 Mitigation

- ✓ Activity 20 - Mitigation to control external corrosion – is it necessary? The company's AIMP document indicated that mitigation strategy was necessary. Therefore the score is 1.
- ✓ Activity 21 - Mitigation strategies to control external corrosion: Polymeric coatings, supplemented by an impressed CP system, were used to mitigate external corrosion. Therefore the score is 1.
- ✓ Activity 22 - Mitigated external corrosion rate, target: Company's AIMP indicated that despite the applied CP meeting the industry-accepted criterion of -850mV "instant off" potential, as measured against a saturated copper sulfate electrode, external corrosion was still found[8]. Therefore the score is 3.
- ✓ Activity 23 - Percentage time efficiency of external corrosion mitigation strategy: No information was available. But it was assumed that the coating was intact and CP was continuously applied. Therefore the score is 1.

3.3.2 Model

- ✓ Activity 6 - Materials of construction: Carbon steel was used as per ASME standard. External coatings were applied as per CSA Z662 requirements[11]. Therefore the score is 1.
- ✓ Activity 7 - Corrosion allowance (wall thickness): The section of pipeline in high consequence areas, such as river crossing, had higher wall thickness (7.92 mm (312 mil)). Therefore the score is 1.
- ✓ Activity 9 - Upset conditions or operation excursions in the upstream segment: No information was available. It was assumed that operation excursions in the upstream segment did not affect this section. Therefore the score is 1.
- ✓ Activity 10 - Potential upset conditions in this sector affecting downstream sector: No information was available. It was assumed that operation excursions in the segment did not affect downstream section. Therefore the score is 1.
- ✓ Activity 11 - Mechanisms of corrosion: Company's Asset Integrity Management Plan (AIMP) appropriately identified potential corrosion mechanisms including environmentally assisted cracking (in particular stress corrosion cracking)[8]. Therefore the score is 1.
- ✓ Activity 13 - Maximum corrosion rate: Available information indicated that the severity of external metal loss was high but no numerical rate was reported. Therefore the score is 4.
- ✓ Activity 14 - Installation of proper accessories during construction: Company's AIMP indicated that the external surface of the pipeline was protected by CP. Therefore, it was assumed that accessories to implement external corrosion strategies were properly installed. Therefore the score is 1.
- ✓ Activity 41 - External corrosion rate, after maintenance activities: No data on maintenance activities were available. It was assumed that maintenance activities did not increase the corrosion rate. Therefore the score is 1.

- ✓ Activity 42 - Percentage difference between targeted mitigated external corrosion rate or corrosion rate from monitoring or inspection technique and corrosion rate before maintenance activities. It was assumed that the corrosion rate before and after the maintenance activities was within 10%. Therefore the score is 1.

3.3.3 Monitoring

- ✓ Activity 28 - External corrosion monitoring techniques: Ground inspection or monitoring the CP current were used. Therefore the score is 2.
- ✓ Activity 29 - Number of probes per square area to monitor external corrosion: No data were available. However it was assumed that adequate numbers of monitoring probes were placed at critical locations. Therefore the score is 1.
- ✓ Activity 30 - External corrosion rate, from monitoring technique: Though no actual corrosion rates were reported, available information indicated that the corrosion rates were generally high. Therefore the score is 3.
- ✓ Activity 31 - Percentage difference between targeted mitigated external corrosion rate and corrosion rate from monitoring technique: No information was available, but it was assumed that the percentage difference was less than 10%. Therefore the score is 1.
- ✓ Activity 32 - Frequency of inspection: Ground inspection was performed three times in 2008 and two times in 2011. Therefore the score is 2.
- ✓ Activity 34 - Percentage difference between targeted mitigated external corrosion rate or corrosion rate from monitoring techniques and corrosion rate from inspection technique: No information was available, but it was assumed that the percentage difference was less than 10%. Therefore the score is 1.

3.4 KPIs for Measurement

- ✓ Activity 35 - Measurement data availability: Company's records management comprised three primary systems (the field office filing system, corporate file systems and supplier record keeping systems)[9]. Therefore the score is 1.
- ✓ Activity 36 - Validity and utilisation of measured data: Company established Corrosion Growth Model & Assessment Flow Charts for establishing data validity and for estimation of long-term corrosion rate using the measured data[9]. Therefore the score is 1.

3.5 KPIs for Maintenance

- ✓ Activity 8 - Normal operating conditions: It was assumed that the pipeline operating conditions were within the established range for the duration of the project. Therefore the score is 1.
- ✓ Activity 15 – Commissioning: There was no documented evidence that the hydrotesting was conducted during initial commissioning of the pipeline or after acquisition of the operating pipeline by new owner. Therefore the score is 4.
- ✓ Activity 37 - Procedures for establishing the maintenance schedule: Company used flow chart to direct maintenance activities. Therefore the score is 2.
- ✓ Activity 38 - Maintenance activities: The maintenance and repair work was generally carried out as planned but sometimes there were some delays. Therefore the score is 3.
- ✓ Activity 43 - Workforce - Capacity, education, and training: the company's training systems are in place: AER audit reported that the company employed many experienced staffs [11]. Therefore the score is 1.
- ✓ Activity 44 - Workforce - Experience, knowledge, and quality: AER audit report[11] indicated that the company had hired several highly experienced staff during the past three years and had increased its workforce capacity in the management oversight area. Therefore the score is 2.
- ✓ Activity 45 - Data management - Data to database: Pipeline Integrity Management Manual indicated that the company had an Enterprise Asset Management (EAM) system. EAM

captured design, material, and regulatory attributes of different assets such as valves, fittings, pumps, meters, pipes, tanks, and vessels. The EAM application was also used to generate and track work orders associated with the inspection, maintenance, or repair of an asset. Therefore the score is 1.

- ✓ Activity 46 - Data management - Data from database: It was included in the EAM system. Therefore the score is 1.

3.6 KPIs for Management

- ✓ Activity 47 - Internal communication strategy: The reporting structure of the positions with key responsibility was well defined in the company's PIMM. Therefore the score is 1.
- ✓ Activity 48 - External communication strategy: PIMM detailed roles and responsibilities for each position. Therefore the score is 1.
- ✓ Activity 49 - Corrosion management review: The PIMM required annual corrosion management requirement. However, there was no document to indicate that this had happened. Therefore the score is 3.
- ✓ Activity 50 - Failure frequency: Though the company had two oil spill incidents but none of them were caused by corrosion. Therefore the score is 1.

3.7 Summary of the Status of KPIs and Status of infrastructure

The greatest advantage of KPIs is the ability to track the implementation of various corrosion control activities. A target level may be defined and used as a benchmark to evaluate the overall implementation of corrosion management activities. In the example presented in this paper, of the 50 KPIs, 33 were implemented properly, 10 were implemented inadequately, and 7 were not implemented or implemented poorly. The overall KPI score is 87 out of 250 (In this scoring pattern, lesser the overall KPI score better the implementation). As a benchmark, KPI overall score of 100 or less may be taken as a measure that various corrosion control activities are implemented properly. In the example presented in the paper the score of 87 indicated that the KPIs to control corrosion were appropriately implemented. For this reason the pipeline did not fail from corrosion (though it had failed due to non-corrosion related event).

The status of implementation of the 50 KPIs may also be graphically presented (as shown in Figure 1). In Fig. 1:

- Green bar indicates that the KPI was implemented appropriately (good); 33 KPIs with respect to corrosion control were implemented appropriately;
- Yellow bar indicates that the KPI was implemented inadequately (Fair); 10 KPIs with respect to corrosion control were implemented inadequately;
- Red bar indicates that the KPI was implemented poorly (poor); 7 KPIs with respect to corrosion control were implemented poorly.

4. Summary

- Pipeline integrity management system (PIMS) helps operators reduce safety risks, achieve operational excellence, extend pipeline service life, and maximize economic value of the company. Implementation of PIMS may be easily and efficiently tracked using key-performance indicators (KPIs).
- Corrosion control is an integral and major component of pipeline integrity management system. Fifty (50) KPIs have previously been identified to implement corrosion control strategies.
- The paper used the publically available failure analysis report to explain how to apply and implement the KPIs. Analysis indicated that the KPIs to control corrosion were appropriately implemented. Consequently the pipeline did not fail from corrosion (though it had failed due to non-corrosion related event).

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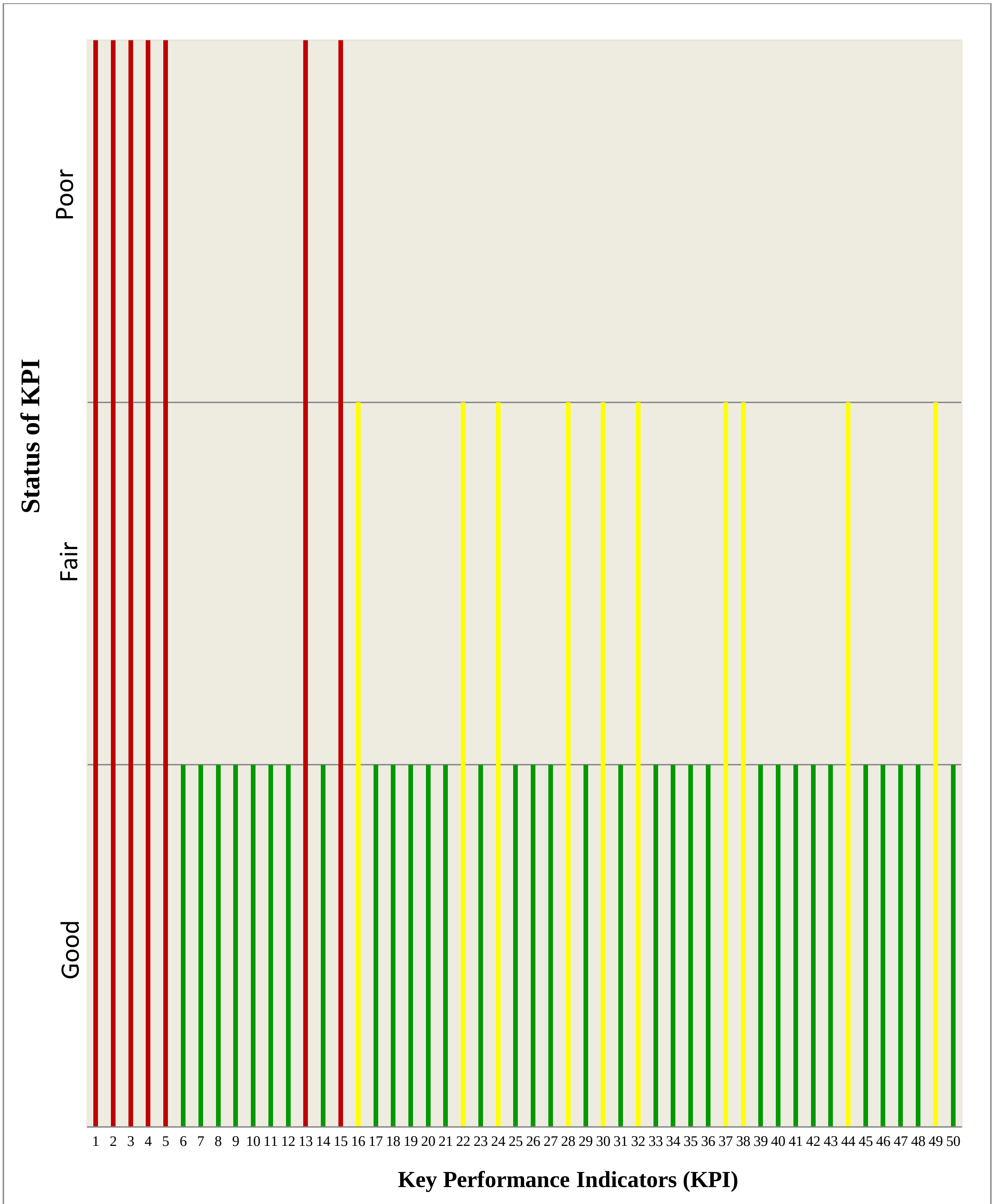

Figure 1. Status of Key Performance Indicators (KPIs) with Respect to Corrosion Control in the Oil Production Pipeline Discussed in this Paper