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Evaluation of Key Performance Indicators (KPI's) in Crude Oil Transmission Pipeline

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Abstract

This paper analyzes the failure of a crude oil transmission gathering pipeline system with the help of 50 key performance indicators (KPIs). This crude oil transmission pipeline has had two failures due to circumferential stress corrosion cracking (C-SCC). Analysis of the KPIs indicates that the corrosion control score (30%) is far lower than corrosion score (70%). Therefore, the company should take additional strategies to control corrosion. By addressing the following KPIs, the company can improve corrosion control score and consequently decrease the risk due corrosion:

- 01 (Segmentation of pipeline)
- 04 (Elucidation of overall risk)
- 11 (Establishment of corrosion damage mechanisms)
- 12 (Establishment of maximum (unmitigated) internal corrosion rates)
- 16 (Development of internal corrosion mitigation strategies)
- 17 (Implementation of internal corrosion mitigation strategies)
- 18 (Establishment of maximum mitigated internal corrosion rates
- 19 (Establishment of effectiveness of mitigation strategies)
- 24 (Identification of internal corrosion monitoring strategies
- 25 (Establishment of number internal corrosion monitoring probes)
- 26 (Comparison of corrosion rates between internal corrosion monitoring techniques)
- 27 (Comparison of mitigated corrosion rates (KPI 18) and corrosion rates from monitoring techniques (KPI 26)
- 32 (Establishment of frequency of inspection – internal corrosion)
- 33 (Comparison of mitigated corrosion rates (KPI 18) and corrosion rates from inspection techniques (KPI 32)
- 39 (Establishment of maintenance activities on internal corrosion)

- 40 (Comparison of corrosion rates before and after maintenance activities)
- 23 (Establish the effectiveness of external mitigation strategies)
- 29 (Establishment of number external corrosion monitoring probes)
- 30 (Comparison of corrosion rates between internal corrosion monitoring techniques)
- 31 (Establishment of accuracy of external corrosion monitoring techniques)
- 32 (Establishment of inspection – external corrosion)
- 15 (Establishment of data collection)
- 49 (Establishment of corrosion review meeting)
- 50 (Frequency of failure)

1. Introduction

The oil and gas industry infrastructures are vastly interlinked network of various pipelines, process centers, and facilities. Transmission pipelines play an integral part in this network as these aid in the transportation of crude oil, refined products, and gas in a safe and reliable way. To ensure the reliability of the assets, it is essential to evaluate and control all possible risks. Corrosion is a predominant risk that can cause catastrophic failure if not controlled properly.

The 5-M methodology (modelling, mitigation, monitoring, maintenance and management) has proven to be effective in the corrosion control of infrastructures and is implemented using 50 key performance indicators (KPIs) [1]. The status of implementation of 50 KPIs is indicated by scores and by color codes (Table 1).

Table 1: Colors and Scores to Indicate the Status of Implementation of KPIs

Color	Score
Not analyzed yet	5
Good	0 to 1
Fair	2 to 3
Poor	4 to 5
N/a	0

This paper analyzes the failure of crude oil gathering pipeline system using the aid of these 50 KPIs. This pipeline comprises of 21 lateral gathering pipelines transporting sweet crude oil from various producing segments [2]. This carbon steel pipeline (wall thickness of 4.8 mm) is externally coated with polyethylene tape and a fiberglass outer wrap.

Two consecutive failures occurred in different locations of the pipeline on 20th July 2011 and 15th August 2011 due to external circumferential stress corrosion cracking (C-SCC). Transgranular stress corrosion cracking (SCC) on buried, high-pressure pipelines occur as a result of the interaction of susceptible metallic material, tensile stress and an aggressive electrolyte. SCC initiates on the external pipeline surface beneath a mechanically damaged coating and grows in both depth and surface directions. Circumferentially oriented SCC (C-SCC) is a subset of transgranular SCC where bending stress is the principle contributor and may be caused by several factors including differential settlement of backfill beneath the pipe and geotechnical ground movement.

2. Context of corrosion control

The status of establishment of “context of corrosion” is evaluated using the KPI’s (Table 2). In general, the KPI’s under this category are evaluated considering the background of the transmission pipelines and the infrastructure.

Table 2: Context of Corrosion Control

KPI	Description	Score	Comments
1	Sub-division of the infrastructure into segments and its characteristics.	4	The infrastructure considered for failure analysis is not divided into manageable segments, but these doesn’t have uniform characteristics. Hence a KPI score of 4 is assigned.
2	Corrosion mechanisms active in the segment	3	External corrosion risk is established and C-SCC is found to be the cause of the failure. However internal corrosion risk is not established. Hence a KPI score of 3 is given.
3	Location of the infrastructure and the related factors	3	The exact location of the oil and gas infrastructure is not known, but the segment of consideration is located 7.5 km north of the northeast Swan hills. The area is free from human intervention. Hence a KPI score of 3 is given.
4	Overall corrosion risk	4	The overall corrosion risk is not established completely. A score of 4 can be allotted considering KPI 2 and 3. Again one cannot neglect that the area is free from contamination.
5	Age of the infrastructure and number of years in operation	1	Originally licensed in the year 1962. But the pipeline was taken over by Pembina pipeline corporation in the year 2000. Hence estimating 10 years of hassle free operation before failure. Hence a KPI score of 1 is assigned.

3. Internal corrosion-Model

Models provide corrosion damage mechanisms (CDMs) and corrosion rate by considering various influencing factors through carefully conducted laboratory experiments and field data. Based on the obtained results, theoretical explanations are provided using thermodynamics and corrosion kinetics. However, results obtained should be considered carefully and the limitations of the models (in terms of factors considered and availability of inputs) have to be accepted. Table 3 summarize the status of implementation of KPI’s for internal corrosion model in the crude oil pipeline investigated in this paper.

Table 3: Internal Corrosion Model

KPI	Description	Score	Comments
6	Material of construction (MOC) and its basis of selection	3	Carbon steel has been used, and seems to be a correct choice of material even though no information regarding the material consideration is available. A KPI score of 3 can be given.

KPI	Description	Score	Comments
7	Corrosion allowance (wall thickness)	3	The wall thickness is 4.8 mm. A KPI score of 3 can be given as accurate predictions and suitability of this corrosion allowance cannot be computed, considering that the infrastructure is in operation for over 10 years.
9	Potential upset conditions in the upstream sector affecting this sector	3	Operating parameters are continuously monitored through SCADA by panel operators and are supported by field operators. Though the potential upset conditions in the upstream sector cannot be listed with the available information, but there is some communication in place to handle issues. Hence a KPI score of 3 is given.
10	Potential upset conditions in this sector affecting the downstream sector	3	A KPI score of 3 can be given, as there is coordination between the panel operators and field foremen so as to cater abnormalities in this segment and also minimize the effect downstream.
11	Corrosion Damage Mechanism (CDM) in the segment	4	Circumferentially aligned stress corrosion cracking (C-SCC) is accounted as the cause of the corrosion failure. However, no information on internal corrosion mechanisms. Hence a KPI score of 4 is assigned.
12	Maximum corrosion rate (internal) established and its basis	5	As far as internal corrosion is considered, there seems to no big attention given. A KPI score of 5 is assigned considering the fact that no data is available.
14	Corrosion related accessories and availability of corrosion professional	3	Corrosion professional should be available as there is an integrity management program (IMP) in place. There is no complete information on the availability of accessories. Hence a KPI score of 3 is assigned.
39	Corrosion rate before and after maintenance activity	5	In general, the corrosion rate should be less after any maintenance activity. There is no information available with respect to the corrosion rate values specifically measured before and after maintenance activity. Hence a KPI score of 5 is assigned.
40	Percentage difference of corrosion rate before and after maintenance activity	5	Again, there is no big importance being given to internal corrosion monitoring and mitigation. Hence, comparing the percentage difference in corrosion rate before and after a maintenance activity may not be done. Hence a KPI score of 5 is given.

4. Internal corrosion-Mitigation

Internal corrosion mitigation should be implemented if models or field experience indicates higher corrosion rates. Table 4 describes the status of implementation KPI's for evaluating the internal corrosion mitigation strategies in the crude oil pipeline investigated in this paper.

Table 4: Internal Corrosion-Mitigation

KPI	Description	Score	Comments
16	Development of optimum corrosion strategy during design stage	4	If the moisture content is controlled, sweet crude oil is not aggressive in nature. Pembina purchased the pipeline from Federated Pipe Lines Ltd. in 2000. Again, with the current resources no information on employment of mitigation strategies at design stage is available. Hence a KPI score of 4 is assigned.
17	Mitigation strategies whether time tested and proven and aligned with operating conditions	5	A KPI score of 5 is assigned, as there is no information on how far IMP is catering internal corrosion mitigation strategies with the information available.
18	Mitigated corrosion rate	5	As far as this case is concerned, no mitigation strategy is exclusively employed for catering internal corrosion in an extensive way. Hence a KPI score of 5 is assigned.
19	Effectiveness of the implemented mitigation strategies.	5	With the available information there are no noteworthy mitigation strategies employed as far as IMP considers internal corrosion. Hence a KPI score of 5 is assigned.

5. Internal corrosion-Monitoring

Estimation of the corrosion risk involves monitoring in the areas of criticality. Model and effective mitigation strategies would provide a general framework for implementing monitoring strategies. Table 5 describes the status of implementation of KPIs for internal corrosion monitoring in the crude oil pipeline investigated in this paper.

Table 5: Internal Corrosion-Monitoring

KPI	Description	Score	Comments
24	Internal corrosion monitoring techniques and types	4	Though the infrastructure is monitored under the IMP scheme, but high importance is not given to the internal corrosion side. One such monitoring technique available is the leak test, which is done in periodic intervals. Hence a score of 4 is given.
25	Number of probes per square area to monitor internal corrosion	5	As such there is no information on the availability of monitoring probes in both the critical and non-critical areas. Hence a KPI score of 5 is given.
26	Internal corrosion monitoring techniques and their corrosion rate comparisons	5	With the available information there is no corrosion rate comparisons available as far internal corrosion monitoring is concerned. A KPI score of 5 will be appropriate.
27	Percentage difference between targeted mitigated internal Corrosion rate and corrosion rate from monitoring techniques	5	With the current resources no information is available regarding the percentage difference in the internal corrosion rate. Hence a score of 5 is assigned.
32	Frequency of corrosion inspection	5	No information is available. Hence a KPI score of 5 is assigned.
33	Percentage difference between targeted mitigated internal corrosion rate or corrosion rate from monitoring techniques and corrosion rate from inspection technique	5	With the current resources no information is available regarding the percentage difference in the internal corrosion rate before and after inspection. Hence a score of 5 is assigned.

6. External corrosion-Mitigation

Table 6 describes the status of implementation of KPIs to mitigate external corrosion in the crude oil pipeline investigated in this paper.

Table 6: External Corrosion - Mitigation

KPI	Description	Score	Comments
20	External corrosion protection	2	The structure is protected with PE tape and fiberglass outer wrap. Hence a KPI score of 2 is assigned.
21	Inspection of coating during the commissioning stage. Are the mitigation strategies time tested and proven to control external corrosion?	3	No information on the inspection of coating during commissioning is available. However, the IMP extensively employs mitigation strategies for external corrosion. However, giving equal weightage to both the points a KPI score of 3 is assigned.
22	Anticipated maximum corrosion rate and how it is established?	2	As such there is no information on how it is established. But, presence of a series of program manuals covering various aspects of pipeline integrity, the anticipated corrosion rate value should be available. Even though data is not available, a KPI score of 2 can be assigned.
23	Percentage of effective implemented mitigation practices	5	Even though IMP is in place, but there were 2 back-to-back failures. Again, preventive mitigation strategies were employed to cater SCC, but the same occurred. Hence a KPI score of 5 is assigned.

7. External Corrosion-Model

Table 7 summarizes the status of implementation of KPIs for external corrosion model in the crude oil pipeline investigated in this paper.

Table 7: External Corrosion - Model

KPI	Description	Score	Comments
6	External corrosion protection (coating and cathodic protection)	2	The external surface is coated with PE tape and outer wrapped with fiberglass insulation. Hence a score of 2 is given.
7	External corrosion protection (coating, insulator, concrete and CP)	1	The external surface of the pipeline is coated with PE tape and a fiberglass insulator as an outer wrap. This KPI is properly implemented and a score of 1 is assigned.
9	Impact of the upset in upstream segment on this segment and whether influence of temperature considered?	0	Influence of upset in upstream doesn’t contribute external corrosion. Hence a KPI score of 0 is assigned.

KPI	Description	Score	Comments
10	Impact of upset condition in this sector and its effects with downstream and again the influence of temperature.	3	Occurrence of upset condition is possible as with the case of back-to-back crude oil leaks. As SCADA is used to monitor the parameters of the pipeline, hence some communication will be in place to minimize the impact downstream. Hence a KPI score of 3 is given.
11	External corrosion mechanisms in the segment and how are these identified?	2	C-SCC is found to be the cause of the failure. But all corrosion mechanisms should be considered. A KPI score of 2 is given. The mechanisms are identified after the occurrence of the failure through external agencies.
13	Maximum corrosion rate and its basis.	3	As such no such value is quoted, but as IMP is in place values would have been recorded. But due to the occurrence of a failure, the entire system seems to be incomplete. Hence a KPI score of 3 is given.
14	External corrosion related accessories and involvement of corrosion professionals.	1	External corrosion related accessories are present. Those required to address mechanical damage, mill defects, corrosion, SCC, coating damage, coating deterioration, unstable slopes and the presence of low-frequency electric resistance welded pipe. Involvement of corrosion professionals is evitable. Hence a KPI score of 1 is assigned.
41	Corrosion rate before and after maintenance activity.	3	Even though IMP module is actively in place, but occurrence of failures indicate that the module needs to be more proactive. Hence a KPI score of 3 is assigned.
42	Comparison of percentage difference in the corrosion rate before and after monitoring/mitigation activities.	3	Even though IMP module is actively in place, but occurrence of failures indicate that the module needs to be more proactive. Hence a KPI score of 3 is assigned.

8. External corrosion-Monitoring

Table 8 summarizes the status of implementation of external corrosion monitoring strategies in the crude oil pipeline investigated in this paper.

Table 8: External Corrosion - Monitoring

KPI	Description	Score	Comments
28	How many monitoring techniques are there and what are they? Are they proven to be effective in monitoring?	3	External corrosion monitoring is being extensively practiced through the IMP module. As discussed earlier, the module covers many areas of pipeline integrity. But, due to back-to-back failures the supremacy of the module is questionable. Especially the C-SCC is critical and has caused these failures. Even though preventive measures have been taken against the same, but still failures couldn't be stopped. Hence a KPI score of 3 is assigned.
29	Number of monitoring probes to cover both critical and non-critical area and how is it established?	4	With the current resources no information is available on the number of monitoring probes. Hence a score of 4 is assigned.
30	How many monitoring techniques do you have? What are the corrosion rates between those techniques?	4	As discussed in previous sections, the IMP module consists of a series of monitoring and maintenance activities as far as external corrosion is concerned. But, no information is available on the difference in corrosion rate between these rates. Hence a KPI score of 4 is given.
31	Has the accuracy of the monitoring techniques been proven for the type of corrosion?	4	Accuracy of the techniques cannot be predicted in general. But, considering the fact that failures pertaining to external corrosion have occurred, the accuracy is questionable. Hence a KPI score of 4 is assigned.
32	How often you perform inspection for external corrosion? And how do you establish the frequency of inspection?	3	The IMP module establishes the frequency of the inspection. No other data is available on what grounds IMP considers before carrying out inspection. Hence a KPI score of 3 is assigned.
34	What is the corrosion rate from inspection techniques? What is the corrosion rate from monitoring techniques?	3	With the available information, there is no data to quote. But, presence of a structured module to cover pipeline integrity, these data should be available. Hence a KPI score of 3 is assigned.

9. Measurement

KPI 35 discusses the availability of the measured data. As IMP is a structured module, hence data availability should not be an issue of concern. However, with the available information a KPI score of 3 can be given.

KPI 36 discusses on the integrity of the measured data. A score of 3 is assigned. The score has been given considering both internal and external corrosion. Again, IMP comes into scenario and similar points are quoted as discussed above.

10. Maintenance

Table 9 summarizes the status of implementation of KPIs on maintenance activities in the crude oil pipeline investigated in this paper.

Table 9: Maintenance

KPI	Description	Score	Comments
8	Normal operating condition and beyond operating windows	2	Every infrastructure falls to abnormal operating windows at times, but there is adequate communication in place to handle the same. Hence a KPI score of 2 is assigned
15	Infrastructure and construction error; design stage corrosion data collection	5	The infrastructure is not free from construction errors because the region of concern is prone to C-SCC attacks due to unstable slopes. Again, design data on corrosion is not available. Hence a KPI score of 5 is assigned.
37	Maintenance schedule (proactive/preventive/reactive)	3	Exact data is not available but again with IMP in place scheduling and sequencing of maintenance activities is a basic requirement. Hence a KPI score of 3 is assigned.
38	Coordination with other parties regarding maintenance activities	3	In general, the, there is no information available with regards to outsourcing for maintenance. Typically, maintenance activities are always done with the aid of contract laborers. Also, IMP is in charge of maintenance. Hence, a score of 3 is assigned.
43	Number of employees per unit surface area and whether they are qualified?	3	Qualified personnel are employed under the IMP scheme. People are also outsourced to attend technical issues. There is no data available regarding the number of employees per surface area. Hence, a KPI score of 3 is assigned.

KPI	Description	Score	Comments
44	Experience and knowledge of personnel	3	There is no data available with regards to the experience and knowledge of the personnel involved. Again, IMP is a series of modules covering all aspects of pipeline integrity. To carry out the monitoring and maintenance activities, supervision of experienced corrosion professionals is required. Keeping this in mind, a score of 3 is assigned.
45	How data from different activities, measurement transferred to database? (Minimal / no human intervention)	3	Exact information regarding the database is not available but again with IMP in place, records would be stored in a database. Hence a KPI score of 3 is given.
46	Storage and retrieval of data	3	Storage and retrieval of data in required format should be available with IMP in place. Yet, no information regarding the same is available hence, a KPI score of 3 is assigned.

11. Management

Table 10 describes the status of implementation of KPIs for corrosion management strategies in the crude oil pipeline investigated in this paper.

Table 10: Corrosion Management

KPI	Description	Score	Comments
47	Effectiveness of internal communication strategy between parties	3	The internal communication strategy is in place and again there is no specific information available on the same. Hence a KPI score of 3 is assigned.
48	Effectiveness of external communication strategy between parties	1	With the information available, Pembina handled the crude oil leak in a comprehensive way. Various governmental agencies were involved and the issues were dealt in a proper way. The leak was contained and proper root cause analysis was carried out. Hence, a KPI score of 1 is given.
49	Review of corrosion control activities	4	With regards to the review of corrosion control activities, there is no information available. But the personnel responsible for carrying out the integrity management program (IMP) should to be reporting above and definitely review meetings should be a part of it. With uncertainty in how far these are effective, hence a KPI score of 4 is assigned.
50	Failure during review period and its frequency	5	Two consecutive failures, cause being the same, but at different locations. Hence, a KPI score of 5 is assigned.

12. Discussions

This study analyzes the reasons for the failure of the sweet crude oil transmission pipeline by correlating it with the status of implementation of 50 KPI's. The pipeline failed due to the transgranular, circumferentially aligned stress corrosion cracking (C-SCC). Efforts should be made to remove the causes of the identified failure (C-SCC).

Even though there have been no reported failures thus far, any time that may be a potential to create other complications. Therefore, risk due to internal corrosion should be considered for the pipeline. Conducting corrosion audits will be useful in identifying potential areas of corrosion failure and also will help in the undertaking of preventive maintenance.

The analysis on the implementation of KPIs to effectively and economically control corrosion, indicates that the percentage score of corrosion control is low (30%) when compared to the corrosion score (70%). By addressing the following KPIs, the corrosion control score can be improved; consequently, the risk due corrosion will decrease:

- 01 (Segmentation of pipeline)
- 04 (Elucidation of overall risk)
- 11 (Establishment of corrosion damage mechanisms)
- 12 (Establishment of maximum (unmitigated) internal corrosion rates)
- 16 (Development of internal corrosion mitigation strategies)
- 17 (Implementation of internal corrosion mitigation strategies)
- 18 (Establishment of maximum mitigated internal corrosion rates
- 19 (Establishment of effectiveness of mitigation strategies)
- 24 (Identification of internal corrosion monitoring strategies
- 25 (Establishment of number internal corrosion monitoring probes)
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- 32 (Establishment of inspection – external corrosion)
- 15 (Establishment of data collection)
- 49 (Establishment of corrosion review meeting)
- 50 (Frequency of failure)

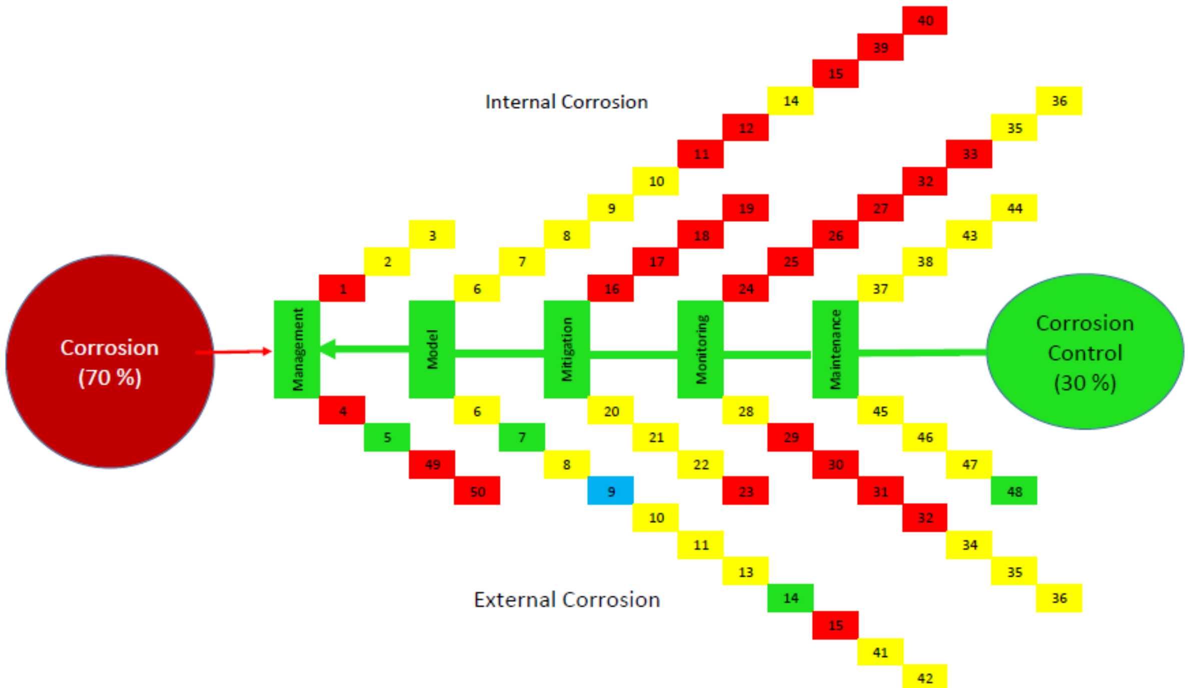

Fig. 1: Status of Implementation of KPIs to Control Corrosion in a Crude Oil Transmission Pipeline

13. Summary

This paper analyzes the failure of a crude oil transmission gathering pipeline system with the help of 50 key performance indicators (KPIs). This crude oil transmission pipeline has had two failures due to circumferential stress corrosion cracking (C-SCC). Analysis of the KPIs indicates that the corrosion control score (30%) is far lower than corrosion score (70%). Twenty-four (24) KPIs have been identified to reduce the risk due to corrosion.

14. References

1. S. Papavinasam, "Corrosion Control in the Oil and Gas Industry", Gulf Professional Publication (2013)
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