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Corrosion Management: A Case Study on South African Oil and Gas Company

Linda Njomane
Faculty of Engineering and the Built Environment
University of Johannesburg
Johannesburg; South Africa
Lindanjomane02@gmail.com

Arnesh Telukdarie
Post Graduate School of Engineering Management
University of Johannesburg, South Africa
arnesht@uj.ac.za

Abstract

Corrosion as a major environmental deterioration phenomenon affect material infrastructures and pipes. The associated risks, impacts, and failures affect production and reduces return of investments globally, which consequence despite the commitments of Oil and gas industries results to spillage, injury, waste, hazard environmental degradation and damage evolution.

A South African Oil and Gas company X in this case study is explored to highlight the risks associated with asset failures; its management due to corrosion and how to contend this mishap in the storage and distribution of refined oil, gas and allied products.

Using a mixed research approach, preliminary results indicate a below average asset availability, an indication that corrosion management techniques existing in the company does not achieve the protection intent due to poor preventive and mitigative activities in use.

Therefore, more desperate aggressive approach with approved corrosion policy, strategy, control standards and checks, plans, procedures and processes, structures, resources and professionals are required to manage corrosion in petrochemical industries.

Keywords
Corrosion, Management Strategy, Corrosion rate, Remaining life, Cathodic Protection

1. Introduction

Corrosion is the major cause of multiple fatalities and the second leading cause of asset failures in the oil and gas industry, (Blystone, 2015; Ratnayake, 2012). Globally, approximately $2.2 trillion economy annually is invested in techniques and managing of corrosion in an attempt to control its impact on the assets. Carbon steel, the most used metal in storage and distribution is prone to corrosion as such requires effective corrosion management (UNEP, 1997; Koch, Brongers, Virmani and Payer , 2007) to reduce the rate of occurrence Morshed, 2007 and loss of unquantifiable indirect costs in safety that lead to loss of life, reputational damage and threatening of license to operate (Hansson, 2011).

Storage tanks and pipelines in company X started failing prematurely, having Loss of Primary Containment (LOPC), with a total of 6 out of 13 inspections done between 2013 and 2016 even before the planned inspection interval. The remaining planned inspections, posed a challenge to the business as the assets failed due to corrosion effects. Decision to repair the assets prolonged due to budgets reallocation, which consequently extended the outages. This

unplanned asset outages subsequently increased the supply constraints. To avoid potential breach of supply contract agreement, contingency plans were activated in terminals where other oil companies are hosted, that resulted to injection of additional resources.

This research, therefore investigates the types, rate, and the impact of corrosion on Company X and the effectiveness of control measures applied. The literature reviews, onsite practical data analysis, interpretations and limitations of this study provide insights into the technical management of tank farms in a corrosive, coastal environment, and suggests best practices possible. Failures, reliability and availability relative to data analysis are essential value add-ins to this study. The effectiveness of the different preventative techniques further provides deeper insights in managing assets in a corrosive environment.

2. Overview

ISO 31000 framework considers Corrosion Management as integral part of the continuous improvement process, including prioritization and allocation of resources. It further states that the benefits are more difficult to recognize and monetize; safer operations, fewer failures, reduced risk leading to reduced liability, and a lower life-cycle cost of the asset (Hansson, 2016). It further underpins the observed/ and or expected corrosion type, the asset life Cycle systems, the return of Investment, asset system criticality, regulatory requirements and mitigation alternatives as key performance index.

2.1 Impact and cost of corrosion.

Corrosion affects society and organizations negatively: high cost (direct and indirect) of replacing materials, environmental impact and reputational damage Hansson, 2011. Direct cost is associated with the actual cost of replacing the steel while indirect costs is difficult to quantify spanning from inconvenience, loss of business and ultimately loss of life (National Research Council, 2009 ; The Institute of Corrosion, 2013). In oil and gas industry, zero tolerance leak is imminent due to fluid properties of the products (Mohamed and Hosseini, 2017). Occurrence of corrosion increases maintenance and downtime of strategic assets and increases the likelihood of process safety incidents (Ritchie, 2011).

Of all failures, Corrosion related accounts for 25% with the real corrosion results to 20-30% of production losses in the oil and gas industry (Ossai, 2012; Harrocks, Mansfield, Parker, Atkinson and Worsley, 2012), and over 50% of leaks attributed to aging assets (Harrocks, et al , 2012). Regrettably, BP, Shell, ConocoPhillips, Exxon, Mobil and Total combined assets estimated at $100 billion are prone corrosion, metals (Nicholson, Feblowitz, NMadden and Bigliani , 2012). Corrosion cost in United Kingdom rose to over $1 trillion in 2012, constitutes about 6.2% of the GDP (Ossai, 2012). Cost of corrosion for Shell alone amount to $400 million in 1995. BP's cost of corrosion of 6 percent reportedly equivalent to its net asset value. Corrosion contributes approximately 85% of all unplanned breakdowns (Ritchie, 2011).

2.2 Types and Factors Accelerating Corrosion

Metals extracted from ore tend to revert to their natural state when exposed to moisture and oxygen (Kean and Davies, 2015). Corrosion occurs in the same metal that has anodic and cathodic sections due to milling imperfections (Roberge, 2012). Different types of corrosion exist but the most common ones in metal are erosioncorrosion and corrosion in the form of : under deposit, microbiological induced, crevice, stress cracking, de-alloying, intergranular, top of the line and galvanic (Wen, Gu, and Nesic , 2007; Sami and Mohamed , 2008; Canadian Association of Petroleum Producers , 2009; Mohyaldinn, Elkhatib and Ismail , 2010; Fang, Brown and Nesic , 2011; Ossai, 2012). These corrosions have failure mechanisms of uniform degradation, pitting and / or cracking.

Corrosion rate is the speed at which corrosion develops (Mohamed and Hosseini, 2017) accelerated by such factors as manufacturing imperfections, soil resistivity and types, salty environments, use of different types of materials, carbon dioxide (CO_2), Hydrogen Sulphide (H_2S), PH levels, presence of moisture, flow dynamics and electrical continuity between tanks and pipelines (Ossai, 2012). Additionally, improper application of protective measures such as coating, incorrect use of inhibitors, installation of cathodic protection on already corroding metal, the type

and nature of product stored on the tank and the pipeline considerably speed up corrosion rate (Kruger, 2001; Wen, et al , 2007; (Mohyaldinn, et al , 2010; Fang, et al, 2011; Ossai, 2012).
Combination of water, CO_2 and H_2S can cause significant corrosion recording corrosion rates of 6mm and 300mm per year respectively (Ossai, 2012). Internal surfaces of carbon steel materials have higher corrosion risk because of possible presence of CO_2, H_2S and water (Su, Yin, Cheng, 2012). Under deposit corrosion forms pitting corrosion that accelerates the rate (Yunze, Yi, Limin, Fei and Xiaona, 2017). Understanding corrosion rate ensures purposeful implementation of mitigating strategies (Kruger, 2001). The corrosion rate of steel for example in the soil ranges from less than 0.2 microns per year to 20 microns per year or more depending on soil aggressiveness. Locality also determines uniformity of corrosion rate: 0.004 – 0.06 mm/year in rural, 0.03 – 0.07 in urban, 0.04 – 0.16 in industrial and 0.06 – 0.17 in marine environments (American Galvanisers Association, 2017).

Other influencing factors include: , the materials used for construction, the selected design and related structures of the facility, the corrosion protection methods and the exposure environments.

2.3 Life Cycle of the Asset

Managing the life of an asset/ asset system an industry acquired, built and /or enhanced demand that the threat of corrosion at each of the significant stages of an asset's lifecycle, from design to decommissioning must be treated as a high priority to achieve optimal effectiveness of the equipment, with deterioration initiating the first day (Det Norske Veritas, 2012). As part of continual improvement processes the review and improvement of the assets constitutes part of the corrosion management strategy (Hansson, 2016) that maintains continuous link between communication and monitoring (figure 1) with the assurance of a safe and economical operation during their intended life (Det Norske Veritas, 2012).

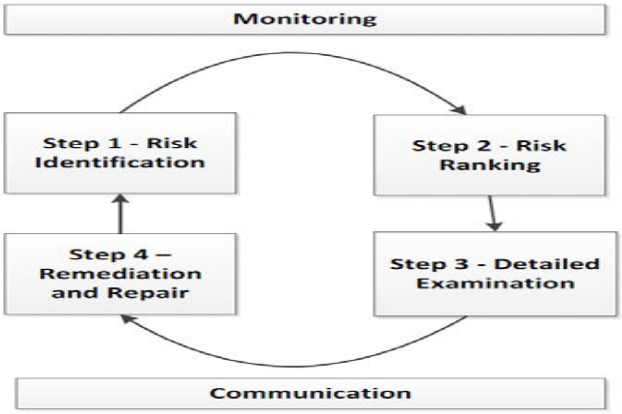

Fig. 1 Life Cycle Asset Corrosion Management

For this to be in compliance with the safety requirements throughout the service life of the installations their operational life requires a continuous amount of condition monitoring, inspections, and maintenance.

2.4 Corrosion Management

Corrosion management is the overall management system and the process of stopping or reducing the rate at which corrosion occurs (Mohamed and Hosseini, 2017) and includes maintenance activity or at best, as part of asset integrity, which is often more linked to an operator's business management systems with the exclusion of higher management domains (Hansson, 2016). It involves the development, implementation, review, and maintenance of corrosion policy overall management (Ossai, 2012). Implications of misunderstanding corrosion management are high probability of failure, increased repair costs and downtime (Morshed, 2007; Al- Arada, Al- Refai, Joshi and Patil, 2015; Debruyn and Al- Ghamdi, 2016). Identifying and designing for corrosion as a threat at design stage improves asset reliability at operation stage (Morshed, 2007). Corrosion Management and control is achieved through application of a proper corrosion management strategy (CMS) and achieving equilibrium between the material and its environment (Ossai, 2012). Corrosion management strategy is a guideline document that ensures that design, operations and maintenance activities are performed in such a way that they protect an asset against corrosion (Morshed, 2007; Tino, Wiryolukito and Abduh, 2008; Hansson, 2016). Corrosion management techniques

are categorized into two approaches, the technological approach and management approach (Al - Arada, et al, 2015). Technological approaches representing the corrosion specific involve design, selection of material, use of protective coating, inhibitors and cathodic protection, other procedures and plans. (Hansson, 2016) however benchmarked the management approach into nine management system domains: policy, including strategy and objectives; stakeholder integration: organization; accountability; resources; communication; corrosion management practice integration; continuous improvement; and performance measures (figure 2).

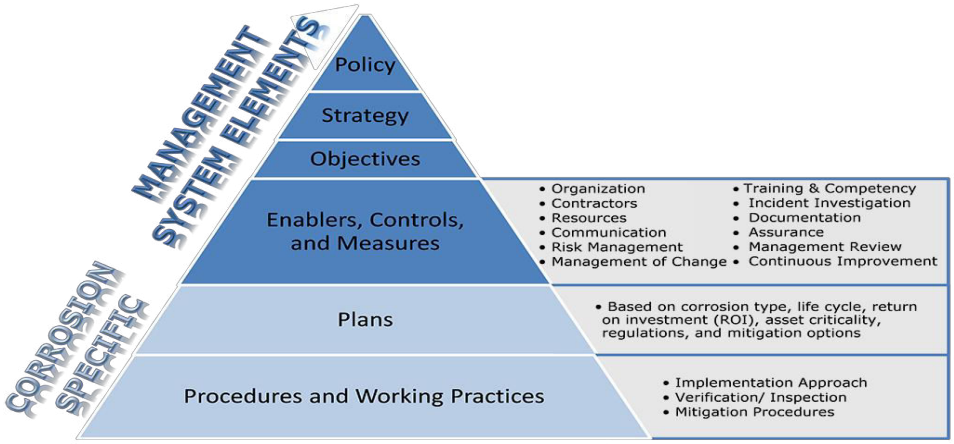

Fig.2 Hierarchy of general and corrosion-specific management elements

Management approaches include inspections, modeling and trending (Ossai, 2012; Mohamed and Hosseini, 2017). Implementing corrosion measures post design can be costly and ineffective (Nyborg, 2010). (Hansson, 2016) indicates that incorporating corrosion control within an existing management system and monetize the impacts, corrosion-related expenditures can be optimized Corrosion management use probabilistic and deterministic approaches. These approaches inform the maintenance strategies of each asset. Probabilistic approached result in more risk-based orientated maintenance while deterministic approach states that an asset is most likely to fail based on its time in service thus resulting in time-based maintenance (Lawson, 2005). Management approaches require competent personnel to be effective (Su, Yin, Cheng, 2012). Corrosion management emphasizes on metrics and establishment of key performance index and capturing costs along the way that are not typically captured within an operation (Hansson, 2016). The following asset-centric equations determine the Reliability, Availability, Maintainability, Remaining life, and Corrosion risk of equipment:

$$MTBF = \frac{Total\ Uptime}{No\ of\ Failures} \quad \text{(MTBF – Mean Time Between Failures)} \quad (1)$$

$$Availability\ (\%) = \frac{Uptime}{Operating\ Cycle} \quad (2)$$

$$Maintainability\ (\%) = 1 - e^{\left(-\frac{t}{MTTR}\right)} \quad \text{(MTTR- Mean Time To Repair)} \quad (3)$$

$$Reliability\ (\%) = e^{\left(-\frac{t}{MTBF}\right)} \quad (4)$$

$$CR = \frac{t_{original} - t_{actual}}{\Delta T\ (years)} \quad \text{(CR- Corrosion Rate)} \quad (5)$$

$$Remaining\ Life\ (years) = \frac{t_{present} - t_{required}}{CR} \quad (6)$$

$$\text{Risk} = \text{Likelihood (Probability)} \times \text{Consequence (Severity)} \quad (7)$$

An effective corrosion management strategy requires a combination of management and technological approaches (Morshed, 2007). Incorrect application of corrosion management techniques can cause more harm than intended protection. Assets are diverse hence corrosion management approaches have to be asset-based (Morshed, 2007). Errors in determining corrosion rate have been picked up thus resulting in inaccurate determination of remaining life (Yuanjie, Dongmei, and Hanling, 2016). Common errors include incorrect design and operating parameters such as type of service, product stored, material, temperature and flow rates, that are used in calculations (Mohamed and

Hosseini, 2017). Correct determination of corrosion rate has an economic saving and improve the reliability and profitability of an asset (Yuanjie, Dongmei, and Hanling, 2016). Corrosion management techniques follow risk-based mitigations through employment of reliability tools such as failure modes, effects and criticality analysis, risk assessment and application of Risk Based Inspection (RBI) strategy (Ossai, 2012).

The most effective method of protection for buried and submerged structures is cathodic protection (Kean and Davies , 2015). Cathodic protection (CP) of either sacrificial anode or impressed current system, according to (Kean and Davies, 2015) is an electrical method of preventing corrosion on metal surfaces by controlling flow of current to the protected. In oil and gas industries of zero leak tolerance, CP is mandatory. Effectiveness of cathodic protection requires a proper design basis package (Kean and Davies , 2015; Det Norske Veritas, 2012). The design package must contain historical data, materials of construction for the structure to be protected, selection of anode materials, current demand, isolation points, determination of complex systems, type of CP, proximity to power source for stray currents, proximity of other structures, soil resistivity, operational and maintenance requirements (Det Norske Veritas, 2012).

(Kean and Davies , 2015) is of the opinion that electrolyte with less than 1500, 1500 – 2000 and above 5000Ω.cm are highly corrosive, moderately corrosive and slightly corrosive respectively. The Authors insist that storage tank bottoms require a current of 2.5mA/m2 and a voltage between -850 to -1000 mV. Understanding the type of soil in which the cathodic protection system operates is important, the authors emphasized. The guideline for potential on soils with neutral pH is -850mV while soils with sulphate reducing bacterial require -950mV. The defect of high levels of cathodic protection in carbon steel is hydrogen induced stress corrosion cracking. Cathodic protection with excessive negative potentials can accelerate corrosion (Kean and Davies , 2015).

Corrosion can also occur in the visible external surface of the metal for inspection while in operational service. For atmospheric corrosion, protective coating is the most effective as it acts as a protective barrier between the metal substrate and the environment (American Galvanisers Association, 2012; (Zhang, Shao, Shi, Wang, Meng, and Li, 2017). Protective coating though cheap in cost, needs stringent quality control process to ensure its effectiveness and usage as process cathodic protection (American Galvanisers Association, 2012; (Zhang et al, 2017).

2.5 Corrosion Management Techniques

These include framework consisting of basic measures to determine the risk and the possible control measures: planning, performance auditing, mitigation and implementation strategies either statutory or corporate compliance policies: health and environmental and safety that assist to reduce unplanned maintenance, increase availability, reduce leaks and cost.

2.5.1 Corrosion Risk Assessment (CRA)

Assessing the risk determines the serious nature of consequence of failure ranked and ranged as high or low risk (Perumal, 2014, 2014). It further defines how to reduce those risks, the metrics for measuring improvements, and calculating the return on investment (ROI) and to identify options to remove, mitigate, or manage the risks (Ossai, 2012). The consequence therefore is a variable dependent on the process medium handled, size of the vessel, hold-up volume, thickness of the vessel, and pressure of the medium (Perumal, 2014, 2014). The service environment, temperature and pressure parameters of oil and gas process are determined by the process requirement hence not much effort on consequence can be achieved, however knowledge and inspection of the plant condition may reduce the probability of failure denoted as risk. Lower risk results to higher safety and reliability. Pipelines transport oil and gas at a high positive pressure than atmospheric, this results to materials and production losses, release of toxic gases, fire, injury to operating personnel nearby and environmental damage. The probability of failure is an estimation of the expected type of corrosion damage occurring on the asset, while the consequence of failure measures the impact of failure evaluated against a number of criteria: potential hazards to environment, risks associated with safety and integrity, or risk due to corrosion or inadequate corrosion mitigation procedure (Ossai, 2012). These criteria must be measurable, realistic and achievable.

2.5.2 Corrosion Based Inspection (CBI)

The level of corrosion inspection can be normal or categorized as Risk Based Inspection (RBI) and this determines the mitigation to be adopted, (Det Norske Veritas, 2012). The findings from risk analysis programs such as the CRA is utilized in the development of optimum plan for the execution of the inspection activities to plan physical inspection procedures and reduce risk to the lowest by focusing mostly on the critical area. It further identifies appropriate inspection method, optimise inspection schedule, develop ranking factors and identify potential ways of risks reduction.

2.5.3 Monitoring

The major key activities proactive or reactive; continuous or periodic; of direct or indirect parameter measure is the one of the techniques that ensures the maintenance of pipelines integrity and the mitigation of the identified corrosion risks. The choice of the monitoring is determined by facility, pressure, fluid composition, inherent technical culture, temperature, and aqueous fluid corrosivity. The collected data are used in the calculation of the remaining life, determination of possible mitigation procedure to adopt an enhancement of serviceability. Oil and gas industries utilizes proactive technique to determine the corrosion standpoint prior to failure (criticality, effect and mode) through the in-line and on-line monitoring system. The in-line monitoring system (biostuds and corrosion coupons) extracts data periodically through the devices installed in the pipelines while the on-line deploys monitoring probe devices such as linear polarization, Fixed ultrasonic and Electrical Resistance.

2.5.3 Mitigation Strategy

This activity deploys a corrective action, on the level of degraded facility utilizing data from the other listed techniques. Enlisted on table 1 are the different mitigation strategies and options, (Ossai, 2012).

Table 1. Mitigation Strategy

Mitigation strategy	Option	Remarks
Appropriate materials	Use of corrosion resistant alloys, non-metallic materials like Reinforced composite, thermoplastic-lined and polyethylene pipelines. Consider use of internally coated carbon steel pipeline systems (i.e., nylon or epoxy coated) with an engineered joining system.	(i) Non-metallic materials may be used as a liner or a free standing pipeline depending on the service conditions. (ii) Selection of appropriate material at construction and major refurbishment stage is necessary.
Chemical treatment	Corrosion inhibitors, biocides, oxygen scavengers, gas blanketing, vacuum deaeration	(i) The presence of small amounts of oxygen (parts per billion) or bacteria will accelerate corrosion. (ii) Provides a barrier between corrosive elements and the pipe surface
Coating and lining	Organic Coatings, metallic coatings, lining, cladding	Useful for internal and external corrosion prevention
Cathodic protection	Sacrificial anodes, impressed current systems, hybrid system	Need ability to monitor performance on-line.
Process control	Identify key parameters: pH, temperature, pressure, Flow rate, water chemistry, pH, chlorides, dissolved metals, bacteria, suspended solids, chlorine, oxygen, and chemical residuals	(i) Changes in operating conditions will influence the corrosion potential. Production information can be used to assess corrosion susceptibility based on fluid velocity and corrosivity (ii) Trends in dissolved metal concentration (i.e., Fe, Mn) can indicate changes in corrosion activity
Design detailing	Ensure ease of access and replacement: (i) Install valves that allow for effective isolation of pipeline segments from the rest of the system (ii) Install binds for effective isolation of in-active pipeline segments	Allows the effective suspension and discontinuation of pipeline segments: (i) Removes potential "deadlegs" from the gathering system (ii) Develop shut-in guidelines for the timing of required steps to isolate and lay up pipelines in each system

Finally, good corrosion management requires human resources and management support (Capcis, 2001; Debruyn and Al- Ghamdi, 2016). All mitigations must be tailored to suit the environment, design, operations and composition of material (National Research Council, 2009). Corrosion management system requires accurate data to be effective. Important steps to be undertaken when formulating a corrosion management strategy includes understanding of an asset and its current performance, design basis, inspection history and intervals, the process in which the asset is used and the threats to the asset (Morshed, 2007; Tino et al, 2008; Ossai, 2012). Carbon steel corrodes easily however the impact of corrosion can be mitigated by use of implementation of corrosion control (UNEP, 1997). Post

the analysis, key performance indicators of the asset have to be stated under which the corrosion management approaches are going to be measured on (Morshed, 2007; Tino et al, 2008).

3. Research Methodology

The research methods adopted for this case study are quantitative and qualitative methods (Weller and Monroe-Gulick, 2014; Rajasekar, Philomination and Chinnathambi, 2017). Quantitative methods used data from historical inspection reports and design data to assess the state of the asset, the corrosion attacks and impacts; to calculate the risk, reliability, availability and maintainability; corrosion rate and remaining life of assets. Qualitative method is applied to such complex system as oil and gas pipelines. Qualitative research helps to draw an in-depth investigation of this phenomena within a specified time frame in a natural context using a combination of appropriate data collection devices with the purpose of richly describing, explaining, assessing and evaluating the corrosion phenomena. Quantitative information is drawn from interviews from service providers and operations team to explain and support the inspection findings and assumptions made. Photographic evidence from site visits is used to draw further conclusions. A gap analysis tool is used to test the implementation and the maturity of corrosion management strategy at Company X (Morshed, 2007). The reason for selecting a mixed research methodology is to balance the quantitative data with qualitative data for more insight on the problems of the asset corrosion problems (Naslund, 2002; Mangan, Lalwani and Gardner, 2004; Murshed and Zhang, 2016).

3.1 Data Collection and Sampling

Data collection for the research only focuses into the distribution storage tanks and pipelines of Company X in South Africa. Two distribution terminals located in coastal towns of Port Elizabeth and Mossel Bay are selected. 100% storage tanks and pipelines (15 tanks and 2 pipelines) in these two terminals are assessed. The results are taken as the indications of the South African cluster and the recommendations are applicable to all the distribution facilities of Company X. Raw inspection data is converted to graphs and inferences are made on what the graphical representation communicates. Further inquiries with the inspection companies, Company X subject matter expects on corrosion, operations personnel, site observations by the researcher and other service providers supporting the corrosion control activities are used to enrich the findings on the inspection reports.

4. Results and Discussion.

Enlisted are the results analysis and inferences drawn from the case study.

4.1 Corrosion Management Systems Gap Analysis

Gap Analysis' identifies any gaps in the existing pipeline integrity management system (PIMS) process and, if required, to prepare a PIMS Manual, which is a level 1 document. Maturity in the implementation of Corrosion Management Strategy (CMS) is assessed using a gap analysis tool benchmarked to CMS variables. The assessment of the pipelines in Company X's facilities shows that all the storage tanks and pipelines are in category 1 (Table 2). Category 1 means that assets are not meeting any of the requirements when compared to the CMS variables. Category 2 and 3 means that there is effort in implementing the corrosion management strategy but not fully embedded. Category 4 indicates that the implementation of CMS is fully embedded.

Table 2. CMS Gap Analysis Tool

Most prevalent symptoms for Asset failures (Corrosion Related)	category of Maturity in CMS	SA Status	Legend
Lack of piping and pressure systems' integrity review datasheets	1 - Asset lacks Corrosion Management strategy CMS		Implemented
Lack of an asset corrosion management strategy document			Not implemented
Lack of long-term inspection planning, and inspection carried out is ad hoc and not risk-based inspection (RBI)			Not fully implemented
Lack of any corrosion control matrices document			As Required
Lack of inspection data processing and trending			
Lack of chemical treatment monitoring and evaluation			
Lack of regular reporting of corrosion issues and no use of corrosion key performance indicators (KPIs)			
Lack of various registers such as dead leg, corrosion under insulation (CUI), anomaly, leaks			
Lack of process flow diagrams			
Lack of an electronic piping specification spreadsheet			
Lack of any audit reports on the Asset CMS			

4.2 Review of Design and Inspection Reports for Storage Tanks

During the review of the storage tanks, design and inspection information of tanks prior to 2009 were not available. Inspection company performed design verification studies to determine the design and inspection code that the tanks are built. Storage tanks in Mossel Bay and Port Elizabeth has similar design features of British Standard (BS) 2654 and American Petroleum Institute (API) 650 and 653; these design codes have similar specifications in terms of the required remaining thickness on the tank floor and shell to accept the tank fit for service. Figure 3 shows that 8 out of 15 storage tanks when opened, have remaining wall thickness on the floor below the rejection limit. During inspections, the tank shell thickness' were found fit for service.

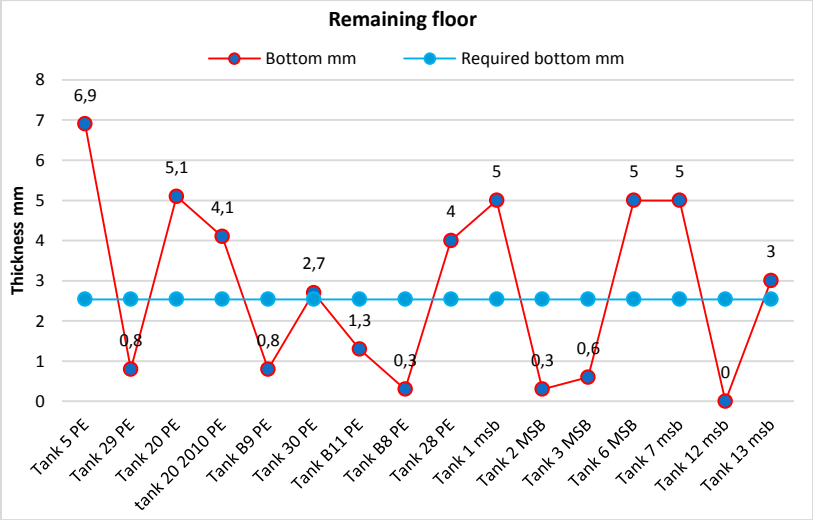

Figure 3. Deepest pits measured on tank floor

Storage tanks inspection reports showed uncoated tank floors on most of the wall indications, except for tank 2 in Mossel Bay. Tanks 5 and 28 in Port Elizabeth contain Jet A1 and are both coated. The application of coating is governed by the strict quality control procedures for any tank that stores Jet A1. Tank 2 in Mossel Bay contains diesel and it is the only coated tank on site. Figure 4 shows that tank 5 and 28 as the least number of indications and tank 2 the most indication compared to all the tanks in Mossel Bay. This confirms the theory that coating can accelerate corrosion rate if it is applied inadequately.

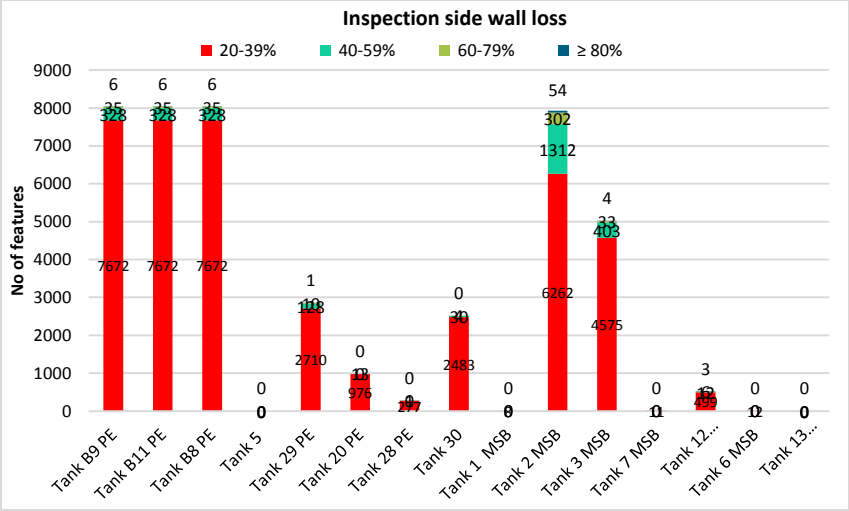

Figure 4. Internal floor features

One of the tank operational activities is to drain the tank when water is detected. An interview with the operations team revealed that the tanks have not been drained for over 5 years because no water is detected during dipping exercise. Further probing into why the water is not detected discovered that the tank sump of the tank is misaligned with the dipping point, Figure 5. Water needs to accumulate for a long time before it is detected by dipping. In tank 1 and 12 in Mossel Bay, 150000 liters of water were drained on the tanks when taken out of service, though the dipping process never detected any water, an inference that for over 5 years the two tanks bottom were submerged in water and this resulted to corrosion occurrence.

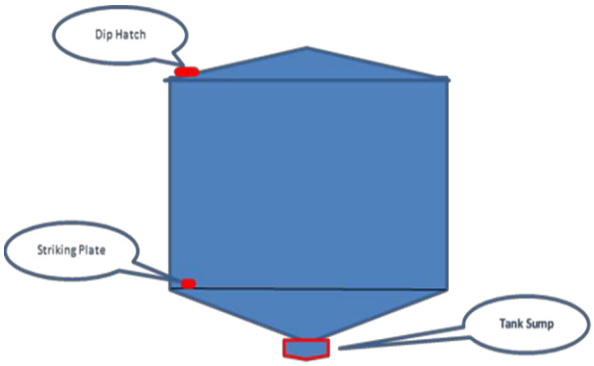

Figure 5. Dip point in relation to tank sump

From the review of inspection reports, it is observed that the inspectors used a generic corrosion rate of 0.05mm/year, below the lowest value expected for structures in marine environment. The highest corrosion rate value obtained in this study is 0.25mm/year in Port Elizabeth and 1.4mm/year in Mossel Bay. Using these values, the remaining life of the tank floors reduces below the approved operational window of 10 years currently satisfied for the tanks. Corrosion rate for Port Elizabeth is higher than the expected uniform corrosion rate ranges from 0.06 – 0.17mm per year.

The use of a generic corrosion rate of 0.05mm per year by the inspection company concludes that wall loss indications between 20-30% can be ignored until the next inspection period of 10 years. As per Figure 5 these indications have the highest numbers and they are distributed across the entire floor. Table 3 shows that the calculated corrosion rate is applied some of the areas of the tank floor will not be able to reach an operating window of 10 years if no mitigation is applied.

Table 3. Remaining life using actual corrosion rate

Tank numbers	Calculated CR	Remaining life @20%	Remaining life @25%	Remaining life @30%	Remaining life @35%	Remaining life @39%
Tank 5	0.02	193	173	153	133	117
Tank 29	0.25	9.04	7.84	6.64	5.44	4.48
Tank 20	0.06	37.67	32.67	27.67	22.67	18.67
Tank B9	0.17	13.29	11.53	9.76	8.00	6.59
Tank 30	0.11	20.55	17.82	15.09	12.36	10.18
Tank B11	0.15	15.07	13.07	11.07	9.07	7.47
Tank B8	0.19	11.89	10.32	8.74	7.16	5.89
Tank 28	0.06	37.67	32.67	27.67	22.67	18.67
Tank 1	0.13	17.38	15.08	12.77	10.46	8.62
Tank 2	0.11	20.55	17.82	15.09	12.36	10.18
Tank 3	0.1	22.60	19.60	16.60	13.60	11.20
Tank 6	0.02	113.00	98.00	83.00	68.00	56.00
Tank 7	0.02	113.00	98.00	83.00	68.00	56.00
Tank 12	0.14	16.14	14.00	11.86	9.71	8.00
tank 13	0.07	32.29	28.00	23.71	19.43	16.00

The calculated corrosion rate on site also agree with the theory that pitting corrosion have a higher corrosion rate than the uniform corrosion. These findings justify the case for Risk Based Inspection (RBI) regime that considers an individual asset instead of a blanket approach. Failure to apply RBI program can expose the business to safety and environmental incidents as the assets have a higher probability to fail before the next inspection date. On the other side, application of RBI can also have tanks such as tank 5 and 28 whose calculated corrosion rates are below the lowest benchmark with extended inspection intervals.

4.3 Cathodic Protection

Storage tanks in Port Elizabeth were fitted with cathodic protection (CP) to protect the tank floors against the underside corrosion. Figure 6 shows that the tanks are attacked by underside corrosion. For CP to be effective the voltage readings shall be between -850 – -1000 mV. Except for tank 20 readings in 2015, all the readings are outside of the protection zone. An interview with inspection company for CP reveals that the design requirements of the system are incomprehensible deducing from all the inspection reports indicate well working condition of the CP system. The only good value information the service provider was the indication that the CP system in Mossel Bay has reached the end of life.

Findings from the Site visits shows that the protected structures in Mossel Bay and Port Elizabeth are electrically non-isolated. Due to non-availability of design philosophy document on site for CP it is unclear if the system was designed to protect non-electrically isolated installation. The conclusion drawn why some tanks are corroding and others not is that tanks with imperfections and potential below the other tanks are corroding fast contrary to others.

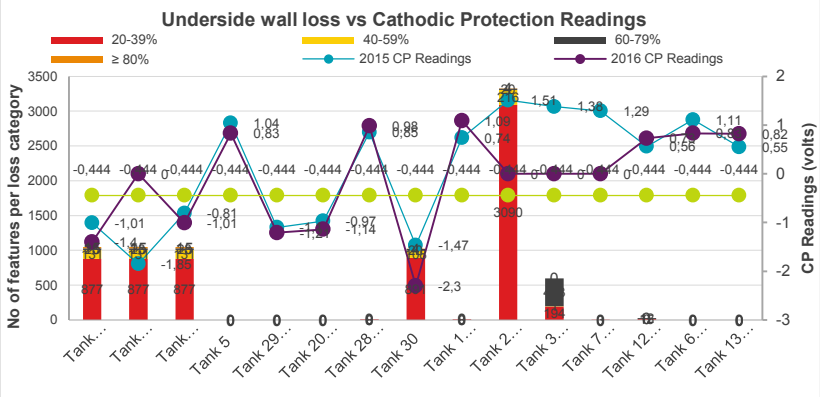

Figure 6. Non-inspection sidewall loss vs CP

4.4 Pipelines Design and Inspection Reports review

The only site with pipelines in the scope is Port Elizabeth (PE). Mossel Bay have no pipelines except for internal site piping, that receives its product via tank transfers from another oil company. PE has two pipelines that connect the terminal with the jetty to enable product transfer from the ship to terminal tanks. The pipelines run over a private property buried underground and rise above ground level as it enters the Company X's battery limit. Similarly,

these pipelines no design data was available. Assumption by the inspection company is that the pipeline is built and repaired in accordance with ASME B31.4 and inspected against API 570.

Pipeline 2 developed a pinhole leak while in-service, and a non-destructive test on the pipeline was conducted to test if it still at the expected operating pressure within its design parameters. Guided wave ultrasonic test for the above ground section and DCVG test for the buried section were tested. The guided wave tests revealed that pipeline no1 except for test point 13 and 14 areas has enough remaining life as illustrated in Figure 8. The section has been cut out and replaced. The flow changes direction at this section of the line where most of the wall loss occurs, Figure 7. Pipeline 2 was taken out of service to replace above ground section. The underground sections had enough thickness, hence, no immediate concerns on it. Port Elizabeth became constrained as line 2 is out service and the company was incurring demurrage costs from Shipping Vessels for failing to discharge timely.

Figure 7. Test Point 13 with the highest wall loss

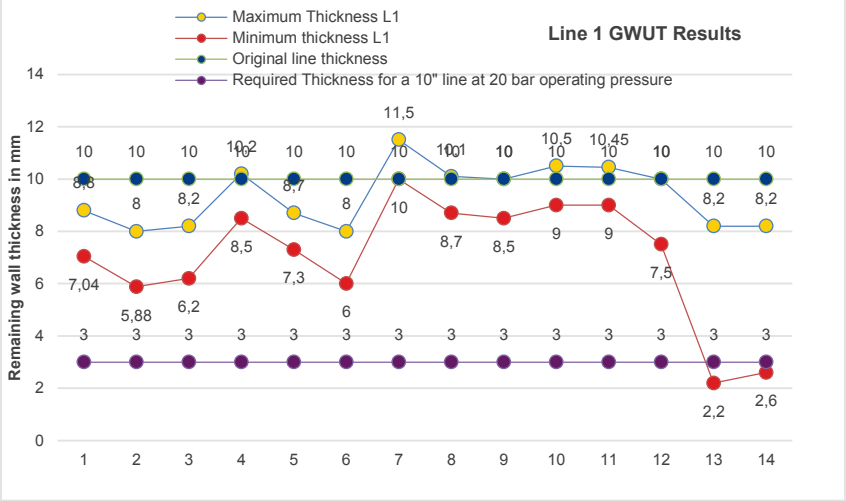

Figure 8. Pipeline Guided Wave Ultrasonic Testing

4.5 Business Impact

The business is negatively impacted by the asset outages and prolonged repair timelines. For 2016, the business disruption cost incurred for PE and Mossel Bay was valued at $1.1 Million US dollars, work repair costs from 2013 to date sum to $4.5 million US dollars. Some tanks are weak and their repair costs are no longer economically viable. Asset availability, reliability and maintainability are all below the key performance indicators when benchmarked with the company's target, figure 9 below. Other loses incurred include: no retails due to stock-outs, road safety exposure when business contingency plans are activated and reputational damage are difficult to quantify.

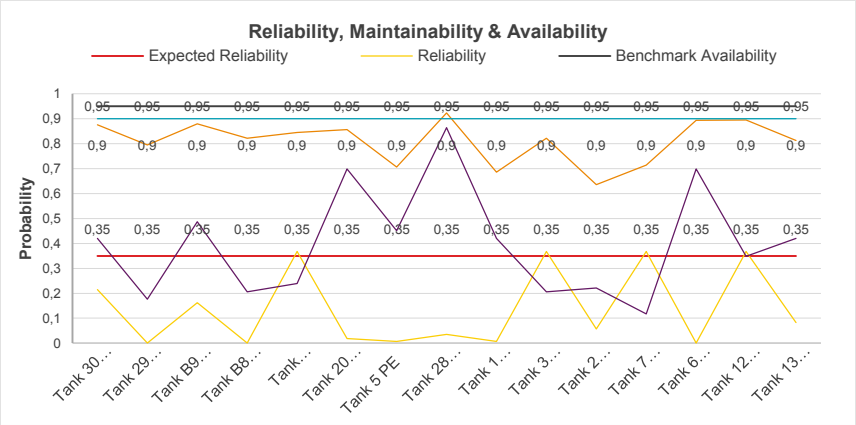

Figure 9. Actual reliability. availability and maintainability

5. Conclusion

The research presents the impact of corrosion. The actual data from site reveals the extent of corrosion impact on Company's X assets and also financial losses due to frequent repairs costs, and business disruptions. Pitting and uniform corrosion on the tanks floors were observed. The corrosion rates observed are below the expected corrosion rate for tanks with coated floors while the corrosion rate is higher on uncoated tank floors. It is clear from this study that there was no integrated system strategy to manage the pipelines and tanks corrosion. Although corrosion control techniques are implemented, there is no investment return realized due to the none working measures as stipulated in the design of these structures. It is recommended that the company must have a working corrosion management strategy, and skilled technical team that will ensure conformity with the assets specifications and requirements throughout the asset lifecycle.

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