Research on Corrosion Management Technology of Petroleum Pipeline and Pressure Vessel

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Abstract. At present, the corrosion management of the upper module pressure vessel and pressure pipeline of the fixed oil production platform and the floating production oil storage and unloading platform lacks localized corrosion rate knowledge base, corrosion mechanism knowledge base and inspection case knowledge base, resulting in low accuracy of evaluation results and the foundation of integrity management is weak. Based on this background, the paper discusses the leading causes of the corrosion process and studies and analyses the primary mechanism. Through careful consideration of pressure vessel design, material selection, manufacturing, coating and slow release and other factors, combined with different corrosion mechanisms, a comprehensive analysis of the corrosion protection of pressure vessels is carried out to find the best method of corrosion protection and corrosion control to ensure Pressure vessels operate safely and typically in petrochemical production.

Keywords: Petroleum pipeline, pressure vessel, corrosion management, corrosion mechanism.

1. Introduction
The pressure vessel is an essential part of chemical equipment in the petrochemical industry. According to the investigation, the container’s failure due to corrosion accounts for about 80% of the total failure. The use of steel buried pipelines to transport oil and natural gas, and other fluids has the advantages of low cost and exemplary safety. However, buried steel pipelines are easily corroded by transport media, groundwater, soil, and messy currents, eventually leading to perforation and leakage, causing economic losses and environmental pollution. Due to the lack of an integrity management team for the management of oil production and transportation equipment in China and the lack of risk-based inspection (RBI) management techniques for pressure vessels and pressure pipelines; various oil production and transportation units have built ERP, EMP, Maximo, Amos, and Amos at different stages. EDIS and other systems related to equipment management, but these systems are not based on the RBI professional management ideas for unified planning and construction from the perspective of pressure vessel and pressure pipeline life cycle management. There is a lack of effective integration and integration between systems, and information exists to a certain extent. Islanding phenomenon: RBI assessment lacks a team of professionals, and most of it depends on foreign consulting service providers to complete, and due to the lack of localized corrosion rate knowledge base, corrosion
mechanism knowledge base, and test case knowledge base, the accuracy of RBI evaluation results is lacking [1]. Therefore, studying the corrosion behavior and protection technology of oil and gas gathering and transportation pipelines in the ocean and flat tidal environment has paramount practical significance for taking effective anti-corrosion measures and preventing accidental damage to development facilities.

2. Analysis of corrosion chemical reaction of oil and gas pipelines and pressure vessels

2.1. Corrosion in liquid ammonia
In general, anhydrous liquid ammonia only produces slight uniform corrosion to steel. However, containers that store liquid ammonia, such as tankers, contact air during filling, maintenance, or discharge. Carbon dioxide and oxygen in the atmosphere promote the stress corrosion of liquid ammonia [2]. This kind of corrosion belongs to the typical anodic dissolution type stress corrosion. The cathode reaction is:

\[
O_2 + 2NH_4^+ + 4e^- \rightarrow 2OH^- + 2NH_3
\]  

(1)

The anode reaction is:

\[
2Fe \rightarrow 2Fe^{2+} + 4e^- 
\]  

(2)

2.2. Corrosion in wet hydrogen sulphide environment
Sulphide stress corrosion cracking has occurred in large numbers in various petrochemical equipment such as liquefied petroleum gas storage tanks and transmission pipelines. The process is as follows. Decomposition of \(H_2S\) in solution:

\[
H_2S \rightarrow H^+ + HS^- 
\]  

(3)

Anode reaction in corrosion reaction:

\[
Fe + HS^- \rightarrow FeS + H^+ + 2e^- 
\]  

(4)

Cathodic reaction:

\[
2H^+ \rightarrow H_2 
\]  

(5)

2.3. Corrosion of \(CO_2\)
\(CO_2\) corrosion is a common type of corrosion that bothers the world's petroleum industry and also troubles the development of my country's oil and gas industry. \(CO_2\). The most typical feature of corrosion is the local pitting, moss-like corrosion, and mesa-like corrosion of the pipeline, among which mesa-like corrosion is the most severe corrosion process [3]. Regarding the corrosion mechanism of \(CO_2\), it is generally believed that \(CO_2\) dissolved in water reacts with water to form \(H_2CO_3\), and then reacts with Fe to make it corroded:

\[
CO_2 + H_2O = H_2CO_3 
\]  

(6)

\[
Fe + H_2CO_3 = FeCO_3 + H_2 
\]  

(7)

However, the majority of \(H_2CO_3\), the solution exists as \(H^+\) and \(HCO_3^-\). Therefore, most of the reaction products are \(Fe(HCO_3)_2\), which decomposes at high temperature to:

\[
(FeHCO_3)_2 = FeCO_3 + H_2O + CO_2 
\]  

(8)

The corrosion product carbonate \((FeCO_3, CaCO_3)\) or fouling product film covers different areas on the steel surface to different extents. The areas with different coverages form a corrosion couple with
strong autocatalysis. This is the local corrosion of $CO_2$. The result of this kind of corrosion galvanic action [4]. This mechanism is also a reasonable explanation for the water chemistry, and once the above process occurs on-site, local corrosion will suddenly become very serious. There are many factors affecting $CO_2$ corrosion. Temperature, $CO_2$ partial pressure, flow rate, alloying elements, $Cl^-$, $HCO_3^-$, $Ca^{2+}$ and $Mg^{2+}$, bacteria, $Fe_C$ concentration, $FeCO_3$ solubility, protective film, heat treatment and microstructure of pipes, etc. have specific effects on corrosion, and the effects of multiple factors The corrosion situation is relatively complicated.

3. The main factors affecting the degree of corrosion

Pressure vessel corrosion is a very complex material or component failure phenomenon. There are many influencing factors, including materials, environment, stress, temperature, etc. The change of any one of these factors will affect the corrosion performance.

3.1. Material factors
Metal materials in the petrochemical industry mainly include 20 series, Q345R, 304, 316L, etc., and the impact on the degree of corrosion is mainly reflected in the following aspects:

(1) The chemical composition and impurity content of the material directly affect the electrochemical reaction rate. In the material, the Mn, S, etc., are easy to produce martensite and bainite high-strength steel during the welding process, which is extremely unfavorable for the equipment to resist SCC. (2) Metal surface morphology. The rougher the grain size of the metal surface, the more likely to occur intergranular corrosion. Taking the stainless-steel lining in the hydrogenation unit as an example, intergranular chromium depletion in the corrosive medium causes intergranular corrosion, and finally, the corrosion fractures along the intergranular, and the material strength almost disappears. (3) Alloying elements. The type and content of alloying elements in the material are different, and the corrosion sensitivity of hydrogen sulfide is also different.

3.2. Operating environment
The influence of environmental factors is mainly reflected in the following aspects: (1) Temperature and pressure. Experiments show that for every 10°C increase in temperature, the corrosion rate will increase by 1-3 times. The greater the pressure, the increase in the solubility of corrosive gases will also accelerate the corrosion. (2) PH value. The corrosion rate of materials that are easy to corrode in acid media increases with the decrease of PH value, and the corrosion rate of materials that are easy to corrode in alkaline media increases with the increase of PH value. (3) Medium flow rate. The increase of the flow rate smoothly accelerates the convection of corrosive media and accelerates corrosion. (4) Improper design and manufacturing. Unreasonable design, improper material selection, and low processing quality in the design are also external environmental reasons that cause corrosion.

4. The corrosion management system of oil pipeline and pressure vessel based on case analysis library
The corrosion case library is mainly composed of user management, case data management, report case query statistics, and network resource retrieval modules. Its functional structure is shown in Figure 1.
Figure 1. Construction of RBI management system for pressure vessels and pressure pipelines

The user management module realizes effective management of users, guarantees the authenticity and security of data, and reasonably grants different users the authority.

The case management module is used to realize the significant entry of the necessary information of the case and ensure the data's integrity. In this module, the function of inputting, editing and modifying case data is realized. Establish different data tables for each factor of the corrosion case, such as the basic situation table of the case, the corrosion location information table, and the detection method information table, etc. The primary data information table needed to establish the case is shown in Figure 2.

Figure 2. The main information table of the case

The case query statistics module is used to implement an effective case query and provide a quick and effective query to relevant case information. Use different keywords such as by device, by medium, by failure mode, etc., for the effective query. The design system should also provide
statistical functions of related failure cases so that inspection personnel and related technical personnel can grasp the failure rules and related cases in time [5]. The network resource retrieval module mainly realizes the collection of related corrosion cases in network resources, such as collecting related corrosion cases from related magazines, books and other network resources.

5. Protection technology and outlook

5.1. Reasonable selection of materials
Titanium and nickel-aluminium alloys have the best corrosion resistance, cast iron and carbon steel are poor, and copper-based alloys such as aluminium bronze and copper-nickel alloys are also more resistant to corrosion. Although stainless steel is resistant to uniform corrosion, it is prone to pitting corrosion.

5.2. Electrochemical corrosion protection technology
Electrochemical anti-corrosion technology refers to an electrochemical protection method in which the electrode potential is reduced based on electrochemical operations such as applying an applied current, thereby reducing the probability of corrosion. Cathodic protection method is the most important method in electrochemical corrosion protection technology, and it has a relatively wide range of applications in the field of oil and gas storage and transportation. There are two types of cathodic protection methods: one is the forced current protection method; the other is the sacrificial anode method. In actual working conditions, the sacrificial anode method is generally used to protect buried pipelines and oil and gas well pipe strings from corrosion, but due to the influence of many factors, the expected anti-corrosion effect is often not achieved [6]. At present, the cathodic protection law has accumulated a wealth of data and practical experience in the oil and gas pipeline industry. It has formed GB/T21448-2008 "Technical Specification for Cathodic Protection of Buried Steel Pipelines": The cathodic protection potential of pipelines should be between -1.2 and - Between 0.85V, or the cathode polarization potential difference of the pipeline is greater than 0.1V (the potential is relative to the saturated copper sulfate reference electrode). The code clearly states that the above criteria are only applicable when the pipeline operating temperature is lower than 40°C, and the interference of dynamic current is not considered. However, most of my country's crude oil pipeline transportation uses heating transportation, and the transportation temperature is around 70°C, which is much higher than 40°C so that the cathodic protection effect may fail. Besides, in actual working conditions, buried pipelines will inevitably be interfered with by dynamic currents such as stray current or alternating current. In this case, the existing specifications can no longer meet the requirements of the working conditions.

5.3. Coating protection
Adding a protective layer on the steel can not only save materials but also achieve high protection performance. With the advent and continuous development of anti-static coatings and heavy anti-corrosion coatings, coating protection technology is increasingly being valued by the petrochemical industry. In engineering, alloy steel precious metals with high corrosion resistance (such as iron, nickel, chromium, etc.), paint coatings or other non-metallic materials are generally used as protective layers. Thermal spraying of Al or Al-based powder core wire on the steel surface can have a good protective effect, and its service life can be increased by more than ten times. If A1203, Ni, and trace rare earth elements are added to the powder core, the anti-corrosion effect will be better.

5.4. Use of corrosion inhibitor
The use of corrosion inhibitors for anti-corrosion mainly uses the anti-corrosion effect of corrosion inhibitors to achieve the purpose of slowing down the corrosion of oil pipes. The anti-corrosion effect is mainly related to the good condition, the type of corrosion inhibitor, the injection cycle, and the injection volume. The technology has low cost and low initial investment, but the process is complex.
and has a greater impact on production. Besides, different good conditions require different types of corrosion inhibitors [7]. Generally, inorganic corrosion inhibitors are mostly used in neutral media, mainly passivation and precipitation types; most of the corrosion inhibitors used in acid media are Organic matter is mainly of adsorption type. However, the current compound corrosion inhibitors also use organic substances in the corrosion inhibitors used in neutral media as needed, and inorganic salts are also added to the corrosion inhibitors used in acidic water media. Different metals have different electron arrangement, potential sequence, chemical properties, etc., and their adsorption and film-forming properties in different media are also different. Therefore, if a protection system is required to be composed of multiple metals, a single corrosion inhibitor cannot meet the requirements. At this time, the compound use of corrosion inhibitors should be considered. There are two injection methods for corrosion inhibitors: (1) Intermittent injection method: After the corrosion inhibitor is injected from the tubing, the well must be shut-in for some time before the well can be opened (the treatment period is generally 2-3 months). Therefore, has a certain impact on production. (2) Continuous injection method: The corrosion inhibitor is continuously injected into the well or tubing mainly through the oil casing or the oil casing and the injection valve in the annular space. The oil and gas well does not need to be shut in, so it has little impact on production.

6. Conclusion
So far, although great progress has been made in the research of protective measures for offshore oil and gas gathering and transportation pipelines, there are still many problems. Taking spraying anti-corrosion as an example, the manifold structure space is narrow, and some small parts cannot be sprayed mechanically, and can only be painted by hand, and the construction quality is difficult to control. The internal anti-corrosion of some small containers is difficult to operate due to the inaccessibility of human beings. The technology in this area is in urgent need of a breakthrough. Therefore, it is a long way to study the corrosion problems and protective measures of marine oil and gas gathering and transportation pipelines. The details and difficulties of many protective methods are of great significance to reduce the harm and loss caused by corrosion. The development of protective measures for offshore oil and gas gathering and transportation pipelines has broad development and application prospects.

References
[1] Nešić, S. Key issues related to modelling of internal corrosion of oil and gas pipelines–A review. Corrosion science, 49 (12) (2007) 4308-4338.
[2] Senouci, A., Elabbasy, M., Elwakil, E., Abdabou, B., & Zayed, T. A model for predicting failure of oil pipelines. Structure and Infrastructure Engineering, 10 (3) (2014) 375-387.
[3] Castellanos, V., Albiter, A., Hernández, P., & Barrera, G. Failure analysis expert system for onshore pipelines. Part-I: Structured database and knowledge acquisition. Expert Systems with Applications, 38 (9) (2011) 11085-11090.
[4] Lenhart, T. R., Duncan, K. E., Beech, I. B., Sunner, J. A., Smith, W., Bonifay, V., ... & Suflita, J. M. Identification and characterization of microbial biofilm communities associated with corroded oil pipeline surfaces. Biofouling, 30 (7) (2014) 823-835.
[5] CHEN, J., WU, M., & ZHU, B. Web-based Environmental Corrosion Failure Case System. Contemporary Chemical Industry, 39 (3) (2010) 336-344.
[6] Dey, P. K. Decision support system for inspection and maintenance: a case study of oil pipelines. IEEE transactions on engineering management, 51 (1) (2004) 47-56.
[7] Velázquez, J. C., Caleyo, F., Valor, A., & Hallen, J. M. Predictive model for pitting corrosion in buried oil and gas pipelines. Corrosion, 65 (5) (2009) 332-342.