ANALYSIS OF STEEL PIPELINE CORROSION IN THE CONTEXT OF OIL AND GAS INDUSTRY

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***ABSTRACT**: In this study corrosion rate of plan carbon steel AISI 1045 has been investigated. Steel piplines used for the transportation of fuel such as gas and oil are usually fabricated from AISI1045 grade. For corrosion study, aerobic and anaerobic conditions are selelcted which represents common environment conditions encountered in the oil and gas industry. Moreover, corrosive environment was sodium chloride based with a molarity of 3.5% in an aquaus solution.AISI 1045 steel coupans were hanged in the salt bath over 10 weeks and change in weight of them were recorded at regular intervals of time. For aerobic and anaerobic conditions, the change in weight difference was only 0.14g and it was also recorded that aerobic conditions experienced higher weight loss which was 0.19% higher than the other conditions investigated in this study. The 10 weeks results were extrapolated and it was observed that weight loss per year was 289.33 g and 124.26 g for anaerobic and aerobic environmental conditions respectively. The corroded samples were further characterised using scanning electron microscopy (SEM) for corrosion products observation and Raman spectroscopy for the identification of corrosion products. SEM revealed the corrosion is linked with pitting phenomenon and corrosion products is composed of oxygen, iron, sodium, manganese and silicon. Finally, the corrosion products were identified to be Fe2O3 based on the peaks observed during Raman Spectroscopy analysis. The identified peaks are 212.63, 207.63 and 271.21 which endorsed that the corrosion product is composed of Fe-oxide. This study provides guidelines for the oil and gas industry to estimate corrosion rate of steel in the salty environments.*

AMS Subject Classification:

Key Words: Corrosion rate, Fuel Industry, Steel, AISI 1045,

1. INTRODUCTION

This study focus on corrosion rate and behaviour of the AISI 1045 steel materials. This steel grade is commonly employed for the manufacturing of piplines in the oil and gas industry. With rapid growth and industraliasation, the consumption of fuel is increasing exponentially which is transported via piplines. Corrosion related failures are unavoidable in the industry however it can be controlled with state-of-art technologies. For this, it is imperative to investigate the real corrosion phenomenon of steel and develop migitations strategies accordingly. It is well understood that corrosion is a natural process which involves chemical reactions with surrounding environment and eventually the material is degraded. It has been reported that global energy demands of natural gas and oil is 60% of the total consumption [6]. Such huge demand can only be meet with efficient transportation systems including via piplines. Considering the huge demand of natural fuel, it is critical to investigate and understand corrosion behaviour of piplines used in the oil and gas industry. Therefore, an analysis of corrosion rate will be performed on a AISI 1045 steel in this study to predict overall corrosion behaviour in different application environments.

2. Background Literature

It is well recognised that fuel transportant is critical to run the economy of any country. For various transportation sources are available and have been adopted. However fuel transportation via pipelines is the most efficient and economicall method. It has been investigated by various researchers that the corrosive environments including saline, acidic, carbon dioxide and hydrogen sulphide are critical factors to evaluate degradation of a steel pipelines in the oil and gas industry[1].

It is well understood that corrosion obstructs the supply of oil and gas to consumers which immensely effects productivity and efficiency in engineering industries. It effects the distribution of oil and gas through pipelines which require high level of safety to operate. It has been recorded that approximately 40% of the worldwide pipeline network have reached its project life (estimated 20 years) and efforts have been continually exercised to further extend its residual life [6].

Corrosion is a natural and unobstrutable chemical process in most of the materials including steel. Oil and gas industry encounters diverse environmental conditions such as temperature, pH and fluid conditions in addition to various ions concentrations (Chlorides, flourides and sulphides etc). Unwanted and unscheduled shut down of oil and gas supply facilities is always associated with significant economic loss. Therefore, it recommended to have regular inspections and migitations strategies in place to avoid unexpected shutdowns [3]. According to NACE corrosion is defined as process of chemical reactions with environment that evetntually deteriorate materials. Annual weight loss of a material is also recognised as corrosion [6]. In this study weight loss method is adopted to investigate corrosion rate of AISI 1045 steel.

De la Rive reported formation of localised electro-chemical cells during corrosion phenomenon [9]. However, Wagner and Traud [10] suggested cathodic and anodic processes in addition to electro-chemical cells during corrosion process. Considering severity of need, various corrosion mitigation technologies and steel grades have been investigated. Steel pipelines corrode due following key reasons; temperature, materials, flow conditions, type of hydrocarbons and sulphur level, efficiency of inhibitors etc [9].

Considering everlasting challenge of the oil and gas industry, corrosion study of steel pipelines is high demanded. Therefore, in this study corrosion behaviour of AISI 1045 steel has been investigated. Steel samples were immersed in the saline/salty (NaCl) solution under static flow conditions. The oxygen affect on corrosion rate is studied by immersing steel samples in the aerobic (oxygen) and anaerobic (oxygen free) conditions. In literature, researchers studied corrosion rate under multiflow and turbulent conditions and reported a significant influence on overall corrosion rate [11,12]. Anodic and cathodic reactions takes place during corrosion process. As results iron dissolve (anodic) and hydrogen release (cathodic).

$Fe = Fe^{2+} + 2e^-$ (anodic reaction)

$2H^+ + 2e^- = H_2$ (cathodic reaction)

Various strategies are used in the oil and gas industry to prevent steel pipeline corrosion, cathode protection is one of them. In this study, effort has been made to evaluale corrosion phenomenon and corrosion rate of AISI1045 steel in saline solution under aerobic and anaerobic conditions.

3. Experimental Plan

For this study, 1045 steel rod was acquired from one of the steel suppliers in Melbourne Austrlaia. Steel coupons of 8 mm thickness and 45 mm diameter dimensions were sectioned and grinded to smooth surface finish. Corrosive media was prepared by mixing a 35g table salt in 1000ml distilled water and was stored in a 500ml glass containers. A total of 32 samples samples were prepared and immersed in the saline solution with the help of fishing wire. In this work, aerobic (oxygen rich) and anaerobic (oxygen free) corrosion conditions under static flow scanerio were investigated. Therefore, 32 samples were immersed in an aerobic and anaerobic conditions at room temperature. Open lid jars represent aerobic and closed lid jars represent anaerobic conditions in this research work. Steel samples were removed after 14 days from the jars and were carefully handled for weight loss measurements. Six measurements were recorded in this study over a period of 12 weeks.

For corrosion product observation, Ziess scanning electron microscope (SEM) equipped with energy dispersive x-ray spectroscopy (EDS) was used. The corrosion product quantification was Raman Spectroscopy, Invia Reinshaw plc was used.

4. Results and Data

The surface of the steel samples was covered with brownish rust which was common observation. The corrosion product get thicker with immersion time and starts spalling-off into the solution. SEM, EDS, Raman spectroscopy and weight loss results are discussed in the next section of this article.

4.1. SEM and EDS Analysis

Scanning electron microscopy (SEM) image of the corroded sample is shown in Fig. 1. It is clear that steel surface has reacted with corrosive environment and a reaction product is developed over the entire surface. It is also clear that some regions have reaced vigously compared to other which is most likely related to pitting corrosion phenomenon, as circled in Fig. 1.

Fig. 2 shows the energy dispersive x-ray spectrum (EDS) analysis of corrosion product. This is summary spectrum of the entire regions to qualitatively determining the elements in the corrosion product. Elements recorded during EDS analysis were oxygen (O_2), sodium (Na), manganese (Mn), iron (Fe) and silicon Si). There composition is given in the Table in Fig.2. All of these elements are expected. For example Na came from NaCl, Fe, Mn, Si from steel and O2 from corrosive environment. By comparing the SEM images, it was observed that surface deterioration was higher in the case of aerobic than the anaerobic conditions. This agreement with the hypothesis that O_2 facilitates corrosion rate of steel.

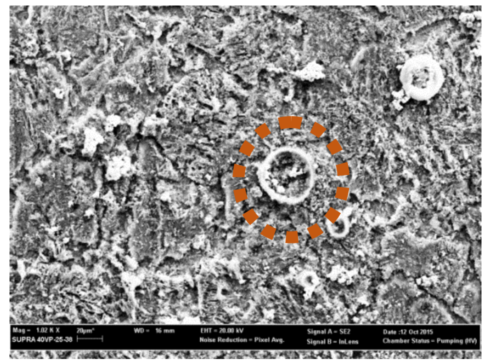

Figure 1. SEM-SEI image of corrosion product

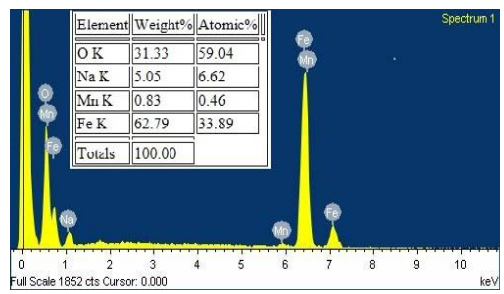

Figure 2. EDS summary analysis of corrosion product

It can summarised from SEM/EDS analysis that entire surface of the steel samples are corroded. Corrosion product thickness increased with immersion time. Pitting corrosion was also identified at selected regions of the samples samples. This regions could be MnS enriched.

4.2. RAMAN Spectroscopy Analysis

Raman spectroscopy was conducted to investigate the corrosion product formed. Various corrosion products can be identified through this technique. Ramadan spectroscopy was adjusted to 100/cm to 1500/cm spectral range with 514nm laser source having exposure time of 50/s and 100% laser power was used. The Raman spectroscopy image is shown in Fig. 3 which reveals reaction product as brighter regions than the overall matrix. The Raman Spectra of the steel samples immersed in solutions under different conditions are shown in Fig. 4. In the anaerobic parameter, the peaks were noted at 130, 212 and 271.For the aerobic parameter, the peaks were noted at 121, 207 and 271 with Fe_2O_3.

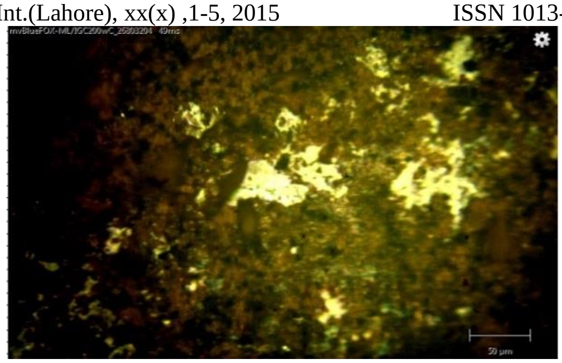

Figure 3. Imges of the corrosion products obtained from Raman spectroscopy

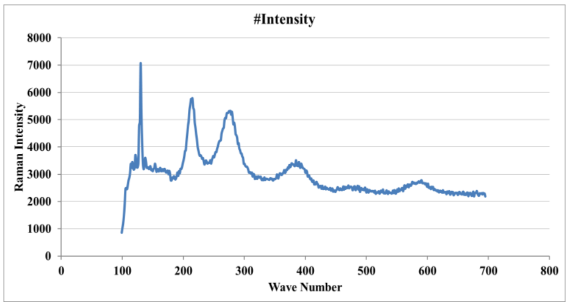

Figure 4. Corrosion product peaks intensity obtained from the Raman spectroscopy

It can concluded from Raman spectroscopy that corrosion product is composed of Fe_2O_3 as suggested by the preaks in Fig.4.

4.3. Weight Loss Measurements

One of the key findings of this was to record steel samples weight loss under various conditions and predict time to failure. For this, weight loss with immersion time was recorded, plotted and is shown in Fig. 5. Here aerobic conditions weight loss vs time plot is shown. It is evident that rate of weight loss/corrosion rate is dramatically increasing with immersion time. In this study, 12 weeks data was collected and to make a prediction, extrapolation technique was used. It was predicted that weight loss per year was 124.26g and 289.33g under aerobic and anaerobic conditions.

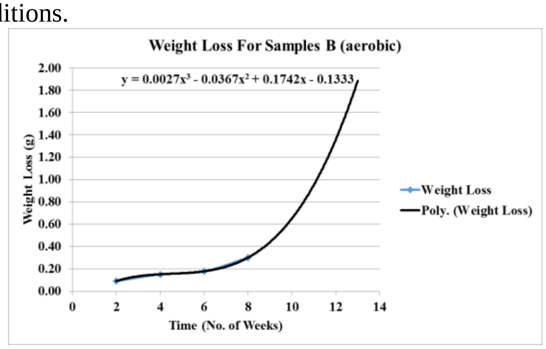

Figure 5. Steel samples weight loss with immersion time with extrapolation method.

5. DISCUSSION

The scanning electron microscopy (SEM) study revealed similar microstructures and mophoology of the corrosion products in both samples immersed under aerobic and anaerobic conditions. As discussed earlier, entire surface of the steel samples are corroded in the saline solution. Pitting corrosion in selected areas was one of the key observations. The qualitative chemical compositions of the corrosion product reveald similar elements including Fe, O_2, Na, Mn in the both samples. Small amounts of Si was also recorded in aerobic samples. These elements are expected as they come from the base material – steel and corrosive environment NaCl.

The corrosion product identify was studied under the Raman spectroscopy. The possible corrosion products are FeOOH and Fe_2O_3 which have been been reported by the earlier researchers. The anodic and cathode reactions at the interface of steel substrate and corrosive media are primary source of corrosion process. It has been reported in the literature that under limited O_2 supply (anaerobic), Fe_2O_3 formation is likely which has also been observed in this study [13,14]. Earlier investigators [15] reported Fe_2O_3 formation at the start of the corrosion process in steel samples. However, under sealed conditions (anaerobic), O_2 contents are gradually depleted in the containers hence Fe_2O_3 formation is in agreement with the Evans model [16,17]. In their work effect of dry wet cycles on the rust/corrosion product growth was investigated. This study findings are in agrrement with their wet conditions part of the model.

From the weight loss measurements, it is viable technique to use extrapolation methods for the prediction of steel pipelines failure. Hence was adopted in this study to predict per year weight loss the AISI1045 steel in the saline solution under aerobic and anaerobic conditions. From extrapolation method, per weight loss for aerobic condition was 289.33g and 124.26g for anaerobic conditions. From this analysis, steel pipelines integrity engineers can plan scheduled shut downs and asset reliability in the oil and gas industry.

6. CONCLUSION

It can be concluded from this study that;

1. The AISI 1045 steel corrode gradually in the saline solutions under both aerobic and anaerobic conditions.
2. There was evidence of pitting corrosion on selected regions of the steel subsrates
3. Corrosion product was composed of O_2, Fe, Si, Mn and Na. Light elements such as Cl, C were not detected during EDS analysis
4. It was suggested that corrosion product was most likely composed of Fe_2O_3 rather than FeOOH. It was suggested by the intensity peaks recorded during the Raman spectroscopy.
5. From weight loss measurement, extrapolation technique suggested per year weight loss of 289.33g and 124.26g

for aerobic and anaerobic conditions under static fluid flow.

Future work

This study is based on the static flow conditions. It is recommended for future work to consider dynamic/turbulent fluid conditions which are normally encountered by the oil and gas infrastructure onshore. Corrosion preventive approaches as suggested by the previous researchers [18-20] shall also be critically investigated to develop overall corrosion mitigation strategies in the oil and gas industry.

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