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Metal Failure Analysis and Maintenance Planning on Gasoline Storage Tank Pipe PT Pertamina Refinery Unit VI

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Abstract

Inspection and corrosion controlling is essential to avoid work accidents and losses to the company. In this study, the authors conducted a case study with PT Pertamina Refinery Unit VI Balongan, which processes crude oil into fuel, non-fuel, and petrochemical products. Material failure analysis was carried out by inspecting the pipes of the gasoline storage tank, which indicated corrosion. Tests were carried out by analyzing pipe thickness, water impurities, XRD, and SEM-EDX. The test results showed pipe thinning from 24 to 20 inches. Corrosion in gas storage tank pipes is caused by iron oxide, the main product of corrosion, and chlorine as a catalyst that accelerates corrosion. In addition, the SEM test shows a flowery structure, indicating surface defects. Apart from that, XRD testing on the deposits that cover the pipes shows the presence of goethite, hematite, and magnetite, which are oxidation products of iron or carbon steel. Controlling chlorine levels and using inhibitors can be one way to manage corrosion in pipes.

Keywords: Pipe, Corrosion, Gasoil, Inhibitor, Physical Metallurgy

INTRODUCTION

PT Pertamina (Persero) has seven Refinery Units, one of which is Refinery Unit VI Balongan with crude oil processing as the main activity. PT Pertamina (Persero) Refinery Unit VI Balongan is designed to process crude oil into fuel, non-fuel, and petrochemical products with a large residual capacity of around 62% of the total feed (Obot, 2021). Other activities are also maintenance equipment carried out by the Stationary and Statutory Inspection Engineer (SSIE) sub-section in the Maintenance Planning & Support (MPS) section so that production activities can run well.

The stationary and Statutory Inspection Engineer (SSIE) is tasked with carrying out inspection activities, planning maintenance of each equipment component at the refinery, providing further recommendations for equipment inspection activities, and being responsible for the rules or regulations used in inspection activities. One of the pieces of equipment that is regularly inspected is the gas storage tank pipe. In the results of periodic inspections, it was found that there was corrosion on the pipes of the gasoline storage tank. The evaluation is carried out by analyzing laboratory data to determine the cause of the damage and making recommendations for planning maintenance and repairs (Hariyandi et al., 2017).

The gasoline storage tank pipe is used as a transportation route for gasoline products resulting from the Refinery Unit process in the exor refinery area (Hariyandi et al., 2017). Sample analysis was carried out through material test results, wall thicknesses, water impurities, and visual observations of corrosion products in the gasoline storage tank pipes (Purbolaksono et al., 2010). Testing and analysis were carried out using the Root Cause Failure Analysis (RCFA) approach to obtain data on the root causes of gas storage tank pipe failure (Mobley, 1999). The analysis results are used to determine recommendations for appropriate maintenance planning so that later repairs and maintenance can be carried out so that the same failure does not occur (Nyoman Adnyana, 2017).

RESEARCH METHODS

This research uses the type of case study research by studying the state of the object of research intensively in the production area of the gasolin storage tank pipe section by focussing on the case of corrosion of the pipe and its environment. There are several stages in the research, starting with the data collection stage, data processing, analysis and discussion, making recommendations and conclusions (Mobley, 1999).

The samples in this case study were a gas storage tank pipe deposit with a diameter of 24 inches and a gasoline storage tank D deposit. Each sample was obtained from visual observations of corrosion deposits formed on the gas storage tank and D tank pipes. The tests carried out included testing the wall thickness of the gasoline storage tank pipe to obtain the remaining thickness of the gasoline storage tank pipe due to the corrosion that occurred. In addition, water impurities in gasoline from storage tanks B, C, and D were tested to obtain the elemental content of compounds in gasoline storage tank products. Both tests were conducted to facilitate analysis and determine the causes of corrosion in the gasoline storage tank pipes.

RESULTS AND DISCUSSION

1. Visual Inspection Observations

Visual inspection observations showed the presence of corrosion deposits in different sections at 6 o'clock and 12-4 o'clock in the gasoline storage tank pipeline. In this visual inspection observation, several things are observed on the deposited sample including characteristics, colour, or other things related to the deposit sample which will be used as data so that later the root cause of corrosion that occurs in the gasoline storage tank pipe can be found. From the results of visual inspection observations, the gasoline storage tank pipe deposit sample shown in Figure 1 is obtained.

Figure 1 Gasoline Storage Tank Pipe Deposit Sample (Source: Sustainability_Report_Refinery_Unit_VI, n.d.)

By visual observation, the two samples have different characteristics, which look like small flakes and chips (Mobley, 1999). The difference in sample characteristics is influenced by the cause of corrosion that occurs on the inside of the gasoline storage tank pipe. The colour of the deposit sample was dominated by brown and some dark grey flakes were found at the bottom of the pipe surface (Ahmad et al., 2010). One of the deposit samples had a different thickness, indicating that the formation of this deposit could have been formed over a long period of time.

2. Water Impurities Testing

Water impurities testing was carried out with the aim of knowing the compound content in the gasoline storage tank (Ranjbar, 2007).Obtained compound elements of water impurities results in gasoline storage tank fluid B, C and D according to **Table 1**.

Table 1 Summary Water Impurities Gasoline from Storage Tank B, C and D

Parameters	Gasoline Storage Tank B (ppm)	Gasoline Storage Tank C (ppm)	Gasoline Storage Tank D (ppm)	Gasoline storage Tank water (ppm)
Cl^-	2712	11674	-	76.15
pH	3.41	7.98	-	-
H_2S	-	-	-	-
HCl (gas)	-	-	(0.2)	-
Water content	-	-	56	-

After laboratory analysis of the fluid in gasoline storage tanks B, C and D, it was found that there were chloride compounds in gasoline storage tanks B and C with different levels (Chattoraj et al., 1997). The presence of chloride in the fluid flowing through the gasoline storage tank pipe affects the corrosion of the gasoline storage tank pipe (Zhou et al., 2020).

3. Wall Thickness Testing

Wall thickness testing is carried out on gasoline storage tank pipes with a diameter of 20 and 24 inches to know the minimum thickness limit on gasoline storage tank pipes. The results of this wall thickness test are used to evaluate the maintenance planning of gasoline storage tank pipes that have been corroded before. The results of wall thickness testing on gasoline storage tank pipes can be seen in **Table 2**.

Table 2 Summary of Wall Thickness

Diameters (")	24 "	20 "
Thick. Nominal	6,40	9,53
Thick. Minimum	4,02	7,51
Minimum Alert This.	3,60	3,60

The results of the wall thickness inspection on the gasoline storage tank pipes show a difference between the minimum and nominal thicknesses. This difference indicates that the pipe wall of the gasoline storage tank is thinning. Several factors influence it, one of which is the occurrence of corrosion inside the gas storage tank pipe wall. This corrosion event can usually occur due to the influence of the fluid flow flowing in the gasoline storage tank pipe containing chloride (Purbolaksono et al., 2010). The content of impurities in this fluid is known from the test results, and chloride is one of the compounds that can cause corrosion inside the gasoline storage tank pipe (Baoyou et al., 2006).

4. SEM Analysis Result

Scanning electron microscope (SEM) testing was carried out on two samples, namely gasoline storage tank A and gasoline storage tank D. The results of SEM observations showed flowery and flakes structures. These structures provide a non-protective layer when on the surface of carbon steel (Zhou et al., 2020). The results of SEM testing on gasoline storage tank A are shown in **Figure 2.**

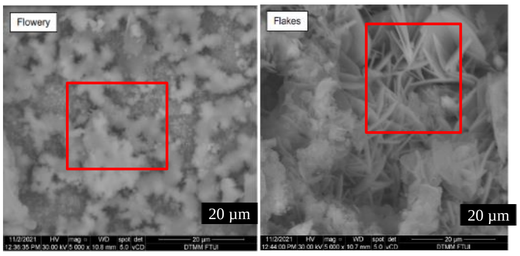

Figure 2 SEM Microscopy Results of Gasoline Storage Tank Deposit A (Source: Sustainability_Report_Refinery_Unit_VI, n.d.)

SEM microphotographs showing irregular flowery structures may indicate a type of surface defect known as a flowery structure. These defects are characterized by small circular indentations or pits on the steel surface arranged in a flower-like pattern. The cause of flowery patterns is thought to be the result of a combination of factors, including the chemical composition of the steel, the manufacturing process, and the presence of certain types of contaminants.

The flowery patterns can negatively impact the performance and integrity of steel by reducing its strength and corrosion resistance (Masuyama, 2007). These patterns can also affect the surface finish of the material and make it more susceptible to wear and fatigue. There is a close relationship between the flake pattern in the SEM examination results and the degree of damage caused by steel corrosion (Othman et al., n.d.). The flakes pattern shows that there has been a rusting process on the surface of the gasoline storage tank pipe. The flake pattern seen on the surface of the corroded steel can provide information about the level. The pattern of flakes seen on the surface of the steel that has been corroded can be a pattern of flakes that are tighter or more tenuous. A tighter flake pattern indicates that the level of damage to the steel is more severe. On the other hand, a tighter flake pattern indicates that there is less damage to the steel (Society of Mechnical Engineers, n.d.).

The results of SEM testing on gasoline storage tank D show the presence of irregular structures and whiskers shown in **Figure 3.** These two structures indicate the presence of corrosion that occurs in steel.

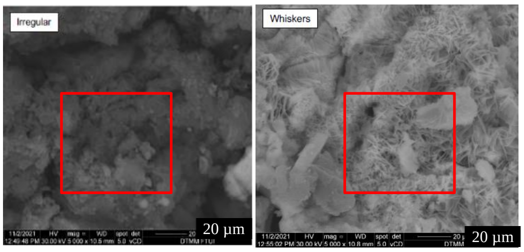

Figure 3 SEM Microscopy Results of Gasoline Storage Tank Deposit D. (Source : Sustainability_Report_Refinery_Unit_VI, n.d.)

SEM microphotography results show the presence of irregular structures that can indicate defects or imperfections found on the surface of the sample on the gasoline storage tank pipe. Some common types of defects that may be seen in irregular structures include inclusions, cracks, voids, or other surface imperfections. These defects may result from manufacturing processes, handling, or exposure to environmental conditions. In addition, irregular structures may also exhibit other microstructural features such as grain boundaries and phases that can affect the mechanical properties of the material on the gasoline storage tank pipe surface. The microphotographic results of irregular whiskers may indicate the presence of whiskers on the surface of gasoline storage tank sample D. The size, shape, and distribution of whiskers can provide information about the conditions that led to their formation and can help identify the root cause of whiskers growth that will affect the durability and wear of gasoline storage tank D.

5. EDX Analysis Result

Energy dispersive x-ray spectroscopy (EDX) testing was conducted on two samples, gasoline storage tank A and gasoline storage tank D. The EDX test results of gasoline storage tanks A and D are shown in **Table 3** and **Table 4.**

Table 3 EDX Result of Gasoline Storage Tank A

Element	Wt%	At%
O	30.45	59.11
Al	01.54	01.77
S	00.86	00.83
Cl	02.93	02.57
Mn	00.64	00.36
Fe	63.57	35.35

Table 4 EDX Result of Gasoline Storage Tank

Element	Wt%	At%
C	63.00	77.85
O	-	15.65
Al	-	00.51
S	-	00.41
Cl	06.33	02.62
Mn	00.57	00.15
Fe	10.63	02.80

The elements detected in the EDX results were mostly oxygen and iron (Baoyou et al., 2006). However, another element that was detected significantly was chlorine. The presence of chloride in an aqueous environment will result in corrosion of the gasoline storage tanks. Elements such as oxygen and chlorine have a major impact on the corrosion of gasoline storage tanks because chlorine can have a significant effect on corrosion. Chlorine is a highly reactive chemical element that can form highly corrosive compounds when it reacts with metals (Othman et al., n.d.). One common form of corrosion that can be caused by chlorine is pitting corrosion which occurs when small, localized areas of a metal surface become heavily corroded, resulting in the formation of small pits or cavities (Purbolaksono et al., 2010). In addition, chlorine can promote corrosion by reacting with other elements present in the environment, such as oxygen, to form corrosive compounds. To prevent corrosion caused by chlorine, it is important to remove or neutralize chlorine from the environment or use corrosion-resistant materials resistant to chlorine attack (Ahmad et al., 2010). In addition, appropriate protective coatings or inhibitors can prevent corrosion of gasoline storage tanks and other metals in chlorine-containing environments.

6. XRD Analysis Result

X-ray diffraction (XRD) energy testing was carried out on two samples, namely gasoline storage tank A and gasoline storage tank D. The results of x-ray diffraction (XRD) testing showed that the compounds detected in the sediment were oxides of iron consisting of goethite, hematite, and magnetite which have been recognized as corrosion products of carbon steel in aqueous environments.

In the x-ray diffraction results of the tested deposits, iron oxide phase compounds were detected. The iron oxidation phase is a phase that forms when the iron is oxidized (Purbolaksono et al., 2010) when chemical bonding between iron and oxygen occurs. The x-ray diffraction analysis showed the presence of certain iron oxide phases, namely hematite (Fe_2O_3), magnetite (Fe_2O_3), and geotite ($FeO(OH)$). The results of XRD analysis of iron oxide compounds can be used to identify the type and crystal structure of these compounds and are useful for understanding the corrosion mechanism of gasoline storage tank pipes so that later maintenance can be carried out on gasoline storage tank pipes.

Table 5 XRD Analysis Results of Gasoline Storage Tank A

Compound Name	Chemical Formula
Iron	Fe
Magnetite	Fe_3O_4

Geothite	FeO(OH)
Hematite	Fe_2O_3

Table 6 XRD Analysis Results of Gasoline Storage Tank D

Compound Name	Chemical Formula
Humatite	Fe_2O_3
Magnetite	Fe_3O_4

7. Pitting Chorrosion Mechanism

The corrosion mechanism that is possible to occur in this case based on the results of XRD, SEM-EDX analysis which shows the presence of goethite, hematite, and magnetite which are products of iron oxidation are as follows:

Anode : $Fe \rightarrow Fe^{2+} + 2e$

Cathode: $2H^+ + 2e^- \rightarrow H_2$ (Acid)

$H_2O + 2e^- \rightarrow H_2 + OH^-$ (Neutral, no oxygen)

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (Neutral, with oxygen)

With reference to the corrosion products found, the corresponding corrosion reactions are as follows:

Anoda : $Fe \rightarrow Fe^{2+} + 2e$

Katoda: $2H^+ + 2e^- \rightarrow H_2$ (Low pH)

$H_2O + 2e^- \rightarrow H_2 + OH^-$ (Neutral, no oxygen)

The reaction at low pH conditions produces hydrogen in the cathodic reaction (Utomo, 2009). On the other hand, there is also a reduction of water molecules at the cathode as the environment also involves water without dissolved oxygen (as per laboratory data on water analysis). Whenever chloride ions are present in the environment, it affects the corrosion reaction due to its role as a catalyst.

$Fe^{2+} + Cl^- \rightarrow FeCl_2$

Chloride ions react with iron ions to form a soluble ferric chloride salt. As a result, the reaction at the anode is shifted towards oxidation so that the production of ferrous ions increases (Nyoman Adnyana, 2017). An aqueous corrosion product involving the reduction of water molecules is the precipitation of amorphous ferrous iron amorphous iron known as lepidocrocite (γ-FeOOH).

$Fe^{2+} + OH^- \rightarrow Fe(OH)_2$

$4Fe(OH)_2 + O_2 \rightarrow 2(Fe_2O_3.H_2O) + 2H_2O$

These lepidocrocite can further undergo oxidation to form other iron oxides such as goethite (α-FeOOH) which can then be further transformed into hematite due to dehydration of $Fe_2O_3.H_2O$ on the carbon surface of steel. hematite (Fe_2O_3) is a corrosion product of carbon steel that we have known visually. The formation of an oxide layer on the steel surface contributes to the depletion of oxygen below the layer which then results in the formation of magnetite (Fe_3O_4) as a product. then results in the formation of magnetite (Fe_3O_4) as a product. This compound was also identified in the results of XRD analysis. The results of the SEM micrography of epidocrocite can be seen in **Figure 4.**

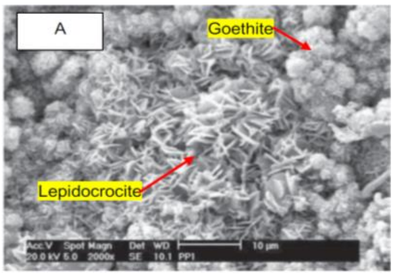

Figure 4 SEM micrographic results of epidocrocite.
(Sustainability_Report_Refinery_Unit_VI, n.d.)

These corrosion products form a layer on the surface of the carbon steel, which then acts as a deposit. Deposits on the internal surface of the pipe are the main cause of general corrosion and pitting corrosion, identified as under-deposit corrosion. The corrosion rate in the area under the deposit is higher than in other areas not covered (Nyoman Adnyana, 2017). It is also known as micro-galvanic because the area covered by the deposit is more anodic than others due to oxygen depletion beneath the deposit layer.

8. Maintenance Planning

recommendations maintenance can be made to the gasoline storage tank pipe including:

1. Using corrosion inhibitors. Corrosion inhibitors can provide internal protection for gas storage tank piping. The selection of corrosion inhibitors must be appropriate according to the type of corrosion or corrosion problems that occur. This is intended so that the protection process can run optimally and inhibit corrosion by considering the environment's characteristics or the fluid flowing in the gasoline storage tank pipe. In addition, cathodic protection can also be an option for corrosion control.
2. Upgrading the material to corrosion-resistant alloys (CRAs) can also be an option in relation to the corrosion problems that occur in gasoline storage tank pipelines. In addition, non-metallic pipes can also be an option not to cause corrosion damage to the pipe.
3. Controlling the level of chlorine and iron oxide in the environment. Controlling the level of chlorine and iron oxide in the fluid flowing in the gasoline storage tank pipe is necessary because according to the deposit sample tested chlorine and iron oxide are the main causes of corrosion in the gasoline storage tank pipe.

CONCLUSION

1. Corrosion events cause damage to gasoline storage tank pipework. There are several types of corrosion that occur including general corrosion, under deposit corrosion, and pitting corrosion. The dominant corrosion products in the form of iron oxides consisting of goethite (FeO(OH)), hematite (Fe_2O_3), and magnetite (Fe_3O_4) are well-known corrosion products of carbon steel in aqueous environments. In addition, chlorine as a catalyst also accelerates the corrosion of gasoline storage tank pipes.
2. Maintenance recommendations that are representative of the existing problems are to control the level of chlorine and iron oxide in the fluid flowing in the gasoline storage tank pipe.

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