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New-build DWT 49999 t Oil/Chemical Tanker: Mapping and Local Monitoring of the Piping System

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Abstract — This article presents an overview of the product tanker piping, its materials and problems. The goal of the study is to map, monitor in loco and point out some of the steel alloys used in the pipelines of a vessel that carries oil, kerosene, gasoline or paraffin. The aim of the paper, besides steel alloys, is to point out very dangerous problems that people mostly ignore, and those are step-by-step maintenance and an open circuit scrubber overboard pipe. The solution to the maintenance part would be the proper maintenance, and timely and continuous thickness measuring of the overboard pipe. During the voyage on a 49999-tonne DWT product tanker, pipelines are mapped and monitored in the field. This is done through weekly recordings over a 6-month period by regularly observing and photographing the pipeline system under various sailing and weather conditions. Each week, a surveillance round is carried out across the deck to look for cracks or areas of corrosion. Since the product tanker was built in 2018 and commissioned in 2019, no structural issues have been identified to date. The major problem observed is the overboard pipe of the exhaust gas cleaning system, which is very frequently corroded by sulfuric acid. Sulphur (from fuel combustion in the main engine) enters the scrubber and comes into contact with the seawater used for cooling. As the cooling water goes overboard in open circuit scrubbers, the sulfuric acid damages the steel part (AISI 316) of the exhaust line. When corrosive, hazardous and explosive products are stored, deck lines, materials and connections must be constantly monitored. The investigation took place on a 2019 product tanker. Measuring the thickness (in mm) of steel piping is used to monitor critical parts and systems, such as the exhaust gas cleaning system, which corrodes due to the formation of sulfuric acid. Real-time diagnostics therefore provides precise information that prevents pipes and components from leaking.

Keywords — corrosion, pipeline, product tanker, stainless steel.

1 Introduction

THE main purpose of oil (product) tankers is to transport refined crude oil products around the world. Oil is transported through onboard pipelines, so it is very important that these pipes are always in good condition. As the product tanker from the paper is one of the medium range tankers that mainly transport refined crude oil, it is a relatively new ship and there are few current problems. The piping systems of product tankers are generally made of stainless steel (AISI 316 or 316L). In addition, the impact of the environment cannot be ignored and appropriate countermeasures must be taken to protect the materials on board. Steel is the most important material in commercial construction from an environmental point of view. Therefore, the way steel scrap is handled is an important issue for the steel industry. Strezov and Scaife (2004) estimate that about 75% of all available steel scrap is already recycled [1]. Steel is a material that can always be recycled, and the main problem is quality. Very often, quality can be affected if the steelmaking process is not carried out in a suitable way to keep the content of e.g. oxygen, hydrogen, sulphur and phosphorus low.

Forged steel is a material made from an alloy of iron, carbon, manganes and other alloying elements. It has lower surface porosity, finer grain structure, higher tensile and fatigue strength, and greater formability than any other processed steel. For this reason, it is the best choice for marine conditions. When the cast steel is forged (high pressure and temperatures around 1200 °C), the material consisting of recrystallized grains becomes ductile and malleable so that it can be formed into any desired product. [2].

Forged steel after appropriate heat treatment has unique properties, such as very good strength, increased hardness and toughness. [2].

One of the greatest advantages of forged steel is that the grain flow follows the shape of the desired object. The grain flow of the bar stock is interrupted by machining, which affects strength. In contrast, when metal is cast, there is no grain flow at all. Another advantage of forged steel is that the metal becomes stronger than the same steel material that is cast or machined. The pressure with which the steel is compressed causes the grains in the steel to deform as they are compressed [2].

A distinction is made between commercial-grade, medium-grade, and high-grade steels. This classification is mostly based on the composition of the steel or the carbon content. Commercial steel belongs to low carbon steels, which contain no more than 0.30% carbon and up to 0.6% manganese. Medium carbon steels have higher carbon content than commercial steel, ranging from 0.3 to 0.6%, and manganese content from 0.6 to 1.65%. The carbon content of high carbon steel can vary from 0.6 to 1.4%, while the manganese content ranges from 0.3 to 0.9% [3].

AISI 316 or AISI 316L stainless steel, also known as marine steel, has on average the following chemical composition: C 0.03 to 0.07%, Cr 16.5 to 18.5%, Ni 10 to 13%, Mo 2 to 2.5%, Mn ≤ 2%, ≤ Si 1%, N 0.11%, P and S max. 0.03% and Fe balance. The addition of molybdenum, for example, gives AISI 316 better resistance to chloride-rich conditions than traditional AISI 304. AISI 316 steel is so popular because it has many excellent properties and is suitable for extreme environments. It has high corrosion resistance, excellent tensile strength, and is very usable in a wide range of temperatures (from -150 to 950 °C). It is very easy to clean and maintain, and it has a high strength to weight ratio [4]. Pipelines that carry cargo should contain at least 2.5% Mo. Manifold valves and reducers should be made out of steel. Discs, seats, and other wear parts of valves must be made of stainless steel with a chromium content greater than 11%. All cargo pipings should be electrically bonded to the ship's hull. The resistance to earth from should not be bigger than 10^6 Ohm. The pipings should be full-penetration butt welded, and fully radiographed [5].

The austenitic microstructure of AISI 316L is resistant to intergranular corrosion due to its low carbon content and the addition of Mo [6]. The corrosion resistance of stainless steel depends on many factors, but primarily on the presence of an adherent, self-healing oxide layer that prevents localised corrosion. When this barrier breaks, the bare metal is exposed, resulting in pitting. This can often be caused by stresses and mechanical damage or even chemical degradation of the surface chromium oxide film [7].

Product tankers mainly carry products made from refined crude oil, such as kerosene and gasoline. Therefore, pipes are distributed on deck for cargo transfer from the terminal or a shore facility to the cargo tanks. There are also pipes for inert gas, used to inert the tanks (to prevent explosion by reducing the oxygen content), bunker pipes (for transferring fuel from the terminal or barge to the bunker tanks) and pipes for fire fighting.

The life cycle of pipes depends on many factors, pipe manufacturing, installation, intended use, temperature and type of products (if corrosive), and decommissioning [8]. In the manufacture of the pipes, it is very important to think about the integrity/corrosion. This often consists of the injection of corrosion inhibitors and the use of internal or external coatings and cathodic protection. Corrosion inhibitors are chemical substances used to slow or prevent the cathodic reaction. Some examples of corrosion inhibitors are chromates, molybdates, nitrates, and tungstate (a divalent inorganic anion obtained by removing both protons from tungstic acid) [9].

An example from the engine room would be the stainless steel pipe used for the exhaust gas cleaning system (EGCS) – Fig. 1. The main component of the exhaust gas cleaning system is the scrubber, which resembles a large boiler and is essentially used to cool and clean the exhaust gases from the main engine. Inside the scrubber, there are also 3 levels of sea sprinklers. After the exhaust gases are cooled, the seawater is discharged overboard and the discharge water is constantly monitored. Cooling is done with seawater from the scrubber's seawater pump, which is located on the lower platform.

The combustion of fuel by the main engine usually produces sulphur, which is passed through the scrubber where it comes into contact with seawater (becoming a source of pollution). When the sulphur comes into contact with water, sulfuric acid is produced. Another important factor is that corrosion of the scrubber inner walls and drain lines is a major source of heavy metals in the scrubber water, outweighing the actual contribution resulting from the transfer of metals from fuels into the scrubber fluids. Contaminants with the greatest environemtal impacts are aromatic hydrocarbons, soot particles and heavy metals such as chromium, nickel, iron, and zinc which are also corrosion-related [10] [11].

The amount of water is regulated to ensure efficient SOx removal from the gases. The scrubber system was designed on the basis that standard seawater has a concentration of 130mg/L HC03 (bicarbonate), based on an alkalinity of 2200μ/mol/l as determined by ISO 9963-1&2. There are two types of scrubbers: open loop and closed loop. The open circuit system is the one described above, where the water used for cooling subsequently goes overboard. This system is more popular than the closed-circuit one, but is prohibited in most ports around the world. The entire discharge pipe of both systems is made of two types of polymeric materials: PFA (perfluoroalkoxyalkane) and PTFE (polytetrafluoroethylene), which are resistant and non-reactive to sulfuric acid [7].

The purpose of this paper is to highlight the potential day-to-day problems that may be encountered on product tankers during the voyage and carriage of hazardous cargo, and to present the importance of monitoring, procedure and mapping of critical components and piping in product tankers.

2 EXPERIMENTAL

The vessel under study is an oil and chemical tanker built in 2019 with a deadweight tonnage of 49999 t DWT. The current draught is 10.9 m, the length overall (LOA) is 183.07 m and the width is 32 m.

Since sulfuric acid and other chemical products are often stored, monitoring changes in pipeline thickness is critical. Therefore, the pipeline is measured with an ultrasonic thickness gage (digital gage REED TM -8811). For safety and logistical reasons, the replacement of the pipes is done in the dry dock of the ship.

Because the exhaust gas cleaning system (EGCS) – Fig. 1, is one of the most sensitive pieces of equipment on board a ship, the thinness of the piping system is constantly monitored. The manufacturer's standard thickness is 25 mm and the instruction is to replace the pipes if the thickness decreases by more than 25% of the standard thickness. The diameter and thickness values were selected from the standard ISO -Standard 1127. The minimum wall thickness of AISI 316 stainless steel pipes should comply with Table 1 [12].

Table 1. Minimum wall thickness of pipes as per external diameter.

External diameter D (mm)	Minimum wall thickness (mm)
10.2 to 17.2	1.0
21.3 to 48.3	1.6
60.3 to 88.9	2.0
114.3 to 168.3	2.3
219.1	2.6
273.0	2.9
323.9 to 406.4	3.6
Over 406.4	4.0

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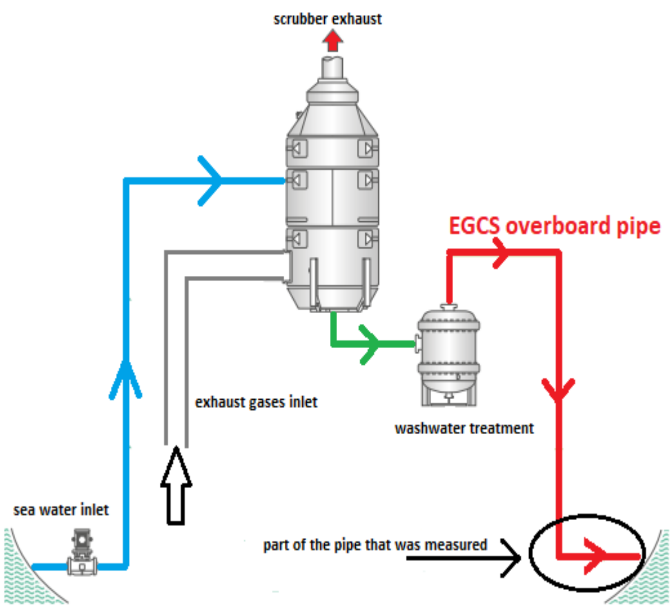

Fig. 1. EGCS operating principle. The blue line represents the seawater pumped by the seawater pump, which is used to cool the exhaust gases. The green line represents the seawater mixed with sulphur. The red line is the discharge pipe (the measurements were made on the last metre of the AISI 316 steel pipe). Modified from [7].

The EGCS drainage pipe consists of two parts. One part is made of two special polymer materials, PFA (perfluoroalkoxyalkane) and PTFE (polytetrafluoroethylene), and the other part is the last meter of the overboard pipe, which is made of forged steel (AISI 316L) [7].

The measurement starts with marking the entire pipe of the exhaust gas cleaning system (EGCS) with a permanent marker, forming 10 x 10 cm squares for precision purposes (recommendation of the digital meter manufacturer - REED TM8811). To accurately measure the steel thickness, a small area of paint is removed from the center of each square (one layer of paint is 3 to 5 mm thick). Then the measurement with the digital gage begins (Fig. 2.).

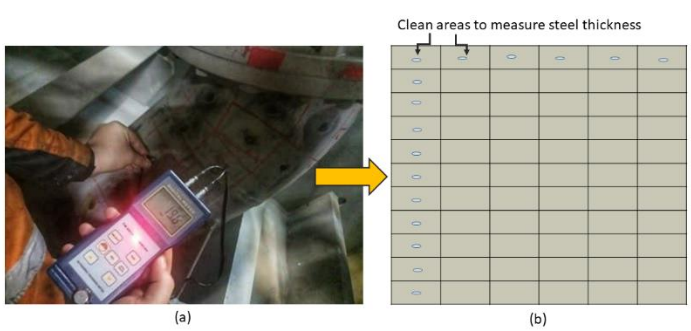

Fig. 2. (a) EGCS pipe thickness measurement with the digital ultrasonic measuring device REED TM -8811 and (b) schematic of how the analysis is carried out.

Each square is marked with a number and a letter, and the thickness obtained from the digital gage is entered into a spreadsheet. At the very end, a calculation is made to determine the extent of pipe wear. For this purpose, the measurements are compared with the manufacturer's table. The table with the calculations is then sent to the company headquarters for further decision-making.

3 Results and Discussion

Measurements of the EGCS overboard pipe taken with the digital meter from the Fig. 2. are entered into the Table 2. The lowest value of any square from Fig.3. should not be less than 18.75 mm.

Table 2. Measurements (in mm) of the EGCS overboard pipe. Lowest measure should not be below 18.75 mm (75% of 25 mm – as advices the manufacturer).

Columns	Rows					
	A	B	C	D	E	F
1	20.3	20.3	20.7	21	19.5	19.5
2	20.5	20.5	20.7	21.7	18.7	19
3	20.7	20.8	21.1	21.2	21.8	18.9
4	20.5	21	21.1	21	18.6	19
5	20.6	21.1	20.6	20.7	19.4	19.1
6	21.1	21.2	18.6	18.7	19.1	18.5
7	21.3	18.9	19.4	21.1	19	18.5
8	22.1	19.5	19.4	19.6	18.9	18.5
9	20.6	22	19.5	19.6	19.5	19.4
10	20.2	20.3	23.1	19.5	21.5	19.6
11	20.8	21	23.1	19.9	19.5	19.4

From the Table 2. it is observed that the taken measures are around or above 18.75 mm. It is established that the default thickness of the EGCS overboard pipe is 25 mm, and the manufacturer noted if the damage exceeds 25% of default thickness, the ship needs to replace the pipe. By calculations, 75% of default thickness is 18.75 mm. If any line falls below 18.75 mm the ship has to go to dry dock to replace the pipe [12].

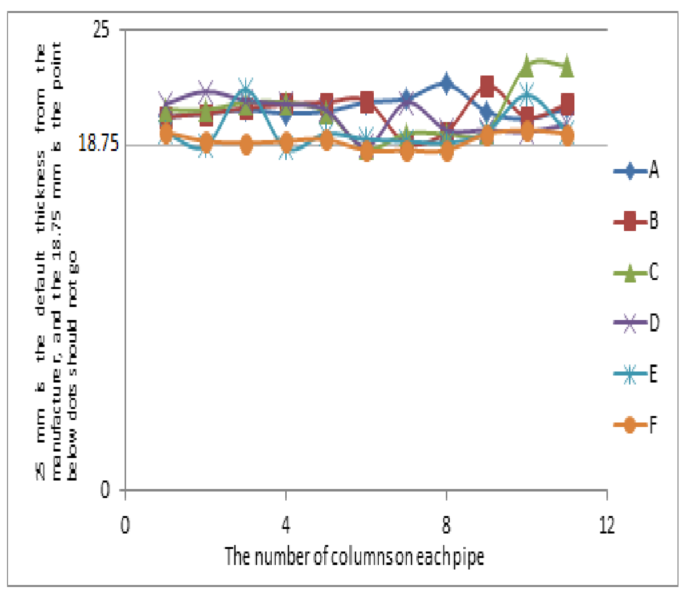

Fig. 3. Distribution of the wall thickness of the exhaust gas cleaning pipe.

The wall thickness of the EGCS overboard pipe (Fig. 3) in almost all measurements is above the critical thickness. X-axis represents the number on of columns on the pipe, while the Y-axis is the value below points in the chart should not go. Dots on each line (1-11) (according to Table 2) represent the number of points, while the A, B, C, D, E, and F parameters represent columns - (details in Fig. 4).

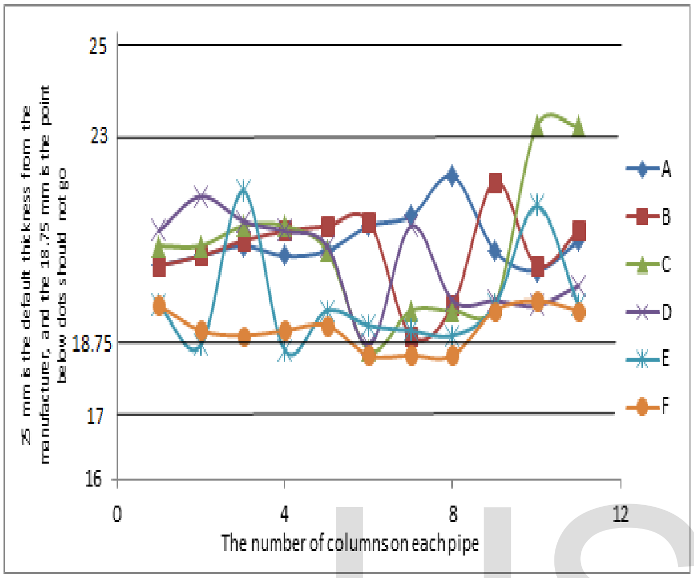

Fig. 4. A closer look to every point from Table 2. measurements of the EGCS pipe. If the wall thickness is below 18.75 mm, the vessel has to replace the pipe in dry dock.

In Fig. 4 and in Table 2, it can be seen in detail that spots D, E, and F are slightly less than 18.75 mm thick. To monitor any changes in wall thickness, measurements were taken over a period of one month.

In open circuit scrubbers, there is probably no solution to this type of problem other than to replace the pipe from time to time, since the last meter of pipe connected to the hull cannot be made of polymer. With a closed loop scrubber system, this problem does not exist because it is a closed system that does not use any piping overboard. The only difference is that the cooling water is not drained overboard after use, but is stored in an independent tank. This creates a closed loop system [7].

The environment that constantly surrounds the ship is unavoidable, whether it is sun, rain or strong waves at sea. The sea itself is also a major problem for the pipes, as there is a lot of salt that forms rust (Fig. 5). The rust (iron oxide) reduces the thickness of the pipes, which can often lead to breaks and cracks.

The crew on board can prevent this if the rust is detected in time and well maintained. This means removing the paint from the problematic areas, proper brushing and scraping treatment, applying a proper protective coating, and finally applying a new coat of paint that is highly resistant to all environmental conditions [13].

Fig. 5. General corrosion associated with a valve on a fire pump on the upper deck of the ship.

Sometimes a rust effect can be seen on the deck floor itself. In that case, the crew will most likely use the chipping procedure. This procedure is usually performed with an air-powered chipping gun. This gun consists of many needles at the tip and scrapes away the paint and rust at the same time. The procedure itself is very slow and requires a lot of patience and time to be done correctly.

The problem can also arise if the maintenance work is not done properly, for example, if a crew member is not dedicated to the task and does not perform the rust removal properly, painting over that part is not a good solution. The crew will likely have to do the same job again because it was not done correctly the last time. Each step must be done correctly to prevent rust. The next factor is the waves. It is well known that the ship sags and swells due to the waves. Therefore, the pipes on the deck are not 100% straight from the stern to the bow (Fig. 6).

A rust effect can also be seen on the deck floor itself. Then, the crew will most likely apply the chipping process. Chipping process is usually done with the chipping gun, which is air driven. That gun consists of a lot od needles on its top, and it is scraping the paint and rust at the same time. The process itself is very slow, and it requires a lot of patience and time to be done correctly.

Corrosion fatigue (CF) is a specific fatigue failure mechanism that occurs when a metallic component is exposed to a corrosive environment and cyclic stresses simultaneously. It is a discontinuous process with crack initiation and growth during transitory periods, resulting in a reduction in the fatigue life of the metal. When a crack develops as a result of fatigue, corrosion can increase crack propagation. On the other hand, pitting or general corrosion is the main cause of corrosion fatigue in the presence of cyclic stresses (Fig. 5). Types of fatigue damage include corrosion, thermomechanical fatigue,

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vibration, and creep fatigue [14].

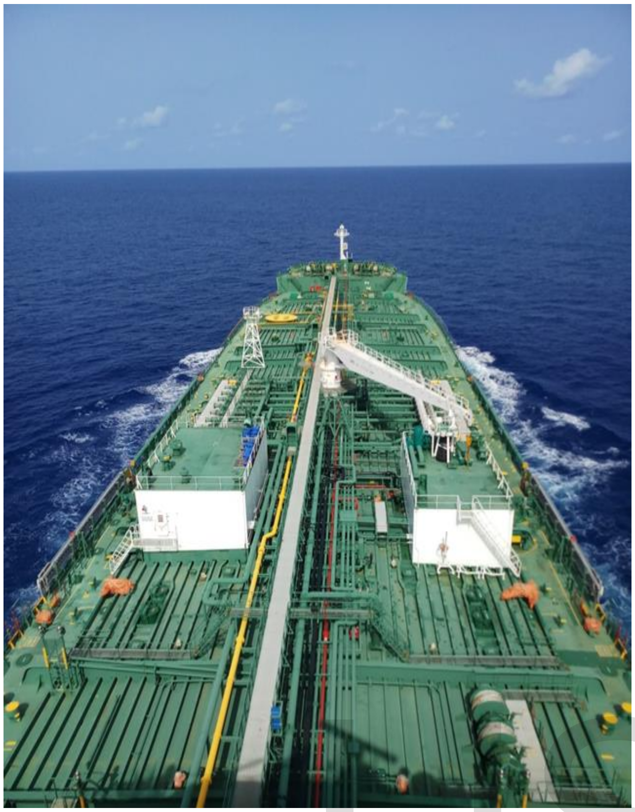

Fig. 6. View from the Funnel top on the arrangement of pipelines.

The term sagging means that the ship is between two waves and the midship area is loaded more than the stern and bow. When the ship sags, the pressure on the deck acts toward the middle, while the stress on the hull portion is opposite. The cargo itself pulls the ship down with its weight. On the other hand, hogging represents the exact opposite effect of sagging. In this case, the ship sails over the wave, so that the stern and bow are subjected to greater stress than the midship area. The pressure acts toward the center in the double bottom area, while the stress on deck is opposite. The weight pulls the ship down in the stern and bow area. If the tubes were straight, cracks and breaks would occur in any rough weather, so some parts of the tubes are as shown in the following pictures (Fig. 7) [15].

Product tankers very often carry crude oil, which contains some volatile organic compounds (VOC). When the cargo is loaded at a terminal, the pipeline from the terminal has a long vertical drop line that causes the cargo to accelerate due to gravity (Fig. 8). This can cause a sudden drop in pressure that promotes cavitation. The crude oil is a complex mixture of different hydrocarbons, and the volatile organic compounds in the crude oil refer to some light end components ranging from hydrocarbon chain C1 to C10. These components may evaporate during loading or transfer operations due to pressure fluctuations. The environmental impact of VOC emissions is their contribution to global warming, especially methane [16]. Various international regulations are regulated and reinforced by laws [17].

Fig. 7. Properly maintained manifolds on deck through which the cargo loading is done.

Fig. 8. A way of pipes on deck in order to prevent cracking and stretching due to sagging and hogging.

The structure of a ship is subjected to stresses in bad weather conditions. The stress to which a ship is subjected as a whole is the most complex problem in structural engineering in two respects: the determination of the stress and the response of the structure. Apart from inertial loads due to ship motion, a ship is subjected to loads from, basically, two sources: water pressure and gravity [15].

4 Conclusion

This paper addresses maintenance inspection routines, problems that can occur due to inferior steel, and environmental issues like salt and weathering, that are of concern in chemical and oil tankers, especially the piping system and chemical tanks.

Another issue is the ship's scrubber system due to the formation of sulfuric acid. The continuous measurement of the thickness of EGCS piping overboard shows that the monitoring of the ship's systems and equipment is crucial to avoid maintenance emergencies or worst situations such as environmental accidents. Another important point is that if the maintenance isn't done properly and the rust isn't completely removed, the crew will soon have to start the work all over again.

The waves are a big problem for the ship because the ship sags for a short time. Therefore, the pipes on the deck don't run 100% straight from the stern to the bow. This is a technical solution designed to prevent sagging, hogging as weel as cracks and breaks due to vibrations [15].

Corrosion fatigue is also a very important factor that occurs in an aggressive environment such as the sea. When a corrosive environment is combined with a fatigue load, there is a severe reduction in the fatigue life of the metal. The solution to this problem is therefore the timely detection and elimination of corrosion [14].

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