Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v47i1.71023

Corrosion in fire protection systems in an offshore unit undergoing decommissioning

Leonardo Silva Araujo[1*], Elie Chahdan Mounzer[1] and Jennifer Rosy Avelino Wavrik[2]

[1]Programa de Pós-Graduação em Engenharia Civil, Departamento de Engenharia Civil, Escola de Engenharia, Universidade Federal Fluminense, Rua Passo da Pátria, 156, 24210-240, Niterói, Rio de Janeiro, Brasil. [2]Programa de Pós-Graduação em Engenharia Civil, Departamento de Engenharia Civil, Centro de Tecnologia, Universidade Federal de Pernambuco, Recife, Pernambuco, Brasil. *Author for correspondence. E-mail: Ls_araujo@id.uff.br

ABSTRACT. The present study addresses corrosion in critical safety systems on an offshore oil and gas platform of the Floating Production Storage and Offloading type. The platform is over 25 years old and is currently being decommissioned. Corrosion on offshore platforms is of significant concern because of the risks associated with compromised mechanical integrity or functionality of fire protection systems. Such compromises can lead to property damage, environmental damage, worker health risks and escalation of fire-related emergencies. To achieve the aims of this study, a bibliographic search was conducted from 2017 to 2023. In addition, other relevant search sources were considered. These included accident data collected by the Brazilian National Agency for Petroleum, Natural Gas, and Biofuels, which is responsible for regulating, contracting, and supervising economic activities in the petroleum industry. Field research was also conducted to assess the operating conditions and integrity of both fixed and portable firefighting systems, as well as the damage caused by corrosive processes in these systems. Ultimately, the study concludes that operators in exploration and production fields are genuinely concerned about the integrity of their systems during the decommissioning process. This concern is aimed at preventing harm to people, the environment, and the company's assets. In addition, operators seek to avoid incidents that could negatively impact the company's reputation with society, investors, and regulators.

Keywords: corrosion; mechanical integrity; decommissioning; fire; risks.

Received on January 19, 2024.
Accepted on April 11, 2024.

Introduction

Brazil is undergoing a significant transformation in its petroleum and natural gas industry. Upon the discovery of large exploration fields in ultra-deep waters, the national petroleum sector has invested in new technologies to facilitate commercial production in these areas. The revitalization of mature oil fields in the Campos Basin, located in the state of Rio de Janeiro, has also become a major focus. Projects to revitalize mature oil and gas fields in the Campos Basin involve investments of more than US$18 billion planned over the next four years. These projects require the deployment of exploration and production units equipped with more advanced technologies. However, to start production processes in these mature fields with new large units, it is essential to decommission less efficient units (Petrobras, 2023).

The Campos Basin, a precursor to deepwater exploration and production in Brazil, began offshore oil and gas exploration and production activities in the 1970s. Major discoveries in the basin included the Garoupa field (1974), the Namorado field (1975), and the Enchova field (1976), with effective commercial production beginning in 1977. Because of these pioneering efforts, most of the exploration and production systems in the basin are now over 30 years old. While these systems have served as a testing ground for the development of technologies for deepwater and ultra-deepwater oil production, they are currently facing technological limitations for the development of new wells and are experiencing mechanical integrity issues because of obsolescence (Pré-Sal Petróleo, 2023). Consequently, and in line with the desire to replace these units with more technologically advanced alternatives, the operators responsible for these exploration and production units have opted for decommissioning. Platform decommissioning can be defined as a series of activities aimed at abandoning a well or stopping an oil and gas exploration, production, or storage unit (Lima et al., 2023). As highlighted by Silva & Mainier (2009), the decommissioning of oil and gas platforms in mature basins can be justified, either individually or in combination, by factors such as low production capacity of obsolete units, declining well productivity, and rising production costs.

According to data from the Brazilian National Agency for Petroleum, Natural Gas, and Biofuels (ANP) (2023a), the Campos Basin hosts 45 platforms out of a total of 152 installed throughout Brazil. Recognized as one of the most important basins in the country, it accounts for an average daily oil production of barrels, equivalent to 28.93% of the national production of oil (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, 2024). As of 2021, there were 45 oil and gas production units in the Campos Basin, 25 of which belong to Petróleo Brasileiro S.A. (Petrobras). The wells operated by Petrobras in this basin have been in operation for more than 40 years. As a result, Campos Basin is characterized by mature fields or fields that have already reached their projected operating life. This maturity of the fields of Campos Basin is reflected in the declining trends in exploration and production, as illustrated by data from the Oil and Natural Gas Exploration and Production Panel, Figure 1 (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, 2018).

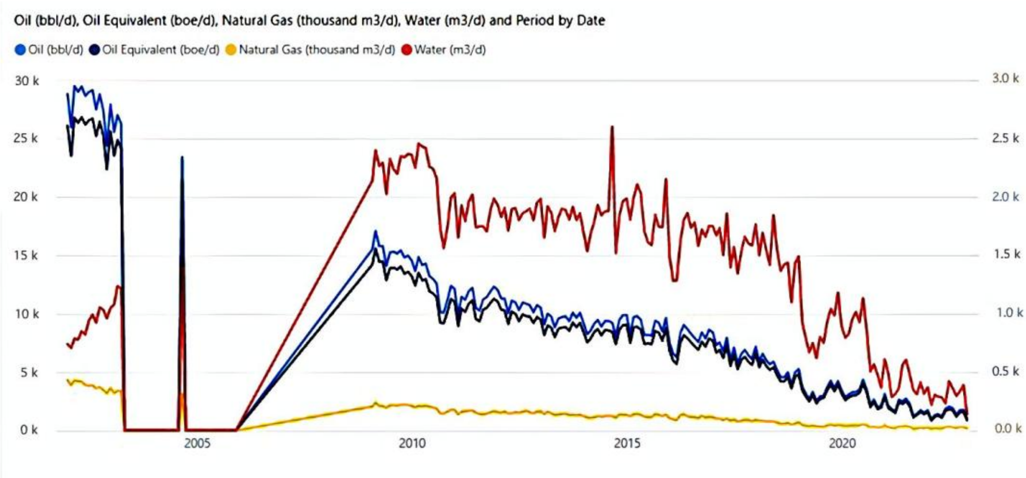

Figure 1. Production decline in the Campos Basin.

Because of the low performance, technological limitations to increase production as well as age of these units, operators of exploration, and production fields may choose to decommission the installed units. They are required to submit plant decommissioning programs (PDI) to the ANP for approval. The Figure 2 illustrates the number of applications submitted to the ANP by operators of exploration and production fields.

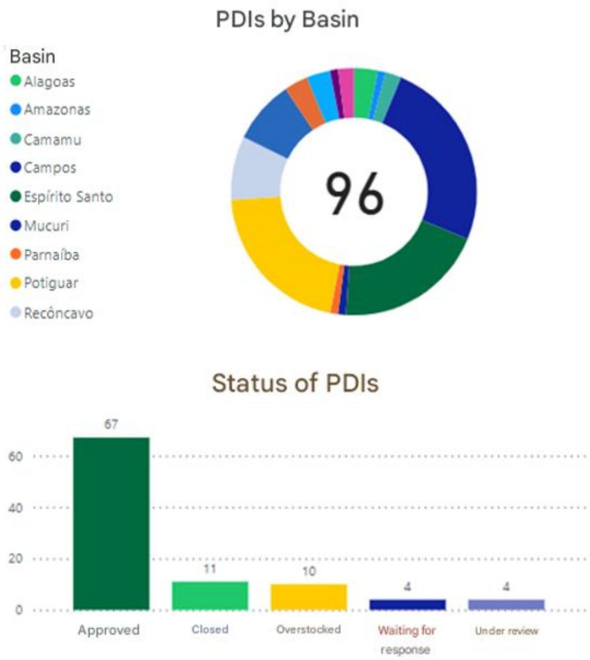

Figure 2. PDIs submitted to the ANP

Historically, the decision to decommission shallow-water oil and gas platforms has preceded similar actions in the Gulf of Mexico, a region under the jurisdiction of the United States of America. According to the Instituto Brasileiro de Petróleo, Gás e Biocombustíveis (2017), most platforms in the Gulf of Mexico have already been decommissioned. Between the beginning of 2002 and January 2016, the Bureau of Safety and Environmental Enforcement (BSEE) received 2,601 applications for decommissioning permits for oil and natural gas platforms in the Gulf of Mexico. From 2010 to 2014 alone, more than 1,000 units were decommissioned at a total cost of approximately $9 billion. However, as of July 2019, only 1,852 oil and gas platforms remain in production out of 7,209 oil units in the Gulf of Mexico under U.S. jurisdiction (Oudenot et al, 2017). Similarly, Lim (2021) and Sommer et al. (2019) have reported that the decline in oil prices in 2014, combined with the aging of exploration and production units, has led to the projected decommissioning of approximately 470 platforms, 5,000 wells, 10,000 kilometers of pipelines, and 40,000 concrete blocks by 2050. This decommissioning is expected for the 1,357 units that have been operating in the North Sea with an average production age of 25 years.

The decommissioning of offshore oil and gas exploration and production facilities is a complex process. This complexity is exacerbated not only by the need to comply with the requirements of public agencies (e.g., the Brazilian Navy, the Brazilian Institute of Environment and Renewable Natural Resources, and the ANP) but also by the lack of national experience in this area. This inexperience often results in units remaining in place longer than desired (Souza et al., 2021). One consequence of prolonged operation and shifting investment priorities is degradation because of corrosive processes. This degradation can lead to loss of containment, structural collapse or weakening of platform structures. It can also be a significant factor in the occurrence of undesirable events, including accidents and incidents involving people or equipment.

In events where loss of mechanical integrity is caused by corrosive processes, the water present in the atmospheric air plays a significant role in material degradation. It is considered one of the most aggressive electrolytes in offshore environments because of its high potential to degrade metallic structures and equipment, whether they are exposed to the atmosphere or submerged, as noted by Gentil (2017). Moreover, the attack of water on metallic materials is not only because of the high concentration of dissolved salts. It is also influenced, in a more complex manner, by the presence of living and/or decomposing organic matter, dissolved gases, and silt.

Corrosion and mechanical integrity

Corrosion usually refers to the process that leads to the deterioration of a material. While it most commonly affects metallic materials, corrosion is not exclusive to metals. Some authors argue that non-metallic materials can also undergo corrosion processes. For example, the deterioration of concrete components when exposed to sulfate attack is an example of non-metallic corrosion. In polymeric materials such as rubber and plastics, loss of elasticity because of oxidation by ozone can also be considered a corrosive process. In addition, wood can corrode when exposed to acids or acidic salts, resulting in a reduction in strength because of hydrolysis of cellulose. The causes of material corrosion are typically associated with electrochemical or chemical reactions influenced by the environment in which the material is located. Alternatively, corrosion can be induced by mechanical stresses to which the material is subjected (Gentil, 2017).

Corrosion damage in the offshore environment can be caused by both chemical and electrochemical mechanisms. As a result, degradation of systems installed offshore can occur because of factors such as differential aeration, electrolytic processes, leakage currents, galvanic pairing, and fracture stresses. A characteristic of this corrosion process is that in many cases there is no observable mass loss in the metal structure during natural degradation. Instead, material failure is often manifested by the development of cracks. These cracks can cause the offshore metal structure to fail or collapse even under relatively low mechanical loads (Wang et al, 2021).

In the offshore environment, besides atmospheric aggression, and the influence of temperature, which accelerates chemical reactions and consequently increases corrosion rates, factors such as relative humidity and the concentration of pollutants in the atmosphere also influence the degradation of materials on offshore platforms (Abo Nassar, 2022). Figure 3 is an adaptation of Aoki (2021) and illustrates the variation in the degradation rate of materials exposed to the atmosphere with changing relative humidity.

According to Abo Nassar (2022), the corrosion process tends to occur preferentially in welded areas. This preference can be attributed to several factors, including galvanic effects, residual stresses, and surface gaps. In the first scenario, the occurrence is attributed to the difference in chemical composition between the base metal and the welded metal, especially in the presence of an aqueous medium or the accumulation of precipitate (electrolyte). This can increase localized corrosion, especially intergranular corrosion. In terms of residual stress, higher levels are typically found in the welded area. This increased stress level promotes mechanisms such as stress corrosion cracking, fatigue corrosion and hydrogen embrittlement. Finally, surface effects can lead to localized corrosion because of surface discontinuities in the welded area, especially if the area is not adequately machined.

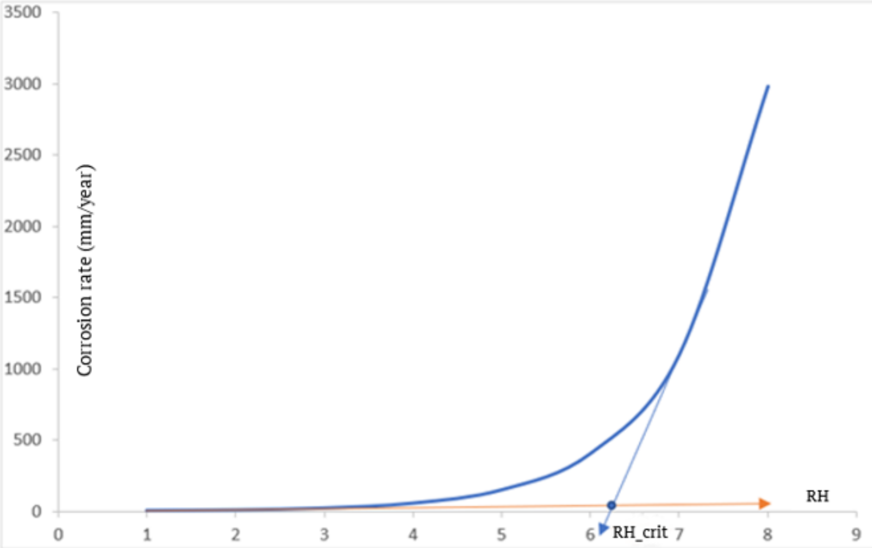

Figure 3. Critical relative humidity for a metal exposed to an atmosphere.

Another area where electrolytes can accumulate is in the so-called crevices, giving rise to so-called crevice corrosion (Figure 4). In this form of corrosion, the gaps, openings or places where dirt or corrosion products are deposited must be large enough for the electrolyte to enter and stagnate between the regions of the metal part. The dissolved oxygen is then depleted locally, initiating the metal oxidation process in that area. In turn, the electrons from this electrochemical reaction move to adjacent regions where they are reduced (Callister & Rethwisch, 2016).

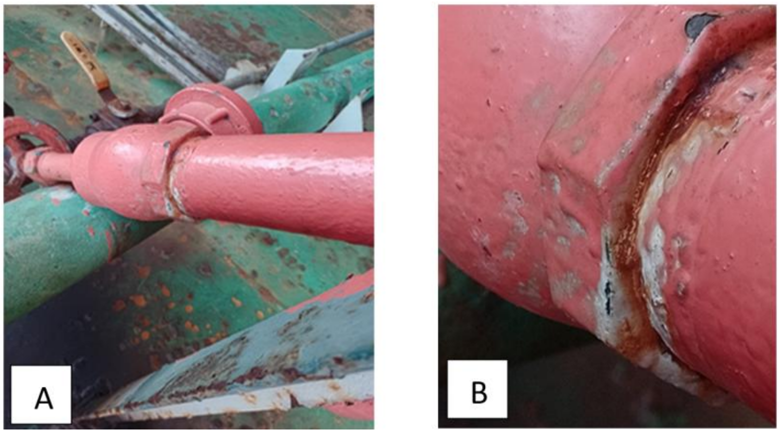

Figure 4. Corrosion in a gap in a hydrant gat valve.

Another form of attack that fixed firefighting systems can suffer, is microbiological or microbial corrosion (Figure 5). Microbiological corrosion is corrosion that develops under the influence of micro-organisms, such as fungi, algae, and most commonly, bacteria. In the latter case, it is also called bacterial corrosion. This type of corrosion can be identified in other systems on an offshore platform, such as the water injection system and oil wells, which also require a large amount of ocean water (collected through pumping systems) to keep the system fed and pressurized. However, since this water is untreated, it can contain sulphate-reducing bacteria that together with the stagnant condition in which this water remains for long periods, is conducive to the occurrence of the deaeration process due to the reaction of oxygen with the walls of the lines, favoring the emergence of anaerobic bacteria. These bacteria, in turn, are responsible for producing insoluble substances - iron oxide and iron sulfide, which not only cause damage to the system's operability by blocking nozzles in deluge systems but also make offshore platforms vulnerable to fines and other penalties imposed by the ANP and the Marinha do Brazil (Gentil, 2017).

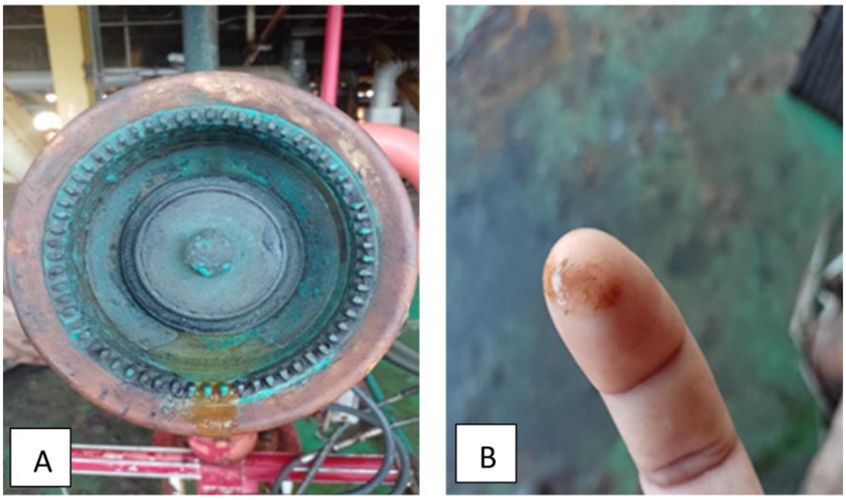

Figure 5. Ferrous oxide residue on the edge of a fire cannon (A). Ferrous oxide residue removed from a fire cannon nozzle (B).

Because of the unique challenges associated with corrosion in offshore structures, systems or equipment, ensuring mechanical integrity has become a critical concern for operators in the oil and gas exploration and production sectors. The integrity of ships and offshore platforms serves as a fundamental pillar for ensuring both operational activities and decommissioning processes. According to Palkar and Markeset (2012) and Animah et al. (2017), there is a growing concern among operators of oil and gas production fields regarding assets that have already exceeded their design life in terms of operational safety, efficiency, and socio-environmental considerations. As a result, these operators are seeking to ensure that their maintenance and integrity plans effectively identify future risks and manage the impacts of asset and equipment degradation.

In Brazilian exploration and production basins, the focus on maintaining the integrity of offshore units is primarily related to compliance with the standards set by the Brazilian Navy, the ANP, and the Brazilian Ministry of Labor and Employment. In order to meet the requirements of these institutions, the units undergo periodic safety maintenance campaigns during which extensive work is performed. However, during the decommissioning phase, these campaigns will be discontinued, and the maintenance teams will be reduced to focus solely on ensuring integrity (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2020a).

With regard to mechanical integrity, the Brazilian Navy has delegated responsibility to the classification societies for compliance with their established rules and regulations. For example, the rules of the American Bureau of Shipping [ABS] (2024), require an inspection to identify any damage, defects, deterioration, or necessary repairs to the hull, machinery, or equipment that affect or could potentially affect the classification of the ship. Recommendations for repairs are made as necessary. Immediate repairs are required when certain conditions are met, such as situations that exceed acceptable limits and result in loss of watertightness, damage from buckling, failure of joints, or fracture of structural members. Extensive wear beyond acceptable limits that could compromise the structural integrity or watertightness of the ship also requires immediate action ([ABS], 2024).

The obligations of mobile platform operators to maintain the mechanical integrity of their vessels, particularly critical equipment, or systems, are outlined in the 1989 Code for the Construction and Equipment of Mobile Offshore Drilling Units, also known as 1989 MODU Code (International Maritime Organization, 1989). These obligations are further supported by NORMAM-01/DPC (Marinha do Brasil, 2005). Failure to comply with the rules, standards, and codes of the classification society, whether national or international, may result in suspension of the marine unit's class until the situation is rectified ([ABS], 2024).

Passive protection in the offshore environment is critical to operational safety. The absence of passive protection can allow fire scenarios to escalate rapidly and reduce the time available for evacuation of the unit. This is because of the potential loss of mechanical integrity in critical structural elements of the offshore unit as well as pressure vessels, boilers, and other equipment containing flammable materials. The lack or degradation of passive protection creates a vulnerability in fire protection barriers, thereby increasing the risk to human life and the environment. In 2018, the ANP issued Safety Alert 002—

ANP/SSM Passive Protection Availability Management (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2018). This alert resulted from regulatory compliance audits conducted by the ANP, with one of its objectives being to alert operators to the risks associated with passive protection system failures. These failures are often due to recurring maintenance management problems, resulting in either total or partial degradation of the system.

Methodology

This research presents a case study of an oil platform undergoing decommissioning in the Campos Basin, located in southeastern Brazil. The methodology used in this study involved conducting a literature review to inform the reader about the corrosion issues prevalent in the offshore environment and the factors that exacerbate this process. These factors include human resource management, prioritization of activities directly related to decommissioning, and delays in the scheduled departure from the site.

Bibliographical search

The literature review included published articles related to the shipbuilding industry and corrosion processes. The objective was to collect information and prior knowledge regarding corrosion in offshore platforms undergoing decommissioning. Articles published between 2017 and 2023 were primarily researched to present a coherent perspective to the reader. However, some older articles were also included because of their relevance to the topic.

Data collection

Data was obtained from Brazilian regulatory agencies and supplemented with photographic records to enhance the reader's understanding. Information on events such as accidents, incidents, records of noncompliance, and others were requested through the Brazilian Federal Government's Access to Information portal for the period from January 2015 to December 2021. These requests were addressed to the operators of the exploration and production fields, the Brazilian Navy, and the ANP. However, in accordance with the Brazilian Freedom of Information Act (Law 12,527 of November 18, 2011), some requests were not fulfilled.

Data acquisition and processing

Data on accidents resulting from structural collapse due to corrosion were obtained from the Oil Workers Union of Northern Rio de Janeiro (OWUNRJ). This union organization proved to be a valuable source of data, as employers are required by law to report such accidents to the workers union. The records collected included work-related accident reports (CAT) from January 2015 to December 2021, with the aim of identifying incidents in which corrosion of structures, equipment, or fittings was a contributing factor. In analyzing the events, it was difficult to distinguish between accidents where corrosion was a contributing cause and those where it was not. As a result, data from OWUNRJ could not be used in this study.

Finally, between the end of the second half of 2021 and the first half of 2022, field imagery has been obtained that illustrates corrosion in offshore units undergoing decommissioning. These units have an average production life of more than 25 years. The analysis focused on the damage to systems and equipment caused by corrosive processes in the offshore environment. The selection of records from the Campos Basin was based on the higher number of decommissioning processes in Brazil and the fact that most production systems are over 25 years old.

Results and discussion

This section illustrates the damage caused by corrosive processes to both active and passive firefighting systems on an oil and gas platform during the decommissioning phase.

Portable fire extinguishers

The base of the metal section supporting the fire extinguisher, Figure 6, canopy has collapsed. The corrosive effects are most evident in the area where the angle bracket joins the containment skid (C). Severe corrosion is also observed in the structure at the junction between the fire extinguisher shelter and the angle bracket (B). Importantly, the loss of equipment necessitates changes to the platform's safety plan, particularly with regard to the availability of portable fire extinguishers.

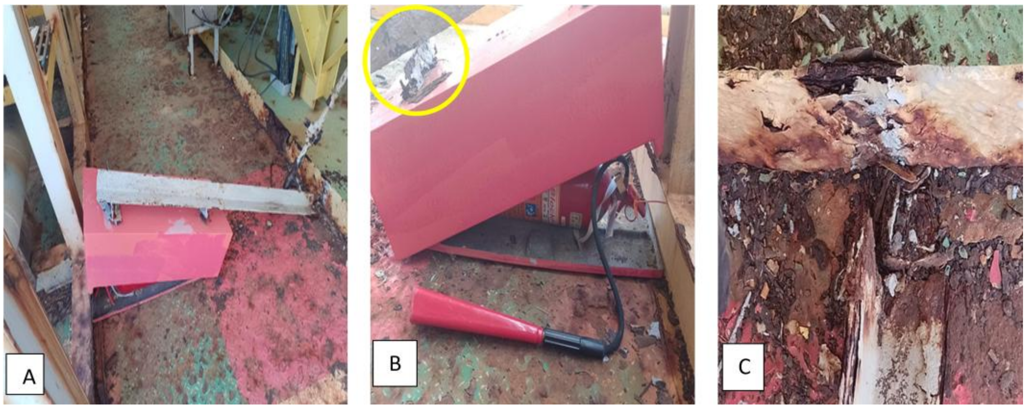

Figure 6. Break in the base of the angle bracket supporting the portable fire extinguisher shelter.

Passive fire protection system

To improve the anchoring of the passive protection mortar to metal structures, the substrate in Figure 7 is reinforced with a metal mesh and anchoring pins (A). The infiltration of electrolytes into cracks or openings in the passive protection system, along with direct contact between dissimilar metals, promotes the galvanic corrosion mechanism that leads to the deterioration of the pins, plates, and metal mesh. As these anchoring accessories deteriorate, their weight contributes to the collapse of portions of the system into the affected area (B), leaving it vulnerable and unprotected.

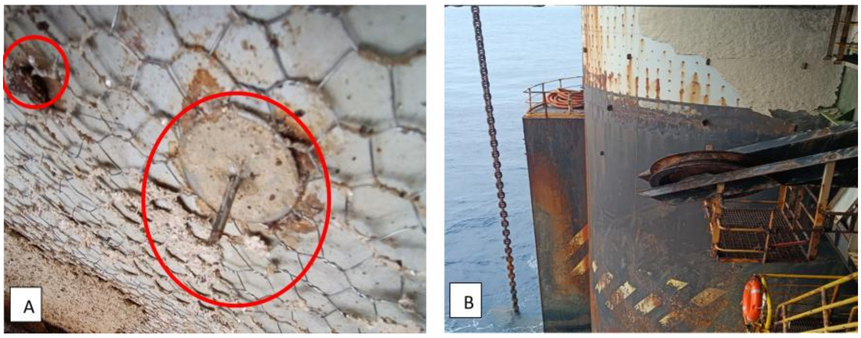

Figure 7. Corrosion of the metal mesh and pins for the anchorage of the passive protection.

As shown in Figure 8, dustiness of the material is another problem that can occur with passive protection mortars in highly corrosive environments. In sections “A” and “B,” the material is easily dislodged by hand and breaks apart, compromising the fire resistance of the metal pipe rack. Some material stripped from the structure is scattered on the deck of the marine unit in granular form or as small fragments.

Figure 8. Spraying of mortar for passive protection.

In Figure 9, in section “A,” corrosion products are visible on the passive protection of the metal structure, accompanied by the formation of cracks. In section “B,” there is a noticeable loss of mortar mass because of diminished material adhesion and the emergence of tensions induced by the corrosive action on the steel. Lastly, in section “C,” there is a risk of the dislodged material posing a hazard by falling onto individuals below.

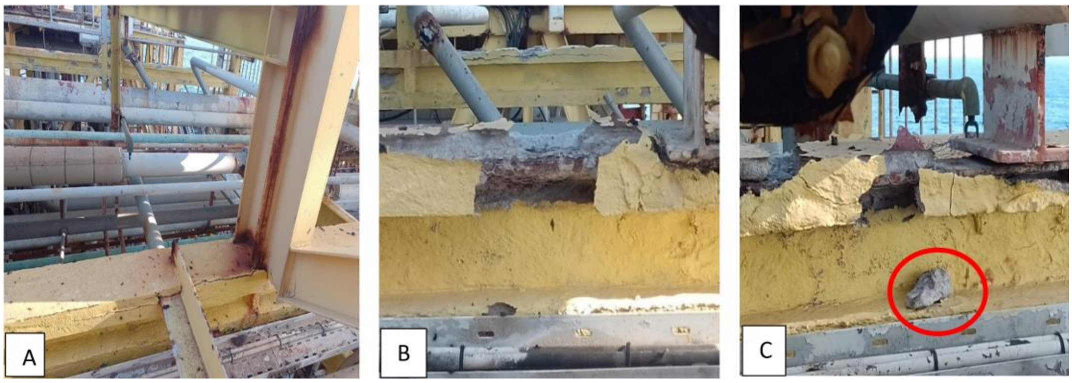

Figure 9. Removal of mortar for passive protection.

Fixed fire suppression systems

In a less severe form, corrosion is evident in a stress concentration area with a larger surface area exposed to the atmosphere. Corrosion of the metal floor has resulted in an increase in the size of the opening through which the hydrant pipe passes. While the opening shown in Figure 10 does not currently interfere with the operation of the equipment, in the event of an emergency, a user's foot could become trapped during operation, or objects could potentially fall onto the floor below.

Figure 10. An enlargement of the diameter of the opening in the metal floor.

In the case below, Figure 11, the hydrant was compromised because of an internal corrosive process in the bolted joint. The system remains pressurized and supplied with seawater that remains stagnant for extended periods of time, which creates an environment for the proliferation of sulfate-reducing bacteria within the system.

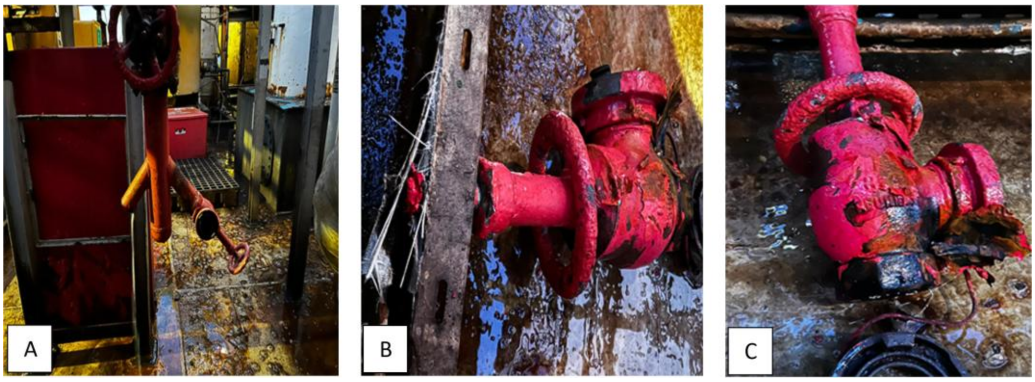

Figure 11. Partial rupture of a fire hydrant.

Internal corrosion is also evident here, with similar characteristics to those described in Figure 12. While a small hole has developed in the weld area of the equipment (B), without timely repair, the equipment is at risk of complete failure. Record "C" displays the iron oxide that has formed inside the equipment and is seeping through the hole.

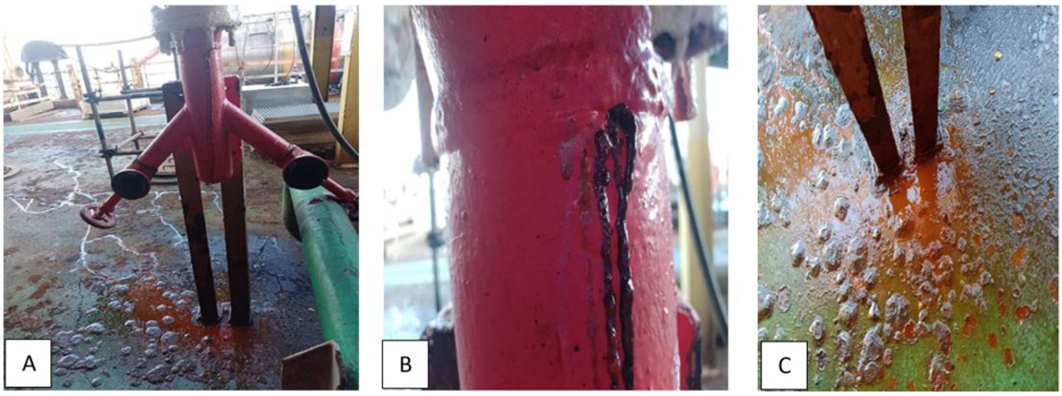

Figure 12. Hole in the fire hydrant.

The Figure 13 shows that the hydrant's primary containment failed at the bottom of the spool (A), specifically in the area where the fluid changed direction (B), necessitating its removal and the installation of a blind flange (C). In "C," an advanced stage of the corrosive process can be seen, with more pronounced effects in the highlighted area "B." In addition, an expansion of the coil thickness can be observed in "B."

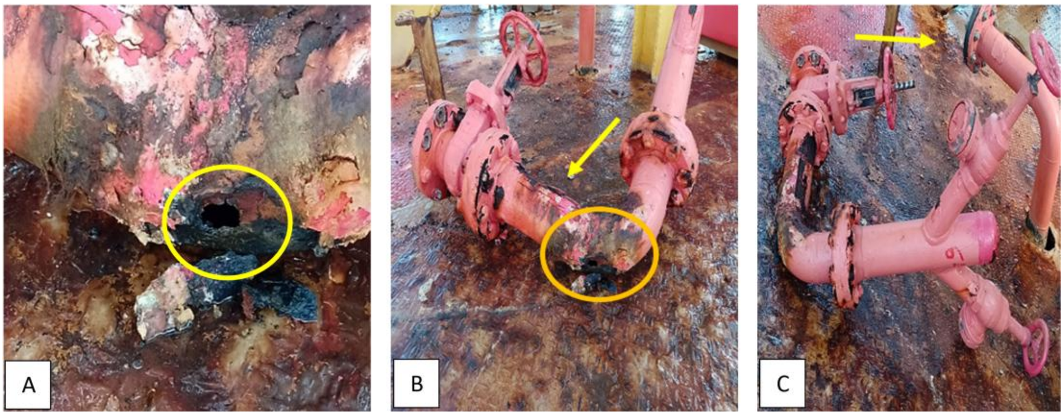

Figure 13. Loss of primary containment in a fire hydrant.

The record in the Figure 14 refers to the equipment comprising the automation system of a fire cannon on the platform. While the corrosion did not directly affect the automation system, the failure of the metal gantry base made it necessary to reinforce the structure with tubular metal profiles. In "B," the structure has significantly collapsed forward.

Figure 14. Corrosion at the base of the metal gantry that supports the loads of the automation system of a fire cannon.

Final considerations

The decommissioning of offshore units is a multifaceted endeavor that requires collaboration across multiple engineering disciplines and raises significant concerns among exploration and production operators. This concern stems not only from the significant costs associated with the process but also from schedule delays, environmental considerations, structural integrity, and occupational safety concerns. This article has addressed compromised structural integrity or failures leading to loss of functionality of fire protection systems on oil platforms undergoing decommissioning. These failures, caused by corrosion processes, render these units vulnerable.

Uncontrolled corrosive processes on decommissioned platforms can lead to accident scenarios that cause severe damage to the offshore unit and pose risks to the professionals involved, which is contrary to the interests of the platform owner. Besides the obligation to restore the integrity of the unit and ensure the well-being of the people involved, occupational accidents damage the company's reputation. In addition, the loss of functionality of fire protection systems can hamper emergency response, potentially resulting in the loss of the facility itself. Finally, fire-related incidents can cause delays in the decommissioning schedule of the marine unit and increase the overall cost of the operation.

Because of the critical importance of maintaining plant integrity, ensuring worker safety, and minimizing environmental impact, measures must be taken to control corrosive processes, rehabilitate structures, or remove them when they are no longer needed. To prevent undesirable events in these units, it is essential to establish dedicated teams tasked with analyzing the risks associated with corrosive processes. These teams should implement control measures that act as barriers to mitigate or eliminate the risks associated with such accidental scenarios, while maintaining the functionality of the fire protection systems.

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