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Preserving Oil Refinery and Petrochemical Facilities to Prevent Corrosion During Inactivity

*Ahmed Kharidege[a], Nasser Abushrenta[b]

[a]The High Institute of Science and Technology, Chemical Engineering Department, Sabratha, Libya.
[b]Elmergib University. Faculty of Engineering-Garaboulli, Chemical Engineering Department, alkhoms, libya.

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ABSTRACT

Due to the unstable situation in certain oil-producing nations, Oil and petrochemical production is projected to decrease so that the option to abandon a plant and temporary shutdown will increase. Therefore, the comprehensive method from the pre-mothballing, mothballing, and recommissioning stages should be developed. Corrosion in refineries is a critical issue affecting various units, necessitating preventive measures such as cathode protection, inhibitors, and protective coatings. Exploring the strategies and methods used for maintaining and preserving oil refinery and petrochemical plants during periods of inactivity to prevent corrosion issues is a crucial. Oil refinery and petrochemical plants are susceptible to corrosion, which can have detrimental effects on their equipment and overall performance. By implementing effective mothballing techniques, such as surface preparation, the use of protective coatings and inhibitors, and adequate storage and monitoring practices, corrosion can be mitigated. This work provides a comprehensive understanding of mothballing methods essential for the longevity and optimal functioning of oil refinery and petrochemical plants.

الحفاظ على مصافي تكرير النفط والمنشآت البتروكيماوية لمنع التآكل أثناء فترات التوقف عن العمل.

*أحمد كريديغ[1]و ناصر أبوشرنتة[2]

[1]المعهد العالي للعلوم والتقنية، قسم الهندسة الكيميائية، صبراتة، ليبيا
[2]جامعة المرقب، كلية الهندسة القره بوللي، قسم الهندسة الكيميائية، الخمس، ليبيا.

الكلمات المفتاحية:
الوقاية من التآكل.
مصافي النفط ومصانع البتروكيماويات.
حالة غير نشطة.

الملخص

بسبب الوضع غير المستقر في بعض الدول المنتجة للنفط، فمن المُتوقع أن ينخفض إنتاج النفط والبتروكيماويات مما يزيد من احتمالية التوقف المؤقت عن تشغيل المنشآت وإيقافها. لذا، فإن وضع منهجية شاملة تغطي مراحل ما قبل الإيقاف المؤقت والايقاف وإعادة التشغيل يُعد أمراً ضرورياً. يُعتبر التآكل في المصافي مشكلة حرجة تؤثر على وحدات مختلفة، مما يستلزم اتخاذ تدابير وقائية مثل الحماية الكاثودية ومثبطات التآكل والطلاءات الواقية. تعد دراسة الاستراتيجيات والطرق المُستخدمة للحفاظ على مصافي تكرير النفط ومصانع البتروكيماويات أثناء فترات التوقف عن العمل للوقاية من مشاكل التآكل أمراً حيوياً. تعتبر هذه المنشآت عرضة للتآكل الذي يمكن أن يلحق الضرر بمعداتها وأدائها بشكل عام. من خلال تنفيذ تقنيات فعالة للإيقاف المؤقت يمكن التخفيف من التآكل، مثل تحضير السطح واستخدام الطلاءات الواقية ومثبطات التآكل وممارسات التخزين والمراقبة المناسبة. يقدم هذا العمل فهماً شاملاً لطرق الإيقاف المؤقت الضرورية لعمر مصافي تكرير النفط ومصانع البتروكيماويات وظهورها بأفضل حالة.

1. Introduction

In the realm of oil refinery and petrochemical plants, corrosion stands out as a major concern due to its potential to cause equipment failure, decreased efficiency, and safety risks. Familiarizing oneself with the distinct categories of corrosion is essential for deploying effective mothballing methods at these facilities. Preserving the integrity of oil refinery and petrochemical plants is a crucial aspect of the industry, playing a key role in ensuring safety, minimizing expenses, and complying with regulations. Corrosion, which can result

*Corresponding author:
E-mail addresses: ahkh@shi.edu.ly, (N. Abushrenta) nmabushrenta@elmergib.edu.ly
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in equipment failures, reduced efficiency, and legal consequences, must be effectively addressed through mothballing techniques.

Although corrosion is commonly linked to rust and metal oxidation, its scope encompasses the degradation of materials from chemical interactions. Various components within oil refinery and petrochemical plants, such as storage tanks, pipelines, valves and pumps, are vulnerable to corrosion from both external factors and internal conditions. The detrimental effects of corrosion often remain unnoticed until identified through inspections [1].

Mothballing programs are essential for preventing corrosion during periods of state of no activity. Proper upkeep approaches executed throughout shutdowns are vital for maintaining the structural integrity of plant property. Techniques like surface practise, defensive coatings, inhibitors, and correct storage methods are fundamental techniques for avoiding corrosion in oil refinery and petrochemical installations. While successful case studies assure the significance of effective mothballing techniques, challenges persist in combatting corrosion during inactive periods.

To ensure the longevity and operational efficiency of oil refinery and petrochemical plants, it is recommended to conduct regular maintenance inspections and leverage advanced asset protection solutions such as inspection services, maintenance programs, engineering consultations, and data management systems [2].

Corrosion in the oil refinery and petrochemical sector is a significant concern due to the high costs involved in maintenance, repairs, and restoration. It impacts the financial well-being of organizations within these industries, with substantial expenses related to energy, materials, labour, and technology. Global oil and gas companies dedicate a large portion of their expenditures to addressing corrosion across production, transportation, storage, and refining facilities.

Corrosion can lead to structural devaluation or replacement, affecting asset availability and safety. Mitigation efforts require additional resources like labour hours and materials, adding financial strain. Inadequate corrosion management practices can result in significant setbacks for productivity and profitability.

To minimize financial losses from corrosion, best practices should be integrated into operations. Strategies focusing on proactive maintenance, timely repairs, and efficient restoration can optimize costs. Lessons from successful corrosion management in various industries provide valuable insights for effective mitigation.

Various methods have been suggested to inhibit corrosion in oil refineries and petrochemical plants while they are inactive. In [3] suggests the use of volatile and migratory corrosion inhibitors, while [4] emphasizes the need for a comprehensive understanding of corrosion mechanisms and the use of modern mitigation techniques such as refinery design, cathode safeguard, inhibitors, and covering protection. [3] introduces the concept of mothballing, particularly for equipment exposed to sour gases, using media such as inhibited diesel and dry inert nitrogen gas. A comprehensive overview of corrosion problems and solutions in the industry, including those related to cooling water and boiler feed water units provided in [5]. These studies collectively highlight the importance of a multi-faceted approach to corrosion prevention, including the use of inhibitors, proper facility design, and the implementation of mothballing techniques.

The main body of the paper comprises seven sections as follows: Section I presents introduction to source and types of corrosion in oil refinery and petrochemical plants. Section II discusses the impact of corrosion on plant infrastructure. Strategies for preventing corrosion during inactivity is presented in section III. Mothballing procedures presented in section IV. Challenges in preventing corrosion during inactivity proposed in section V. While section VI describes recommendations for implementing effective mothballing programs. Finally, section VII presents the conclusion.

1.1 Corrosion source in oil refinery and petrochemical plants

Corrosion in oil refineries and petrochemical plants is caused by harsh substances such as crude oils, natural gas, and petroleum products. When these substances interact with high temperatures, pressures, and specific chemical compounds, they result in the deterioration of materials. The chart below illustrates the major sources of corrosion.

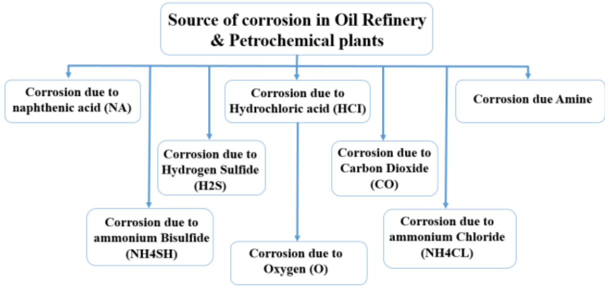

Fig. 1: The chart shows the major sources of corrosion.

1.2 Types of corrosion in oil refinery and petrochemical plants

Corrosion poses a significant challenge to oil refineries and petrochemical plants, impacting equipment reliability and process efficiency. Various types of corrosion are commonly observed in these industrial settings, including general corrosion, pitting corrosion, crevice corrosion, galvanic corrosion, intergranular corrosion, tension-related corrosion cracking, fatigue corrosion [6].

Superficial Corrosion: Superficial Corrosion presents itself through roughening, etching, pitting, or blistering of the paint or plating on equipment surfaces. Additionally, powdery deposits may be visible on surfaces affected by superficial corrosion.

Galvanic Corrosion: Another form of corrosion that poses a danger to oil refinery and petrochemical plants is galvanic corrosion resulting from dissimilar metals coming into contact, initiating an electrochemical reaction known as galvanic action. Galvanic corrosion can result in pitting damage that proves difficult to detect as it often occurs in concealed areas within plant equipment. Fig. 2 depicts some examples of corrosion types.

Fig. 2: Some types of corrosion.

Intergranular Corrosion: recognizable by flaking metal surfaces and typically stems from irregularities in the metal's production process. Spotting intergranular corrosion can be challenging owing to its characteristics, yet it can have adverse effects on plant equipment if left unattended.

Tension-Related Corrosion: Within oil refinery and petrochemical plants, tension-related corrosion cracking may arise when equipment is exposed to corrosive settings while under tensile stress. This type of corrosion frequently impacts metal systems like landing gear components and can result in structural malfunctions if not proactively managed.

Abrasion-Induced Corrosion: this corrosion occurs due to slight rubbing between mated surfaces within plant equipment, leading to pitting damage and accumulation of fine debris. The presence of moisture exacerbates this form of corrosion, rendering it a significant concern in oil refinery and petrochemical plants. Regular inspections and proper lubrication practices can effectively help diminish risks associated with abrasion-induced corrosion. Fig. 3 Some failure parts caused by corrosion.

Fig. 3: Some failure parts caused by corrosion.

2. Impact of corrosion on plant infrastructure

Dealing with corrosion in oil refinery and petrochemical plants is a pressing concern that can have significant financial and operational repercussions, as well as pose risks to safety, productivity, and the environment [6]. Oil tank corrosion is a major source of expensive equipment failures and reduced operational functionality. Over time, corrosion decreases a tank's integrity and eventually penetrates the tank structure, initiating tank bottom perforation. As shown in Figure 4, this can cause oil to leak into the environment which can result in huge clean-up costs. Protective coatings play a crucial role in preventing corrosion by acting as a protective barrier between metal surfaces and their surroundings. When coatings fail, vulnerable areas prone to fatigue failure emerge, heightening the chances of leaks and undermining the structural integrity of tanks. Proper surface preparation techniques are vital for ensuring the effectiveness of protective coatings [7].

Fig. 4: Shows of tanks corrosion.

One of the primary obstacles in corrosion prevention for the duration of intervals of state of being inactive lies within the necessity for ordinary tank renovation that carries proper floor training and coating applications to uphold tank strength, layout, and functionality. Corrosion safety measures like coatings are instrumental in extending the longevity of storage tanks by using stopping rust and other forms of deterioration. Advanced oxidation strategies are also effective solutions for addressing chronic pollution in wastewaters from the oil refinery and petrochemical enterprise.

3. Strategies for preventing corrosion during Inactivity

3.1 Maintenance during shutdowns

Mothballing during shutdowns stands out as a critical element in upholding the reliability and functionality of oil refinery and petrochemical plants. Even when these facilities are not in use, they remain susceptible to corrosion and various types of deterioration, which can result in expensive repairs and disruptions in operations. Ensuring proper maintenance is conducted during shutdowns is crucial for maintaining the long-term dependability of the plant infrastructure [8]

One of the primary culprits behind diminished reliability in oil refinery and petrochemical plants is corrosion. Corrosion can manifest in different areas of the plant, including water walls, super-heater tubes, deaerators and feed-water heaters. Distinct forms of corrosion, such as under-deposit attack, low PH corrosion, and stress corrosion cracking, have the potential to impact different components of the infrastructure. To avert corrosion during shutdowns, it is crucial to implement maintenance techniques that specifically target these issues.

To effectively combat corrosion, maintenance during shutdowns encompasses several crucial processes:

1) Keeping proper PH and alkalinity levels is essential to manage corrosion stemming from dissolved gases like oxygen and carbon dioxide.
2) Adequate surface preparation techniques are vital for eliminating any existing deposits or contaminants that could lead to corrosion.
3) Application of protective coatings on surfaces serves as a shield against corrosive agents.
4) Utilizing inhibitors to diminish corrosion by reducing chemical reactions on metal surfaces.
5) Adherence to proper storage practices is also pivotal in preventing corrosion in idle equipment.

It should be emphasized that off-line boiler corrosion due to oxygen infiltration can occur during periods of inactivity if proper protocols are not followed. Low PH conditions resulting from oxygen interactions with iron can exacerbate corrosion damage further. In Fig 5, Dust, lint, and dirt accumulation in oil tubes can significantly impact their performance and safety. Hence, implementing effective maintenance practices during shutdowns is imperative to safeguard the plant infrastructure from these risks [9].

Fig. 5: Some failure parts caused by corrosion.

3.2 Surface Preparation Techniques

Effective surface preparation techniques are essential for maintaining the structural integrity and corrosion resistance of oil refinery and petrochemical plants [10]. The cornerstone of surface preparation lies in cleaning methods, which are crucial for eliminating contaminants and establishing a pristine surface for subsequent protective coatings. Additionally, thorough inspection procedures play a pivotal role in identifying any pre-existing corrosion or damage that necessitates remediation before applying protective measures.

Cleaning methods within oil refinery and petrochemical plants focus on eradicating dirt, grease, oil, and other substances that could compromise the adhesion of protective coatings. Various techniques such as pressure washing, solvent cleaning, abrasive blasting, and chemical cleaning can be utilized based on the nature and extent of contamination present on surfaces.

Inspection procedures are critical for detecting any existing corrosion or damage that may have already affected the plant infrastructure [9]. Visual inspections, ultrasonic testing, magnetic particle inspection, and radiographic testing are commonly employed methods for evaluating the condition of surfaces in oil refinery and petrochemical plants. These inspections aid in assessing the degree of corrosion and formulating suitable strategies for mitigation.

3.3 Protective Coatings

Preserving the structural integrity and longevity of oil refinery and petrochemical plants is heavily reliant on the use of protective coatings to combat the detrimental effects of corrosion on critical surfaces. These coatings are diverse, each serving a unique purpose in safeguarding storage tanks and equipment within the industry [11].

One prominent type of protective coating utilized is polyurethane coatings, renowned for their exceptional chemical resistance and robustness. Tailored for various storage tanks in oil refinery and petrochemical settings, these coatings offer a reliable defence mechanism [12]. Polymeric linings crafted from materials like polyethylene or polypropylene serve as ideal solutions for tanks containing water or harsh chemicals due to their outstanding corrosion resistance. Choosing the appropriate protective coatings based on the specific environmental conditions of their application is crucial to maximize their effectiveness in preventing corrosion during periods of facility inactivity. Overall, these coatings are indispensable in safeguarding oil refinery and petrochemical plants, forming a protective barrier against corrosion and upholding the integrity of pipes and storage tanks equipment [13].

Fig. 6: Kinds of anti-corrosion coating for pipeline.

3.4 Inhibitors

Using of inhibitors plays a vital role in preventing corrosion during inactive periods. Corrosion inhibitors are chemicals that help reduce the corrosion rate without significantly changing the concentration of corrosive agents when present at appropriate levels in the system [14]. They are essential for ensuring the operational integrity of field pipelines, downhole equipment, and other facilities exposed to factors that promote corrosion. Fig. 7 showing the world consumption corrosion inhibitors in 2023.

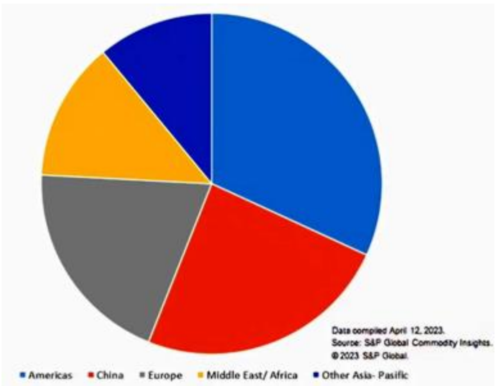

Fig. 7: World consumption corrosion inhibitors in 2023 Pie chart.

Types of inhibiters: As illustrated in Fig 8, the flowchart provides an overview of how corrosion inhibitors are classified based on their properties and applications. Selecting the right corrosion inhibitors is crucial to meet industry standards effectively. These inhibitors should protect plant infrastructure components while not disrupting production processes. Additionally, they should be thermally stable at operational temperatures and have good solubility in water to create a protective layer on metal surfaces [14]. It is important that inhibitors require low dosage levels to provide anti-corrosion protection and can inhibit various types of corrosion, including general, localized, crevice corrosion, and bacteria-induced corrosion. Furthermore, their effectiveness should remain consistent across different climates and environments.

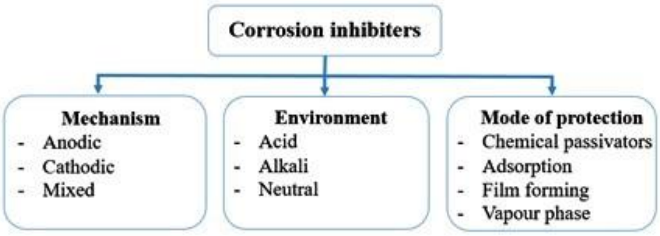

Fig. 8: shows types of corrosion inhibitors.

Organic corrosion inhibitors are commonly used in acidic conditions and primarily work by forming protective films on metal surfaces through adsorption mechanisms. These inhibitors are effective in preventing corrosion in oil refinery and petrochemical plants and can be categorized based on their physical state (liquid or gas), type of protective film formed, and electrochemical action mechanism [15].

3.5 Storage practices

Proper storage practices are essential for safeguarding the equipment and materials utilized in oil refinery and petrochemical plants. Effective storage techniques can prevent corrosion and ensure the prolonged mothballing of assets during inactive periods. Optimal strategies for storing equipment and materials involve the utilization of suitable storage methods, the establishment of monitoring systems, and adherence to specific guidelines to uphold the integrity of stored items [16].

A critical aspect of storage practices is the selection of the most appropriate storage method based on the type of equipment or material being preserved. For instance, underground spaces like depleted reservoirs are commonly utilized for natural gas storage due to their cost-effectiveness. On the other hand, above-ground tanks are employed for storing crude and refined oil, finished oil products, and natural gas. In cases where land-based facilities reach capacity, tanker ships may be utilized for temporary storage, albeit at a higher cost.

In addition to selecting the proper storage method, the implementation of monitoring systems is crucial for ensuring long-term mothballing. These systems enable operators to monitor environmental conditions within storage facilities, including temperature, humidity levels, and exposure to corrosive elements [17]. Regular monitoring of these factors allows maintenance teams to detect any deviations from optimal conditions and take corrective measures to prevent corrosion or damage [18].

4. Mothballing procedures

The flow chart outlining the process of “Mothballing.” This term refers to preserving equipment or facilities that are not currently in use but may be needed again in the future. The below diagram illustrates a flow chart detailing the process of "Mothballing," which involves preserving equipment or facilities that are not currently in use but may be required in the future.

Starting by identifying the equipment or facilities to be mothballed, then determine the duration of the shutdown and evaluate the mobility of the media (e.g., fluids, gases) within the equipment and develop a plan for managing media mobilization during mothballing, then acquire the necessary tools and resources and calculate the mothballing Mileage: Estimate the cost and effort required, then assess potential risks during mothballing. Lastly, carry out the mothballing process and assign personnel for testing. The Fig. 9 below shows the mothballing process procedure.

Fig. 9: Showing mothballing process procedure.

5. Challenges in preventing corrosion during inactivity

While it is crucial to implement strategies for preventing corrosion during the downtime of oil refinery and petrochemical plants, there exist various challenges and constraints that must be overcome. One major challenge is the considerable cost associated with corrosion. The oil refinery and petrochemical sector faces substantial financial losses due to corrosion, with annual expenses running into Millions of dollars across different areas such as storage tanks, pipelines, refining, and production.

Another limitation pertains to safety concerns and potential drawbacks linked to mothballing methods. Conventional techniques can result in safety hazards, loss of nutritional value, colour changes, alterations in texture, contamination by pathogens, undesirable flavours, and high energy consumption. These drawbacks highlight the need to explore innovative conservation methods that can enhance shelf life without compromising safety or quality standards. Combining emerging and traditional mothballing approaches could prove to be a successful tactic for enhancing efficiency in preserving quality attributes while prolonging shelf life.

Furthermore, economic considerations need to be taken into account when implementing combined mothballing methods. Although innovative strategies like cooling, UV irradiation, active coatings, and modified atmosphere packaging hold promise in extending shelf life and upholding quality standards, their practical application commercially necessitates a thorough assessment of cost-effectiveness. Evaluating the economic viability of these methods is crucial to ensure their feasibility in real-world settings.

6. Effective Mothballing Programs

In order to successfully carry out mothballing initiatives for oil refinery and petrochemical plants, it is essential to adopt a strategic methodology that encompasses various tactics customized to prevent corrosion during periods of inactivity. A key suggestion for executing efficient mothballing programs is to prioritize maintenance activities during shutdowns. Regular inspections, upkeep, and asset safeguarding solutions can guarantee the safe, effective operation of oil refinery and petrochemical assets while adhering to industry regulations. These services encompass surface preparation methods, protective coatings, inhibitors, and proper storage procedures to minimize the impact of corrosion on plant infrastructure.

Moreover, integrating non-destructive testing (NDT) techniques can be pivotal in recognizing and resolving corrosion issues before they escalate. NDT assessments serve as a quality assurance measure for sectors like oil & gas by identifying material irregularities or fractures at an early stage. Methods such as ultrasonic testing (UT), radiographic testing (RT), magnetic particle testing, and eddy current testing play a crucial role in averting costly leaks, distortions, and operational breakdowns that could jeopardize plant infrastructure.

7. Recommendations for Implementing Effective Mothballing Programs

In order to successfully carry out mothballing initiatives for oil refinery and petrochemical plants, it is essential to adopt a strategic methodology that encompasses various tactics customized to prevent corrosion during periods of inactivity. A key suggestion for executing efficient mothballing programs is to prioritize maintenance activities during shutdowns. Regular inspections, upkeep, and asset safeguarding solutions can guarantee the safe, effective operation of oil refinery and petrochemical assets while adhering to industry regulations. These services encompass surface preparation methods, protective coatings, inhibitors, and proper storage procedures to minimize the impact of corrosion on plant infrastructure.

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8. Conclusion

Corrosion in the oil refinery and petrochemical sector is a significant financial concern globally. Developing nations struggle even more with combating corrosion expenses. The direct costs of maintaining corroded structures strain finances, while devaluing or replacing assets adds to the economic burden. Labour and material requirements for mitigation efforts increase operational expenses and decrease asset availability.

Due to varying energy consumption and unpredictability in certain oil-producing nations, which causes periodic production stoppages, safeguarding oil refinery and petrochemical plants is of paramount importance to uphold the durability and sustainability of infrastructure in oil refinery and petrochemical plants. Corrosion poses a persistent threat in these facilities, leading to various forms of corrosion gradually affecting plant infrastructure. Essential strategies for corrosion prevention during inactive periods include prioritizing maintenance during shutdowns, employing surface preparation methods, protective coatings, inhibitors, and following appropriate storage practices.

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10. References

[1] Hussain, Chaudhery Mustansar, et al. "Handbook of Corrosion Engineering: Modern Theory, Fundamentals and Practical Applications."(2023).

[2] Groysman, Alec. Corrosion for everybody. Springer Science & Business Media, 2009.

[3] National Association of Corrosion Engineers. *Corrosion of Oil-and Gas-Well Equipment*. Division of Production, American Petroleum Institute, 1958.

[4] Al_qasaab, et al. "Corrosion Mechanism and Countermeasures in Oil Refineries-Comprehensive." Journal of Petroleum Research and Studies 13.4 (2023): 78-97.

[5] Groysman, Alec. Corrosion in systems for storage and transportation of petroleum products and biofuels: identification, monitoring and solutions. Springer Science & Business Media, 2014.

[6] Kermani MB, Smith LM (1997) CO_2 Corrosion Control in Oil and Gas Production: Design Considerations. The Institute of Materials, European Federation of Corrosion Publications, London.

[7] Nalli K (2010) Corrosion and its Mitigation in the Oil and Gas Industry. An Overview. PM-Pipeline Report.

[8] Popoola, Lekan Taofeek, et al. "Corrosion Problems During Oil and Gas Production and its Mitigation." International Journal of Industrial Chemistry 4 (2013): 1-15.

[9] Energy Institute. Guidance for Corrosion Management in Oil and Gas Production and Processing. Energy Institute, 2019.

[10] Guan, Shiwei William, et al. "Advanced Onshore and Offshore Pipeline Coating Technologies." China International Oil and Gas Pipe Technology Conference & Expo, 14–17 September 2005, Shanghai, China. 2005.

[11] Guyer, J. et al. An Introduction to Cathodic Protection. Guyer Partners, 2017.

[12] Pedeferri, Pietro, and Marco Ormellese. Corrosion Science and Engineering. Vol. 720. Cham: Springer, 2018.

[13] Baeckmann, W. von, Wilhelm Schwenk, and Wolfgang Prinz. Handbook of Cathodic Corrosion Protection: Theory and Practice of Electrochemical Protection Processes. Gulf Pub. Co., 1997.

[14] Graeme, W. "Corrosion Protection of Metals in Marine Environment." J. Metal Corrosion Protection, Chemistry Department, University of Auckland (2010).

[15] Shang, Zheng, and Jinyang Zhu. "Overview on Plant Extracts as Green Corrosion Inhibitors in the Oil and Gas Fields." Journal of Materials Research and Technology 15 (2021): 5078-5094.

[16] Koch, Gerhardus H., et al. Corrosion Cost and Preventive Strategies in the United States. No. FHWA-RD-01-156, R315-01. United States. Federal Highway Administration, 2002.

[17] Groysman, Alec, and Alec Groysman. "Corrosion Problems and Solutions at Oil Refinery and Petrochemical Units." (2017): 37-99.

[18] Gutzeit, et al. "Corrosion in Petroleum Refining and Petrochemical Operations." ASM Handbook. 13 (1987): 1262-1287