AN OVERVIEW OF CORROSION IN THE OIL AND GAS INDUSTRY: CHALLENGES AND SOLUTIONS

By

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ABSTRACT

Corrosion is a widespread and expensive issue in the oil and gas sector, and presents significant dangers to infrastructure and the environment. It costs more than $1.4 billion per year, including direct spending for equipment maintenance and replacement and indirect costs such as lost productivity and environmental damage. This study examines the subject of corrosion in the oil and gas industry and its ramifications, both financially and environmentally. This study analyzed the oil and gas sector, its infrastructure, and various forms of corrosion, including uniform corrosion, crevice corrosion, galvanic corrosion, Microbiologically Influenced Corrosion (MIC), stress corrosion cracking, and Sulfide Stress Cracking (SSC). This study emphasizes the need for frequent equipment maintenance and inspection to prevent corrosion and reduce its impact on industry and the environment.

Keywords: Corrosion, Oil and Gas Industries, Types of Corrosion, Corrosion Mechanism, MIC.

INTRODUCTION

Corrosion poses a significant threat to the oil and gas sector, as it can occur in various circumstances, including production wells, pipelines, storage tanks, and refineries (Kermani & Harrop, 1996). The main causes of corrosion are temperature, pressure, moisture, and exposure to corrosive chemicals such as hydrogen sulfide (Wu, 1998). Corrosion can lead to equipment failure, leaks, and spills, posing a danger to both human health and the environment (Shipilov, 2009). The impact of corrosion is significant in the oil and gas industry, both financially and environmentally (D'Aliso, 2017). According to the National Association of Colleges and Employers (NACE) International, the yearly cost of corrosion in the oil and gas industry is expected to exceed $1.4 billion. This includes replacement as well as indirect costs, such as lost productivity and environmental damage (Koch et al., 2005). Furthermore, corrosion-related incidents in the oil and gas industry can have severe environmental consequences, such as oil spills and water contamination, which can harm delicate ecosystems, wildlife, human health, and livelihoods (Prasad et al., 2020).

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9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

1. Literature Review

Aalsalem et al. (2018) present a comprehensive review and detailed comparison of the most recent systems or techniques developed for monitoring various anomalous events that are involved in the three sectors (upstream, midstream, and downstream) of the oil and gas industry. And also describe the important requirements for WSNs to be deployed in the oil and gas industry. Finally, the critical challenges faced by the oil and gas industries are highlighted.

Al-Janabi (2020) mention that the main component of the midstream sector is pipelines, which are a very convenient means of transporting gases and liquids over long distances. The third component is the downstream sector, which includes crude oil refineries, petrochemical plants, and the distribution of petroleum products. A clear distinction between the upstream and downstream sectors is the service conditions, for example, fluid composition, pressure, and temperature, where the operators have more control and influence over them in the case of downstream operations.

Kazemi and Szmerekovsky (2015) proposes a deterministic mixed integer linear programming (MILP) model for the downstream Petroleum Supply Chain (PSC) network to determine the optimal Distribution Centre (DC) locations, capacities, transportation modes, and transfer volumes. The model minimizes multi-echelon and multi-product costs along the refineries, distribution centers, transportation modes, and demand nodes. The relationship between strategic planning and multimodal transportation was further elucidated.

Hanga and Kovalchuk (2019) showed that the Oil and Gas Industry (OGI) has always been associated with challenges and complexities. This involves many processes and stakeholders, each of which generates a large amount of data. Due to the global and distributed nature of the business, processing and managing this information is an arduous task. Many issues, such as orchestrating different data sources, owners, and formats; verifying, validating, and securing data streams as they move along the complex business process pipeline; and obtaining insights from data for improving business efficiency, scheduling maintenance, and preventing theft and fraud, need to be addressed.

Appel (2012) developed an integrated Mixed Integer Linear Programming (MILP) model for optimizing a multi-period Global Positioning System (GPS) to simultaneously determine the Central Processing Facility (CPF) location, pipeline (routes and diameters) installation and expansions, well site-CPF connections, the flow rate of each pipeline, and the operating pressure of each node in each time period.

2. Overview of the Oil and Gas Industry and its Infrastructure

The oil and gas industry is a multinational enterprise that plays a crucial role in supplying energy worldwide. The exploration, production, processing, transportation, and marketing of oil and gas products are all parts of this industry. Oil and gas infrastructure is vast and complex, with numerous upstream and downstream facilities and activities (Aalsalem et al., 2018).

Upstream activities involve the exploration and production of oil and gas from underground reserves, which are achieved by drilling wells located onshore or offshore. Large platforms, either fixed to the ocean floor or floating, are often used for offshore drilling. After extraction, oil and gas are transported to processing plants through pipelines or ships (Bret-Rouzaut & Favennec, 2011).

Midstream activities involve transporting crude oil and natural gas from production facilities to refineries where they are refined. Pipelines are used to transport crude oil and natural gas liquids, whereas tanker trucks are used to deliver natural gas. The midstream industry also includes processing facilities, such as gas-processing plants, which purify natural gas (Al-Janabi, 2020).

Downstream operations involve refining crude oil into petroleum products such as gasoline, diesel, and jet fuel, as well as the distribution and marketing of these products to customers. Refineries use complex processes to separate crude oil into various components, which are then processed and blended to create different types of fuels. Completed products are transported to distribution and retail locations using pipelines, ships, and vehicles (Kazemi & Szmerekovsky, 2015). Figure 1 depicts the various activities of the oil and gas industries.

3. Infrastructure

The oil and gas industry has a vast infrastructure, comprising a wide variety of facilities and equipment. Midstream activities include pipelines, storage tanks, and processing facilities, in addition to wells and drilling platforms utilized in upstream operations. Downstream businesses includes refineries, distribution terminals, and retail stores (Hanga & Kovalchuk, 2019).

Offshore drilling platforms are among the most intricate and beautiful infrastructure in the industry. These platforms

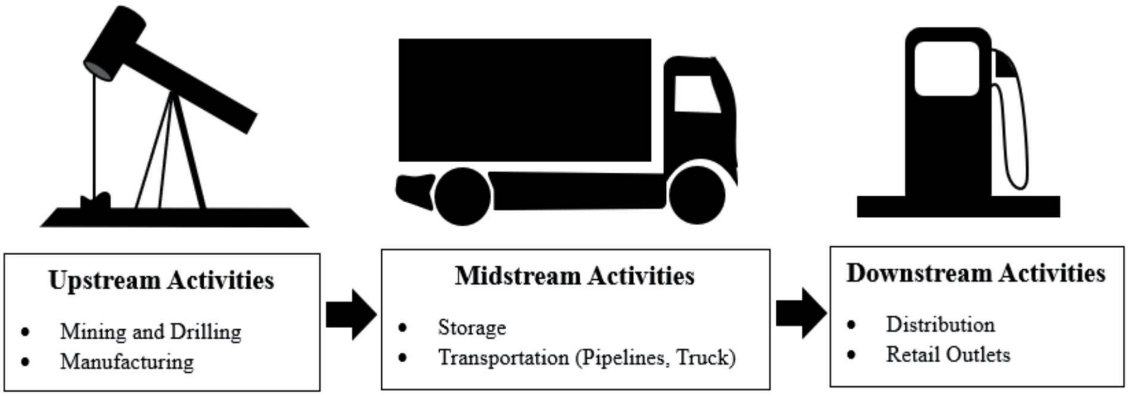

Figure 1. Different Activities of Oil and Gas Industries

require specialized equipment, such as drilling rigs, pumps, and blowout preventers (Appel, 2012).

Well sites and pipelines are examples of onshore infrastructures. Well sites are often situated in distant locations, necessitating substantial infrastructure to move personnel and equipment to and from the site (Hong et al., 2020). Pipelines deliver crude oil, natural gas, and natural gas liquids across vast distances, and must be maintained and inspected regularly to guarantee safe operation (Lilly et al., 2007).

4. Types of Corrosion in the Oil and Gas Industry

4.1 Uniform Corrosion

This type of general corrosion develops evenly throughout the surface of the metal as a result of environmental exposure. Uniform corrosion is often induced by metals in contact with air, gases, water, or other chemicals. If not treated, this may lead to material thinning and material failure (Nogara & Zarrouk, 2018). The uniform corrosion is shown in Figure 2.

4.2 Crevice Corrosion

This occurs when tiny crevices or gaps between metal surfaces come in contact with corrosive environments. They are often found in bolts, gaskets, and other components with microscopic gaps or crevices. Crevice corrosion may be difficult to detect because it generally develops in inaccessible regions (Kadry, 2008). Figure 3 shows the representation of crevice corrosion.

4.3 Galvanic Corrosion

Galvanic corrosion occurs when two different metals come into contact and are exposed to corrosive

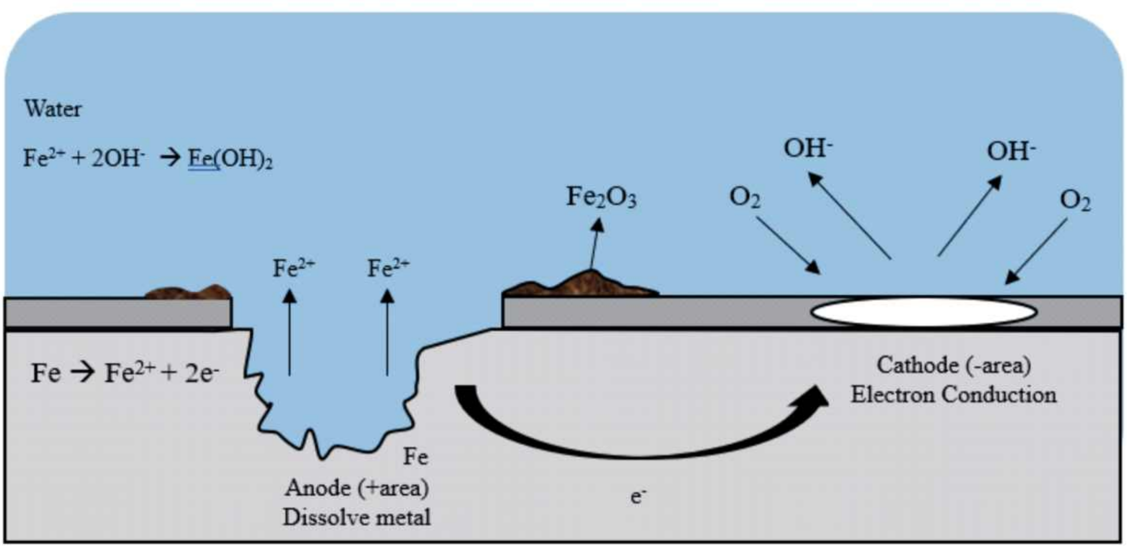

Figure 2. Representation of Uniform Corrosion

environments. Because of the electrochemical interaction between the two metals, the less noble metal in the pair undergoes rapid corrosion. Galvanic corrosion can be avoided by employing metals in the galvanic series that are close together or by placing a non-conductive barrier between the two metals (Nergis et al., 2019). Galvanic corrosion is represented in Figure 4.

4.4 Microbiologically Influenced Corrosion (MIC)

This occurs when microorganisms such as bacteria or fungus invade a metal surface and produce a corrosive environment. MIC may cause localized or widespread corrosion and are especially difficult to detect and prevent. It is observed in oil and gas pipelines, as well as other components exposed to water and organic materials (Khan et al., 2021). A basic view of the function of Sulfate Reducing Bacteria (SRB) in Microbiologically Induced Corrosion (MIC) is shown in Figure 5.

4.5 Stress Corrosion Cracking (SCC)

Stress Corrosion Cracking (SCC) occurs when metal is subjected to tensile stress in a corrosive environment. This form of corrosion may result in a catastrophic collapse because of the rapid development of fractures. SCC is often found in oil and gas pipelines as well as other components exposed to severe stress and corrosive conditions (Parkins, 2011). Figure 6(a) represents the cause of SCC, and in Figure 6 (b), the process is represented.

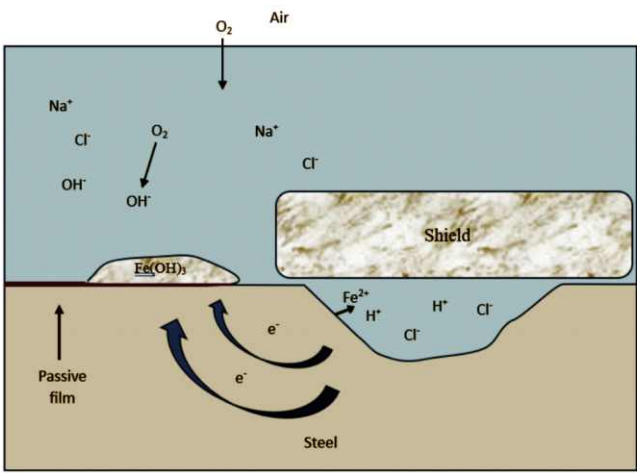

Figure 3. Crevice Corrosion Representation

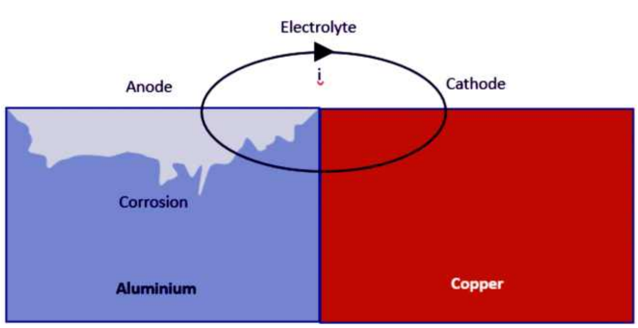

Figure 4. Representation of Galvanic Corrosion

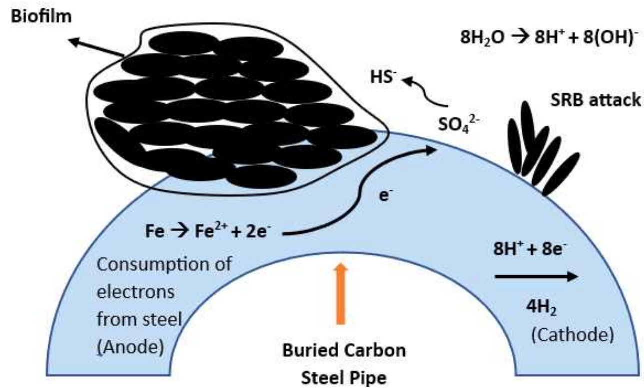

Figure 5. Basic View of the Function of Sulfate Reducing Bacteria (SRB) in Microbiologically Induced Corrosion (MIC)

4.6 Sulfide Stress Cracking (SSC)

Sulfide Stress Cracking (SSC) occurs when metals are subjected to the corrosive hydrogen sulfide. This has the potential to induce fractures to grow and spread, resulting in material failure. SSC are often encountered in oil and gas pipelines, as well as in other components exposed to sour gas or other sulfur-containing environments (Grimes et al., 2014). Figure 7 presents the sulfide stress cracking.

5. Factors Contributing To Corrosion in the Oil and Gas Industry

Understanding these factors and taking proactive measures to address them can help reduce the risk of corrosion-related equipment failure and safety incidents in the oil and gas industry.

5.1 Environmental Conditions

The environment in which the metal is placed has a significant impact on corrosion. Factors such as temperature, humidity, pH, and the presence of specific chemicals can contribute to corrosion. For example, high temperatures and humidity can accelerate corrosion, whereas exposure to acidic or alkaline solutions can

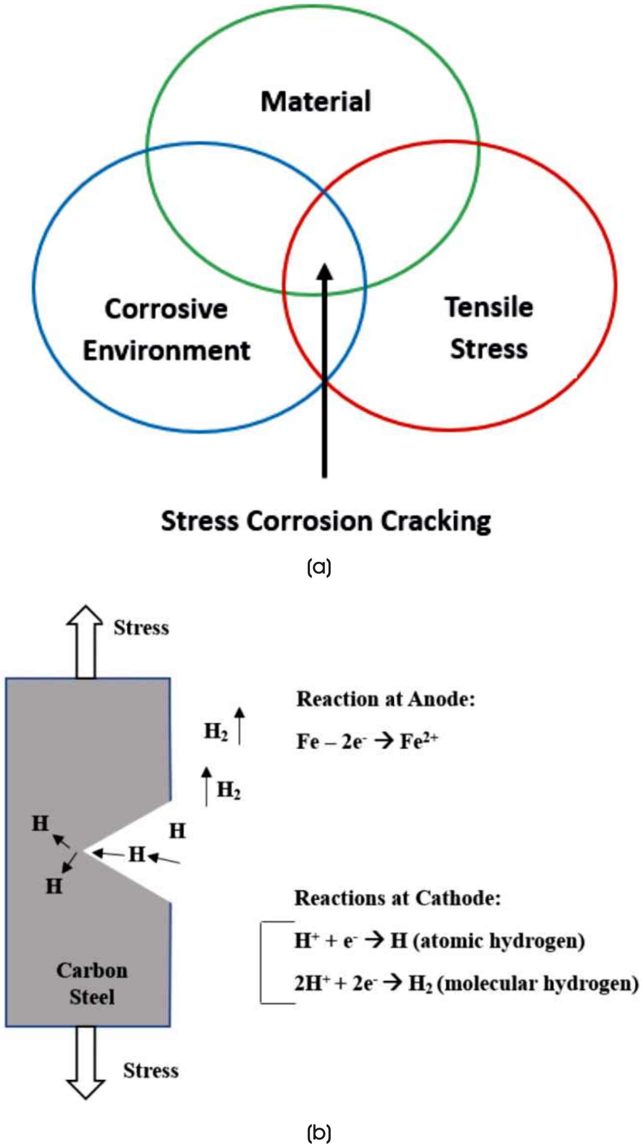

Figure 6. (a) Cause of Stress Corrosion Cracking, (b) Process of Stress Corrosion Cracking

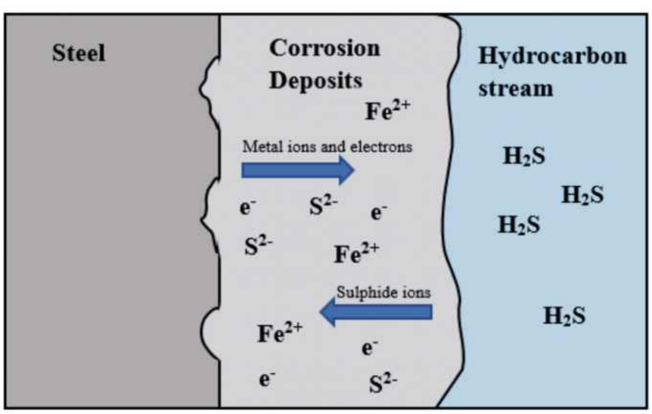

Figure 7. Representation of Sulfide Stress Cracking

cause significant corrosion (Wasim et al., 2018).

5.2 Fluid Composition

The composition of the fluid or gas being transported also plays a role in corrosion. High levels of corrosive substances, such as hydrogen sulfide or carbon dioxide, in fluids increase the risk of corrosion. Similarly, gases containing moisture or other contaminants can accelerate corrosion (Kermani & Morshed, 2003).

5.3 Material Selection

The materials used in oil and gas equipment affect the corrosion rate. Corrosion-resistant materials such as stainless steel can help reduce corrosion rates. However, some materials are expensive and may not be suitable for many applications (Alamri, 2020).

5.4 Operational and Maintenance Conditions

The way the equipment is used and maintained also contributes to corrosion. High-pressure or high-temperature equipment, for example, are more prone to corrosion due to the greater stress on the metal. Similarly, poor maintenance procedures can result in the accumulation of corrosive chemicals and formation of cracks, as shown in Figure 6. (a) Cause of Stress Corrosion Cracking, (b) Process of Stress Corrosion Cracking vulnerabilities in metal (Amani & Hjeij, 2015).

5.5 Microbial Activity

Microorganisms, such as bacteria and fungus also contribute to corrosion in the oil and gas sectors. Microbial activity generates corrosive conditions and increases corrosion rates, particularly under wet conditions (Little & Lee, 2015).

5.6 Welding and Fabrication Techniques

Poor welding and fabrication techniques can lead to corrosion. Welding procedures that generate a large amount of heat can change the metallurgical structure of the metal and create weak spots that are more prone to corrosion (Sadeghian & Iqbal, 2022).

6. Safety and Environmental Risks Associated with Corroded Oil and Gas Infrastructure

Corroded oil and gas infrastructure poses environmental and safety problems. Corrosion damages the structural integrity of equipment and pipelines, leading to leaks, ruptures, and other issues with dire consequences (Khan et al., 2021).

Leaking oil or gas from damaged pipelines can contaminate the environment, harm local wildlife and ecosystems, and pollute water sources, making them unsafe for consumption and recreational use (Alawode & Ogunleye, 2011). Corrosion-related failures can also result in property loss, either directly through explosions or fires or indirectly via pollution or environmental damage (Hansson, 2011).

6.1 Economic Impact of Corrosion-Related Failures and Downtime

Corrosion-related failures and downtimes have significant economic impacts on the oil and gas industries. When equipment fails due to corrosion, oil and gas companies incur revenue losses from production downtime. This can be a costly endeavor, especially when production numbers are substantial or prices change (Sakib et al., 2021).

Equipment and infrastructure failures caused by corrosion incur substantial repair and replacement costs, particularly in offshore locations with limited access and harsh operational conditions (Koch, 2017). Corrosion-related failures and downtime cost billions of dollars annually in the oil and gas industry (Obanijesu et al., 2010).

7. Corrosion Prevention and Mitigation Strategies

Corrosion prevention and mitigation measures are crucial for maintaining the safe and dependable operation of oil and gas equipment and buildings. Various methods can be used to prevent or mitigate corrosion.

7.1 Material Selection

The selection of appropriate materials for equipment and buildings is crucial for the prevention of corrosion. Materials should be selected based on their corrosion resistance in particular settings and operating circumstances. In the oil and gas industry, corrosion-resistant metals such as stainless steel are often employed (Schmitt et al., 2009).

7.2 Coatings and Surface Treatments

Coatings and surface treatments should be applied to equipment and buildings to create corrosion-resistant coatings (Kumar & Kumar, 2021; Kumar & Kumar, 2022; Kumar, 2022; Kumar et al., 2020). Examples of coatings include paint, epoxy, and polyurethane coatings, whereas surface treatments include passivation, which involves creating a protective oxide layer on the metal surface (Gray & Luan, 2002).

7.3 Cathodic Protection

Another method for preventing corrosion is to provide an electrical current to the metal surface. This can be accomplished using sacrificial anodes (less noble metals that corrode preferentially to the protected metal) or impressed current systems (which employ an external power source to deliver a constant protective current) (Wilson et al., 2013).

7.4 Corrosion Inhibitors

Compounds added to fluids or coatings to slow the rate of corrosion are called inhibitors. Inhibitors function by interacting with the metal surface to generate a protective layer that aids preventing additional corrosion (Tiu & Advincula, 2015).

Overall, a complete and integrated strategy is necessary for effective corrosion prevention and mitigation, including careful material selection, coating and treatment, cathodic protection, and corrosion inhibitors.

8. Inspection and Monitoring Techniques for Corrosion Detection

Inspection and monitoring strategies are critical in the oil and gas sectors for identifying corrosion. Early corrosion detection assists in avoiding catastrophic failures, ensures safe operation, and reduces maintenance costs (Roberge, 2007). There are several commonly used corrosion-detection techniques.

8.1 Visual Inspection

Visual inspection is the most basic and widely used approach for corrosion detection. This entails inspecting the equipment or structure for corrosion indications, such as rust, discoloration, pitting, or cracks (Bastian et al., 2019).

8.2 Ultrasonic Testing

Ultrasonic testing detects corrosion in metals by using high-frequency sound waves. The waves pass through the metal and are reflected back, thereby providing information on its thickness and quality (Ahmad & Bond, 2018).

8.3 Radiography

Radiography is the detection of corrosion in metals using X-rays or gamma-rays. The rays pass through the metal and produce an image on a film or digital detector, indicating corrosion or flaws (Nasrazadani & Hassani, 2016).

8.4 Magnetic Particle Inspection

Magnetic particle inspection detects corrosion in ferromagnetic metals using magnetic fields and iron-oxide particles. The particles were drawn to corrosion spots, making them easy to identify (Gul et al., 2019).

8.5 Eddy Current Testing

Eddy current testing uses electromagnetic fields to identify corrosion and other flaws in metals. The method is very effective for identifying surface fractures, thinning, and pitting (Shaikh et al., 2006).

Operators can detect corrosion in its early stages, identify possible problem areas, and take remedial action before a breakdown occurs by employing these procedures. Frequent inspection and monitoring programs also assist in ensuring the safety and dependability of the oil and gas infrastructure, extending the life of equipment, and reducing downtime and maintenance costs (Nezamian et al., 2016).

9. Discussion

Corrosion is a major problem in the oil and gas sector and can occur in various locations such as production wells, pipelines, storage tanks, and refineries. Temperature, pressure, moisture, and exposure to corrosive substances such as hydrogen sulfide are the primary causes of corrosion. Corrosion can be catastrophic, leading to equipment failure, leaks, and spills, which can harm the environment and human health (Kumar et al., 2019a; Kumar et al., 2019b; Bedi et al., 2019; Kumar et al., 2021). Corrosion costs the oil and gas sector more than $1.4 billion each year, including both direct and indirect expenses. Corrosion-related accidents can have severe environmental consequences such as oil spills and water pollution, which can be detrimental to the environment and human health. The oil and gas industry has vast infrastructure, including upstream, midstream, and downstream facilities, making maintenance and inspection challenging.

In the oil and gas business, several types of corrosion can occur, including uniform corrosion, crevice corrosion, galvanic corrosion, microbiologically induced corrosion, and stress corrosion cracking (Harsimran et al., 2021; Kumar et al., 2018; Kumar et al., 2020a; Kumar et al., 2020b; Kumar et al., 2022; Singh et al., 2023). Corrosion has unique properties and impacts on equipment, making it essential to recognize and prevent corrosion. Corrosion can be challenging to detect since it often occurs in inaccessible areas, and microbiologically driven corrosion can be extremely difficult to diagnose and avoid. Overall, the corrosion that occurs at high temperatures can be reduced by applying suitable combinations of coating materials, process parameters, and substrates (Kumar & Kumar, 2020; Sharma et al., 2021). Several researchers have reduced corrosion by applying metallic coatings using thermal spray processes (Kumar & Kumar, 2018; Kumar et al., 2018a; Kumar et al., 2018b; Kumar & Kumar, 2022; Kumar & Singh, 2022).

Conclusion

Corrosion remains a major challenge in the oil and gas industry, leading to significant financial loss, safety hazards, and environmental pollution. Corrosion prevention is critical in the oil and gas industry, and numerous approaches, including protective coatings, cathodic protection, and chemical inhibitors, can be employed to lower the risk of corrosion. To maintain the safe functioning of oil and gas infrastructure and to preserve the environment and human health, thorough knowledge of corrosion types, causes, and prevention strategies is required. Preventive maintenance and inspection programs should be implemented to ensure that corrosion is detected and addressed before significant damage is caused. It is crucial to effectively address corrosion challenges, frequent inspections, and maintenance procedures in place to identify and prevent corrosion, ensuring that the equipment operates safely and sustainably in the oil and gas industry.

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